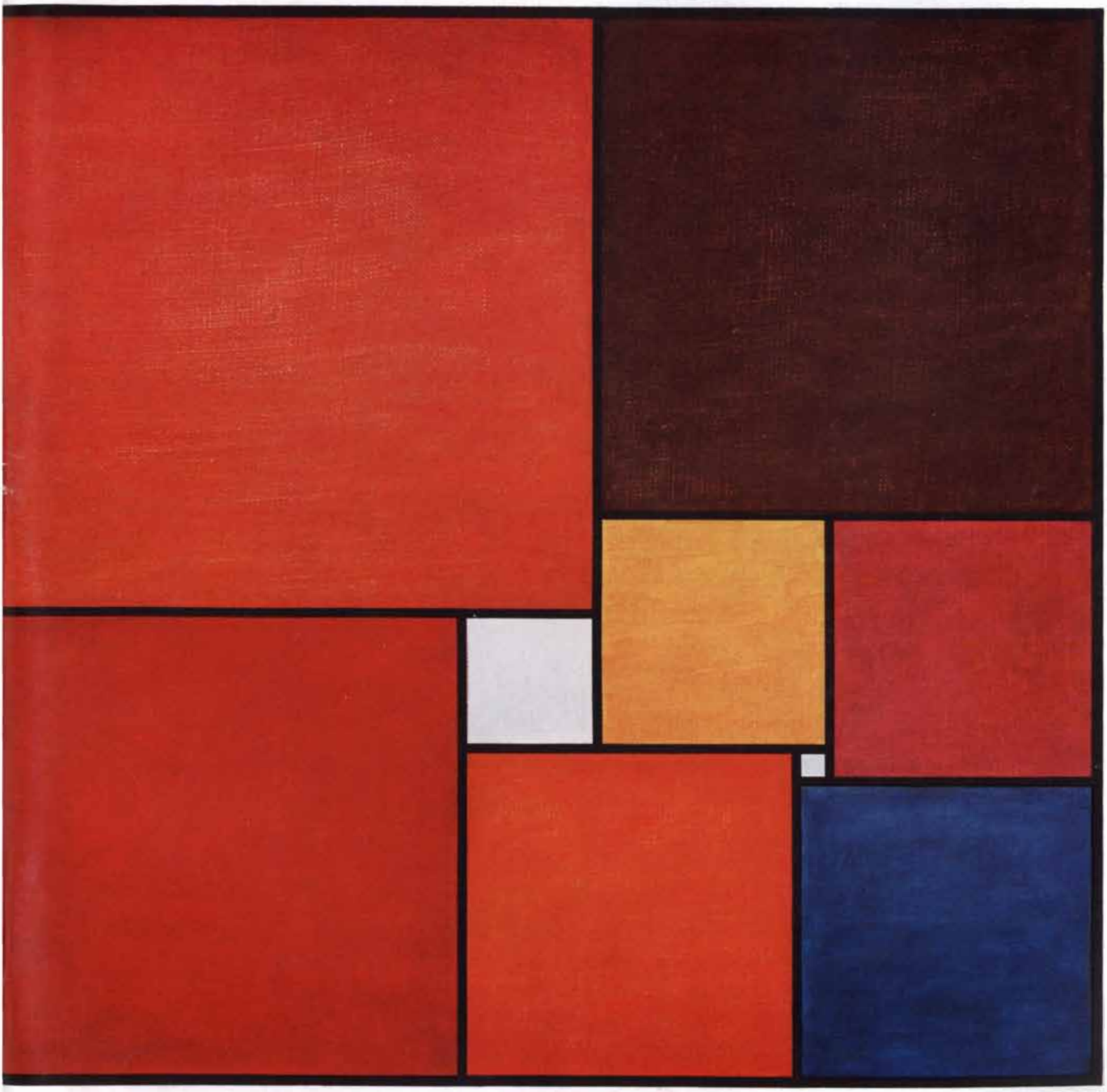
SCIENTIFIC AMERICAN



"PERFECT" RECTANGLE

FIFTY CENTS

November 1958

Progress Report on

TITANIUM PARTS FOR EXTREMES OF TEMPERATURE AND STRESS

More than 1,350,000 pounds of titanium were fabricated by the Tapco Group of Thompson Ramo Wooldridge Inc. last year. From our experience as the major fabricator of this metal has come broad experience in techniques of design, testing, joining, shaping, heat-treatment, and forming, for all ranges of temperatures from sub-zero applications such as pressure bottles for gaseous helium at −320° F. (Fig. 1) to jet engine parts operating up to +750° F. (Fig. 2)

SOLVING DESIGN PROBLEMS. Proper compromise between useful characteristics of titanium and its limitations is a vital factor in designing with this new metal. For example, on a pressure vessel (Fig. 1) the welding along a seam affected the strength and ductility of the vessel in the vicinity of the weld. By using the vast titanium design experience of the Tapco Group, it was possible to redistribute stressed areas so they would fall within the weld capability.

Another design technique used by Tapco involved the "pre-design" development and testing of each individual process and technique to be combined in the final composite design. This "pre-design" development method helps Tapco engineers determine the best design factors, forming and joining methods, and the probable performance results *before* expensive tooling and man-hours are put into fabricating expensive titanium.

FORGING TITANIUM. By precision-forging titanium jet engine blades and vanes at the rate of 65,000 pieces per month, the Tapco Group has developed a unique "state-of-the-art" background on titanium forgings. For example, titanium slugs 2½″ in diameter weighing 8.2 pounds (Fig. 2) have been forged by Tapco into vanes and blades requiring no air-foil finish-machining.

Figure 1—Testing a Tapco-made forged-and-welded titanium pressure vessel under actual operating conditions at 5,000 psi and −320° F.

At Tapco, methods have been developed to move large volumes of titanium with relatively low forging pressures and maintain the same precision of dimension and contour common to the precision forged steel parts. For example, titanium compressor blades have been forged to finished size with trailing edges as thin as 0.010″ in thickness and with form tolerances ranging from 0.006″ to 0.010″. The methods employed by Tapco in producing these titanium forgings result in a reduced cost by more efficient forging techniques, such as avoiding excessive flash and machining tolerances, as well as processing scrap.

HEAT-TREATING TITANIUM. Tapco Group heat-treatment techniques have developed titanium alloys with strengths as high as 200,000 psi in formed parts (see Table I).

WELDING AND BRAZING TITANIUM. Research and development work on welding and brazing methods by the Tapco Group have brought out im-

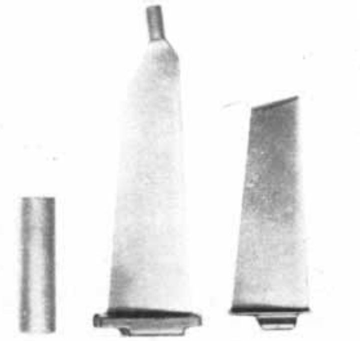


Figure 2—Example of titanium forging produced by the Tapco Group for use in jet engines. Shown left to right are the cut off slug, forged blade and finished blade.

proved techniques of joining. Titanium is successfully joined by controlled techniques . . . heliarc, spot, seam, consummable electrode welding, both manually and automatically.

Brazing of precision assemblies is accomplished by induction and furnace methods. • • •

To learn more about the knowledge and experience of the Tapco Group with titanium, write us, defining your design problem or idea in some detail.

NOMINAL PROPERTIES OF TITANIUM ALLOY PARTS PRODUCED BY THE TAPCO GROUP

ALLOY	CHEMICAL ANALYSES							Room Temperature Tensile Properties				PART
	AL	V	Fe	Cr	Mo	Mn	Sn	Ultimate Tensile Strength, psi	Yield Strength (0.2%), psi	Percent Elongation in 4D	Percent Reduction of Area	
Ti6AL-4V	6.0	4.0	—	—	—	—	—	150000	145000	18	50	Stress relieved blades.
Ti6AL-4V	6.0	4.0	—	—	—	—	—	170000	165000	18	45	Heat treated blades.
Ti6AL-4V	6.0	4.0	—	—	—	—	—	140000	130000	12	25	Turbine wheel.
Ti6AL-4V	6.0	4.0	—	—	—	—	—	155000	140000	10	25	Heat treated cryogenic vessels.
C130AM	4.0	—	—	—	—	4.0	—	140000	125000	25	40	Stress relieved blades.
C130AM	4.0	—	—	—	—	4.0	—	145000	140000	15	35	Large turbine wheel.
C130AM	4.0	—	—	—	—	4.0	—	160000	155000	15	35	Small turbine wheel.
Ti150A	—	—	1.5	2.7	—	—	—	140000	130000	25	50	Stress relieved blades.
Ti140A	—	—	2.0	2.0	2.0	—	—	150000	145000	20	45	Stress relieved blades.
C135AMo	7.0	—	—	—	4.0	—	—	170000	165000	15	40	Stress relieved blades.
C135AMO	7.0	—	—	—	4.0	—	—	190000	185000	12	25	Heat treated blades.
Ti155A	5.0	—	1.3	1.4	1.4	—	—	185000	180000	15	30	Stress relieved blades.
Ti155A	5.0	—	1.3	1.4	1.4	—	—	200000	190000	10	15	Heat treated blades.
MST 821	8.0	—	2.0Cb	1.0Ta	—	—	—	145000	140000	18	40	Annealed blades.
Ti 8-1-1	8.0	1.0	—	—	1.0	—	—	155000	150000	18	45	Annealed blades.
A110AT	5.0	—	—	—	—	—	2.5	125000	120000	18	40	Comp. case assembly.
A70	—	—	—	—	—	—	—	95000	80000	25	50	Vanes.

Table I — Typical chemical and mechanical characteristics of titanium alloys fabricated by the Tapco Group for a wide range of services.

TAPCO GROUP
OF
Thompson Ramo Wooldridge Inc.

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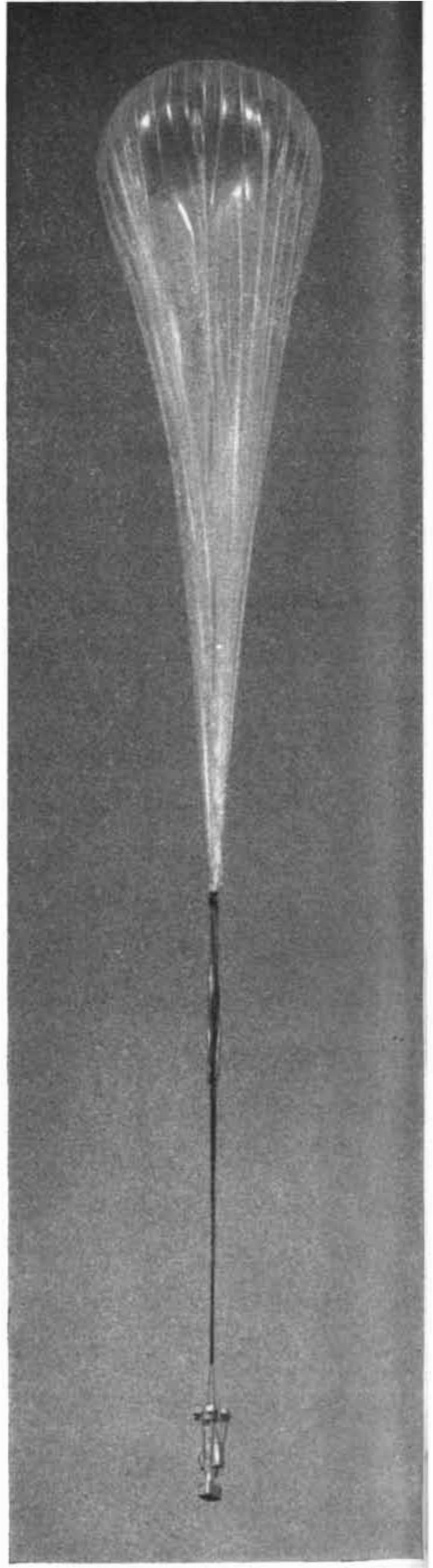
THE P-E SPECTRUM

news of advanced systems and instruments from Perkin-Elmer

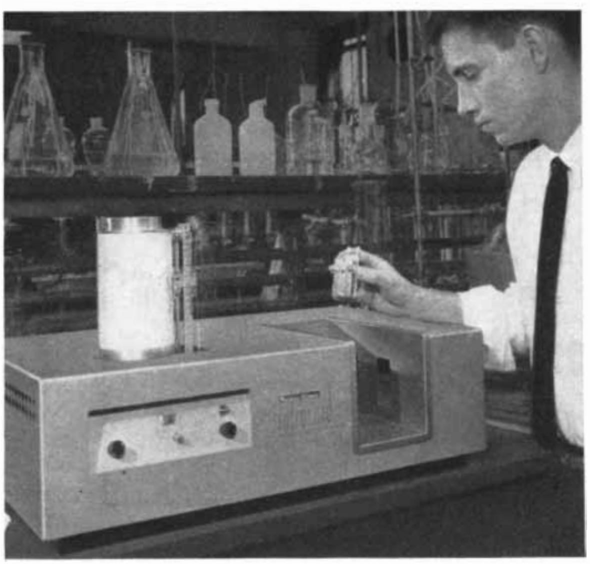


LARGER BALLOON-BORNE SOLAR TELESCOPE PLANNED ▶

The success of Project Stratoscope I last fall, when the sharpest photographs of the sun ever obtained were taken by a special balloon-borne telescope from over 80,000 feet, has led to plans for building a larger telescope to photograph the planets and other celestial objects. Perkin-Elmer, which designed and built the 12-inch sun telescope, is currently engaged in the design and study for a 36-inch telescope. A television link is planned to control the telescope from the ground. The Stratoscope projects are sponsored by the Office of Naval Research and are under the direction of Dr. Martin Schwarzschild of Princeton University.

◀ "NEW CONCEPT" POTENTIOMETER HELPS CHECK OUT B-58 AUTOMATIC FLIGHT CONTROL SYSTEM

A mobile test set, built by Eclipse-Pioneer Division of Bendix Aviation Corp. to check out the complex automatic flight control system of the B-58 Hustler bomber, utilizes a unique type of a.c. potentiometer developed by Perkin-Elmer. The Vernistat* is based on a new concept in relating shaft rotation to voltage. In the B-58 test set, several Vernistats provide accurate sources of test voltages used to simulate control system signals. An alternative method of supplying voltage levels would have necessitated several additional components and would have cost four times as much as the Vernistat system.



◀ COLLEGES ADOPTING NEW, LOW-COST INFRARED INSTRUMENT

A new, easily operated infrared spectrophotometer is finding ready acceptance in college chemistry curricula, according to a recent survey. A third of all A.C.S. accredited colleges offering chemistry degrees, and almost half of all A.C.S. accredited colleges offering graduate chemistry degrees own at least one Perkin-Elmer INFRACORD* instrument, the survey showed. Chief reason for the INFRACORD's popularity, aside from its low price, is its simple operation—a wide range of useful infrared analytical work can be performed by students with only a few hours of previous instruction in infrared theory and techniques.

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Established 1845 **SCIENTIFIC AMERICAN** November, 1958 Volume 199 Number 5

ARTICLES

DEPARTMENTS

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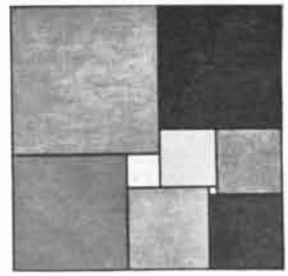

THE COVER

The painting on the cover, which resembles an abstraction by the artist Piet Mondriaan, is actually a representation of a "perfect" rectangle, that is, a rectangle made up of squares of unequal size (see "Mathematical Games," page 136).

THE ILLUSTRATIONS

Cover painting by Mary Russel

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44-46	Mount Wilson and Palomar Observatories
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It will pay you to review the properties of these fibers and see how they fit in with your plans. Chances are that Du Pont fibers can make an important contribution to one of your products or processes. Du Pont's testing and research activities and experience offer you an authoritative source of assistance. Let us help you with your next materials problem.

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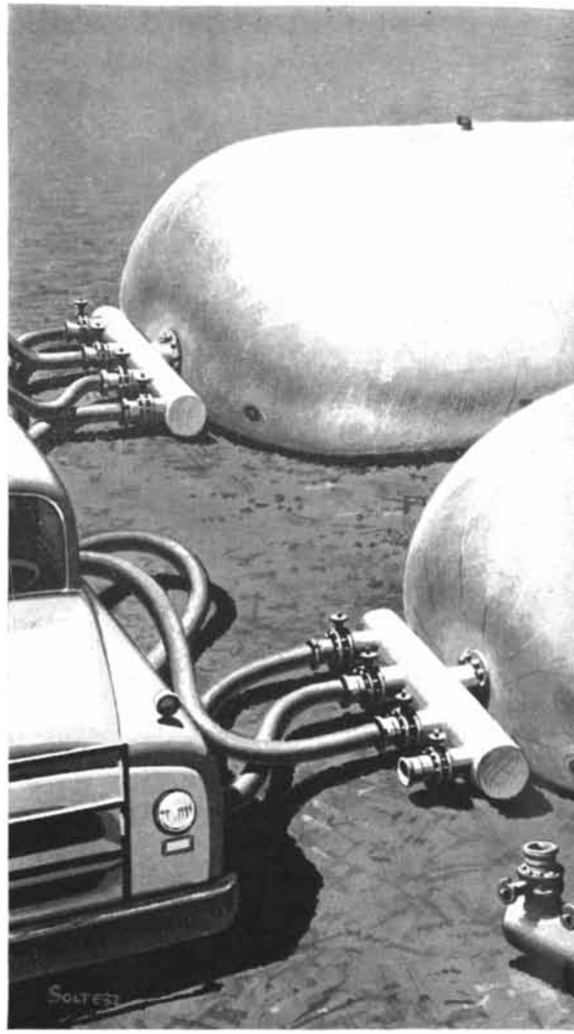
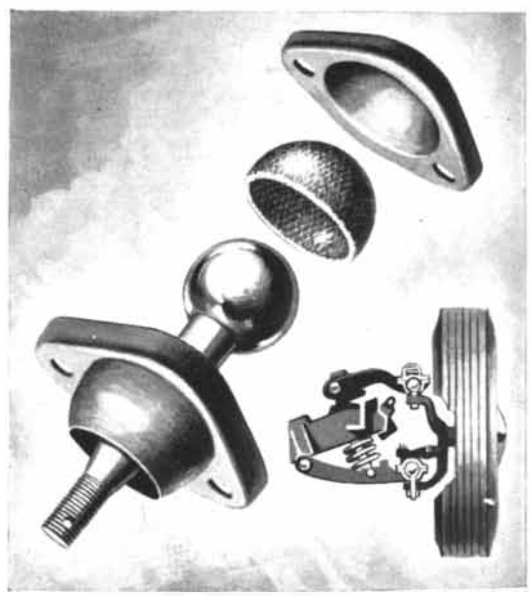
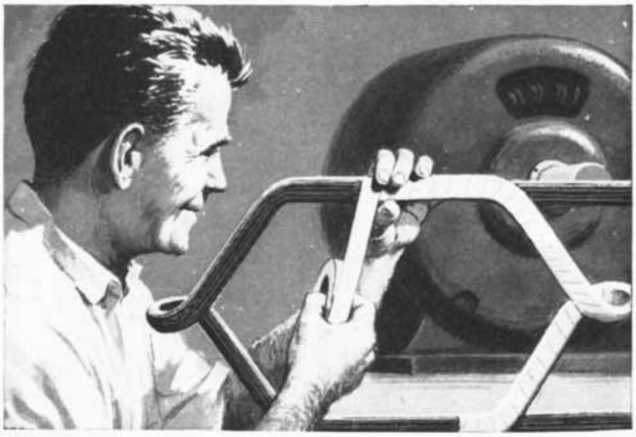




CHASSIS LUBRICATION may soon be a thing of the past for all automotive joints subject to high loads at low speeds. A new ball joint lined with a fabric of "Teflon" is designed for use in steering and suspension systems. The "Teflon" fibers provide an extremely low coefficient of friction. Substitution of the new "self-lubricated" ball joint can eliminate kingpin wear, high initial steering torque and slip-stick motion.

STORAGE TANKS CALLED "WHALES" because of their size and shape are made of nylon fabric coated with neoprene rubber. The nylon lends high tensile strength and light weight to the construction. Nylon is unaffected by grease, oil or moisture and will not rot in contact with soil. The tanks have a capacity of 15,000 gallons and, when empty and rolled up, are easily transported into rough country. Cost of transport to a remote oil field in one instance was $12.50, compared with $175 for moving a steel tank of the same capacity. The tanks can be rolled up into a package 8 feet long by 2½ feet in diameter. A small truck can carry about seven of these big tanks, and they are easily loaded by two men. The light weight of these storage tanks makes it possible to ship them by air.

INDUSTRIAL FIRE HOSE has always led a short, tortured life . . . dragged over rough floors through oil and chemicals, stored outdoors with the fabric outer jacket exposed to mildew damage. That's why hose manufacturers have switched to jackets of "Dacron". "Dacron" has high resistance to damage by abrasion, chemicals and mildew. The new hose has important *performance* advantages. It can be stored in half the space needed for conventional hose. It's only three-fourths the weight, too—so it handles easier and faster.



NON-WOVEN FABRICS are coming into their own with the availability of man-made fibers. High-grade electrical tapes are made of non-woven fabrics of "Dacron" polyester fiber. "Dacron" has great strength and will not absorb moisture. The non-woven tape stretches to give a secure, snug fit in coil winding. The result is neat appearance with up to one-third increase in dielectric strength.

Enjoy the "Du Pont Show of the Month"—on CBS-TV

LETTERS

Sirs:

It is customary in certain literary circles, when asked what's wrong with man today, to reply glibly that of course his universe has been pulled out from under him by science and that having nothing left in which to believe he therefore produces a literature of despair. But many sober people—in and out of literary circles—are sick and tired of such despair as realism is producing on the stage and in the novel. "Why," they ask, "must we have the never-ending flow of nothingness: the grim parade of the sordid, the rotten, the hopeless, the lost?" The answer, I believe, lies partly in the proper understanding by literary (and other) people of what science really is, and never have I seen the explanation more lucidly made than in the pages of your September issue.

Consider three of the most prominent "house-wreckers" on the modern scene: Darwin, Freud and Einstein. Can any sane man who has a glimmering of science accuse these men of "wrecking" the universe? Of course not. As one after another of your articles demonstrates, scientists are *builders;* it is in the nature of scientific inquiry, at its highest, to seek after a *unity* in nature. To accuse Einstein of wrecking Newtonian mechanics is like accusing Shakespeare of wrecking Petrarch—and Seneca, and Plautus, and all of the great poets who

Scientific American, November, 1958; Vol. 199, No. 5. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York 17, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer.

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preceded him. Great artists, like great scientists, are builders.

But where are the builders in the arts today? Samuel Beckett? Ionesco? Tennessee Williams? The authors of the flood of novels and plays appearing yearly that do nothing but point to the worst in human nature?

Are these people builders? I think rather that they are vandals, who throw their stink-bombs into the structure and run off in glee to turn in the alarm. "Look," they shout, "the house is burning; the house is burning. Albert Einstein told me, and Sigmund Freud told him, and Charles Darwin told him . . . etc."

As a matter of fact, as the various articles in your magazine should make clear, the house isn't on fire at all. Of course, it's by no means air-conditioned: but neither was London in 1600, nor Florence a century before that, nor Athens many centuries earlier.

But it is the business of the poet and the scientist to—in Bronowski's excellent phrase—"outstrip the facts." Thus science, in its essence, is poetry: the scientist is continually creating and recreating the universe, leaping into the unknown much as the poet leaps when he creates the "stately pleasure-dome." To accuse such a man of undermining the universe is to reflect abysmal ignorance of one of the most important and thrilling developments in the history of man. . . .

GILBERT ABERG

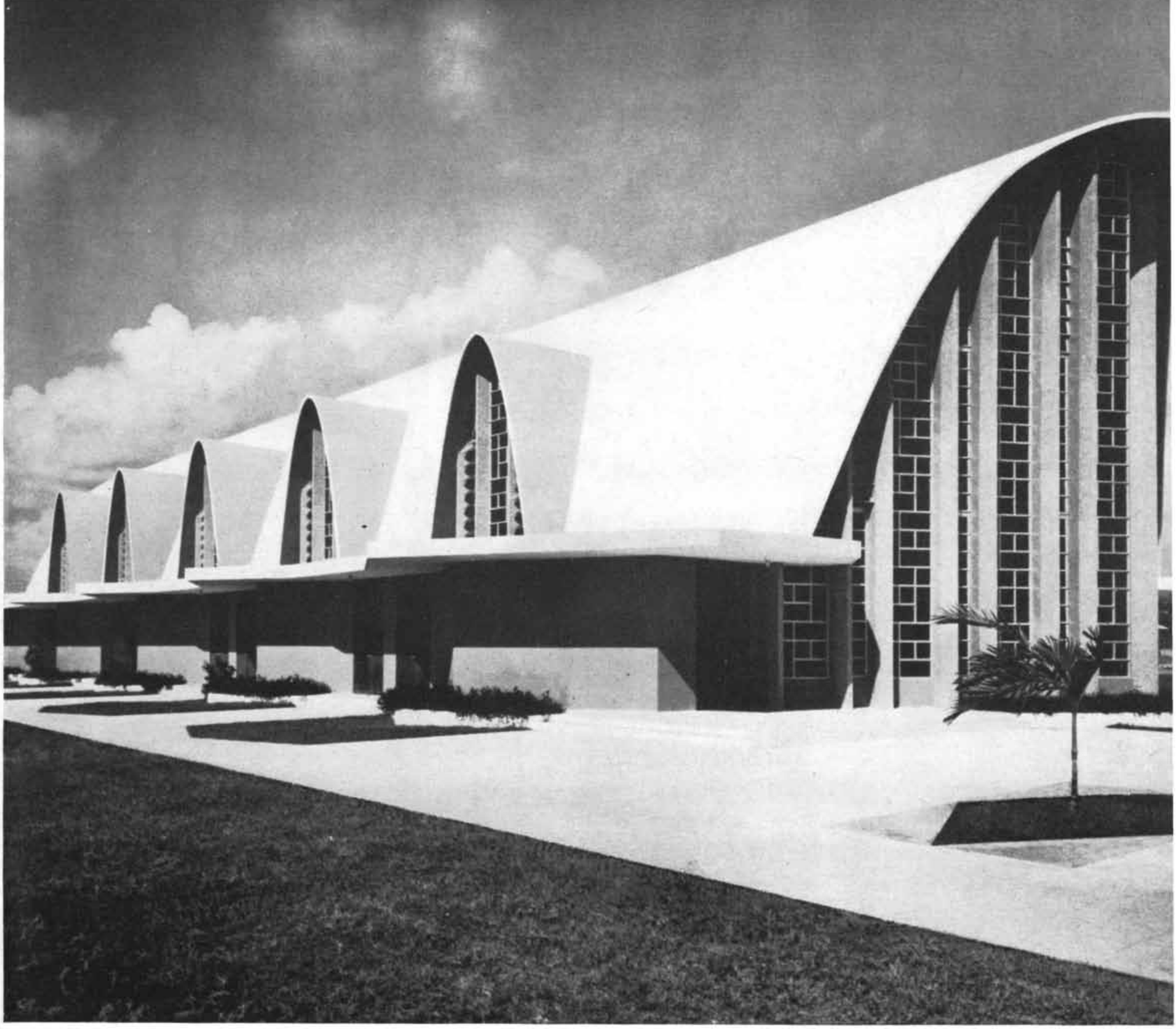
State College, Pa.

Sirs:

The caption beneath the photograph on page 58 of my article ["Magnetic Resonance"; SCIENTIFIC AMERICAN, August] conveys an impression which should, in fairness to Professor Jonathan Townsend of the Washington University physics department, be corrected. The apparatus shown is actually the very sensitive one referred to in the article and developed by Professor Townsend for the biological experiments; the laboratory is his, not Professor Barry Commoner's. The biological samples are prepared in Professor Commoner's very fine laboratories elsewhere on the University campus. In fact, one of the remarkable features of Washington University is the extent to which such cooperative research ventures take place among the various departments and laboratories.

GEORGE E. PAKE

Stanford, Calif.



Coatings to protect anything under the sur

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Providing a new systems approach that follows through from initial plan to final production, the Bendix Systems Division serves as the *focal point* for the twenty-five strategically located divisions that constitute the Bendix Aviation Corporation. The new building, designed for engineering and managing of major weapons systems, is adjacent to the Graduate Engineering School of the University of Michigan in Ann Arbor.

This structure and its additions will accommodate a staff of 1,000 including engineers and scientists who will explore new concepts in such fields as communications, guidance and control, infrared, data processing, aerodynamics and propulsion, radar, acoustics, and countermeasures.

Weapons systems now being developed by this Bendix division include air defense network improvements, global weather reconnaissance, special radar applications for detecting ballistic missiles and low-flying aircraft, underwater surveillance, mission and traffic control, and a supersonic aerial target system for testing operational capabilities of the latest weapons.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER, 1908: "After losing to Wilbur Wright the prize of the French Aero club for the longest flight up to October 1, Henry Farman has shown himself to be, after all, one of the world's most daring aviators, while at the same time he has opened a new era in aeroplane flight. Mr. Farman has accomplished the first cross-country flight in an aeroplane. On Oct. 30 he soared aloft above the military camp at Chalons, France, flew straightaway across country at a height of 100 feet, and did not alight until some 20 minutes later, when he reached the outskirts of Rheims, after traversing a distance of 17 miles."

"And so it seems that our worst fears regarding the $24,000,000 Blackwell's Island (Queensboro) Bridge are verified. A little over a year ago, that other great cantilever structure, the Quebec Bridge across the St. Lawrence, crumpled up under its own weight and fell into the river below. Naturally, public attention was at once directed to the Blackwell's Island Bridge. The Bridge Department consented to an investigation by Prof. Burr, of Columbia University, and Messrs. Boller and Hodge, bridge engineers. The results are simply appalling. They mark this bridge as the most monumental case of faulty design in the history of long-span bridges, for, if it is opened and subjected to the loads it is intended to carry, the strains, in some of its members, will exceed the safety point by as much as 47 per cent!"

"Rear Admiral Holiday, Chief of the Bureau of Docks and Yards, recently spent three weeks investigating the new naval base site at Pearl Harbor in the Hawaiian Islands. He states that there are 5,000,000 cubic feet of coral and sand, which must be dredged out to provide the required depth. The estimated cost of the harbor, which is to be finished in 1912, is $5,000,000."

"Prof. E. B. Frost, director of the Yerkes Observatory, calls attention to the recent increase of brightness of

Morehouse's comet. He writes on Oct. 29: 'The comet on that date was visible to the naked eye, and three or four degrees of tail could readily be seen in a small field glass. Three spectrum plates were obtained at Yerkes. Two of these had exposures of one hour. No continuous spectrum was perceptible on the date mentioned. Indeed, seven bands were very conspicuous. Hence the important inference is reached that the comet's light was very largely intrinsic.' "

"As already noted, Count Zeppelin, on the 23rd ultimo, brought out his fifth airship for trial. The new airship is the remodeled *Zeppelin III* of 1906, lengthened by eight meters. Among the new features is a telegraph line connecting the two cars. On November 7 Crown Prince Frederick William ascended with the Count and made a trip to Donaueschingen, Baden, where the Emperor arrived by rail shortly after the arrival of the airship. The Emperor conversed with his son through a megaphone, and afterward the Crown Prince returned in the airship to Friedrichshafen."

"The fourth contest for the Vanderbilt Cup will be memorable because, for the first time, the famous trophy was won by an American in an American-built car. It occasions no surprise that the honor should fall to a Locomobile. The race comprised 11 laps of 23.45 miles. Robertson made the fastest lap of the race in the winning car in 20 minutes and 54 seconds, or at the rate of 67.32 miles per hour."

"Debrix has invented an ingenious method of measuring the distance of a vessel which cannot be seen, because of darkness, fog, or intervening objects. The method is based on the difference between the velocities of sound and Hertzian waves."

SCIENTIFIC AMERICAN

NOVEMBER, 1858: "The result of the calculations lately made by the well-known astronomer, Professor Struve, of the University of Dorpat, relative of the true geographical positions of St. Petersburg and Moscow, and the distance between the two capitals of the empire, is that the actual length of the railroad is by astronomical observation no less than 88 versts (about 60 miles) shorter than

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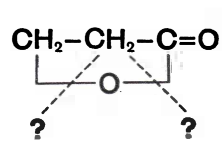
BPL is now being evaluated for use in the textile and leather industries . . . as a component in the processing of plastics, paints, dyestuffs and synthetic fibers . . . in starches and adhesives . . . in medical and hospital applications . . . in agricultural and food technology . . . in nucleonics and astronautics.

Among the multitude of uses yet to be developed, tested, and produced, may be one in which you're interested. As always, we'll be more than happy to help you, if we can.

For further information on Celanese BPL, and/or evaluation samples, just write on your letterhead. Celanese® BPL™



*BPL's unique chemical structure gives it "difunctionality"—the ability to react with other chemicals, in two different directions, to produce various important derivatives.

Basic reasons .... for improved products

Acids	Functional Fluids	Polyols	Agricultural	Paper
Alcohols	Gasoline Additives	Plasticizers	Automotive	Pharmaceutical
Aldehydes	Glycols	Salts	Aviation	Plastics
Anhydrides	Ketones	Solvents	Building	Surface Coatings
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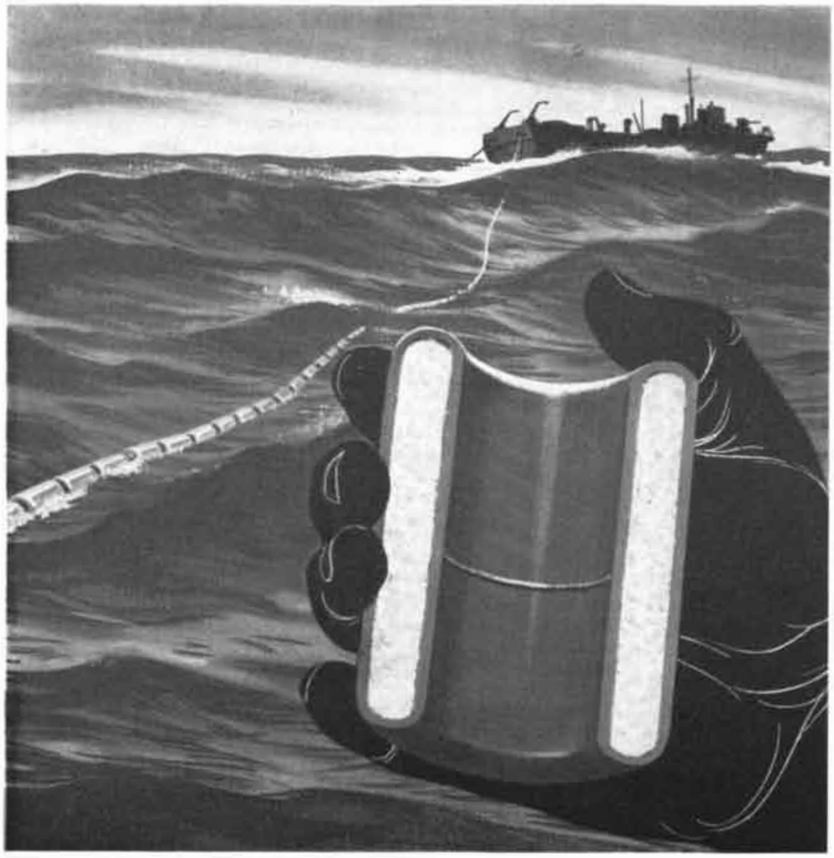

its nominal length of 607 versts, or in other words, that the government on whose account the railroad was constructed, has had to pay about one seventh of the value, or twelve millions of roubles, more than it ought to have paid. As the rolling stock of the St. Petersburg and Moscow Railway is furnished by an American company, who are paid for the same at so much per verst, it follows that in this quarter the Government have been paying also a most fearful overcharge. The Emperor was in the most violent state of excitement on learning the above, and gave immediate orders for the strictest investigation into the facts of the case to be made, with a view to inflict the most summary punishment on the parties inculpated in this nefarious transaction."

"It will be recollected that our government sent out Lieut. Gillis to take observations of the solar eclipse which was total in some parts of South America on the 6th of last month. He has written a brief letter on the subject to Professor Henry, of the Smithsonian Institution, in which he states that his telescope was mounted near Olmos, in Peru, and his observations were favorable. The brilliant protuberances usually observed with instruments, shooting from the sun's disk, on this occasion became distinct to the naked eye."

"In New York there is one physician to every 610 inhabitants; in Massachusetts, one to every 605; in Pennsylvania, one to every 561; in North Carolina, one to every 802; in Ohio, one to every 465; in Maine, one to every 884; and in California, one to every 147. We can envy Maine and pity California, for some must swallow physic at a frightful rate in the Golden State."

"About two years since New York City was visited by Alexis St. Martin, of Canada, who has an opening in his abdomen (the result of a gunshot wound) through which his stomach can be examined, and the operations of digestion observed. His case has hitherto been considered the most wonderful in the world, but one more wonderful than that of St. Martin is now in New York. During the past week, M. Groax, a native of Hamburg, exhibited to the faculty in the Columbia University Medical College his own beating heart, in the same manner that St. Martin did his stomach. This case however is a natural phenomenon, Mr. Groax having been born with a slit in his breast, by which his heart and a part of his lungs can be observed."

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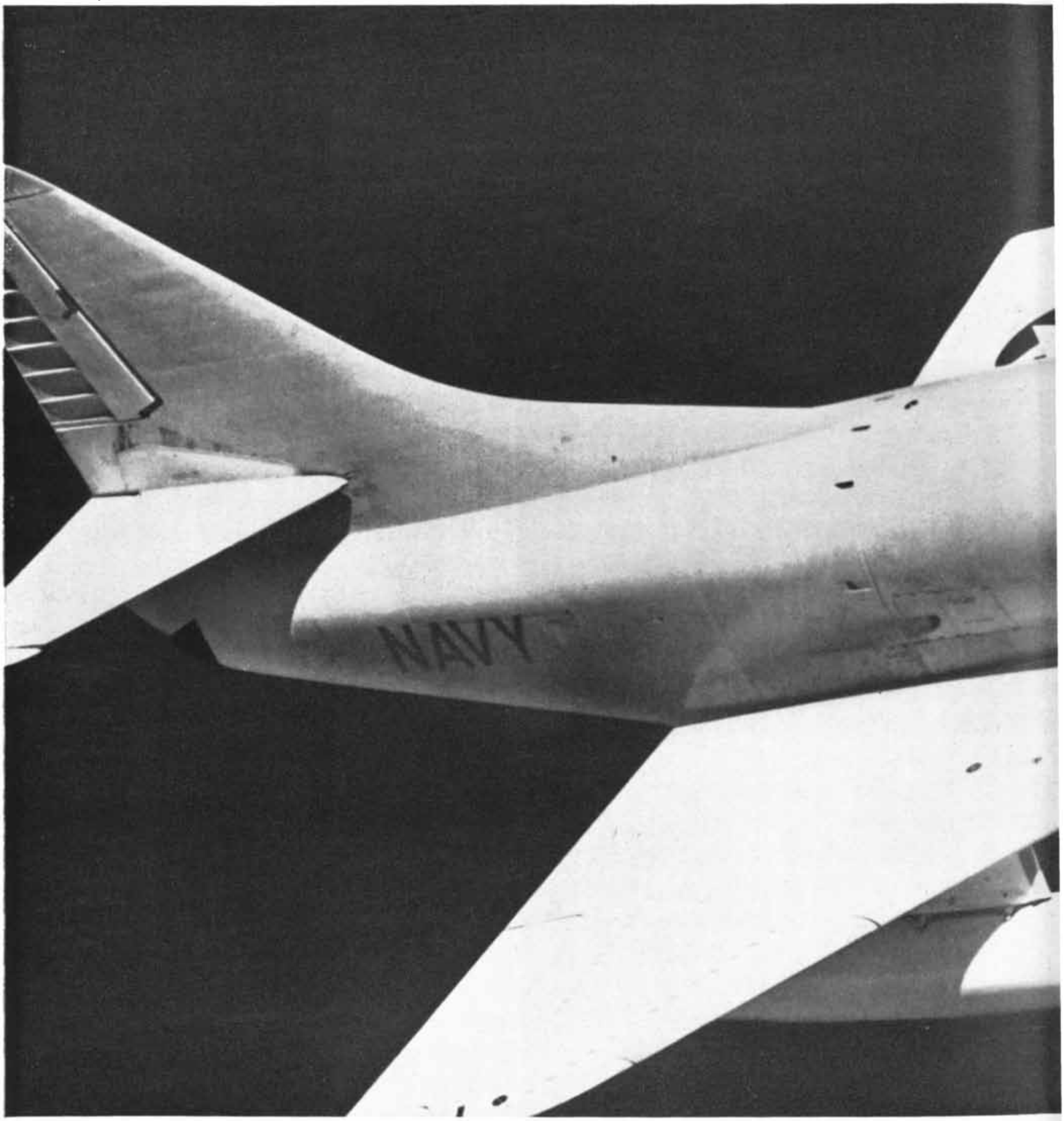

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or anti-aircraft. Numbers of Douglas Skyhawks are on active duty with U. S. carrier units now engaged in patrolling sensitive areas around the world. They are in service for both the Navy and Marine Corps.

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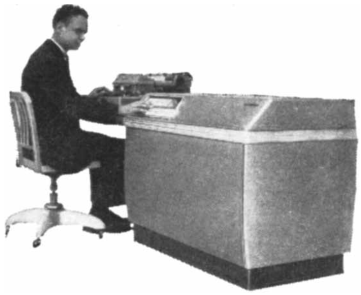
THE AUTHORS

ABRAM F. JOFFE ("The Revival of Thermoelectricity") is a leading Soviet physicist and a member of Russia's central scientific body, the Academy of Sciences, in which he heads the Institute of Semiconductors. Born in 1880, Joffe studied at the Technological Institute in Leningrad (then St. Petersburg) and the University of Munich. For many years he worked in collaboration with Wilhelm Konrad Röntgen, the discoverer of X-rays. Later he headed the Leningrad Physical-Technical Institute and the State X-Ray and Radiology Institute.

NORTON D. ZINDER (" 'Transduction' in Bacteria") was born in New York City and there pursued an accelerated course of studies which carried him through the Bronx High School of Science and Columbia University by the time he was 18. Proceeding to the University of Wisconsin, he acquired a Ph. D. in medical microbiology in 1952. By that time Zinder—then 23 years old—had not only shared in the discovery of "transduction" but had married and become a father. In 1952 Zinder returned to New York to join the staff of the Rockefeller Institute.

MARGARET and GEOFFREY BURBIDGE ("Stellar Populations") are a husband-and-wife team—she being an astronomer, he an astrophysicist. The Burbidges, who are English, met 10 years ago in a University of London lecture hall. At that time she was employed in the University of London Observatory, while he was a physicist. Their courtship resulted in his conversion to astrophysics and also in their marriage. In 1951, when Geoffrey Burbidge came to the Harvard College Observatory as an Agassiz Fellow, his wife became a fellow of the University of Chicago's Yerkes Observatory at Williams Bay, Wis. (the Burbidges commuted between the two places). In 1953 the Burbidges returned to England, where he worked for two years in the Cavendish Laboratory of the University of Cambridge. Since last year they have collaborated at the Yerkes Observatory.

H. E. HUXLEY ("The Contraction of Muscle") is also English. He comes from Birkenhead, Cheshire, and studied theoretical physics at the University of Cambridge, where his undergraduate career was interrupted by five years of



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ROYAL McBEE · *data processing division* radar research for the Royal Air Force (his work in this line was rewarded with a membership in the Order of the British Empire in the New Year's Honours List of 1947-48). Huxley returned to Cambridge to study for the Physics Tripos examinations. "I had originally intended to become a nuclear physicist," he says. "But when I finished off my undergraduate degree, it seemed a more attractive proposition to think of applying the ideas and methods of the physicist to the biological field. Whilst working in the Medical Research Council Unit in Cambridge on crystalline proteins, I was struck by the fact that although the hydrated crystals gave excellent X-ray diffraction patterns, the dry crystals gave very poor ones. I wondered whether the same thing might not be true of muscle, previously examined only in a dried state. Apparatus was assembled to get a low-angle X-ray diffraction pattern from wet, living muscle. I found immediately that this material gave an excellent pattern." As a Commonwealth Fellow at the Massachusetts Institute of Technology, Huxley continued this research with the electron microscope, and later, after returning to Cambridge, with phase-contrast and interference microscopy. In 1956 he joined the staff of University College London. He is not related to Thomas, Aldous or Julian Huxley.

MANUEL J. GORDON ("The Control of Sex") works in the Animal Reproduction Laboratory of Michigan State University. An Ohioan, he worked hard at commercial courses in a Cleveland high school until his second year, when, he says, "I became so bored that I would be AWOL for weeks at a time. As a result, I came very close to being expelled." After his service as a World War II army draftee, Gordon decided to become a scientist, and asked his high-school principal for grade transcripts. "I'll never forget," he says, "how his pleasant face transformed into an expression of sickened horror and disbelief as he looked at my records. With no attempt to spare his feelings, I matriculated at Ohio State University in June, 1946, and received a B.Sc. in zoology in March, 1949. All of my graduate work was done at the University of California under Curt Stern."

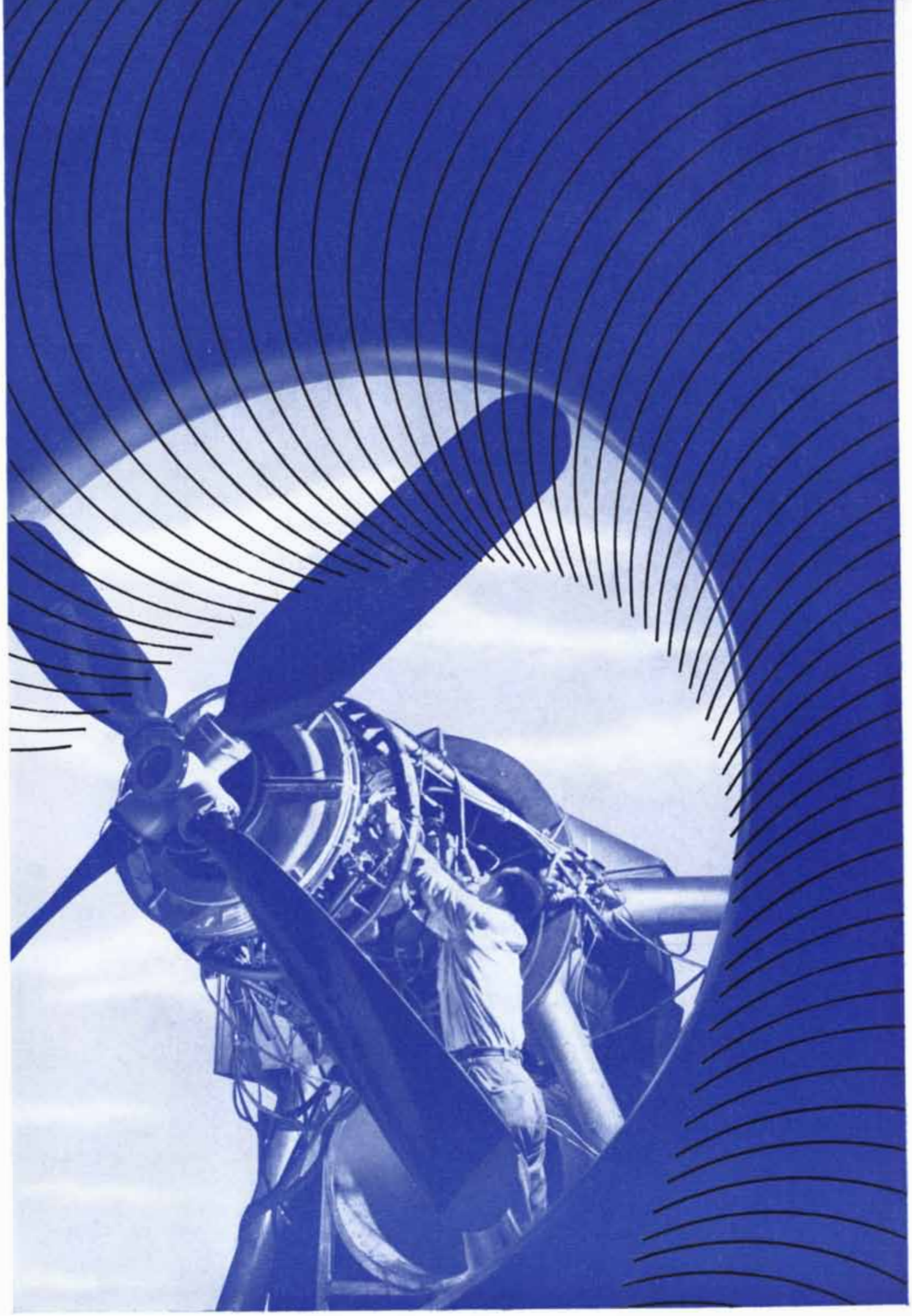
SULLIVAN J. MARSDEN, JR. ("Drilling for Petroleum") is associate professor of petroleum engineering at Stanford University. Marsden began his career at Stanford during World War II as a student of chemical engineering. But a year as research chemist on the

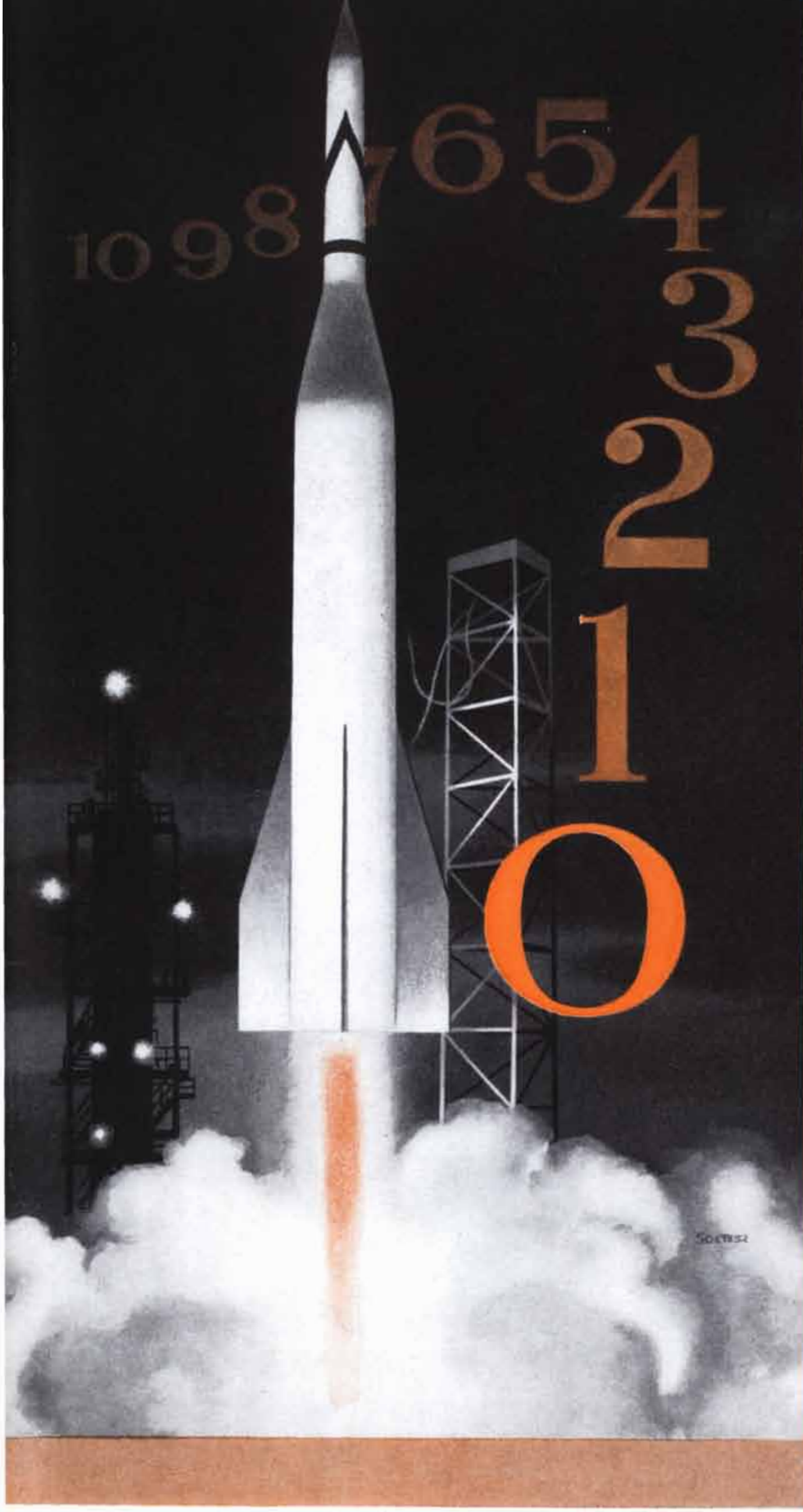
Manhattan Project at Oak Ridge turned his interest to physical chemistry. He returned to Stanford, where he took a Ph.D. in physical chemistry under the late J. W. McBain. Then he accompanied McBain to India, to help found the Indian National Chemical Laboratory. Marsden served for three years as assistant director of the laboratory. In 1953 he returned to the U. S. to study and teach petroleum production at Pennsylvania State University and, since 1957, at Stanford.

T. P. BANK ("The Aleuts") was field director of the University of Michigan's Aleutian expeditions from 1948 to 1955. A botanist by training, he studied at Harvard University and at the University of Michigan, from which he holds an M.S. degree. In 1955, after completing his Aleutian work, he traveled on a Fulbright research scholarship to Hokkaido, the northernmost island of Japan, to study the remains of an early race of Eskimo-like migrants from Siberia. He then served for a year as a research associate of the University of Michigan's Museum of Anthropology. Since 1957 Bank has headed the Institute for Regional Exploration, a private research organization. Last year he traveled on a National Science Foundation grant to Thailand, where he chaired the subcommittee on ethnobotany at the Ninth Pacific Science Congress.

A. V. WOLF ("Body Water") is a student of water metabolism whose work has been devoted mostly to the physiology of the kidney and of thirst. At the Walter Reed Army Institute of Research, where he heads the Renal Section, he has recently been specializing on the problems of the castaway at sea, including the question of sea-water drinking. Wolf is the author of the article "Thirst" which appeared in the January, 1956, SCIENTIFIC AMERICAN, and he has recently completed a book on this subject, also entitled *Thirst*. As a sideline Wolf has engaged in building experimental artificial kidneys (he belongs to the recently founded American Society for Artificial Internal Organs). Wolf did undergraduate work at the College of the City of New York, received a Ph.D. from the University of Rochester, and taught for 10 years at the Albany Medical College before going to Walter Reed.

ROBERT W. WHITE, who reviews *Social Class and Mental Illness* in this issue, is professor of clinical psychology and chairman of the Department of Social Relations at Harvard University.





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Sir James Jeans . . . on the quest for knowledge

"Yet we may reflect that physics and philosophy are at most a few thousand years old, but probably have lives of thousands of millions of years stretching away in front of them. They are only just beginning to get under way, and we are still, in Newton's words, like children playing with pebbles on the sea-shore, while the great ocean of truth rolls, unexplored, beyond our reach. It can hardly be a matter for surprise that our race has not succeeded in solving any large part of its most difficult problems in the first millionth part of its existence. Perhaps life would be a duller affair if it had, for to many it is not knowledge but the quest for knowledge that gives the greater interest to thought — to travel hopefully is better than to arrive."

—Physics and Philosophy, 1942

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The Revival of Thermoelectricity

The Seebeck and Peltier effects dispense with moving parts in the transformation of energy from heat to electricity. Long regarded as curiosities, they are now generating a technological revolution

by Abram F. Joffe

Farms and pioneer settlements in many regions of the U.S.S.R. remote from electrical power grids today enjoy the advantages of electric light, electrified machinery and radio, thanks to a new kind of generator. This generator has no moving parts, but converts the heat of a kerosene lamp or a wood stove directly into electrical power. In the cities of the nation, apartment dwellers are soon to be furnished with an inexpensive refrigerator which operates on a quite opposite effect. This refrigerator has no motor or compressor and no refrigerant fluid; it uses electrical energy directly to pump the heat out of its interior. A variation of this effect applied to the heating of indoor working and living spaces promises to achieve great economy in the use of electrical energy for such purposes.

In the modern world, developments of this scope are never the exclusive province of one country. When I visited the U. S. earlier this year, I found scientists and engineers fired with these possibilities and working actively to realize them. Evidently we stand on the threshold of a new era in power engineering, heating and refrigeration. This prospect flows from the now-rapid advance of thermoelectricity: the direct transformation of thermal energy into electrical energy and the reciprocal transformation of electrical energy into heat.

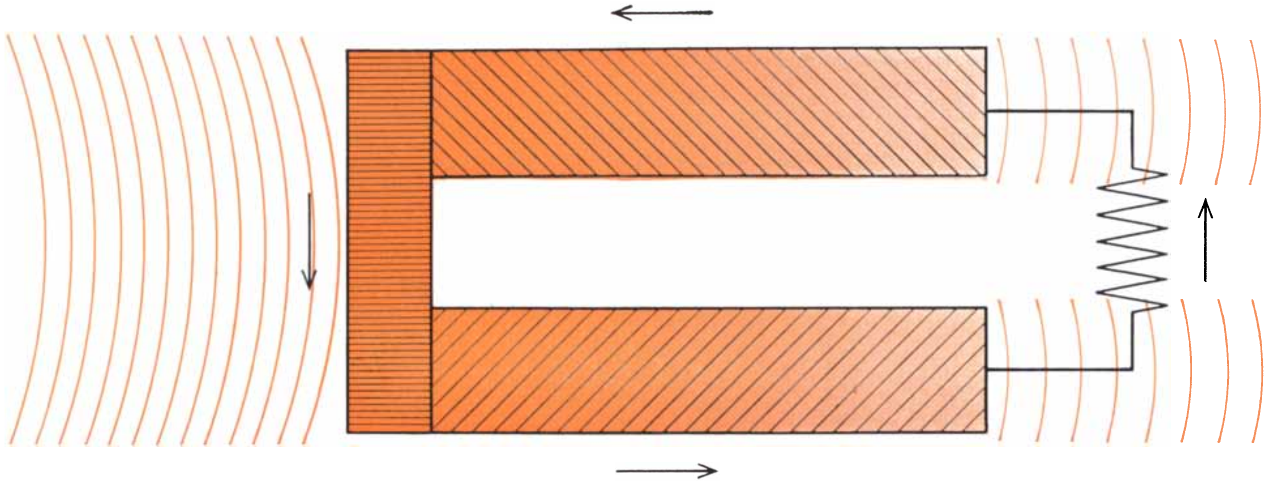
Thermoelectricity is not a new science. It is, in fact, just as old as our knowledge of the electromagnetic effects upon which electrical technology is based. The history of electromagnetism began in 1820, when Hans Christian Oersted reported his observation that a magnetic needle is deflected by the flow of an electric current in a nearby conductor. Only a year later Thomas Johann Seebeck reported his observation that a magnetic needle held near a circuit made up of two different conductors is deflected when part of the circuit is heated. Unhappily this promising discovery was obscured by the discoverer's own misjudgment. A comparison of the Oersted and Seebeck observations suggests naturally that a current was flowing in Seebeck's circuit. That is the way Seebeck's contemporaries interpreted his discovery. But, alas, Seebeck did not. He thought he had shown that magnetization may be caused by a difference in temperature, and attempted to explain terrestrial magnetism by the temperature difference between the Equator and the poles.

Seebeck's error had two different kinds of consequences. In trying to convince his opponents that his effect was magnetic rather than electric in origin, and thus not related to the electrical properties of the substance, Seebeck investigated an enormous number of different materials, not only metals but also metal oxides, minerals and other compounds. Among these were substances which we now call semiconductors and which we use today in thermoelectric generators.

On the other hand, in his unyielding battle against electric current, Seebeck succeeded in discouraging himself and others from attempting to use his thermoelectric effect as a source of current. Yet it has been found that the substances he used in his experiments can transform heat into electricity with an efficiency of about 3 per cent. This compares favorably with the mechanical efficiency of the steam engines of his day. In the laboratories of the time, moreover, the only machines for producing electric current were extremely weak electrostatic generators. Not until half a century later was electricity successfully generated by electromagnetic machines driven by steam engines.

It is hard to say how the history of electrical engineering and electronics might have unfolded had Seebeck's discovery been wisely used. For a long time it would have provided the best source of electric energy. But this is not what happened. The rapid development of electromagnetism diverted the interest of succeeding generations of physicists away from thermoelectricity. Certainly one could expect no significant thermoelectric effects from metals, and these were the only conductors used in electrical engineering for the next 100 years. Seebeck's mineral semiconductors were ignored even in the design of thermocouples for temperature measurement, the sole application of thermoelectricity throughout this period. The Seebeck effect became a curiosity, relegated to the last pages of physics textbooks.

For a century the marvelous possibil-



SEEBECK EFFECT brings about conversion of heat into electric energy: heat input to "hot" junction *(left)* of two dissimilar semiconductors causes current to flow from hot to cold end of semiconductor *(n-type)* at bottom and from cold end to hot in semiconductor *(p-type)* at top. An electric current is thus made to flow through the entire circuit, including the output element at right.

ities of thermoelectricity remained asleep, like the princess in the fairy tale.

This slumber was momentarily disturbed in 1834. A French watchmaker, Jean Charles Athanase Peltier, discovered that the passage of a current through the junction between two different conductors is associated with a thermal effect. But like Seebeck, Peltier failed to understand his discovery. He saw it only as showing that Ohm's law may be disobeyed by sufficiently weak currents. The true nature of Peltier's discovery was clearly demonstrated in 1838 by Emil Lenz, a member of the St. Petersburg Academy. He placed a drop of water on the junction; when he made the current flow in one direction, the water froze; when he made it flow in the other, the ice melted.

Could anyone fail to see that the junction liberated heat when the frozen drop melted and that it absorbed heat when the drop froze? Peltier's discovery ought to have found important applications, since it opened a new way to obtain cold and heat. But this discovery also spent 100 years in the kingdom of sleep.

The true meaning of Seebeck's and Peltier's discoveries was appreciated by scientists before the middle of the 19th century. Until the 1930s, however, attempts to apply them met with no success. This situation has changed radically in the last few years. What is it that has happened? What has ended the century-long sleep of thermoelectricity?

The prince who has awakened the princess is the semiconductor.

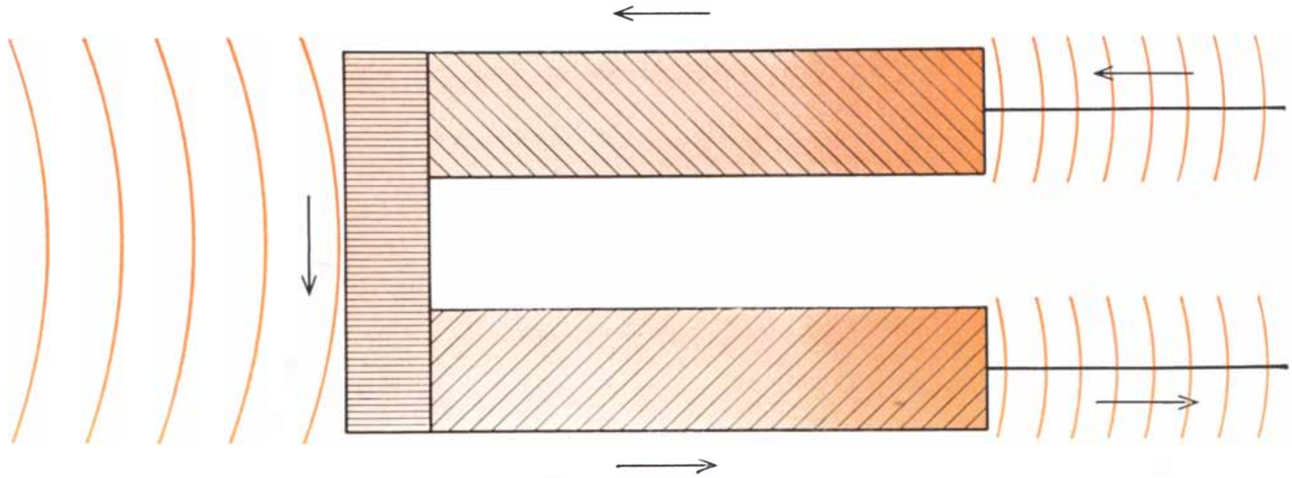
In 1926 a U. S. engineer named Lars O. Grondahl showed that an oxidized copper plate conducts an electrical current easily in one direction, but offers a very high resistance in the other. Thus if an alternating current is passed through such a plate, the current will flow for all practical purposes only in one direction. In effect the plate becomes a rectifier. Soon afterward it was found that, when such a plate is illuminated, a current is produced. The discovery of these properties in copper oxides attracted the attention of physicists to the large class of materials with low electrical conductivity which we now know as semiconductors. Investigation soon disclosed that such substances possess many other remarkable properties unknown in metals. Upon these properties are based the transistor, the solar battery and related developments in technology. In addition, it was found that thermoelectric effects are an order of magnitude larger in semiconductors than in metals.

This observation raises some fundamental physical questions that lie at the heart of future developments in thermoelectricity. Why is it that semiconductors have such a high thermoelectric advantage over metals, the "full" conductors of electric current? Why is it that semiconductors alone make thermoelectricity a fruitful realm of technology? Complete and exact answers to these questions require an excursion into quantum theory. One of the basic properties of this theory, however, is that it cannot be represented by a simple model. In attempting to make quantum theory easy to understand, we necessarily misrepresent it. For this reason I shall restrict this explanation to more familiar concepts that can be stated in the language of everyday experience.

We think of a current in a metal as the flow of electrons. In a metal each atom contributes at least one electron able to move freely within the metal. In semiconductors, on the other hand, only a very few atoms release such free electrons. The number of electrons available for current flow in a semiconductor is hundreds or thousands of times less than in a metal, and this accounts for the low conductivity of these substances.

When one end of a semiconductor—or a conductor, for that matter—is hotter than the other, electrons leave the hot end more often than they do the cold end. They tend to flow toward the cold end, and, since they are all negatively charged, the cold end soon becomes charged negatively with respect to the hot end. Now it is well known that like electric charges repel one another and unlike charges attract one another. The negatively charged cold end thus begins to repel the electrons flowing from the hot end. After a short time the flow of electrons from the hot end reaches equilibrium with the return flow from the cold end. The charges no longer accumulate, but the cold end remains negatively charged. The fewer the electrons available for the return flow, the higher will be the voltage attained at the cold end before equilibrium is reached. Since the number of free electrons is much smaller in a semiconductor, a temperature difference in a semiconductor will produce a much greater voltage than in a conductor. This is the essence of the thermoelectric advantage possessed by semiconductors.

Different semiconductors develop greater or lesser voltages. In all semiconductors the voltage increases with



PELTIER EFFECT, the reverse of the Seebeck effect (*opposite page*), makes thermoelectric cell act as refrigerating or heating unit. Electric input to the cell as shown here cools the junction at left, causing it to absorb heat, and heats the ends of the semiconductors at right, causing them to give up heat. By reversing the direction of the current the junction can be made to give up heat.

the difference in temperature between the hot and cold ends. The voltage across a given semiconductor when one of its ends is warmer than the other is the measure of its characteristic thermoelectric power, which is expressed in volts per degree centigrade. Semiconductors display thermoelectric power some hundreds of times greater than that of metals. But since metals develop only a few millionths of a volt, the thermoelectric power of semiconductors is still very small. Even when the difference in temperature of the two ends of a semiconductor is several hundred degrees, the semiconductor develops only 10ths of a volt. This, however, is enough to make thermoelectricity useful.

Semiconductors possess still another thermoelectric advantage not found in metals at all. In some types of semiconductor material the voltage differential between the hot and the cold end is set up not by the flow of negatively charged electrons but by the flow of positively charged "holes" vacated by electrons. As a result, the cold end in such a semiconductor becomes positively charged. The two types of semiconductor are designated as "*n*-type" (hot end positive) and "*p*-type" (cold end positive). In both types, of course, the direction of the current (electron flow) is from the positive to the negative end, as inside a battery [see "The Junction Transistor," by Morgan Sparks; Scientific American, July, 1952].

Let us now construct a thermoelectric circuit to generate an electric current. We take two semiconductors of opposite types, an *n*-type and a *p*-type, and join them at their hot ends [*see illustration on the opposite page*]. Between their cold ends we place a conductor through which we wish to pass a current. This conductor may be the armature of an electric motor, a lamp, an electrolytic bath to reduce aluminum, or any other device using an electric current. Let us assume that a high temperature is maintained at the hot junction, and that the cold ends of the semiconductors are maintained at a lower temperature. The current produced in the *n*-type semiconductor flows from the hot to the cold end, while that in the *p*-type semiconductor flows from the cold end to the hot. The current thus flows around the whole circuit, including the electrical device. Such a thermoelectric cell, it is true, yields only 10ths of a volt, whereas technological applications require dozens and hundreds of volts, *e.g.*, the 100 to 200 volts used in the home. To obtain these voltages in a thermoelectric generator we need only join hundreds of individual thermoelectric cells together.

The quality of a thermoelectric cell, however, is not only determined by the voltage it will produce. Two other factors must be taken into account: its electrical and thermal conductivity. If the voltage it produces is to be delivered as useful current, then it must have high electrical conductivity. The same is true of any other generator: we want the electrical power outside, where we can use it. On the other hand, if a thermoelectric cell is to convert a high percentage of the heat energy into electrical energy, it must have low thermal conductivity. The principal deficiency of thermoelectric cells, as contrasted with other heat engines, is that most of the heat supplied to the hot end flows directly and wastefully, by heat conduction, to the cold end. Thus the ratio between the useful electrical output and the heat input in a thermoelectric cell is low.

These three factors—the thermoelectric power and the electrical and thermal conductivity—are inherent in the semiconductor material. Temperature is another important factor; the higher the temperature of a cell, the greater its electrical output. One of the prime objectives of current research is to develop materials with high inherent thermoelectric quality that will withstand high temperatures. The best materials developed to date convert heat to electricity with an efficiency of about 10 per cent.

We may compare this to a steam-driven electric plant whose efficiency is about 30 per cent, or to a gasoline or kerosene engine with an efficiency upwards of 40 per cent. Clearly this comparison does not speak in favor of thermoelectric cells. But we have omitted the factor of time. We should recall that Seebeck's first thermoelectric cells had an efficiency of 3 per cent, just as high as the steam engines of their day. In the intervening century the efficiency of steam engines has been improved by a factor of 10, while thermoelectric technique—as represented by thermocouples made of metal—was permitted to drop backward by the same factor, to an efficiency of only .3 per cent. Semiconductors have now improved the situation somewhat. Thermoelectric cells today are not 100 times less efficient than steam engines, but only three times.

Is this the best we can do? Before agreeing that it is, let us consider the question from yet another aspect. Efficiency is an important characteristic of a machine, but it is not the only one. In order to obtain electrical energy from a steam engine, one must construct a furnace, a condenser, a steam boiler, a steam engine and a dynamo. This is complex and expensive equipment. A thermoelectric generator requires only a heater and a cooler; it has no moving parts. In many cases this advantage may more than compensate for lower efficiency, especially since an efficiency of 30 per cent can be obtained only from very powerful steam turbines. The efficiency of small steam engines may be as low as 10 per cent.

Thus for small power requirements, when one needs merely a few kilowatts of electricity, thermoelectric generators can compete with steam engines. For very low power requirements (as in radio, telegraph and telephone communications) thermoelectric generators provide the best engineering solution. And we must remember also that an efficiency of 10 per cent is not the limit for thermoelectric generators. The efficiency will increase significantly if one is able to go on to higher temperatures. If the temperature of the hot end could be raised to 600 degrees centigrade, for instance, the efficiency would go up to 18 per cent.

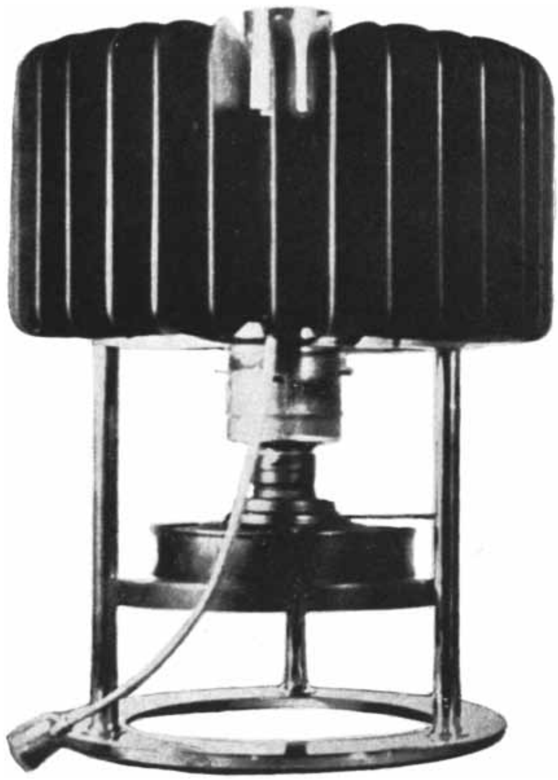
Even at their present efficiencies, however, thermoelectric generators are rendering effective practical service at many places that otherwise would be deprived of electric power. The thermoelectric generator shown in the illustration at left below obtains from the heat of an ordinary kerosene lamp enough electrical energy to power a radio receiving-set. Such thermoelectric lamps are being produced by tens of thousands in the U.S.S.R. and are in wide use.

Imagine someone living in the far north of our country, to whose dwelling such a lamp is brought. Although the snows and the tundra separate him from the rest of humanity, he is suddenly able to use a radio to hear the news of the day and music, and to learn about the life of his country. At our laboratory in Leningrad we receive moving letters from such hermits.

On the agricultural lands of the U.S.S.R. separate groups of farmers often work far apart. They are able to communicate with the farm headquarters by means of radio transmitters whose range is 30 miles or more. Such radio stations are supplied with electrical energy by thermoelectric generators which develop about 15 watts when heated by a kerosene stove. In isolated communities stoves heated by wood or some other local fuel can be used to generate from a few hundred watts to a full kilowatt for illumination or communication. At an output of one kilowatt this generator uses only 5 per cent of the heat supplied; the remaining 20 kilowatts or more of heat can be used to warm the pens of livestock.

And how much heat is expended uselessly! All heat engines give up more than half of their heat to the air, and this at temperatures at which thermoelectric generators could supply significant amounts of additional electrical energy. Let us recall, for instance, how hot the exhaust pipes of automobiles are. Anyone who lives in the modern technological world and is not without imagination can think of dozens of applications for semiconductor thermoelectric generators.

Of course our greatest source of heat now going to waste is the sun itself. Each square meter exposed to the sun receives power at the rate of about a kilowatt. Over the entire earth this adds up to about 100,000 billion kilowatts, a million times more than all of the electrical power produced throughout the world. In just a few days the sun supplies as much energy as can be recov-



THERMOELECTRIC TECHNOLOGY IN U.S.S.R. has produced the devices shown on these two pages. The kerosene-lamp chimney at left employs the Seebeck effect to generate enough electric current to power a radio. The three devices at right employ the Peltier

ered from all known coal and oil reserves, accumulated over billions of years. The plants responsible for this accumulation transform less than 1 per cent of the energy received from the sun into chemical reserves.

Solar energy indeed has its weak points. With 5 per cent efficiency, a million-kilowatt power plant would require an area of 10 square miles and would function only on sunny days and during daylight. The area necessary, however, is not a significant point; more important are the capital and maintenance costs. If a solar generator costs much more per kilowatt than a steam or hydroelectric plant, then solar generation of electricity is unprofitable. So far solar power plants, designed around conventional steam systems or around the most advanced solar batteries, have proved too expensive even on paper.

But let us now consider thermoelectric solar generators. Calculations and preliminary experiments indicate that small thermoelectric units are entirely feasible, even allowing for the cost of the large steerable mirrors necessary to concentrate the sunlight. Such units could be used to pump water from underground wells and irrigate desert land. This possibility strongly commends itself: irrigated deserts are the world's best gardens. It is still difficult to say anything about large thermoelectric solar plants. Yet one should never forget that a region with dimensions of the order of 100 kilometers could provide enough electric power for the whole earth. Perhaps thermoelectric cells will yet find their place in both the small- and large-scale exploitation of solar energy.

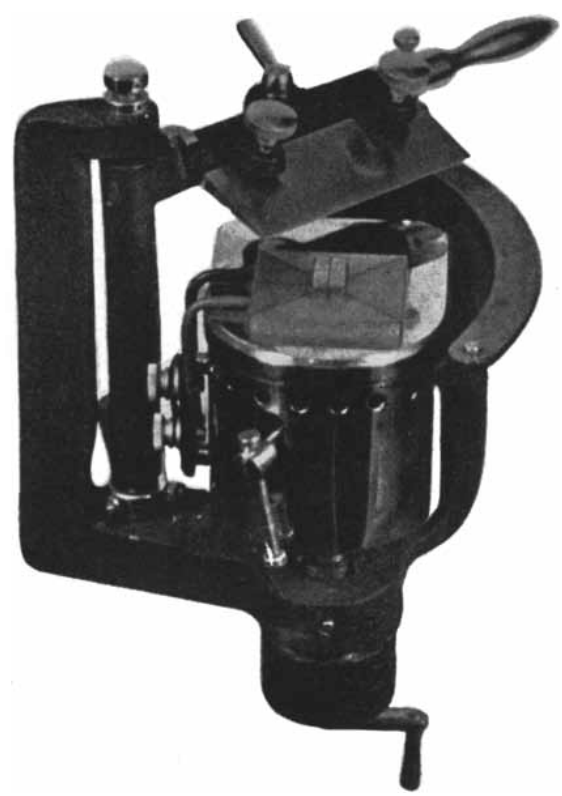
It must be pointed out, however, that the thermoelectric generation of electricity still faces many technical difficulties. The high temperatures necessary for good efficiency are harmful to semiconductor materials; oxidation reduces their thermoelectric quality and heat stresses tend to cause cracks. Low-temperature thermoelectric generators can be discussed with more confidence. A generator which we constructed 10 years ago, and which has been operated at room temperatures or lower, still has its original properties.

The transformation of heat into electricity is, of course, only half the story of the thermoelectric cell. It can transform energy the other way and, in doing so, serve the opposed functions of heating or cooling. To see how it does that, let us look again at the illustration on page 32. There, with the cell acting as a generator, the hot junction receives heat, while the cold gives off part of this heat. The remaining heat is converted to the electrical energy which produces the current flowing around the cell. What Peltier discovered is that the current which flows across the hot junction extracts heat from it and transfers this heat to the cold junction.

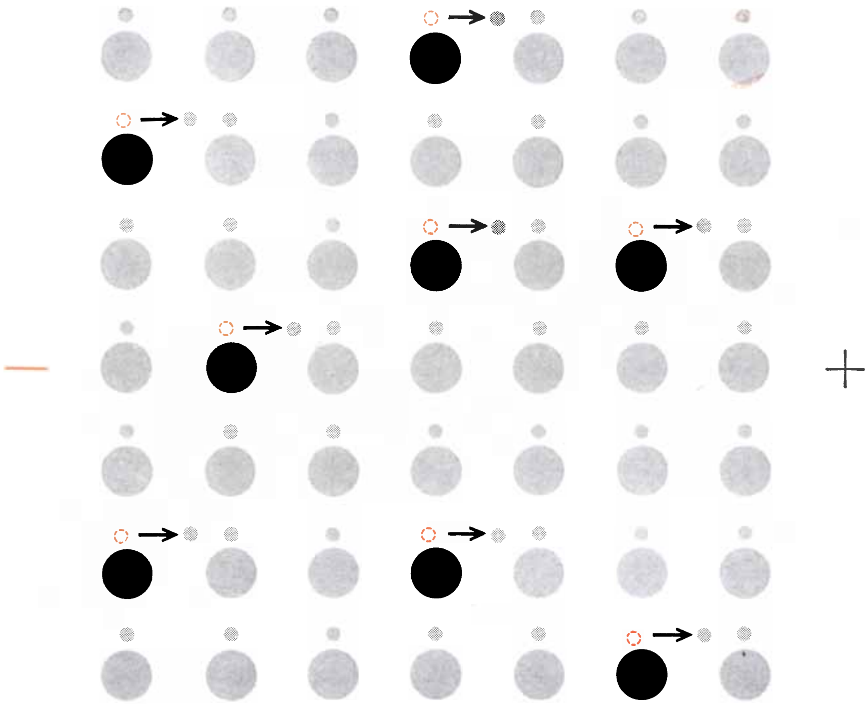
Now if we supply electrical energy instead of heat to the circuit and cause a current to flow through it, this current will necessarily extract heat from the hot junction and liberate heat at the cold junction. Thus the electric current will cool one junction and heat the other. This is the operating principle of thermoelectric refrigerators and heaters.

The thermoelectric refrigerators developed in our laboratories for domestic use have an efficiency approaching that of the more complicated and expensive refrigerators currently in use. Some of the conventional units use less electrical energy, but this is not particularly important, since the energy expended is not great. The cost of thermoelectric cells, moreover, runs considerably below the cost of electric motors and compressors.

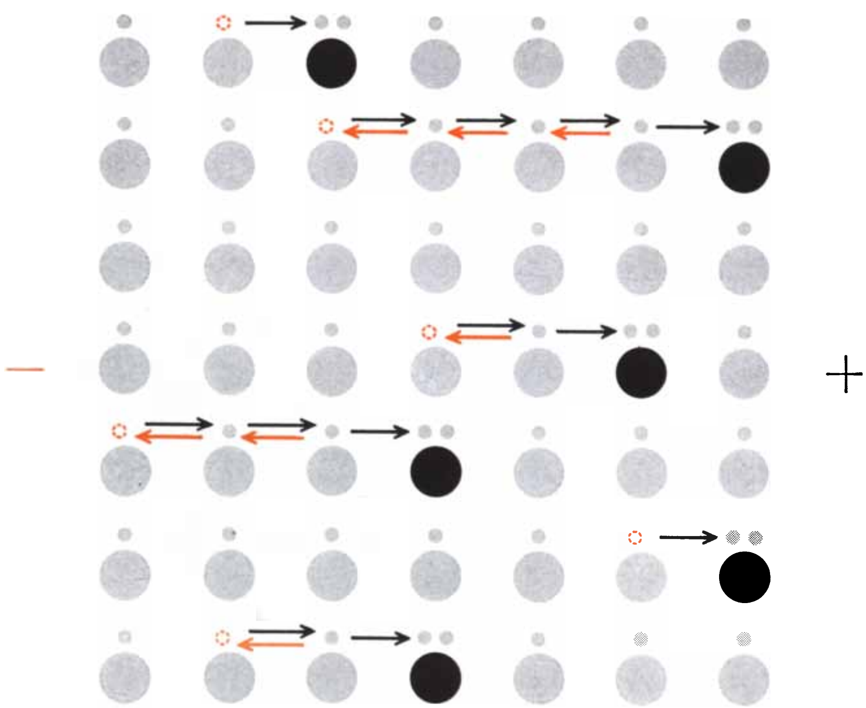
The cost of the cell, however, is not



effect for refrigeration. The domestic refrigerator second from left is the prototype of a mass-production unit. Third from left is a constant-temperature container for transporting biological specimens; at right is a microtome with a refrigerated specimen-holder.



N-TYPE SEMICONDUCTOR is a crystalline material composed of an element like germanium (*gray balls*) which has tightly bound electrons (*small gray balls*), plus an "impurity" element (*black balls*) which has loosely bound electrons that are free to conduct electricity. The free electrons are shown moving toward the right in the direction of the potential gradient. Positive "holes" (*colored circles*) vacated by electrons are stationary.



P-TYPE SEMICONDUCTOR material contains an impurity element (*black balls*) with fewer electrons than it needs to satisfy the bonds to its neighboring atoms in the crystal. Electrons from the neighboring atoms move in to satisfy the deficiency, leaving positive holes, which are in turn filled by other electrons. Thus the holes can wander through the crystal. Under an applied voltage their direction of motion is opposite that of electrons.

the whole story. A bigger item of expense is the heat-exchange system needed to remove the heat from the refrigerator. In addition, since thermoelectric cells operate on direct current, a rectifier must be used where power is supplied by alternating current. As yet it is hard to predict what thermoelectric refrigerators for the home will cost when they are mass-produced. The prospects are, however, very hopeful.

When it comes to large-scale refrigeration, as in the food industry, the thermoelectric cell does not compete successfully with mechanical systems. Here the amount of energy consumed is far from immaterial, and modern machines use it with greater efficiency than any thermoelectric cell so far developed or in prospect. We must therefore assume that the applications of thermoelectricity to refrigeration will be restricted to those cases in which it is more important to avoid complex machinery than to keep down the amount of electrical energy expended.

There are many such cases. Although it is easy to obtain heat from an electric current, to use it for cooling has always required electric motors and compressors. But where is this bulky gear to be placed if, for instance, one would like to be able to vary the temperature of an object observed under a microscope? A small microscope stage provided with thermoelectric refrigerating cells requires only a few watts to lower the temperature of the specimen down to 50 degrees below zero centigrade, or, by changing the direction of the current, to raise it to 80 degrees above. This provides the biologist and the chemist with a much-needed facility. Another useful device is a rod that is cooled or heated by thermoelectric cells. As soon as a current is passed through it, frost appears on its surface, and in a minute or two the temperature drops to 30 degrees below zero. This rod can be used to cool any object, such as the skin of an animal or the air in a small box. Changing the direction of current quickly heats the rod, and water boils on its surface. If something has to be heated or cooled, it cannot be done more conveniently than by this device. The stronger the current, the greater the temperature change in both cases. Moreover, the temperature is subject to precise control, to within .001 degree.

We now have about 30 thermoelectric devices for various purposes, and they are all useful. It is hardly worth enumerating them. Rather I would call on the ingenuity of the reader; he will undoubtedly be able to think up 30 other applications!

Instead, I should like to direct the reader's attention to still another aspect of the matter: namely, heating by means of thermoelectricity. What occurs is at first glance unexpected. In order to heat a room with an ordinary electric heater at the rate of a kilowatt, the heater must also use up electrical energy at the rate of a kilowatt. But if thermoelectric cells are used for this purpose, the expenditure of half a kilowatt or less will yield the same result!

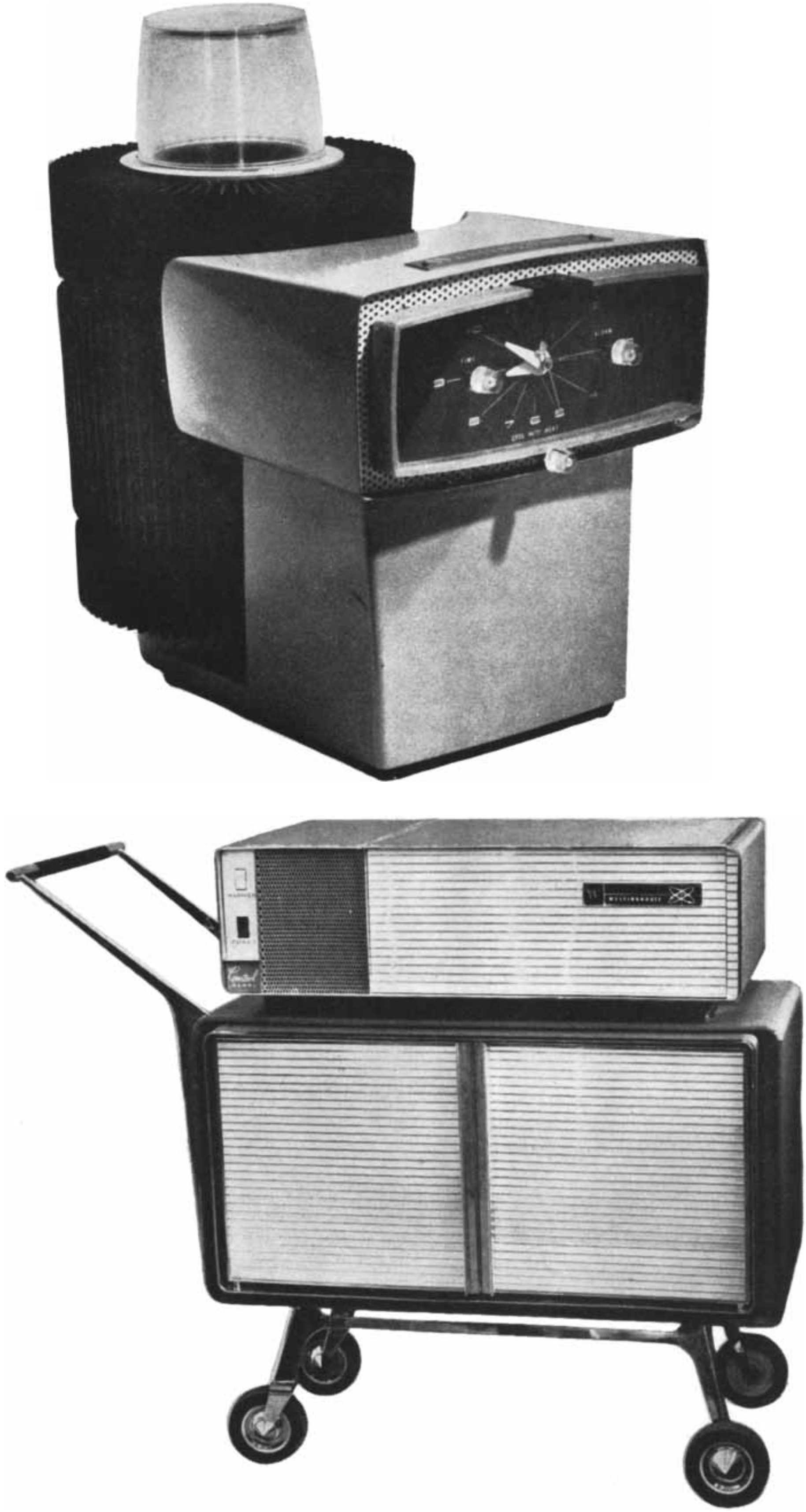
One might think that thermoelectric cells shake the very foundation of science: the law of conservation of energy. But of course this is not so.

This extra heat supplied to the room is not created from nothing, but is transferred from a colder source, such as from the water supply. The thermoelectric cell, acting as a "heat pump," removes heat from the water, and transfers this heat to the room together with the heat supplied by the current. Even though the heat reservoir may be at a low temperature, its heat can be delivered at a higher temperature by means of thermoelectric cells. The less the temperature difference between the reservoir from which the heat is removed and the warm one to which it is supplied, the less electrical energy is needed. At a temperature difference of 10 degrees our thermoelectric cells can transfer heat with an expenditure of one fifth of a kilowatt for every kilowatt delivered; at a temperature difference of 20 degrees the energy expended goes up to one third of a kilowatt, and at 30 degrees to one half a kilowatt. Mechanical heat pumps used for this purpose have always been extremely complicated.

On this note we shall cease enumerating the devices which have already been developed and which may yet be developed from semiconductor thermoelectric cells.

If in disappointment the reader says, "Why nothing has yet been done," let him remember that the pace of modern ideas is constantly accelerating. Aviation and radio have grown rapidly and moved forward briskly. Cinema and television have unfolded even more quickly.

Now thermoelectricity is unfolding before our eyes. It is only in the last two or three years that this field has been opened. Let us see what will happen in the next three to five years!



THERMOELECTRIC TECHNOLOGY IN U. S. has produced these prototypes of products recently publicized by Westinghouse Electric Corporation. Clock-controlled bottle-warmer (and cooler) at top and hostess cart at bottom use Peltier effect for refrigeration and heating.

"TRANSDUCTION" IN BACTERIA

A virus can transfer genetic material, and thereby hereditary traits, from one bacterium to another. The phenomenon sheds light on the behavior of viruses and the mechanism of heredity

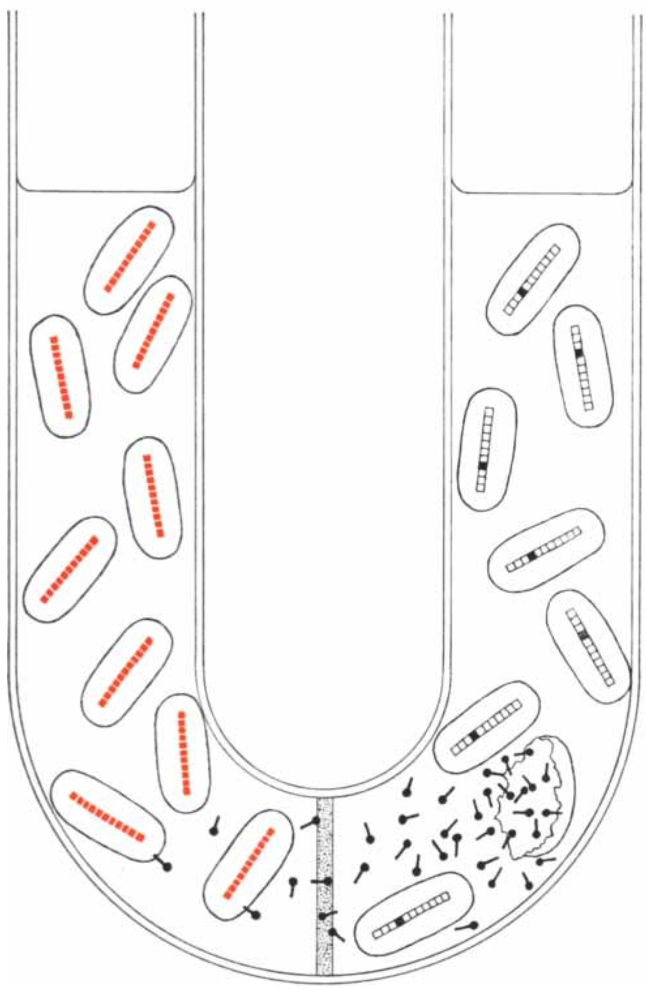
by Norton D. Zinder

Viruses first made their existence known as especially tiny germs that cause disease in animals and plants. Then it was discovered that a virus can multiply itself only inside the living cell; the new viruses are released, and the cell dies. During the time it is inside, the virus vanishes in the biochemical system of its host, so that its activities there have been largely obscure. Bit by bit, however, the life story of the virus is being pieced together. As the parts fall into place, the virus is assuming a new identity. From the point of view of the biologist the germ has become a valuable ally in the exploration of the life processes of the cell.

Geneticists have found viruses particularly useful as a means of getting at the mechanism of heredity. The typical virus is a bit of genetic material encapsulated in a protein coat. As such it may affect the genetics of its host in important ways. This was first observed in the case of viruses that infect bacteria. At times these viruses cause a latent infection; they do not kill their host but become a part of its genetic apparatus. The latent virus then acts like a bit of the bacteria's genetic material and induces new traits in its host. In this role it may be reproduced through many generations along with the bacteria's own genes before it resumes its existence as a separate virus. It is such a latent virus infection which causes the normally innocuous diphtheria bacillus to make its lethal toxin.

This article is concerned with a discovery which implicates the virus even more deeply in the genetic processes of its host. It now appears that a bacterial virus can carry the bacteria's own genes from cell to cell. Like a disease carrier, it infects one bacterium with hereditary material picked up from another.

This "transduction" of bacterial heredity was discovered by accident and good luck in an investigation that was at first not concerned with viruses at all. The discovery occurred during an attempt to induce sexual mating in the bacteria which cause a disease in mice resembling typhoid fever in man. Mating is a rare process in bacteria. A bacterium ordinarily multiplies simply by dividing into two cells, each of which usually has the same genetic constitution as the other. In 1946, however, Joshua Lederberg and Edward L. Tatum (then at Yale University) found that a bacterium in one strain of the bacillus *Escherichia*



U-TUBE EXPERIMENT led to discovery of transduction. At bottom of tube was a filter. On left side of filter was one strain of the bacterium *Salmonella typhimurium*; on right side, another strain. The strain at right harbored "latent" virus (*small black square on* *coli* could mate under certain conditions with a bacterium in another strain of the same species, and thus give rise to bacteria with some characteristics of both strains. There seemed to be no reason why *E. coli* alone among bacteria should have the ability to mate, so in 1949 Lederberg and I (then at the University of Wisconsin) undertook to induce mating in another species.

For our first experiment we chose two strains of the mouse-typhoid bacterium, *Salmonella typhimurium*. Each strain lacked the capacity to synthesize a particular amino acid needed for its growth, but was able to make the amino acid which the other strain could not produce. If mating occurred, some of the offspring should be able to synthesize both factors; they could then be isolated by transfer to an agar medium that did not contain either of the two amino acids. On such a medium the parent strains would not be able to proliferate, but the new cells would form visible colonies in a few hours. Accordingly we mixed cells of the two parent strains and spread them on the selective agar. Colonies of the new type of cells appeared; apparently we had succeeded in mating *Salmonella*.

To be sure that the new cells were the product of mating, we tried to mate strains that were distinguished from each other by more than one trait. The offspring of bacterial mating may combine genes from their two parents in any proportion. We could therefore expect to find a variety of new cells, some more like one parent and some more like the other. We were surprised to find, however, that the offspring of these matings all resembled one parent, except for the trait by which they were isolated and which was supplied by the other parent. The transfer of only one trait at a time was not consistent with the idea of a mating process. Furthermore, one of the two strains always acted as the donor, and the other as the recipient, of the genetic trait.

We considered first the simplest alternative: the change was merely a random mutation. But this possibility had to be rejected because the change appeared much more frequently in mixed cultures of the parent strains than in unmixed cultures. Nor could it be an increase in the mutation rate in the mixed cultures, for the new trait of the recipient strain was always related to traits of the donor strain. We concluded that we had stumbled upon an instance of bacterial "transformation." In this process the genetic traits of one strain of bacteria are transformed by contact with the genetic material of another strain. No contact between the cells is necessary. In familiar instances of transformation, in fact, the cells of the donor strain are dead, and their genetic material—the deoxyribonucleic acid, or DNA, contained in their chromosomes—is released into the culture medium. The recipient strain incorporates some of this free DNA into its chromosomes, and thus acquires traits of the dead strain [see "Transformed

schematic chromosome*). Occasionally one of these bacteria released live viruses (*tadpole-shaped objects*) which passed through filter (*first drawing*). In strain at left the viruses multiplied rapidly (*second drawing*). Some of the viruses (*colored*) carried bits of genetic material of the strain at left back through the filter to become part of genetic material of the strain at right (*third drawing*).

VIRUS PARTICLES used for transduction of *Salmonella* are enlarged some 60,000 diameters in this electron micrograph made by Keith R. Porter of the Rockefeller Institute.

Bacteria," by Rollin D. Hotchkiss and Esther A. Weiss; SCIENTIFIC AMERICAN, November, 1956]. Though well-established in certain species of bacteria, transformation had never been observed in *Salmonella*.

To test the transformation hypothesis, we now grew our two *Salmonella* strains in a specially constructed U-shaped tube. One strain was grown in one arm of the tube; the other strain, in the other arm. Between the two arms was a filter which prevented mating contact between the two strains [*see illustration on pages 38 and 39*]. To promote the exchange of substances secreted by the two strains, we gently flushed the nutrient broth from one side of the tube to the other. When the two strains were transferred to a selective medium, some offspring of the recipient strain showed a new trait picked up from the donor strain. Transformation seemed to be the answer. We then performed a more conventional transformation experiment, treating the recipient culture with pure DNA extracted from the donor strain. This, unexpectedly, had no effect at all. With our hypothesis now shaken, we went back to the U-tube. This time, with the idea of eliminating the possibility of transformation, we added an enzyme which destroys free DNA. In spite of the presence of the enzyme, genetic changes appeared just as before. We were obliged to discard transformation as well as mating, and to look for another explanation.

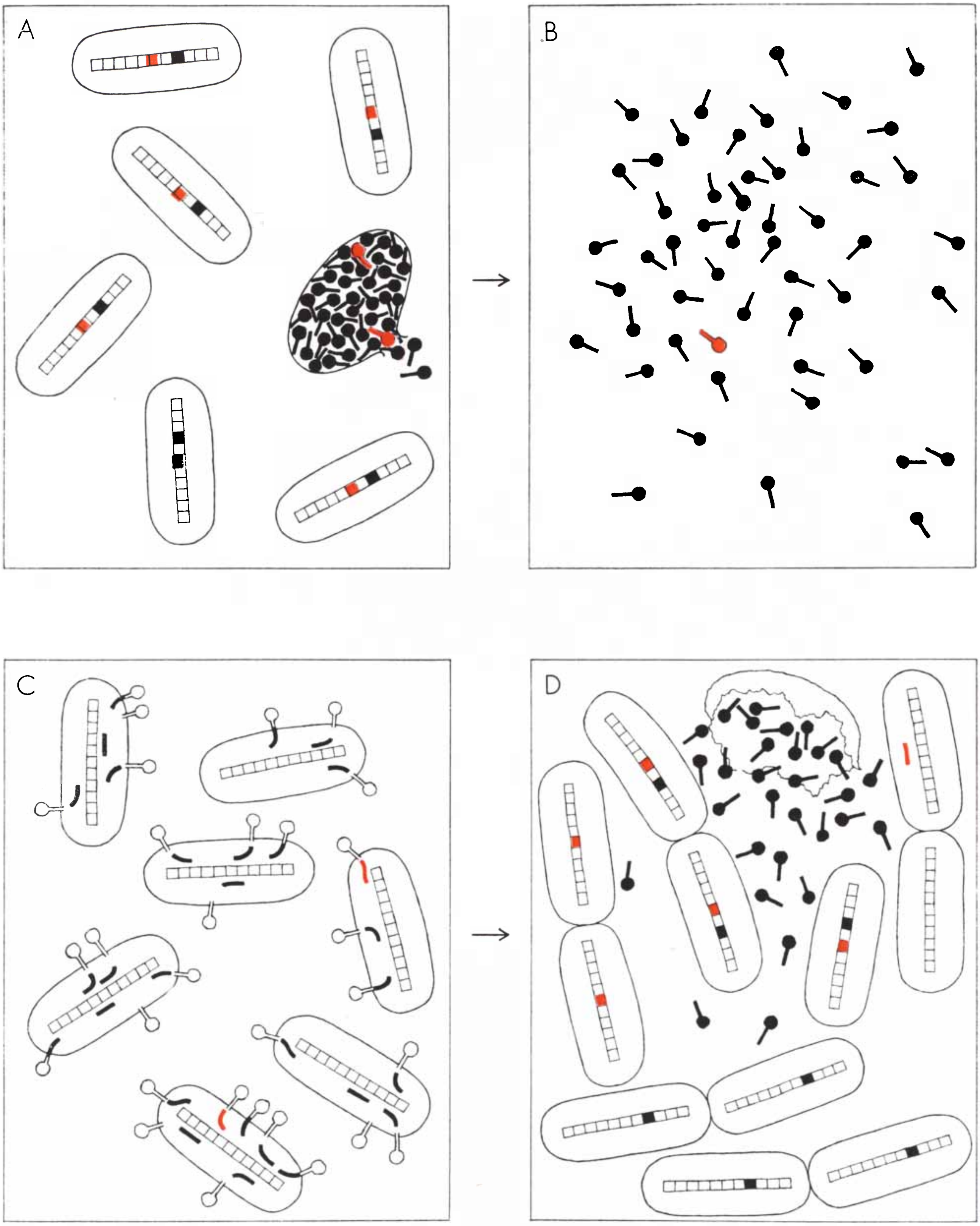
What could be happening in the U-tube? The donor bacterium passed its genetic material to the recipient in pieces small enough to pass through the filter, but the pieces were not damaged by the DNA-destroying enzyme. Both parents had to be present for the transfer to take place, but they did not have to be in direct contact. We wondered whether the donor perhaps gave off something other than DNA which could affect the heredity of the recipient. To test this idea, we added broth filtered from a culture of donor cells to a culture of recipient cells. No heritable changes resulted. However, when we grew the two strains together and filtered the broth, this fluid did produce changes in a fresh culture of recipient cells. At this point we realized there were two steps in the process: first the recipient had to produce something to stimulate the donor, and then the donor could send genetically active material back to the recipient.

Now we made a further discovery: once a culture of donor cells had been stimulated by exposure to fluids from the recipient strain, the fluid from this culture could stimulate other donor cells. The stimulating material was somehow reproduced in the donor bacteria. This reproductive capacity made us think of bacterial viruses. Viruses are small enough to pass with ease through the filter in the U-tube, and the protein coat of the virus protects its DNA from the enzyme which destroys free DNA.

The most familiar bacterial viruses are so destructive that an infected culture virtually disappears before your eyes. Obviously we would have noticed a virus of this type immediately. The "temperate" virus that causes a latent infection is harder to detect. Killing off only a small fraction of the cells, a latent infection may scarcely change the density of a culture. But occasionally one of the latent viruses regains its original form, multiplies in the cell and bursts forth to invade others. As a result a little free virus is always present in a culture of bacteria harboring a latent infection.

Sure enough, when we looked for viruses in cultures of donor *Salmonella* which had been treated with stimulating fluids, we found large numbers of virus particles. Further experiments indicated that virus activity and stimulating activity went hand in hand, and confirmed the fact that the virus was the stimulating agent.

It was but one step further to the theory that the viruses also acted as carriers of genetic material from donor to recipient bacteria. We hesitated to take this step, for the theory implied too much. It suggested, for example, that the



TRANSDUCTION requires first (A) a culture of donor cells which is infected with virus. Liquid filtered from this culture contains viruses (B), some of which carry genetic material from the bacteria (*colored*). Another strain of bacteria can be infected with this virus (C). Some of them (D) then produce more virus (*top*), some acquire genes of the donor bacteria (*colored square*), some acquire the genes of latent virus (*black square*), and some receive both. Occasionally a cell takes in a bacterial gene but does not incorporate it into its chromosome (*upper right*); gene is not duplicated when cell divides, so only one daughter cell receives it.

viruses of human diseases may carry genetic material from one host cell to another. But no other theory could explain the compelling evidence that the bacterial virus and the carrier of the genetic material from the donor to the recipient bacteria were identical in physical, chemical and biological properties.

The *Salmonella* mystery was now easily resolved. One of our two strains (the recipient) carried a temperate virus as a latent infection. The second strain (the donor) was especially susceptible to this virus. When the two were mixed, an occasional infective virus developed in the recipient strain and invaded a cell of the donor strain. When the offspring viruses erupted from the dying cell, most of them had genetic cores of virus DNA synthesized from the substance of the bacterial cell. But some of them incorporated particles of *Salmonella* DNA unchanged in their genetic cores. The normal viruses went on to cause infections in other bacterial cells, active or latent depending upon the strain of the bacteria. Those that carried bacterial DNA and invaded the recipient strain of bacteria brought about entirely different consequences. Instead of killing their host, they simply disappeared. The DNA they brought with them took its place in the chromosomes of the recipient cell and modified the nutritional or other characteristics of the cell's offspring.

It was pure chance that one of the strains chosen for our studies contained a latent virus, and that another was susceptible to this virus. We had certainly not expected to encounter a new genetic mechanism, and, considering the many factors that had to be in harmony, the discovery was extremely fortuitous.

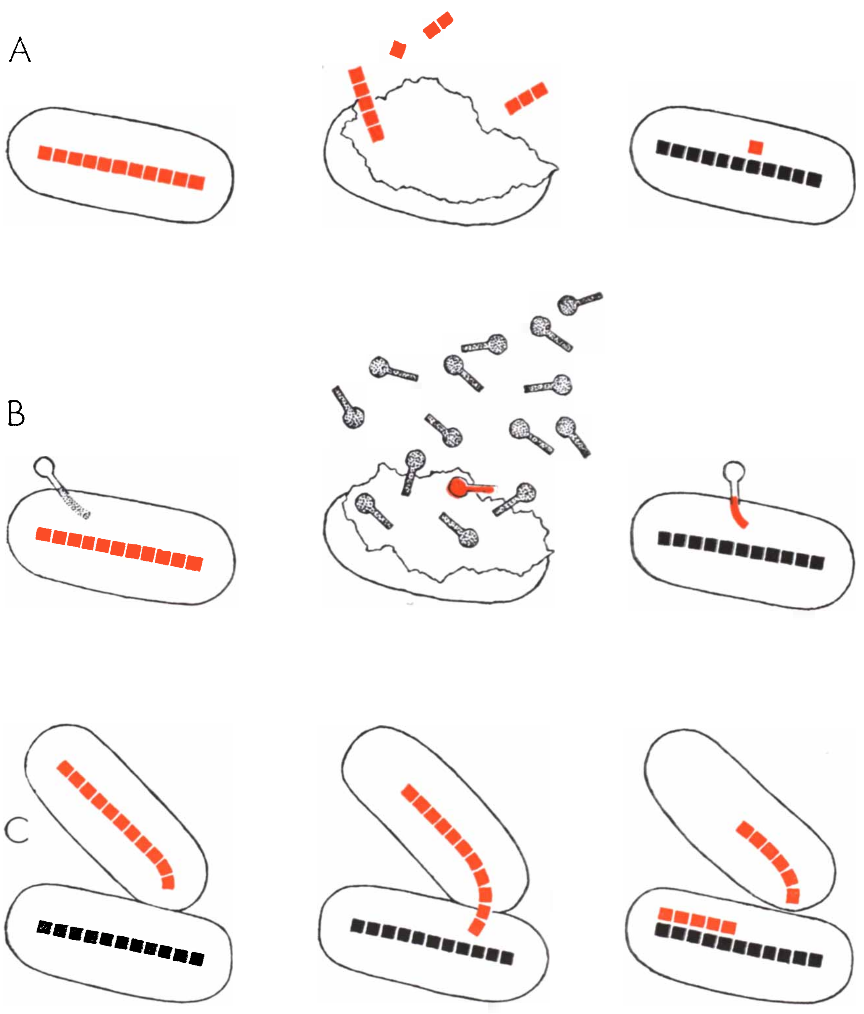
In some ways the transduction of genetic traits by a virus closely resembles latent infection by a virus. The difference between the two processes lies in the nature of the genetic material carried by the virus, whether it is DNA picked up from a bacterial chromosome or true virus DNA. The DNA in a virus of a given strain has the same composition as the DNA in other viruses of the same strain. In latent infection this DNA will always take the same station in the host cell's chromosome, and will induce the same change in the characteristics of the host cell. The traits associated with latent virus—a new synthetic capacity or a change in the cell wall—appear in every cell harboring the virus. If the bacterial cells lose the virus genetic material, as evidenced by the disappearance of free virus from the culture, they simultaneously lose the trait associated with the virus.

On the other hand, the bacterial DNA carried by the virus may vary in composition, and each kind of DNA may be capable of producing a different trait. The properties of this DNA do not depend on the virus at all, but only on the bacterium from which it came. In the virus's new host, the bacterial DNA takes a station in the chromosome corresponding to the position it had occupied in the chromosome of the previous host. Only a very few of the cells in a culture will gain traits by transduction, but once incorporated such traits remain even after the strain loses the virus DNA.

Actually the transduction of a new trait to a bacterium is not always accompanied by a latent infection. Conversely a virus can take the latent form in a bacterium without establishing a transduction. Whether one virus particle can produce both effects is uncertain; a given cell is usually invaded by more than one virus. It is quite possible that a virus must lose some of its own DNA in order to acquire bacterial DNA, and as a result it may no longer be able to produce an active infection.

The piece of DNA that is picked up by the virus must be very small indeed. It was thought for a time that this fragment might correspond to a single gene unit, since a virus particle appeared to transfer just one bacterial trait at a time. In the course of our work, however, we discovered several traits which the virus regularly transfers in pairs. The piece of DNA carried by a virus must therefore be large enough for at least two genes, the two presumably lying adjacent or closely linked in the chromosome.

Studies of the swimming ability of



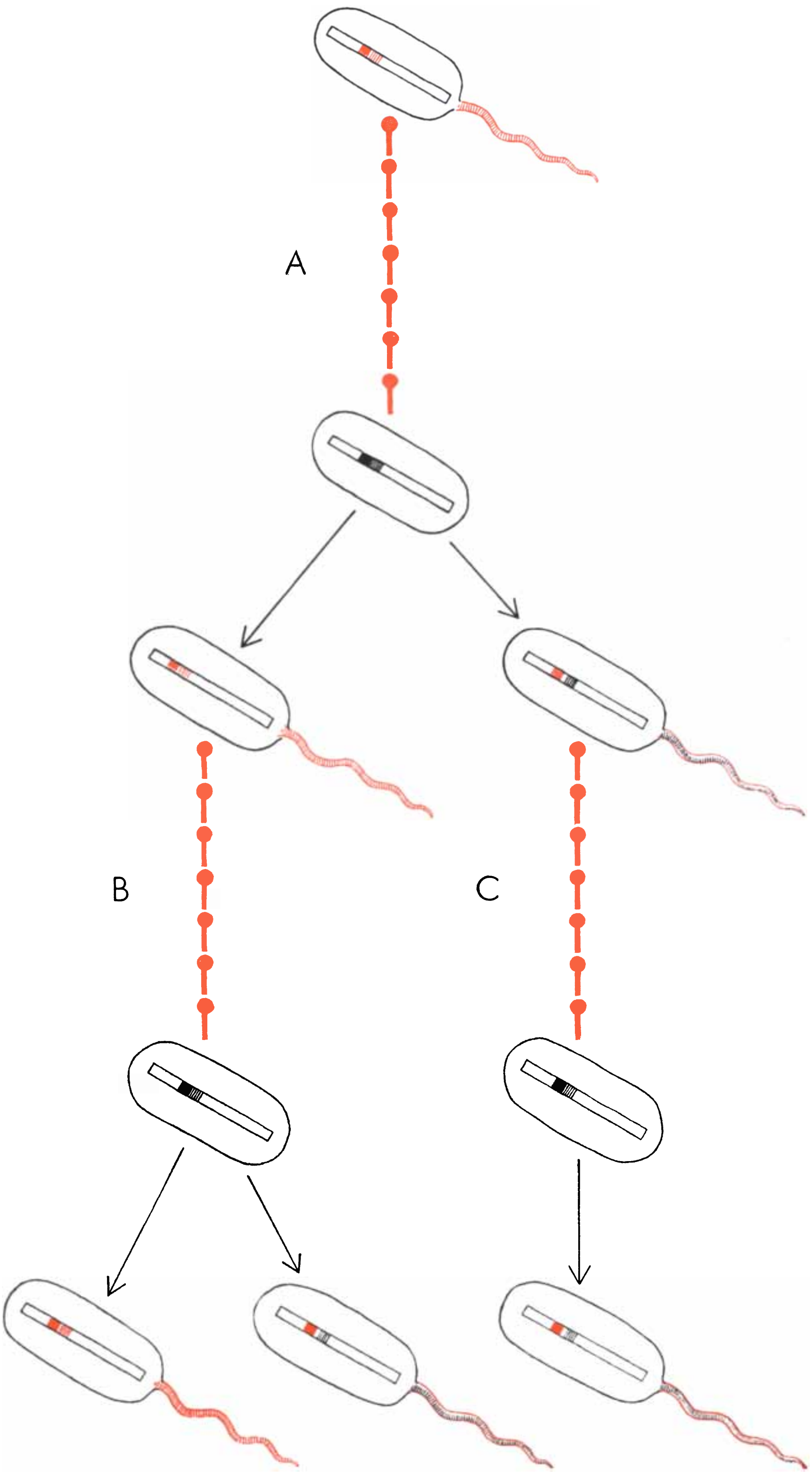
THREE METHODS of transferring genetic material from one bacterial cell to another are known. In "transformation" (A) the cells are disrupted to free the genetic material (*colored*), a small bit of which may then enter another cell. In transduction (B) viruses which can infect the cells carry genetic material from one to another. In mating (C) the material is passed by direct contact of cells, and a greater quantity can be transferred at one time.

Salmonella led us to the first pair of linked genes. Some *Salmonella* strains have whiplike tails (flagella) with which they can swim through liquids or semisolid gelatins; others have no tails and cannot move. The tailless bacteria stay put and grow into colonies wherever they are placed, but the others swim off and spread in a cloudy swarm throughout the culture medium. The swimming strains are of different types, distinguished by the proteins of which their tails are made. We found that the ability to swim depends on two genes—one to determine whether or not the tail is made, and the other to determine the specific protein of which it is made. A tailless cell may already have a dormant gene for a kind of tail protein; if it acquires a gene for tail-making by transduction, it will make a tail of the protein type determined by its own gene. Almost as often, we found, the tailless cell will pick up a new gene for tail protein along with the tail-making gene; as a result it produces a tail of the donor's type instead of its own. The new genes introduced by transduction push out the corresponding genes in the bacterial chromosome and take their place.

The linkage between genetic traits revealed by transduction offers a clue to the linkage of the genes in the structure of the chromosomes. Transduction thus promises to be a useful tool in the important task of "mapping" chromosomes.

Bruce Stocker, a British bacteriologist, has demonstrated an abortive mode of transduction. The transducing DNA does not, in this case, replace a gene in the chromosome of the recipient cell, but by its very presence it induces a new trait. When the cell divides, however, the new gene is not duplicated, and only one of the daughter cells exhibits the trait. Stocker made this interesting discovery in an investigation of the swimming trait, when the recipient cells produced a trail of colonies rather than a spreading swarm. The colonies along the trail consisted entirely of tailless cells. But the trail had been laid by the swimming daughter cell which moved on to the next site after each division.

It seems possible to move any heritable trait from one cell to another by transduction. We have succeeded in transducing almost every trait we can reliably detect by experiment, including drug resistance, motility factors and antigenic factors. Transduction has been demonstrated in many kinds of *Salmonella*, in related species and in mating strains of *E. coli*. But ironically no one has succeeded in mating *Salmonella*.



TRANSDUCTION TO MOTILITY revealed that two genes, presumably linked in the bacterial chromosome, can be carried together in a virus. Virus (A) from a culture of tailed cells (*top*) was used for transduction of untailed cells. Two types of motile cells resulted: some (*right center*) had received only the gene for tail-making and made tails of the protein type for which they already had a latent gene; an equal number (*left center*) had tails like the donor because they had also received a tail-protein gene. Transductions of untailed cells were repeated with virus from each of the new types of cells. One (B) gave rise to two types of tailed cells; the other (C) produced only one type of tailed cell.

Stellar Populations

Fifteen years ago Walter Baade observed that stars are divided into two populations. His concept opened up a broad field of study, and now astronomers classify stars into five populations instead of two

by Margaret and Geoffrey Burbidge

During the fall of 1943 there were a few nights of almost ideal observing conditions at the Mount Wilson Observatory. The air was exceptionally steady, the temperature nearly constant and the surrounding valley lay in the darkness of the wartime blackout. Walter Baade of the Mount Wilson staff seized the opportunity for another try at a long-standing problem—to photograph separate stars in the central region of the great spiral nebula in Andromeda. All previous photographs with the 100-inch telescope on Mount Wilson, the most powerful instrument then available, had shown this region only as a hazy blur of light.

The combination of favorable circumstances and of Baade's great technical skill and ingenuity was successful. His now-famous plates revealed that the blur was actually a dense mass of faint, reddish stars. He also succeeded in resolving stars in the two small companion nebulae of the Andromeda nebula: M 32 and NGC 205. As Baade himself has explained in SCIENTIFIC AMERICAN [see "The Content of Galaxies"; September, 1956], a study of these newly resolved objects suggested that all stars are sharply divided into two classes: one, which Baade called Population I, whose brightest members are hot, blue stars; and one, which he named Population II, whose brightest stars are cool and red, but very large. He concluded that the stars of Population I were relatively young, while the stars of Population II were quite old. Most of the stars near the sun, and those which had long been visible in the arms of the Andromeda spiral, fell into the first group; those in the central region of the Andromeda nebula, and in the so-called globular clusters of our own galaxy, into the second.

After 15 years of investigation our picture of stellar populations has grown less simple and perhaps less surprising. Instead of supposing that all stars fall into just two groups, widely separated in age and location in the galaxies, we now believe that there is a more nearly continuous spectrum of ages, from very ancient stars to those still in the process of birth. We still divide them into classes, but these are more numerous, and one tends to merge into the next. To appreciate how the current view has developed, let us retrace the steps since Baade's original findings.

The brightest stars in his Population I are bluish white, with surface temperature of some 30,000 degrees absolute, and the brightest of them shine with the brilliance of 100,000 suns. As we have said, the great majority of stars near the sun seemed to belong to this group, as do the stars which had been resolved on photographs of the arms of the Andromeda nebula and other nearby spiral galaxies.

On the other hand, no members of Population I were found between the arms or in the central regions of spiral galaxies, or in the so-called elliptical galaxies, which have no spiral arms. In these regions the brightest stars (in Baade's Population II) are 50 to 100 times fainter than those in Population I, and their surface temperatures are relatively low—only 3,000 or 4,000 degrees. Their color is distinctly red, and Baade was struck by their similarity to the brightest stars in the globular clusters of our own galaxy. These dense clusters, each containing some 100,000 stars, are distributed around the galaxy in a roughly spherical volume [*see illustration at top of page 49*].

Thus far we have spoken only of the brightest stars in the various regions. Each population also contains a whole array of fainter members, which seemed to fall into the same population grouping. All these stars can also be classified in another way: by means of the well-known temperature-luminosity diagram, in which intrinsic brightness is plotted against temperature. When this is done, the stars fall into a well-defined pattern, with the two populations occupying different parts of the diagram [*see illustration on page 47*]. The band running from upper left to lower right is known as the "main sequence." There are Population I stars along its entire length, but members of Population II are found only below a certain point near the middle.

Now it is known that the brightness of stars on the main sequence depends on their mass. In fact the brightness increases as the square of the mass at the lower end of the main sequence, and as the third or fourth power at the upper end. If one star has twice the mass of another, it will be four to 16 times as bright. But the mass of a star is a measure of the amount of fuel it has available to burn in the thermonuclear reactions which produce its radiant energy, and the brightness is a measure of its rate of burning. Therefore the lifetime of the star (the time required to consume all of its nuclear fuel) is proportional to the

LUMINOUS CLOUD of interstellar matter in the constellation of Scutum Sobieski was photographed with the 200-inch telescope on Palomar Mountain. The matter is made luminous by the hot young stars of Population I embedded in it. In such regions stars are probably being formed at the present time. Small dark patches of dense matter can also be seen; some of them may represent an early stage in the formation of stars.

GREAT NEBULA IN ANDROMEDA was photographed by the 48-inch Schmidt telescope on Palomar Mountain. The arms of this spiral galaxy, the disk of which is seen at an angle, are outlined by the dark lanes that lie between them. Population-I stars are found in the arms; Population-II stars, in the bright central region. The small blobs above and below the disk are small satellite galaxies.

mass divided by the brightness. Because brightness increases so much more rapidly than mass, the bright, hot stars at the upper left in the main sequence must burn themselves out much faster than the fainter stars do. In fact, the brightest and hottest appear to be less than a million years old.

Thus Baade's Population I contains relatively young stars. They are so young as a group that some must even now be in the process of formation. Indeed, we can probably see this happening in our own galaxy. There are some faint, irregularly flickering stars in the Great Nebula in Orion whose unsteadiness is almost certainly due to their youth. They have not settled down to an orderly existence on the main sequence. Some of them may even be growing yet, drawing to themselves more of the surrounding gas and dust.

We can now understand why Population I stars exist only where Baade found them, in the spiral arms of galaxies. Formed recently, they have not had time to move away from the region containing the raw materials out of which they were made. And for some reason, probably having to do with magnetic fields, interstellar gas and dust are concentrated in spiral arms. Between the arms and in the central parts of spiral galaxies, as well as in the whole of elliptical galaxies, there is no dust and very little gas.

These regions are the domain of Population II. There is good reason to suppose that they have been dust-free for a very long time, and so all the Population II stars must be quite old. It is easy to see, then, why their main-sequence members extend only to stars slightly brighter, and about 20 per cent heavier, than the sun. All the brighter ones that must have been on the upper part of the main sequence came to the end of that phase of their lives long ago, and there has been no material to make replacements.

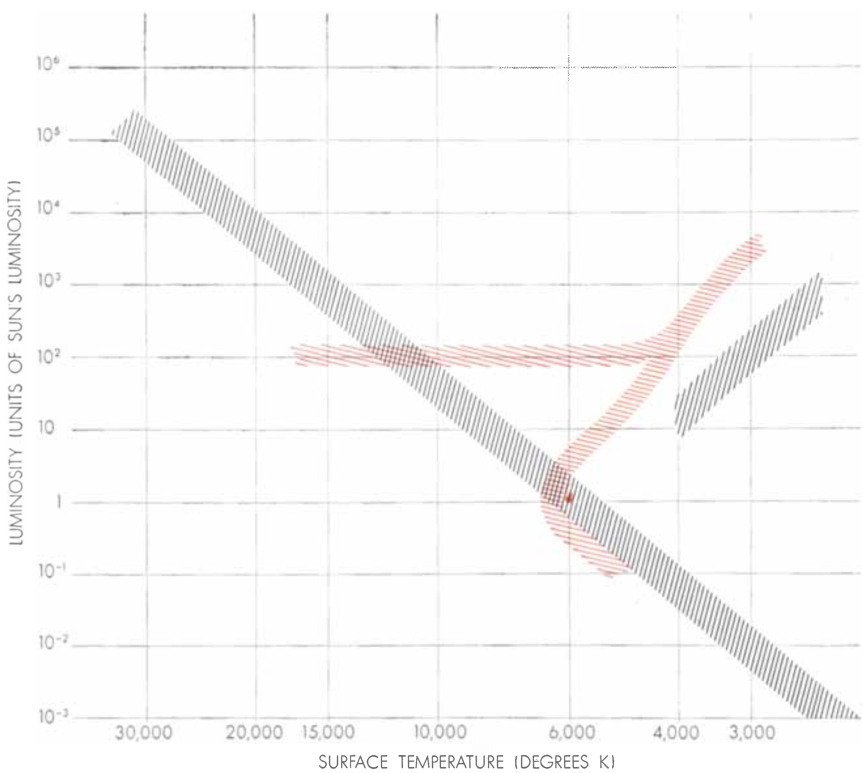
How does a star leave the main sequence? Theories of the nuclear reactions in stars show that most of their hydrogen is consumed and converted to helium deep in their interiors. As time goes on, the core in which the hydrogen has been totally consumed grows larger and larger. When the core comes to contain about a 10th of the whole mass of a star, the star's internal structure becomes unstable. To restore equilibrium its material must be rearranged. In the process the star expands fairly quickly, and its surface layers cool; it becomes a "red giant." This is what has happened to the red stars that are the brightest members of the globular clusters, and to those which appear on Baade's photographs of the Andromeda nebula and of its companions.

Eventually a red giant uses up all the nuclear fuel in its center and comes to the end of its life as a normal star. Then it may become a supernova, disintegrating in a giant thermonuclear explosion, or it may suffer a series of lesser explosions known as nova outbursts. Such must have been the fate of the bright stars of Population II. In Population I there are also some red giants, but they are about 15 times less bright than those of Population II. Examination of their spectra has shown that the chemical compositions of the two types of red giants are not the same. In the Population II red giants the heavier elements such as calcium and iron are only about one one-hundredth as abundant with respect to hydrogen as they are in the red giants of Population I. Thus the members of Population II must have been made out of material that was relatively poor in the heavier elements.

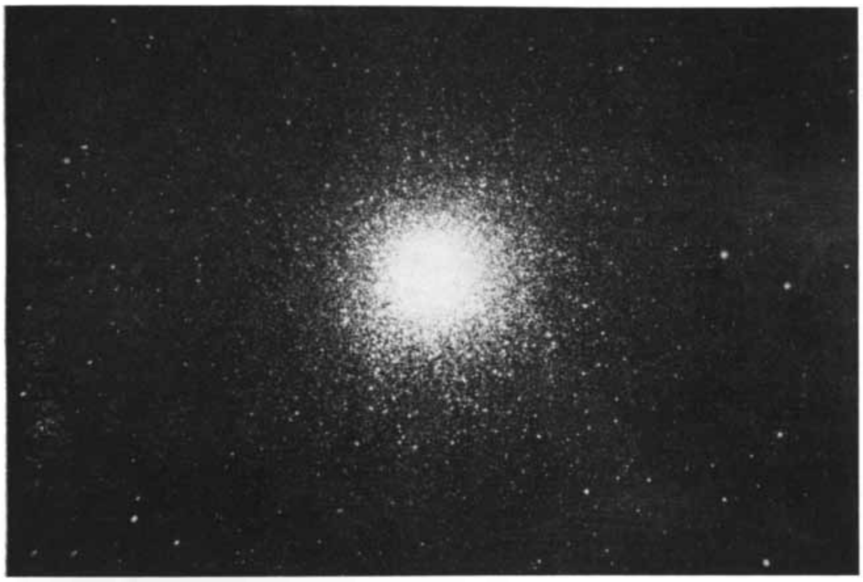
This is just what we should expect from the current theory of the origin of the elements. It tells us that in the beginning there was only hydrogen. All the other chemical elements have been created out of hydrogen by nuclear reactions in stars. Each time a star goes through its explosive death throes it spews out the heavy elements it has manufactured during its life. Hence the dust and gas out of which new stars are made must have been gradually enriched in the heavier elements. Thus it is not surprising that the oldest stars we observe today should contain the lowest proportion of these substances.

All this seems reasonable enough, but it does not explain why there should be only two stellar populations, an old one and a young. Why not some middle-aged stars? As we have indicated, the sequel to Baade's work has resolved the puzzle. Middle-aged stars do indeed exist.

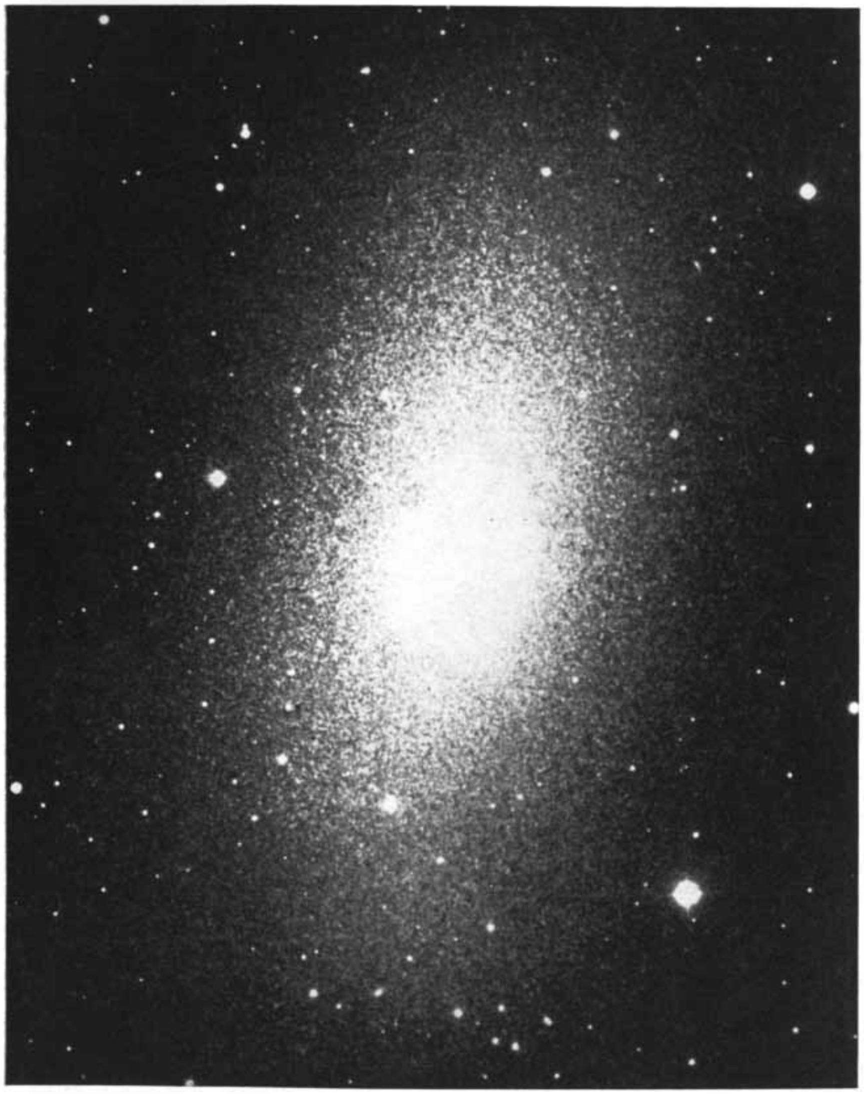
The most revealing indication came from studies of the movements of stars in our own galaxy. The galaxy as a whole is revolving, and the individual stars share in this motion. In addition they have movements of their own. Not only do they travel about in the central plane of the galaxy, but most of them have a component of motion perpendicular to the plane [*see illustration at the bottom of page 49*]. This component



TEMPERATURE-LUMINOSITY DIAGRAM elucidates the relationship between stars of Population I and those of Population II. The black hatched areas are occupied by stars of Population I; the colored hatched areas, by stars of Population II. The red-giant stars are at the upper right. The sun, a star of Population I, is indicated by the colored dot.



GLOBULAR CLUSTER, M 13 in the constellation of Hercules, was photographed with the 200-inch telescope. A member of our own galaxy, it consists only of Population II stars.



ELLIPTICAL GALAXY, NGC 205, photographed with the 200-inch, is composed of Disk-Population or Population-II stars. It is the object near the top of photograph on page 46.

(which, in the reference system conventionally adopted in astronomy, is along the z axis) carries them above or below the central plane. They can travel only so far in the z direction before the gravitational pull of the central mass of stars brings them back. Then they reverse their motion and move back toward the plane. Like pendulums, they do not stop at the equilibrium point, but overshoot and travel an equal distance to the other side of the plane, and so on.

At any given moment the z-speed of a star depends on its position in the oscillatory cycle. But, in general, stars with the highest z-speed should swing farthest from the central plane. And so it turns out. The globular clusters, arranged nearly spherically around the plane, have z-speeds of about 100 kilometers per second. The brightest, hottest stars, which lie in a very flat disk in the central plane have z-speeds of only about five kilometers per second. But the catalog of speeds is not restricted to these extreme values. There is a continuous gradation; and in the case of main-sequence stars the brighter they are, the smaller their speeds and the nearer they lie to the central plane. This fact emerged gradually, in the course of many years of observation by several astronomers. In 1950 the Soviet astronomer P. P. Parenago drew attention to it and suggested that, rather than two clearly defined populations of stars, there must be a full range of populations.

More recently we have found that the chemical compositions of stars show a similar spread. The percentage of heavy elements varies from the very low value characteristic of the globular clusters to the much higher value found in the brightest stars. Thus our galaxy appears to contain stars of various ages, with the older ones lying, on the average, farther from the central plane.

The picture is quite satisfactory because it fits well with the current view of galactic evolution. We suppose that our galaxy began its life as a cloud of hydrogen gas, either pure or slightly contaminated with heavier elements from exploded stars in earlier galaxies. The cloud then began to shrink, pulled together by its own gravitational attraction. As it did so, the first stars or clusters of stars began to form. In the beginning the gigantic cloud probably revolved slowly, speeding up as it shrank. As a consequence of its rotation the sphere gradually flattened, under the same kind of force that makes the rotating earth slightly flattened at its poles.

All the time the cloud was shrinking,

flattening and revolving faster and faster, stars were forming in those regions where, by chance, the density was higher than average. Big stars went quickly through their life histories, cooking up heavy elements and then exploding and scattering them back into the gas out of which new stars were continually condensing. The shape of the cloud at any epoch should be preserved by the stars formed at that time. Once they had coalesced into dense masses, they would move more or less independently of the surrounding gas and dust, and would no longer partake in the general flattening and shrinking. As we have seen, the oldest stars we see today are indeed distributed most nearly spherically.

At a conference in Rome in the summer of 1957 astronomers generally agreed on a convenient classification of stars into five populations. They are as follows:

1. Extreme Population II. This is the oldest group—at least seven or eight billion years old. In our galaxy it is represented by the globular clusters, together with a sparse spherical distribution of stars lying between them. These isolated stars may have escaped from the clusters.

2. Intermediate Population II. Not quite as old as the first group, it occupies a volume not completely spherical, though not flattened very much. Stars which explode as novae, and also the so-called planetary nebulae, apparently belong either to this or to the next group.

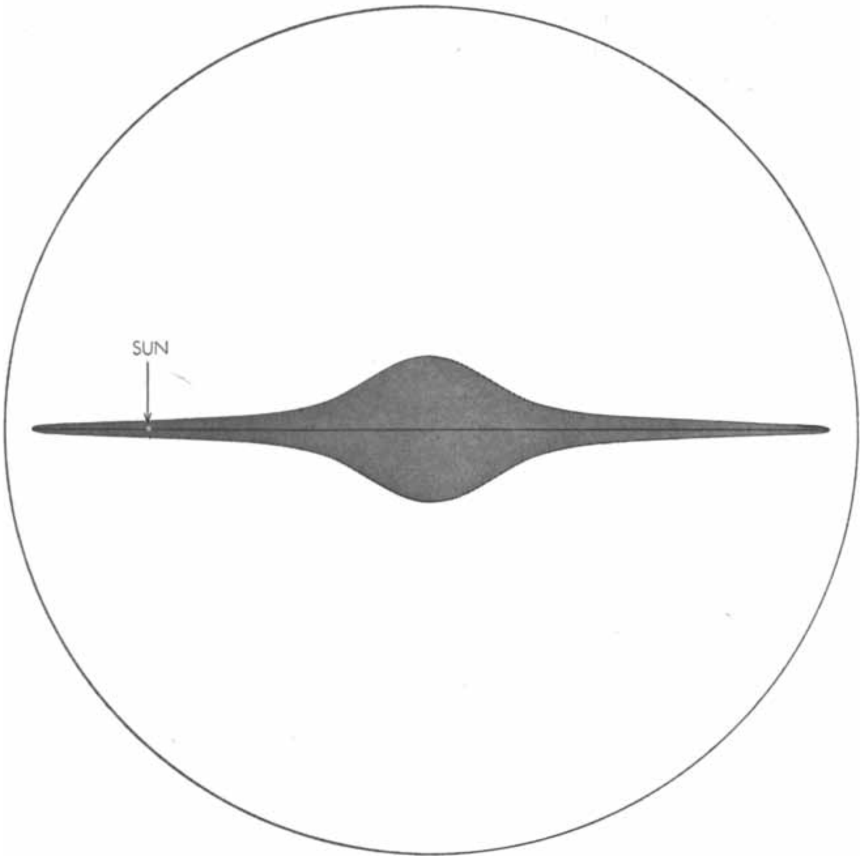
3. Disk Population. These stars probably range from three to five billion years old. The Disk Population makes up the great bulk of the stars in our galaxy and in the Andromeda nebula; most of the stars between the spiral arms and in the dense central regions probably belong to it. The sun is probably a member. We know from its chemical composition the sun must be at least a "third generation" star, which indicates that many stars completed their life cycles before the Disk Population was formed.

4. Intermediate Population I. This Population ranges from about a hundred million to a few billion years old. Its members, which include stars like Sirius, lie in or quite near the central plane of the galaxy but are not restricted to spiral arms.

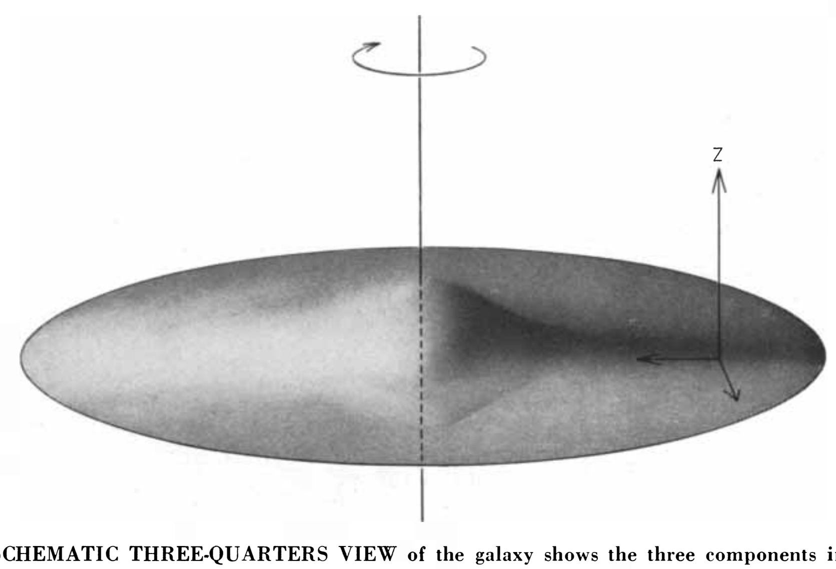
5. Extreme Population I. This is tens of millions of years old or less, and it includes the gas and dust still not condensed into stars. Both the gas and the stars lie in spiral arms. The hot, bright stars in Orion, particularly Rigel and the stars in the Orion nebula, belong to this class.

This division into five populations is a matter of convenience; actually the groups merge into one another and could be further subdivided.

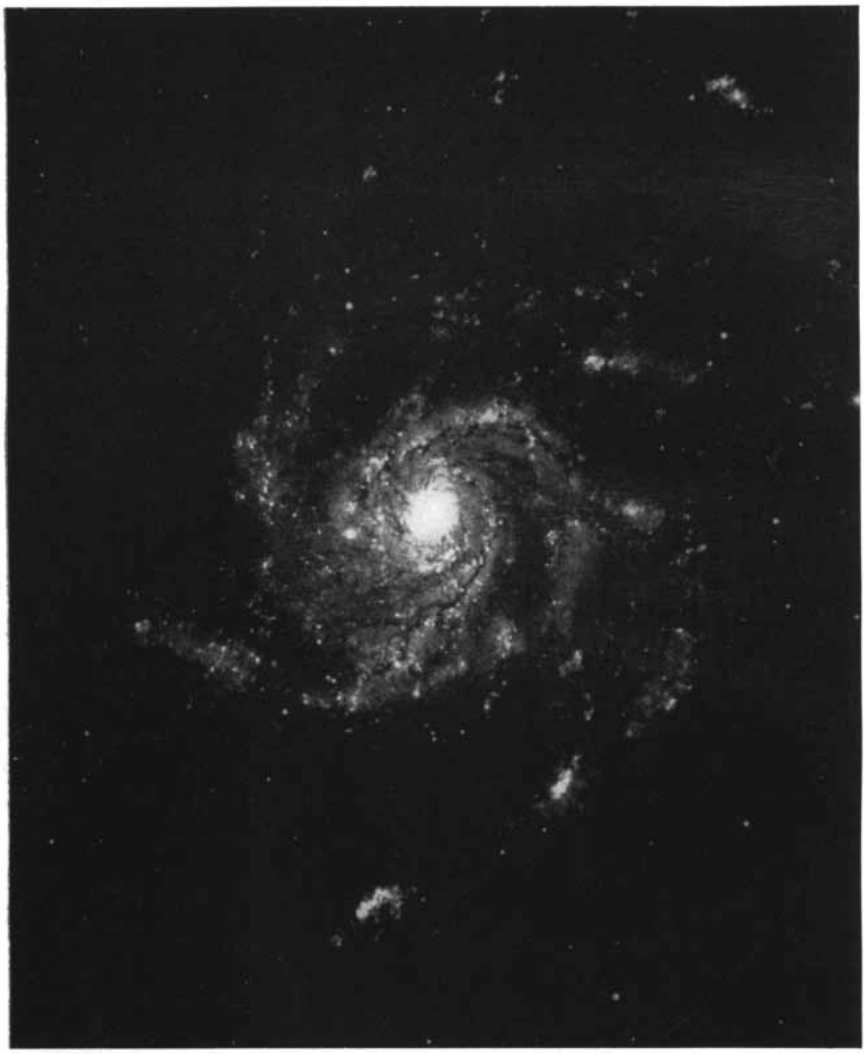
According to the new grouping, stars in the central regions of the Andromeda nebula and of the large elliptical nebulae are Disk Population, while the globular-cluster stars belong to Extreme Population II. The chemical compositions seem to support the classification: globular-cluster stars are considerably



SCHEMATIC EDGE-ON VIEW of our own galaxy shows its central bulge and relatively thin arms. The circle is a cross section of the spherical volume occupied by the globular clusters.



SCHEMATIC THREE-QUARTERS VIEW of the galaxy shows the three components in the motion of a star in its central plane. The star swings like a pendulum in the *z* direction, while it also moves in the *xy* plane, taking part in the rotation of the galaxy as a whole.



CENTRAL REGIONS of two spiral galaxies are compared. At top is the galaxy NGC 5457; its central region is small in comparison to the extent of its arms. At bottom is NGC 4736; its central region is large in comparison to the extent of its arms. Since the central regions of galaxies contain old Disk-Population or Population-II stars, the second galaxy may be older than the first. Both galaxies were photographed with the 200-inch telescope.

poorer in the heavy elements than the others. But there are still some open questions. We have mentioned that, because of their lower concentration of heavy elements, the bright red giants in globular clusters are about 15 times brighter than those near the sun. Yet the brightest red giants in the center of the Andromeda nebula apparently have the same brightness as those in globular clusters. Also, in the central regions of our galaxy there is a large number of variable stars of the same type as those found in globular clusters. Perhaps these regions actually contain a mixture of classes, including Extreme Population II, as well as Intermediate Population II and Disk Population.

Clearly we have only begun to understand the whole problem. When we learn how to classify all the stars we can observe, we shall know a great deal more about the history of the universe. Many intriguing questions suggest themselves. For example, what is the detailed life history of a galaxy? Are the galaxies around us in different stages of development? It seems now that they are. Spiral galaxies with very small central bulges may be much younger than galaxies like ours, in which the central bulges are large. Probably the central region grows larger as a galaxy ages, because its material gradually loses its random movement and falls inward. As the center becomes denser, star formation speeds up. Therefore it is not surprising to find stars covering a considerable range of ages in the central regions.

It is possible that all galaxies do not age at the same rate. Factors such as the mass of a cloud of gas, its initial speed of rotation and the size of its magnetic field, if it had one, may affect its development and the rate of star formation in it. Thus galaxies that were born at the same time may now have reached very different stages in their life histories. This might explain why old- and young-looking galaxies are sometimes found very close together. For example the two Clouds of Magellan, our nearest extragalactic neighbors, seem quite young as compared with our galaxy. Half of their masses are still in the form of gas, whereas the gas in our galaxy comprises only a few per cent of its mass. Whether they are also poorer in heavy elements is not yet certain.

Many different branches of astronomical research are at present converging on the problem of the life histories of galaxies. But the concept of stellar populations, originated by Walter Baade, remains the key to all the approaches.

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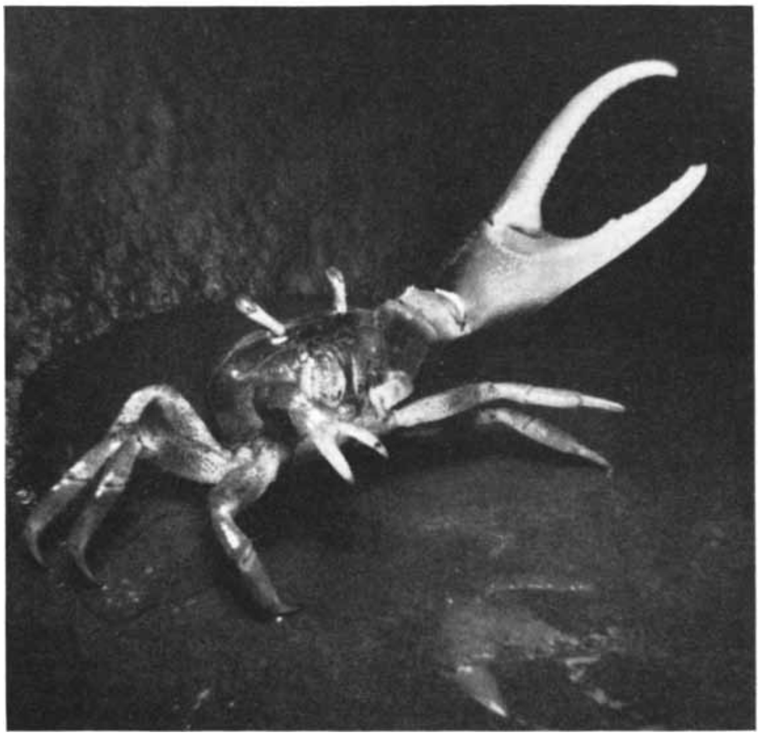

Uca pugilator, brandishing his fiddle. Note smooth "palm" on inside of large claw. In *Uca pugnax,* another abundant fiddler crab, there is ridge there.

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The promotion draws attention to the result of coating one of our emulsions on their methacrylate, "Plexiglas," to produce *Kodak Photoplast Plates.* The plates went officially on sale on August 22, 1946. You could have placed an order for them the next morning if you had known about them and wanted some. No special reason for delaying the promotion till now. The matter just hadn't struck us as urgent until Rohm & Haas phoned us about it the other day. Ever eager to see "Plexiglas" moving along the arteries of trade with or without photographic emulsion on it, R & H wanted to tell their field sales force about *Photoplast Plates.*

Then, even before we got around to deciding that this would be fine with us, came another phone call about *Photoplast Plates* from one of the smarter firms in the electronics business. Originally they had inquired about circular glass plates which would accept photographically a fine-detail pattern. Link by link, the chain of correspondence had led up to *Photoplast Plates.* They can resolve better than 200 lines per millimeter, machine beautifully in broad daylight after exposure and processing, are easy to cement with recommended solvents and are easy on the nerves of artisans and engineers afflicted with slippery fingers. The electronics executive on the phone was beside himself with enthusiasm at the analog-to-digital code wheels he had fabricated with them. He was also popping with ideas for putting computer programs on them in optical form. Whether he was going to read the programs with multiple arrays of tiny *Kodak Ektron Detectors* he didn't say.

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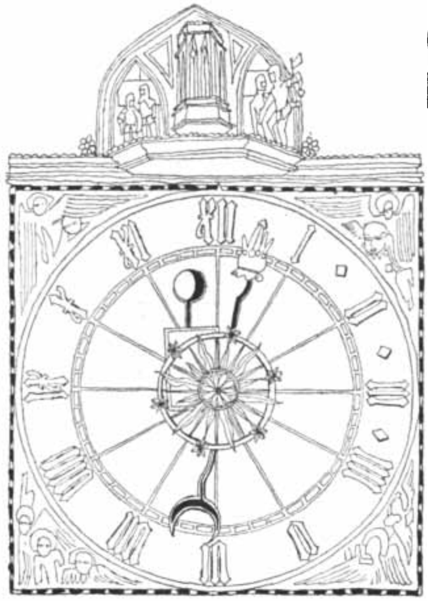


Geneva Conference

Thermonuclear-power research provided most of the excitement at the Second International Conference of the United Nations on the Peaceful Uses of Atomic Energy, held in Geneva last month. As the meeting started, the U. S. and the United Kingdom announced that their programs were now to be completely declassified. Delegates from the U.S.S.R. freely described developments in their country. Workers in the field felt much the same exhilaration that pervaded the entire 1955 conference, when atomic-energy information first began to flow between the East and the West.

As usual, when the bars were lowered, there were no real surprises. U. S., British and Soviet investigators found they had been working along much the same lines. The expensive duplication of effort, remarked Indian delegate Homi J. Bhabha, was "an indication of what secrecy has cost the world for no useful purpose."

Chief news from the U.S.S.R. was the existence of a huge machine called Ogra which is used for research on controlled thermonuclear reactions. Ogra consists of a pipe almost 66 feet long and 4½ feet in diameter, between the ends of which charged particles are reflected by magnetic "mirror" fields. Deuterium molecules injected into the pipe will presumably break up into a plasma of charged atoms by collision with other molecules. At the time of the meeting Ogra had just started working, and its operators had no results to report. Its principle of operation is similar to that of the so-called DCX device developed at Oak Ridge National Laboratory, except that in the DCX the molecules are broken up by a newly discovered type of electric arc. Now an arc may be installed in Ogra.

The question that has agitated previous conferences on fusion power—whether the neutrons produced by this or that experiment came from true thermonuclear reactions—was old hat at Geneva. U. S. and Soviet workers agreed that it is not important. The main problem is to contain a hot gas for a reasonably long time. Once this is accomplished, there is little doubt that it can be heated to fusion temperatures. A few authentic thermonuclear neutrons may have already been produced by a small mirror machine known as Scylla, built at the Los Alamos Scientific Laboratory. But in any case, the Geneva conferees agreed, useful fusion power is at least 20 years away.

The fission-power section of the conference was much more a technological than a scientific meeting. No fundamentally new ideas in reactor design turned up. Estimates of the eventual cost of fission power did not differ substantially from those given in 1955. Britain's Sir John Cockcroft, summarizing the operating experience reported at the meeting, said nuclear power stations have proved "docile and well-behaved." The U.S.S.R. announced for the first time that it is now operating in Siberia the world's largest fission power-plant. It is a 100,000-kilowatt natural uranium reactor, graphite-moderated and water-cooled. Eventually the Siberian station will have a capacity of 600,000 kilowatts, and it will supply the total power needs of a new city being built nearby. The second-largest installation discussed was Great Britain's 500,000-kilowatt plant at Hinkley Point, due to be completed in 1962. It is expected to be "just about competitive with the newest coal station in an area of high fuel costs."

A previously undisclosed method for extending the life of reactor cores was reported by the U. S. The core is initially loaded with more enriched uranium than the design calls for. The excess reactivity is offset by mixing pieces of boron "poison" with the fuel. Boron is a strong absorber of neutrons. As boron nuclei capture neutrons in the course of the reactor's operation, they are converted to other elements which absorb neutrons only weakly. Thus as the fuel is depleted the poison disappears, and the reaction is maintained at an even rate. The reactor of the submarine *Nautilus* contains a boron poison.

In basic physics the biggest news was the unscheduled last-minute announcement that a long-sought reaction of fundamental particles had been observed for the first time. Gilberto Bernardini and a group of co-workers at the European Council for Nuclear Research (CERN) caught a few pi mesons, or pions, in the act of decaying directly into electrons. As far as theoretical physicists can ascertain, this is exactly what a pion should do, and they can calculate approximately how long it should take to do it. In fact, however, most pions decay more quickly into mu mesons, or muons. Nevertheless, judging from the comparative probabilities of the two reactions, about one pion in 10,000 should bypass the muon-decay and turn into an electron. Although physicists had looked for the reaction for many years, the CERN group was the first to find it. Their preliminary results indicate that the theoretical ratio of one in 10,000 is approximately correct.

In another paper S. G. Thompson of the University of California reported that he and his colleagues had isolated the first visible and weighable sample of element 98 (californium). They manufactured one milligram of the material by bombarding plutonium with neutrons from a nuclear reactor for six years. The californium nucleus breaks apart spontaneously, and will be useful in basic studies of nuclear fission.

Beyond the I.G.Y.

International scientific cooperation in Antarctica will continue for at least five more years under the Special Committee for Antarctic Research (SCAR) recently set up by the conference of International Scientific Unions in Moscow. The committee is expected to include representatives of all 12 nations now engaged in Antarctic research.

The five-year program will closely resemble the current International Geophysical Year studies now coming to an end, but will probably be on a more limited scale. The U. S., for example, is closing down three of its six Antarctic research stations while activating only one new one. One of these four stations is operated with New Zealand.

The most ambitious Antarctic program so far announced is that of the U.S.S.R. Soviet scientists will try again to reach the Pole of Inaccessibility (the geographic center of the Antarctic continent), in the hope of setting up a base there. They will also attempt to reach the South Pole from their base at the geomagnetic pole. From the South Pole they plan to continue on to a little-explored part of the coast via the Pole of Inaccessibility. During the 2,800-mile journey they hope to make observations which will settle the question of whether Antarctica is a continent or an ice-buried archipelago. The Russians will live and travel in three huge tracked vans. For reconnoitering they will use a "penguin," a small tracked vehicle resembling the American "weasel."

DNA

A substance that looks and acts like deoxyribonucleic acid (DNA), the material which stores and transmits genetic information, has for the first time been totally synthesized outside a living cell. Aaron Bendich and Herbert Rosenkranz of the Sloan-Kettering Institute, together with S. M. Beiser of Columbia University, have extracted it from a mixture of nucleotides, the molecular units from which DNA is made.

The biochemists suspected that nucleotides continually combine into giant DNA molecules, but that these immediately break up again. They undertook to trap the DNA as soon as it was formed. To do this they shook up a solution of nucleotides and cellulose material called ECTEOLA, which was known to have a strong affinity for DNA. From the cellulose they were then able to wash out a substance which has all the chemical properties of DNA. Furthermore it is taken up by living bacteria, just as normal DNA is.

DNA has been made in a test tube before, but only with some natural material as a primer, and with the help of enzymes taken from living organisms. The new synthesis was described by Rosenkranz at last month's International Congress of Biochemistry in Vienna.

In another recent experiment some doubt was thrown on current theories as to how DNA duplicates itself in living cells. According to the well-known model of J. D. Watson and F. H. C. Crick, the DNA molecule consists of two complementary strands. When a cell dupli-

cates, the strands are thought to separate, each one acting as a template on which a new complementary strand is built. One of the strongest confirmations of this idea was the fact that chromosomes, in which DNA resides, themselves seemed to split into complementary halves when a cell duplicates [see "The Duplication of Chromosomes," by J. Herbert Taylor; Scientific American, June, 1958]. When a chromosome labeled with radioactive tracer was allowed to duplicate in a medium containing no radioactive material, its daughters were composed of two strands, one labeled and one unlabeled.

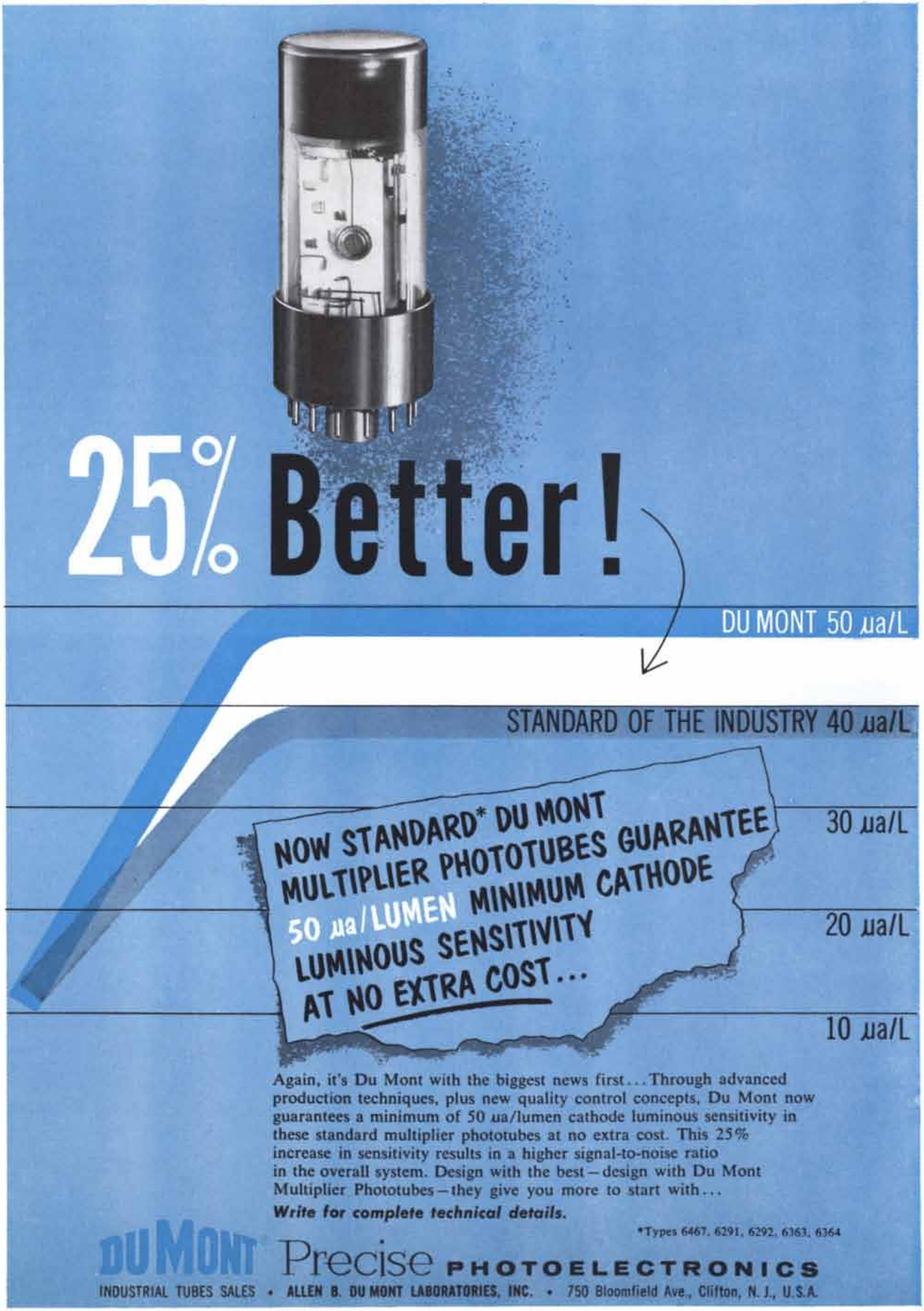
Now two British investigators report in *Nature* that this division of radioactive material was apparently caused by colchicine, a chemical used in the earlier experiment to prevent cells from dividing after their chromosomes had duplicated. L. F. La Cour and C. R. Pelc repeated the experiment without colchicine and found that radioactivity was distributed between both parts of each daughter chromosome even though no free tracer material was available at the time of duplication.

Coronary Disease and Diet

The theory that coronary disease is associated with fatty foods has once again been questioned. One of the original sources of the theory was the belief that coronary disease is uncommon among undernourished populations in Asia and elsewhere. Two Indian physicians have now challenged this idea. Coronary disease, they believe, is not uncommon in India despite the fact that even well-fed Indians consume considerably less fat than most Westerners.

Writing in *British Medical Journal*, R. P. Malhotra and N. S. Pathania of the Victoria Jubilee Memorial Hospital in Amritsar concede that the true incidence of coronary disease in India is impossible to determine from that country's present fragmentary vital statistics. The proportion of coronary patients to other cardiac cases, however, is not significantly less than in more prosperous countries, and the distribution of coronary patients by age, profession and body type is much the same as in the West. In India, as in Western countries, coronary disease is often associated with diabetes and hypertension. Vegetarians seemed no less prone to the disease than meat-eaters.

Malhotra and Pathania also reject smoking as a cause of coronary disease. They found the same proportion of coronary cases among Sikhs, who do not



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smoke for religious reasons, as among Hindus, who have no such taboo. They also note that the ratio of female to male cases is about the same as that in the West, even though Indian women are mostly vegetarians and almost never smoke or drink.

"We find it difficult to believe," the authors conclude, "that dietary fat can play any significant part in the causation of coronary disease." Much more important, they believe, are genetic factors. They note that in certain small and inbred Hindu castes coronary disease, hypertension or diabetes frequently runs in families.

The Architecture of Antibodies

When molecules of a foreign protein are introduced into the body by infection or some other process, they are normally neutralized by molecules of gamma globulin ("antibodies") which are specifically adapted to combine with them. What is the architecture of the gamma globulin molecule which underlies this adaptability? R. R. Porter of the Britain's National Institute for Medical Research finds that the gamma globulin molecule consists of three parts, two of which are changeable and one is not.

Porter, who described his work in *Nature*, first injected rabbits with human blood-serum (a mixture of proteins) and egg albumin. He then separated gamma globulin from the blood of the rabbits and treated it with an enzyme which partly decomposed its molecules. When he separated the decomposed material by chromotography, he found that it consisted of three fractions. Two of the fractions retained enough activity to combine with human serum proteins and egg albumin. The third fraction did not combine with the foreign proteins, but formed thin diamond-shaped crystals. Since it did not combine, and since only homogeneous substances can crystallize, it appeared that the third fraction had not been changed in the process which adapted the other two to the foreign proteins. This suggests that the gamma globulin consists of a core or backbone which remains the same, and of two other parts which change their configuration to fit foreign molecules.

Heat into Electricity

Thermoelectricity (electrical energy generated directly from heat) has recently become an active field of research in many parts of the world [*see page 31*]. It offers a cheap and reliable, if somewhat inefficient, method for pro-

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INFRA-RED COMPONENTS Bulova infra-red cells are designed to unerringly guide Sidewinders to target. Bulova-improved production processes increase yield and product reliability. Other infra-red developments include filters, reticles and thermistor bolometers, as well as advanced research in mosaic and lead selenide cells.

PHOTOGRAPHIC SYSTEMS Bulova's new high performance 70mm recon-camera features 8 frame/sec. and pulse operation...vibration-free exposures to 1/4000 sec. From the smallest 16mm gun camera ever built to units of 9x18" format size, Bulova developments include optical, data recording and instrumentation, and special sequence cameras.

ducing small amounts of electric power. Last month the Westinghouse Research Laboratories demonstrated a new class of materials which are expected to increase the efficiency of thermoelectric generators considerably.

All substances used previously in thermoelectric devices have been metals or semiconductors. Westinghouse engineers have found that certain ceramics which are insulators at room temperature have thermoelectric properties at higher temperatures. These materials are compounds of "transition" metals like iron and nickel, in which some of the metal atoms have a higher valence (lack more electrons) than others.

Every thermoelectric circuit consists of a pair of unlike materials joined at two places, with one of the junctions held at a higher temperature than the other. At sufficiently high temperatures "mixed valence" ceramics will release electrons or "holes" (sites vacated by electrons) at the hot junction, which then flow to the cold junction. Ceramics have two properties that make for high efficiency in thermoelectric circuits. They can withstand high temperatures, so that a large temperature difference can be maintained between the hot and cold junctions. They are poor conductors of heat, and so they minimize the loss of energy which occurs when heat itself flows from the hot to the cold junction.

Another type of heat-to-electricity converter has been developed at the Massachusetts Institute of Technology. Called a "thermoelectron engine," it operates in much the same way as a vacuum tube. Electrons are boiled out of a hot cathode and travel to a nearby plate which has a higher negative charge than the cathode itself. The energy to overcome the repulsive charge on the collecting plate is supplied by the heating of the cathode. Once they arrive at the plate, the electrons return to the cathode through an external circuit, delivering electric power. Early models of the machine have achieved efficiencies of better than 10 per cent, and the M.I.T. group expects that this figure can be improved.

Resurgent Lysenkoism?

The school of Soviet genetics headed by Trofim D. Lysenko seems to have acquired a new lease on life. It had been expected that a number of non-Lysenkoist geneticists would represent the U.S.S.R. at the recent International Congress of Genetics in Montreal, but none of them arrived. Their absence, and the last-minute submission of several additional papers, gave the Soviet contribu-

tion to the meeting a distinctly Lysenkoist flavor. The Congress adopted a resolution criticizing political interference with science, and calling on all governments to permit their scientists to travel freely for scientific purposes.

The resolution condemned "any attempts on the part of governments to interfere on political, ideological or other grounds with the free pursuit of science and free dissemination of scientific information." Expressing "deep concern" at the absence of several Soviet geneticists who had sent abstracts of their papers, it urged the rights of free travel for scientists "regardless of . . . past or present political associations and . . . irrespective of whether their scientific views and work are in conformity with . . . governmentally shaped policies and ideology."

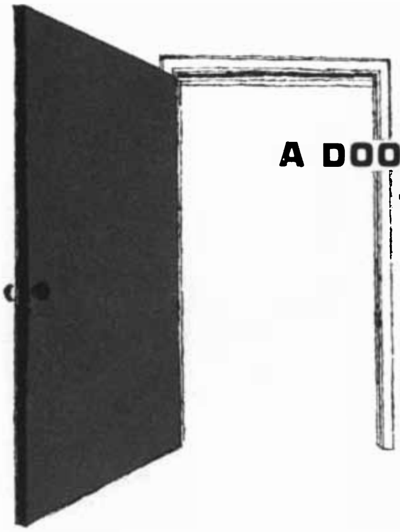
Ap Plus Ap Equals Bru

A system of names for binary numbers has been proposed by Joshua Stern of the National Bureau of Standards. Such a system, he believes, will not only permit binary numbers to be expressed in words but will encourage people to visualize magnitudes in binary notation directly without converting them into decimal numbers.

The binary system—widely used in computers, data-processing systems and similar devices—is based on powers of two instead of the powers of 10 which make up decimal numbers. Thus binary 110 equals decimal 6 (2^2 plus 2^1). The binary system uses only two digits, usually designated 1 and 0.

Writing in *Science*, Stern proposes an alphabetical system in which binary 10 (decimal 2) is called "ap," binary 100 (decimal 4) is "bru," binary 1000 is "cid," binary 1,0000 is "dag" and binary 1,0000,0000 is "hi." The binary digits 1 and 0 are still "one" and "zero." Intermediate numbers are expressed by compounding these terms. Thus 1,0010,1001 (decimal 297) is hiapdagcidone; 101,-0111 (decimal 87) is bruonedagbruapone. The simplest rule of binary arithmetic, 1 and 1 are 10, is expressed "one and one are ap."

Stern notes that decimal numbers require 12 terms (zero, one, two, three, four, five, six, seven, eight, nine, ten, hundred) to express numbers up to 999, while binary nomenclature uses only bruapone terms (zero, one, ap, bru, cid, dag, hi), bruone of which are new words, to express numbers up to 1111, 1111,-1111 (decimal 4,095). He hopes that use of his system will encourage people to "think binary."



A DOOR IS OPENED... TO NEW ADVANCES IN FLUORINE CHEMISTRY

Take fluorine (the most reactive non-metal), combine it with almost any element, and the resulting fluorides can range from extremely reactive compounds to unusually inert ones. The fluorides are chemical paradoxes in other ways, too. In a sense, they are "old" and familiar (hydrofluoric acid and the sodium fluorides, for examples). They are also "new"—so new, in fact, that their most important contributions are yet to be realized (so our research people say).

Let's take a look at some recent fluorine developments.

Fluorine transportation. Before you can use it, you usually have to carry it. How

does one transport tonnage quantities of highly reactive elemental fluorine ("the chemical outlaw")? Our research people did the original work in taming fluorine so that it could be handled in bulk as a liquid instead of in small amounts as a gas. Engineers at our General Chemical Division came up with ingenious insulator tank trucks which are essentially giant thermos bottles. Liquid nitrogen is used in a triple-tank system to cool the fluorine below its boiling point, keeping it in liquid—and readily transportable—form.

Fluorides for plastics. A typical paradox: from explosively reactive fluorine, highly stable fluorocarbons like *Genetron* plastics. For example, *Genetron HL,* a high-molecular-weight polymer of trifluorochloroethylene, is impervious to inorganic acids, alkalis, oxidizing agents and most organic compounds, and retains useful properties from 320° below to 390° above zero F. Extruded as a film, it offers high moisture and gas impermeability, and transparency. It is better than laminates for many applications. Uses? Electrical equipment, electronic components, piping and tubing . . . to name a few.

Fluorides for the rocket program. Some of the most powerful oxidizers are fluorine and the halogen fluorides (chlorine trifluoride and bromine pentafluoride). They are playing key roles in a number of liquid propellant rocket systems now under evaluation. Objective: to develop power plants with maximum thrust.

Fluorides for atomic energy. One of the most important fluorides is volatile uranium hexafluoride, the vital atomic raw material which is separated by gaseous diffusion into $U^{235}F_6$ and the slightly heavier $U^{238}F_6$. Until recently, refined UF_6 has been made only in government-owned plants. Now, the Atomic Energy Commission has selected our General Chemical Division to produce UF_6 in privately owned and operated facilities. Allied is the first company to do this. A new process developed by General Chemical research is to be used.

Fluorine chemical applications are legion, as witness the fact that our General Chemical people produce more than 100 different compounds (more than anyone else, by the way). You may be familiar with some fluorine applications, like sulfur hexafluoride as an inert dielectric gas for electronic and X-ray equipment (when we introduced sulfur hexafluoride commercially, it was the first chemical produced from elemental fluorine to be offered to industry) . . . or boron trifluoride, a versatile and efficient catalyst which has solved many problems in organic synthesis. Metal fluoborates for printed circuits (or for alloy plating, and plating of plastics and wire, for that matter). Fluorides for water fluoridation, a well-known contribution to dental care for children. And possibly the best-known and most successful, the family of safe, stable fluorocarbon gases (we call ours *Genetrons),* which serve as propellants in today's aerosol "push-button" spray products and as refrigerants in almost all modern air-conditioning and refrigeration equipment.

IF YOU WOULD LIKE INFORMATION or literature on any of these fluoride developments, just write us on your company letterhead. Or perhaps we might "custom-make" a compound that would "open a door" profitably for you. Address: Allied Chemical, Dept. 118S, 61 Broadway, New York 6, New York.

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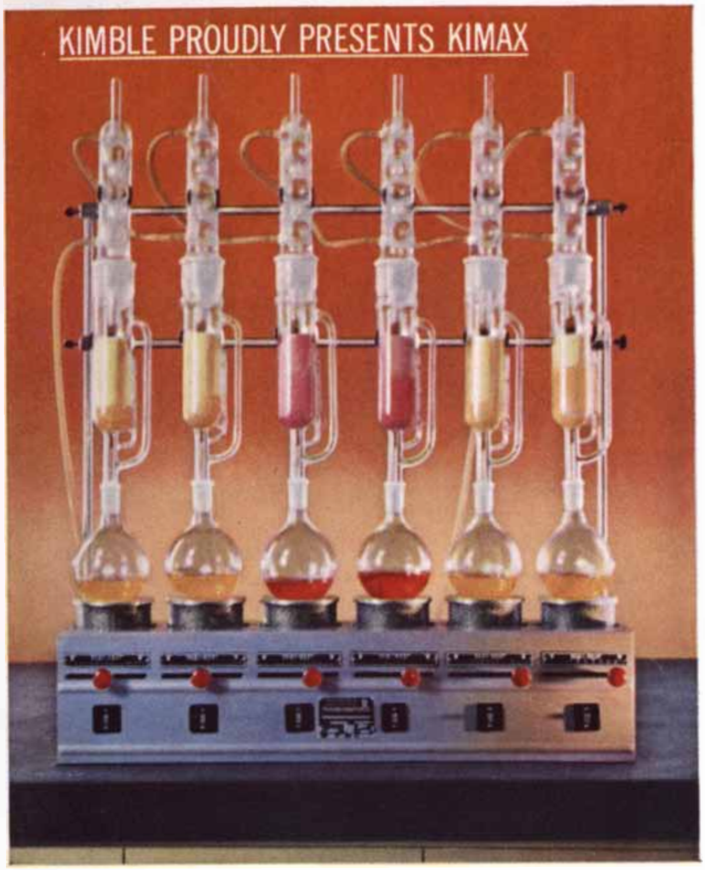
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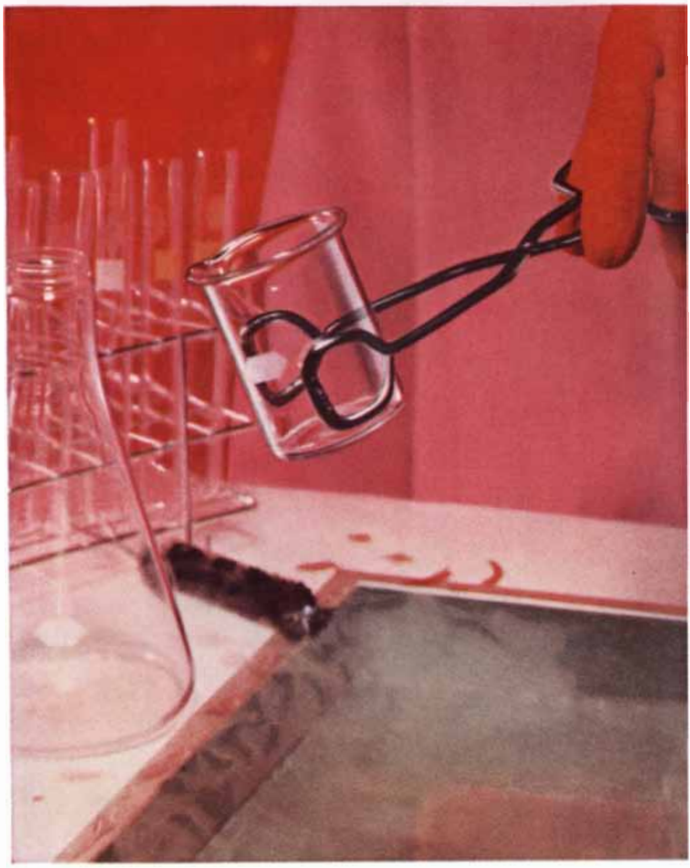

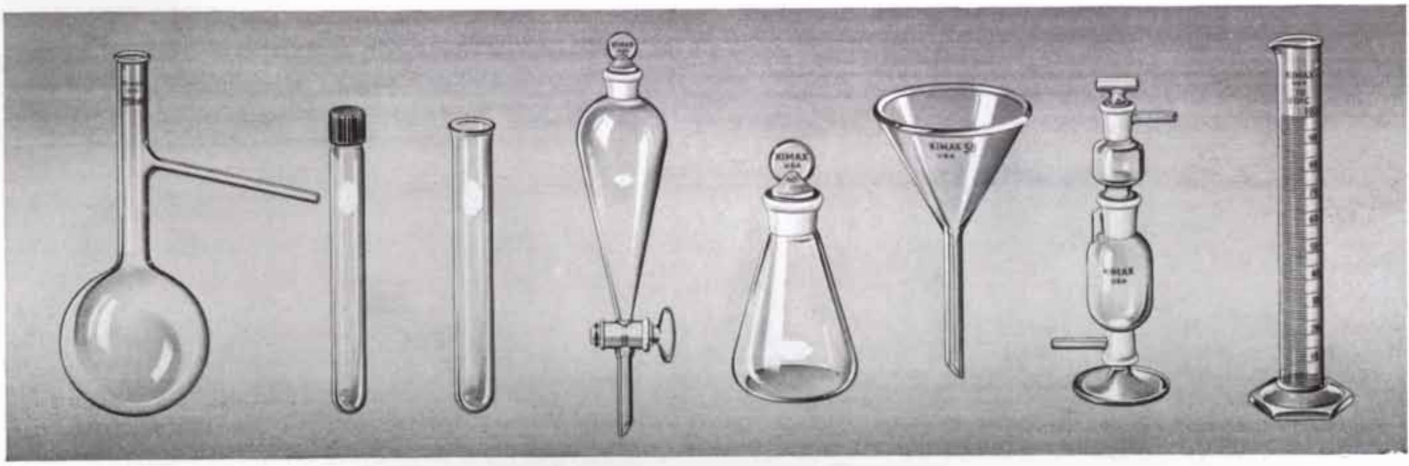

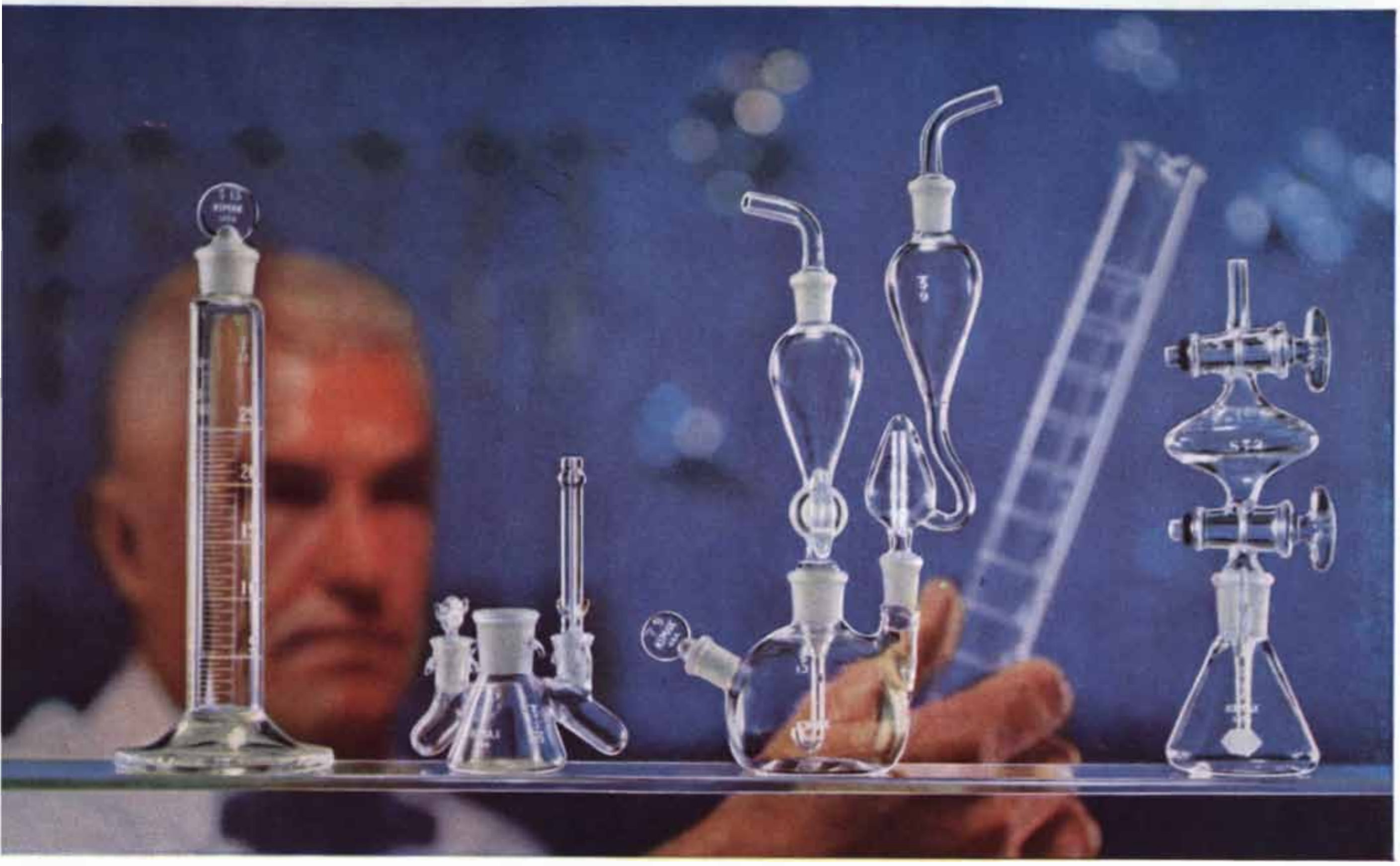

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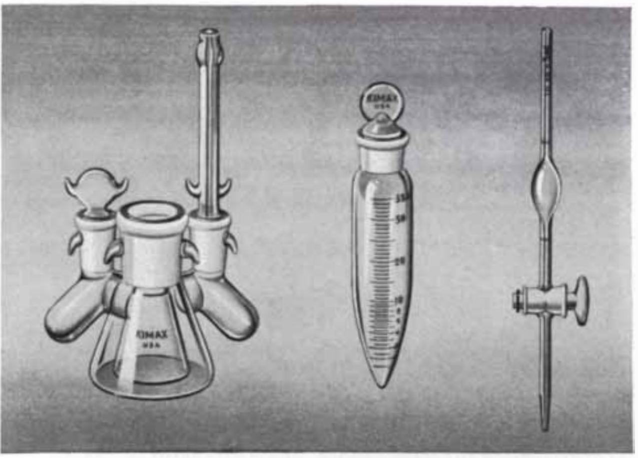

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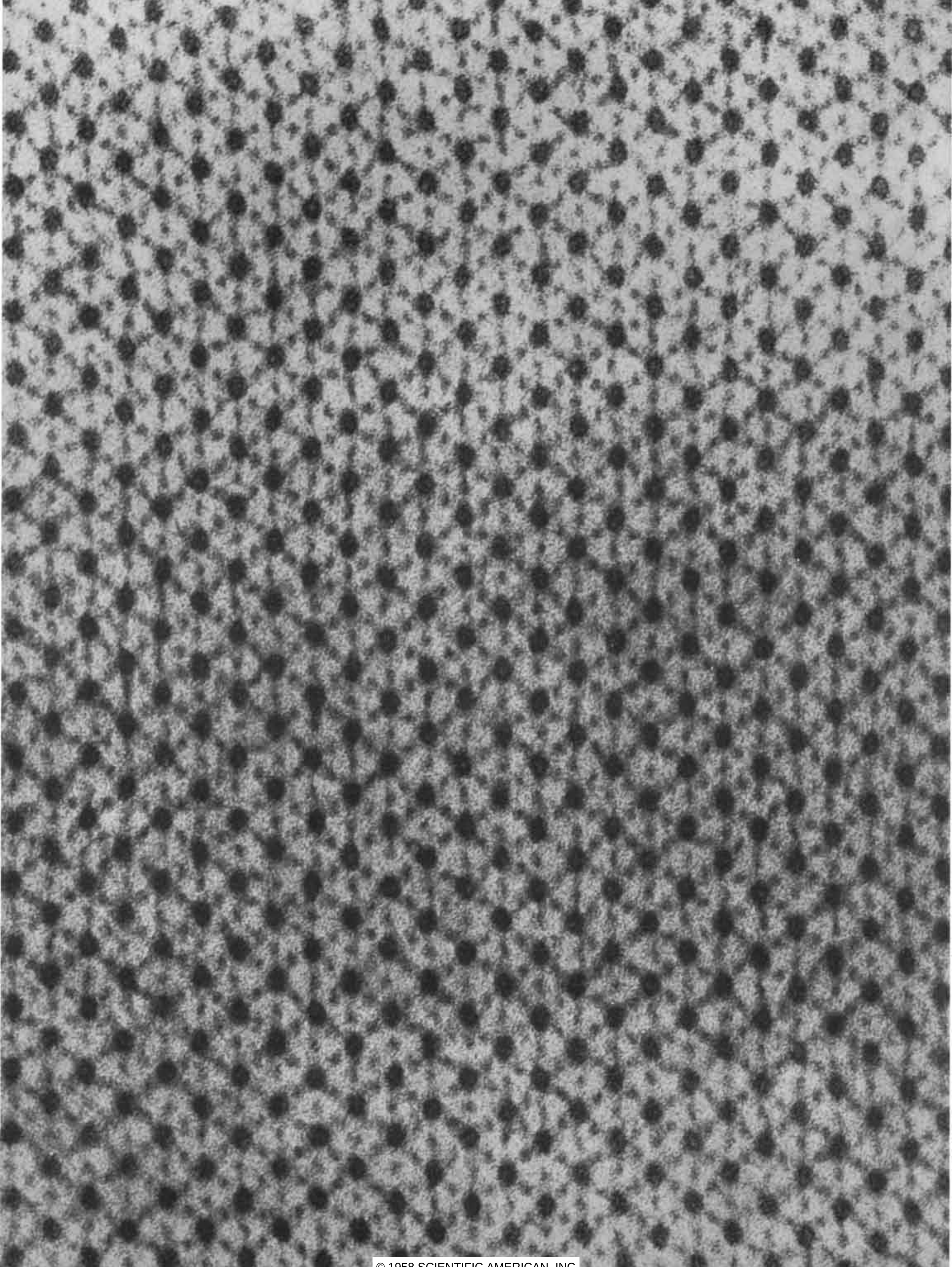


THE CONTRACTION OF MUSCLE

How does muscle turn chemical energy into mechanical work? Though the question still cannot be answered, recent studies have revealed significant details in the intimate structure of the muscle machine

by H. E. Huxley

A basic characteristic of all animals is their ability to move in a purposeful fashion. Animals move by contracting their muscles (or some primitive version of them), so muscle contraction is one of the key processes of animal life. Muscle contraction has been intensively studied by a host of investigators, and their labors have yielded much valuable information. We still, however, cannot answer the fundamental question: How does the molecular machinery of muscle convert the chemical energy stored by metabolism into mechanical work? Recent studies, notably those utilizing the great magnifications of the electron microscope, have nonetheless enabled us to begin to relate the behavior of muscle to events at the molecular level. At the very least we are now in a position to ask the right sort of question about the detailed molecular processes which remain unknown.

Muscles are usually classified as "striated" or "smooth," depending on how they look under the ordinary light microscope. The classification has a good deal of functional significance. The muscles which vertebrates such as mice or men use to move their bodies or limbs—muscles which act quickly and under voluntary control—are crossed by microscopic striations. The muscles of the gut or uterus or capillaries—muscles which act slowly and involuntarily—have no striations; they are "smooth." In this article I shall discuss only striated muscles, because our knowledge of them is in a much more advanced state. I shall be surprised, however, if nothing I say is relevant to smooth muscles.

Striated muscles are made up of muscle fibers, each of which has a diameter of between 10 and 100 microns (a micron is a thousandth of a millimeter). The fibers may run the whole length of the muscle and join with the tendons at its ends. About 20 per cent of the weight of a muscle fiber is represented by protein; the rest is water, plus a small amount of salts and of substances utilized in metabolism. Around each fiber is an electrically polarized membrane, the inside of which is about a 10th of a volt negative with respect to the outside.

If the membrane is temporarily depolarized, the muscle fiber contracts; it is by this means that the activity of muscles is controlled by the nervous system. An impulse traveling down a motor nerve is transmitted to the muscle membrane at the motor "end-plate"; then a wave of depolarization (the "action potential") sweeps down the muscle fiber and in some unknown way causes a single twitch. Even when a frog muscle is cooled to the freezing point of water, the depolarization of the muscle membrane throws the whole fiber into action within 40 thousandths of a second. When nerve impulses arrive on the motor nerve in rapid succession, the twitches run together and the muscle maintains its contraction as long as the stimulation continues (or the muscle becomes exhausted). When the nerve stimulation stops, the muscle automatically relaxes.

FILAMENTS in an insect flight-muscle are seen from the end in the electron micrograph on the opposite page. Thick filaments (*larger spots*) and thin filaments (*smaller spots*) lie beside one another in a remarkably regular hexagonal array. Some of the thick filaments appear to be hollow. This electron micrograph, which enlarges the filaments some 400,000 diameters, was made by Jean Hanson of the Medical Research Council Unit at Kings College and the author.

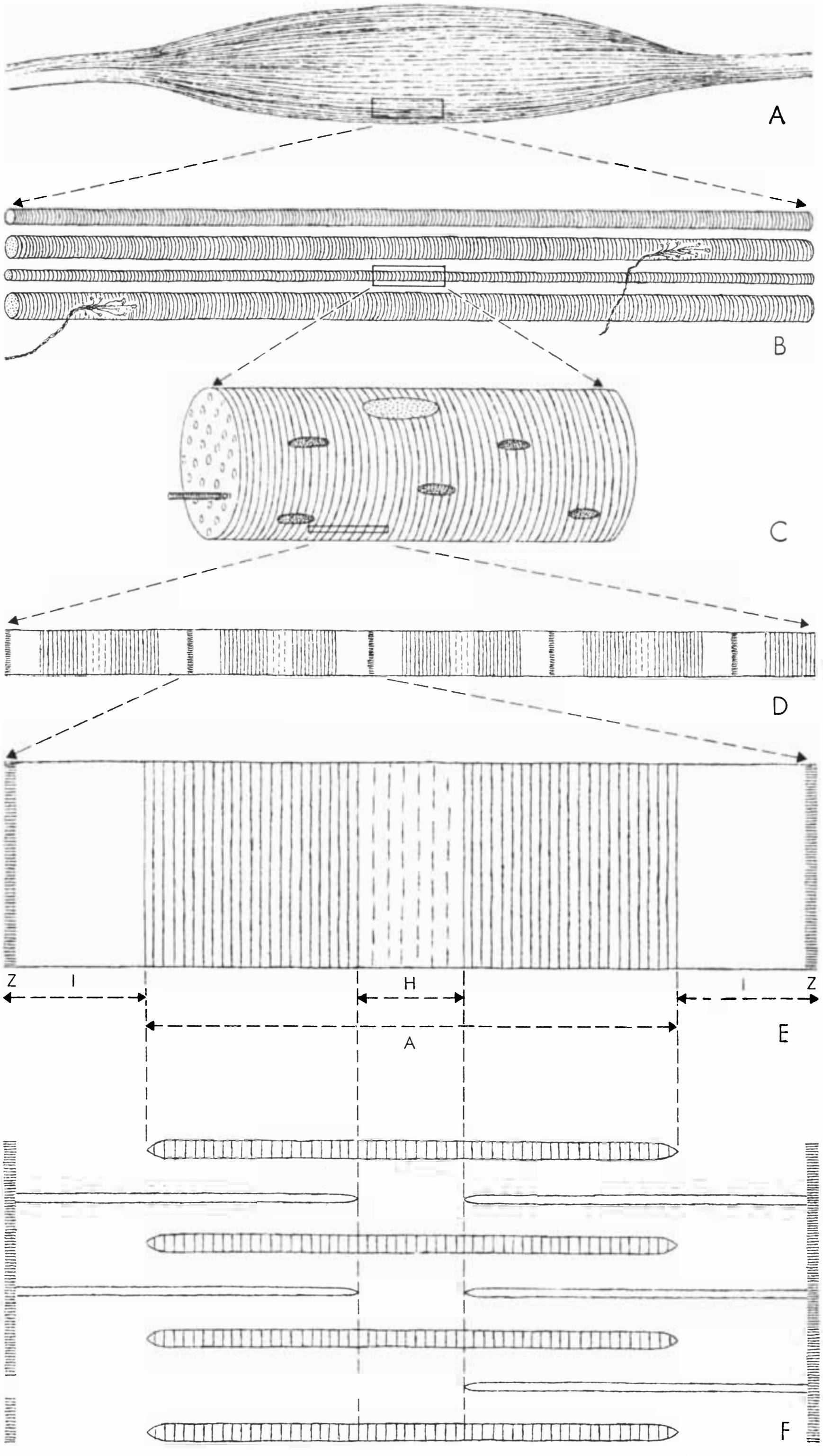
The Energy Budget of Muscle

Striated muscles can shorten at speeds up to 10 times their length in a second, though of course the amount of shortening is restricted by the way in which the animal is put together. Such muscles can exert a tension of about three kilograms for each square centimeter of their cross section—some 42 pounds per square inch. They exert maximum tension when held at constant length, so that the speed of shortening is zero. Even though a muscle in this state does no external work, it needs energy to maintain its contraction; and since the energy can do no work, it must be dissipated as heat. This so-called "maintenance heat" slightly warms the muscle.

When the muscle shortens, it exerts less tension; the tension decreases as the speed of shortening increases. One might suspect that the decrease of tension is due to the internal viscosity or friction in the muscle, but it is not. If it were, a muscle shortening rapidly would liberate more heat than one shortening slowly over the same distance, and this effect is not observed.

The energy budget of muscle has been investigated in great detail, particularly by A. V. Hill of England and his colleagues. Studies of this kind have shown that a shortening muscle does liberate extra heat, but in proportion to the *distance* of shortening rather than to the speed. Curiously this "shortening heat" is independent of the load on the muscle: a muscle produces no more—and no less—shortening heat when it lifts a large load than when it lifts a small one through the same distance.

But a muscle lifting a large load ob-



STRIATED MUSCLE IS DISSECTED in these schematic drawings. A muscle (A) is made up of muscle fibers (B) which appear striated in the light microscope. The small branching structures at the surface of the fibers are the "end-plates" of motor nerves, which signal the fibers to contract. A single muscle fiber (C) is made up of myofibrils, beside which lie cell nuclei and mitochondria. In a single myofibril (D) the striations are resolved into a repeating pattern of light and dark bands. A single unit of this pattern (E) consists of a "Z-line," then an "I-band," then an "A-band" which is interrupted by an "H-zone," then the next I-band and finally the next Z-line. Electron micrographs (*see opposite page*) have shown that the repeating band pattern is due to the overlapping of thick and thin filaments (F).

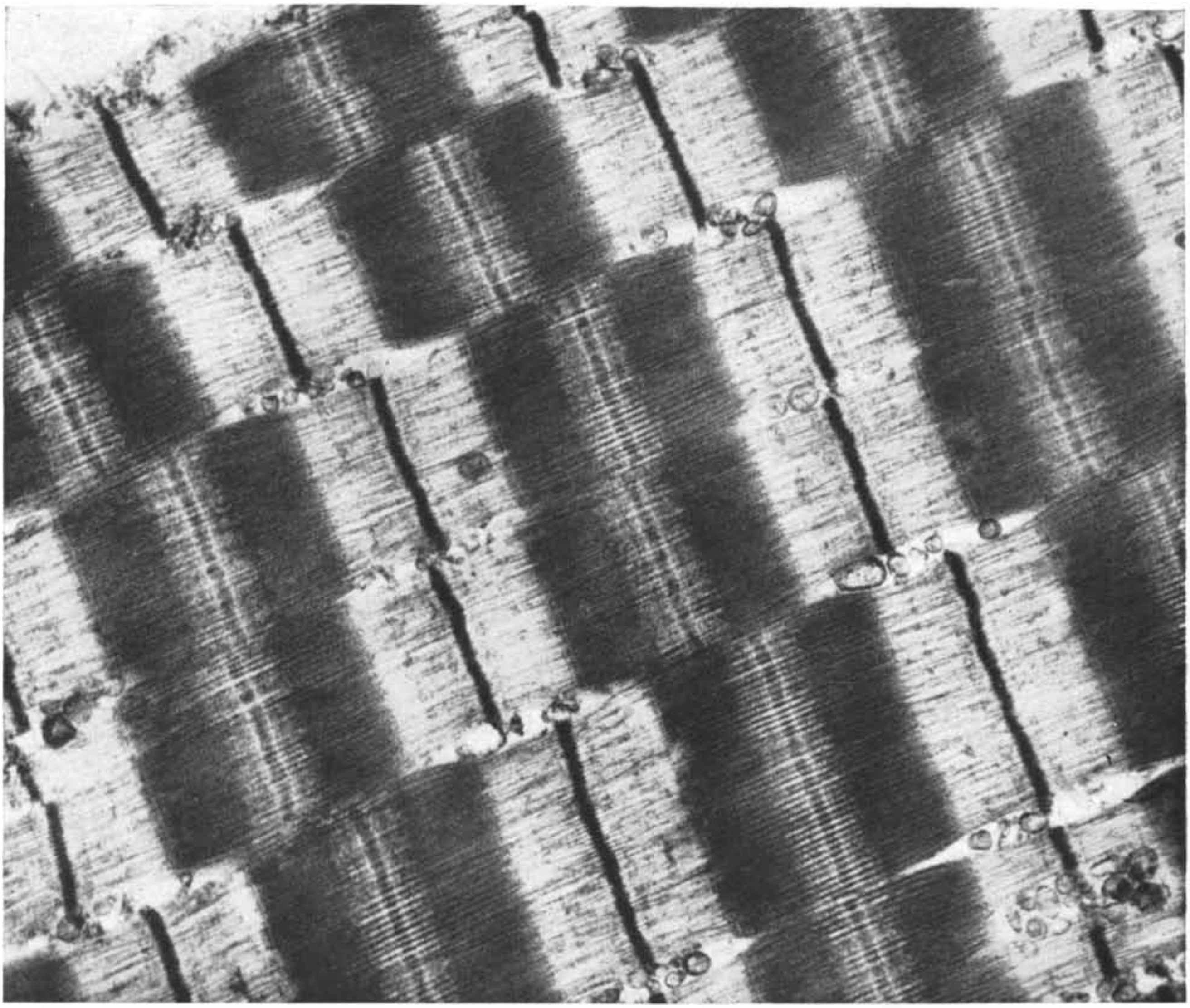
viously does more work than a muscle lifting a small load, so if the shortening heat remains constant, the total energy (heat plus work) expended by the contracting muscle must increase with the load. The chemical reactions which provide the energy for contraction must therefore be controlled not only by the change in the length of the muscle, but also by the tension placed on the muscle during the change. This is a remarkable property, of great importance to the efficiency of muscle, and new information about the structure of muscle has begun to explain it.

From the chemical point of view, the contractile structure of muscle consists almost entirely of protein. Perhaps 90 per cent of this substance is represented by the three proteins myosin, actin and tropomyosin. Myosin is especially abundant: about half the dry weight of the contractile part of the muscle consists of myosin. This is particularly significant because myosin is also the enzyme which can catalyze the removal of a phosphate group from adenosine triphosphate (ATP). And this energy-liberating reaction is known to be closely associated with the event of contraction, if not actually part of it.

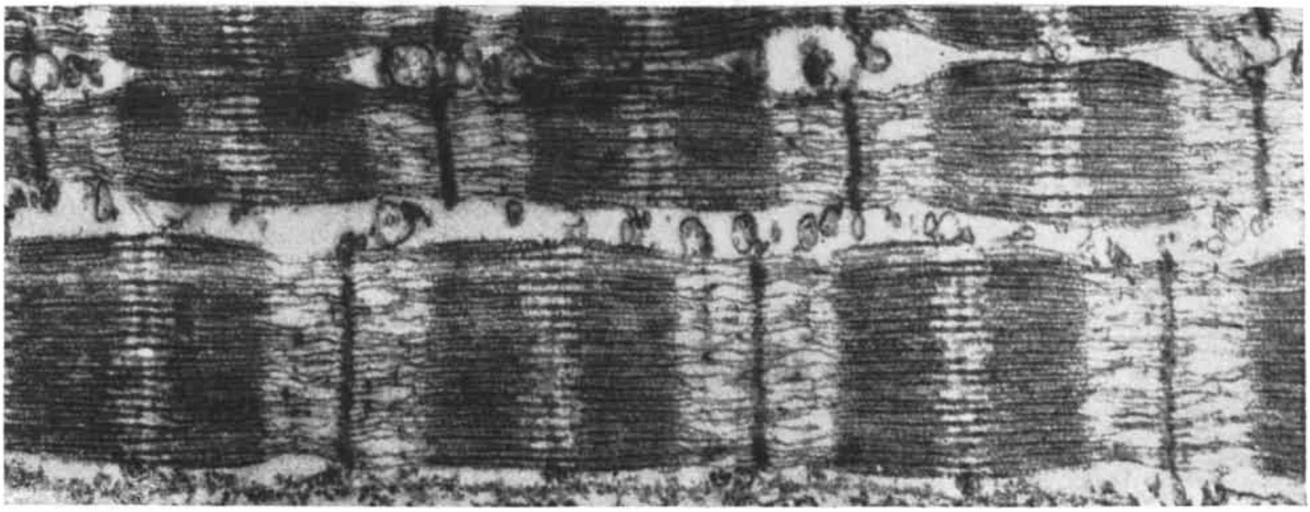
Myosin and actin can be separately extracted from muscle and purified. When these proteins are in solution together, they combine to form a complex known as actomyosin. Some years ago Albert Szent-Györgyi, the noted Hungarian biochemist who now lives in the U. S., made the striking discovery that if actomyosin is precipitated and artificial fibers are prepared from it, the fibers will contract when they are immersed in a solution of ATP! It seems that in the interaction of myosin, actin and ATP we have all the essentials of a contractile system. This view is borne out by experiments on muscles which have been placed in a solution of 50 per cent glycerol and 50 per cent water, and soaked for a time in a deep-freeze. After this procedure, and some further washing, practically everything can be removed from the muscle except myosin, actin and tropomyosin; and this residual structure will still contract when it is supplied with ATP.

The Structure of the Fiber

The most straightforward way to try to find out how the muscle machine works is to study its structure in as much detail as possible, using all the techniques now at our disposal. This has proved to be a fruitful approach, and I



STRIATED MUSCLE from a rabbit is enlarged 24,000 diameters in this electron micrograph. Each of the diagonal ribbons is a thin section of a muscle fiber. Clearly visible are the dense A-bands, bisected by H-zones; and the lighter I-bands, bisected by Z-lines.

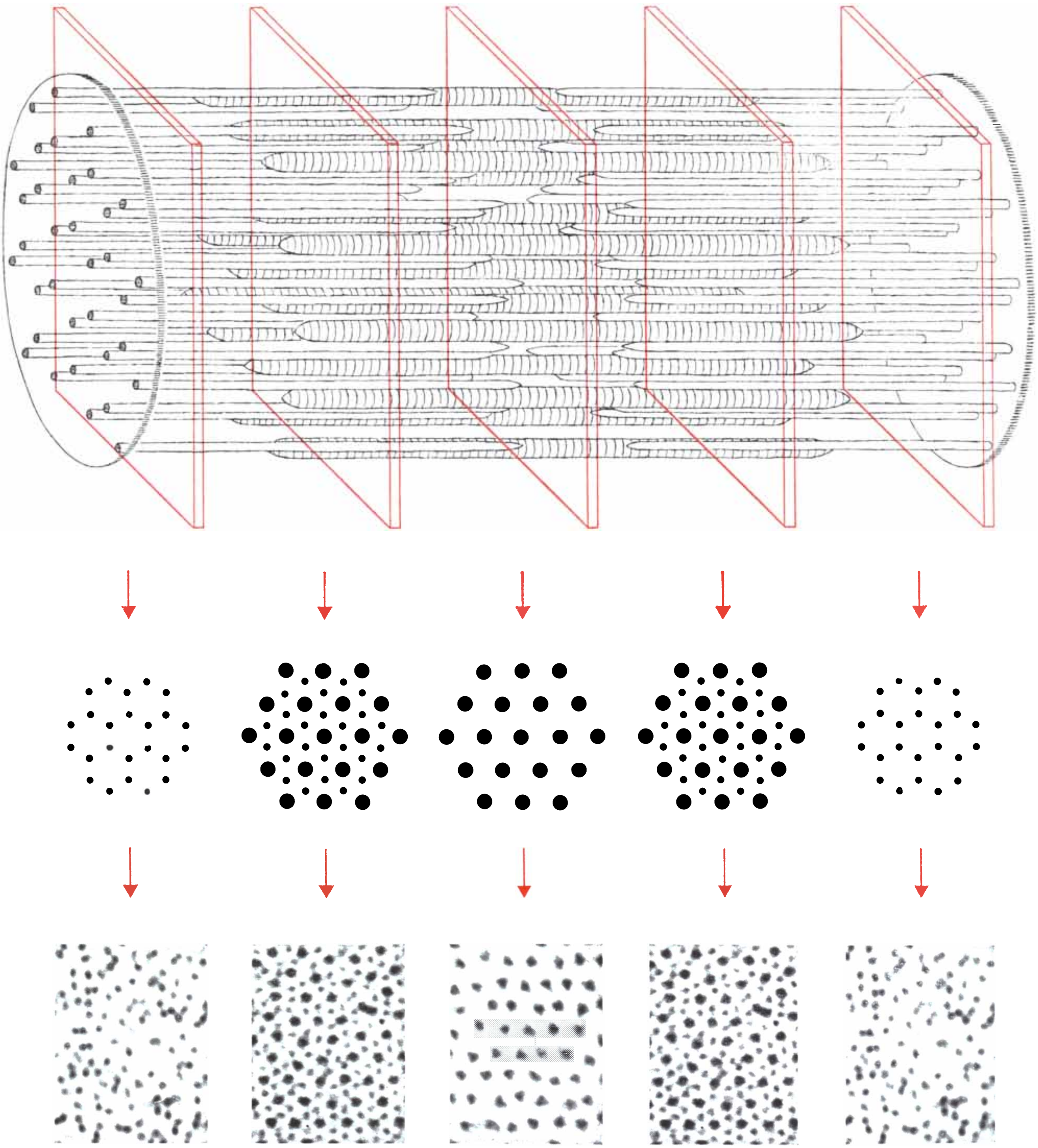


EXTREMELY THIN SECTION of a striated muscle is shown at much greater magnification. The section is so thin that in some places it contains only one layer of filaments. The way in which overlapping thick and thin filaments give rise to the band pattern can be clearly seen. Although the magnification of this electron micrograph is much larger than that of the micrograph at top of page, distance between the narrow Z-lines is less. This is because the section was longitudinally compressed by the slicing process.

shall briefly describe its results. Much of the work I shall discuss I have done in collaboration with Jean Hanson of the Medical Research Council Unit at King's College in London.

The contractile structure of a muscle fiber is made up of long, thin elements which we call myofibrils. A myofibril is about a micron in diameter, and is cross-striated like the fiber of which it is a part. Indeed, the striations of the fiber are due to the striations of the myofibril, which are in register in adjacent myofibrils. The striations arise from a repeating variation in the density, *i.e.*, the concentration of protein along the myofibrils.

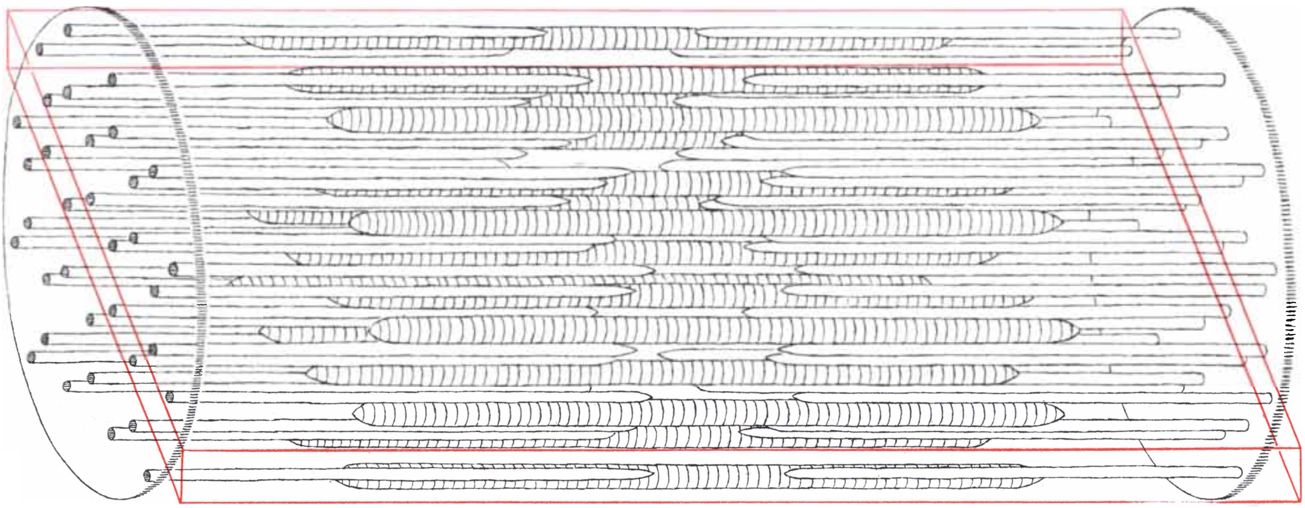
The pattern of the striations can be seen clearly in isolated myofibrils, which are obtained by whipping muscle in a Waring blendor. Under a powerful light microscope there is a regular alternation of dense bands (called A-bands) and lighter bands (called I-bands). The central region of the A-band is often less dense than the rest of the band, and is known as the H-zone. When a

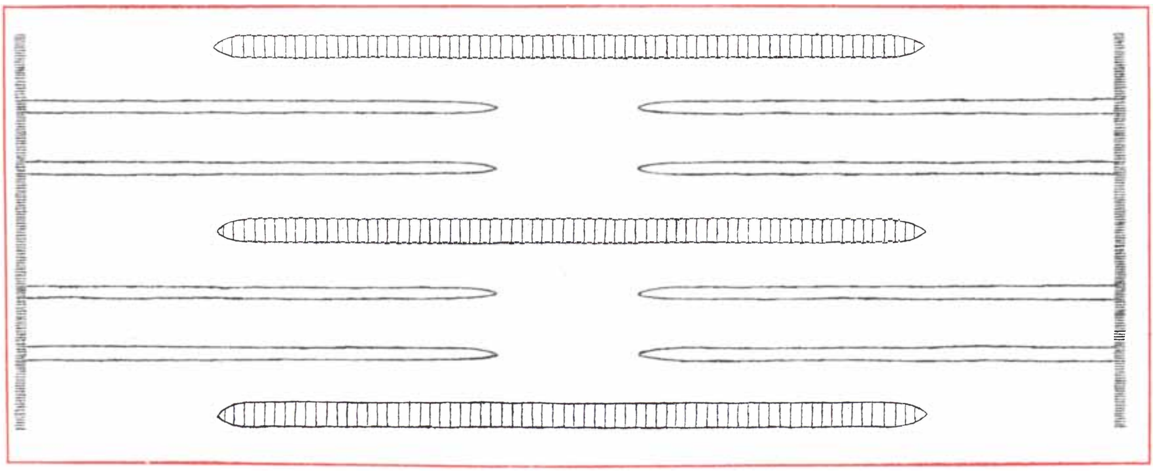


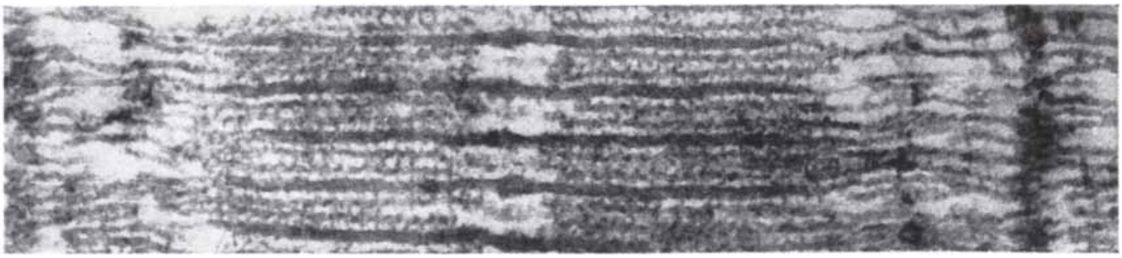
TRANSVERSE SECTIONS through a three-dimensional array of filaments in vertebrate striated muscle (*top*) show how the thick and thin filaments are arranged in a hexagonal pattern (*middle*). At bottom are electron micrographs of the corresponding sections.

striated muscle from a vertebrate is near its full relaxed length, the length of one of its A-bands is commonly about 1.5 microns, and the length of one of its I-bands about .8 micron. The I-band is bisected by a dense narrow line, the Z-membrane or Z-line. From one Z-line to the next the repeating unit of the myofibril structure is thus: Z-line, I-band, A-band (interrupted by the H-zone), I-band and Z-line.

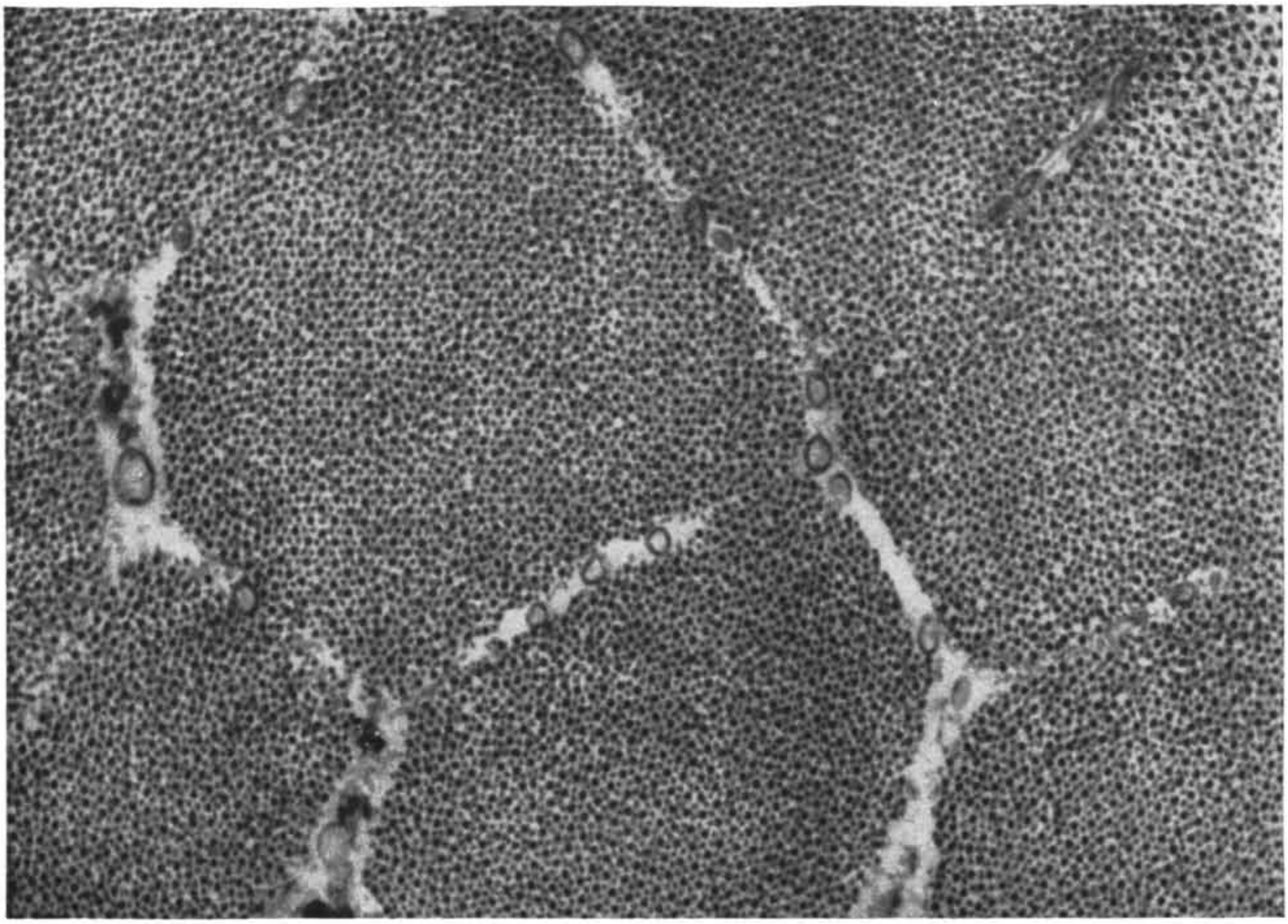
When myofibrils are examined in the electron microscope, a whole new world of structure comes into view. It can be seen that the myofibril is made up of still smaller filaments, each of which is 50 or 100 angstrom units in diameter (an angstrom unit is a 10,000th of a micron). These filaments were observed in the earliest electron micrographs of muscle, made by Cecil E. Hall, Marie A. Jakus and Francis O. Schmitt of the Massachusetts Institute of Technology, and by M. F. Draper and Alan J. Hodge of Australia. And now thanks to recent advances in the technique of preparing specimens for the electron microscope,







LONGITUDINAL SECTION through the same array shows how two thin filaments lie between two thick ones. This pattern is a consequence of the fact that one thin filament is centered among three thick ones. At bottom is a micrograph of the corresponding section.



SEVERAL FIBERS in a vertebrate striated muscle are seen from the end in an electron micrograph which enlarges them 90,000 diameters. Within each fiber is the hexagonal array of its filaments. This pattern, in which one thin filament lies symmetrically among three thick ones, differs from the pattern in the insect muscle on page 66, in which one thin filament lies between two thick ones.

it is possible to examine the arrangement of the filaments in considerable detail.

For this purpose a piece of muscle is first "fixed," that is, treated with a chemical which preserves its detailed structure during subsequent manipulations. Then the muscle is "stained" with a compound of a heavy metal, which increases its ability to deflect electrons and thus enhances its contrast in the electron microscope. Next it is placed in a solution of plastic which penetrates its entire structure. After the plastic is made to solidify, the block of embedded tissue can be sliced into sections 100 or 200 angstrom units thick by means of a microtome which employs a piece of broken glass as a knife. When we look at these very thin sections in the electron microscope, we can see immediately that muscle is constructed in an extraordinarily regular and specific manner.

A myofibril is made up of two kinds of filament, one of which is twice as thick as the other. In the psoas muscle from the back of a rabbit the thicker filaments are about 100 angstroms in diameter and 1.5 microns long; the thinner filaments are about 50 angstroms in diameter and two microns long. Each filament is arrayed in register with other filaments of the same kind, and the two arrays overlap for part of their length. It is this overlapping which gives rise to the cross-bands of the myofibril: the dense A-band consists of overlapping thick and thin filaments; the lighter I-band, of thin filaments alone; the H-zone, of thick filaments alone. Halfway along their length the thin filaments pass through a narrow zone of dense material; this comprises the Z-line. Where the two kinds of filament overlap, they lie together in a remarkably regular hexagonal array. In many vertebrate muscles the filaments are arranged so that each thin filament lies symmetrically among three thick ones; in some insect flight-muscles each thin filament lies midway between two thick ones.

The two kinds of filament are linked together by an intricate system of cross-bridges which, as we shall see, probably play an important role in muscle contraction. The bridges seem to project outward from a thick filament at a fairly regular interval of 60 or 70 angstroms, and each bridge is 60 degrees around the axis of the filament with respect to the adjacent bridge. Thus the bridges form a helical pattern which repeats every six bridges, or about every 400 angstroms along the filament. This pattern joins the thick filament to each one of its six adjacent thin filaments once every 400 angstroms.

The arrangement of the filaments and their cross-bridges, as seen in the electron microscope, is so extraordinarily well ordered that one may wonder whether the fixing and staining procedures have somehow improved on nature. Fortunately this regularity is also apparent when we examine muscle by another method: X-ray diffraction. Muscle which has not been stained and fixed deflects X-rays in a regular pattern, indicating that the internal structure of muscle is also regular. The details of the diffraction pattern are in accord with the structural features observed in the elec-

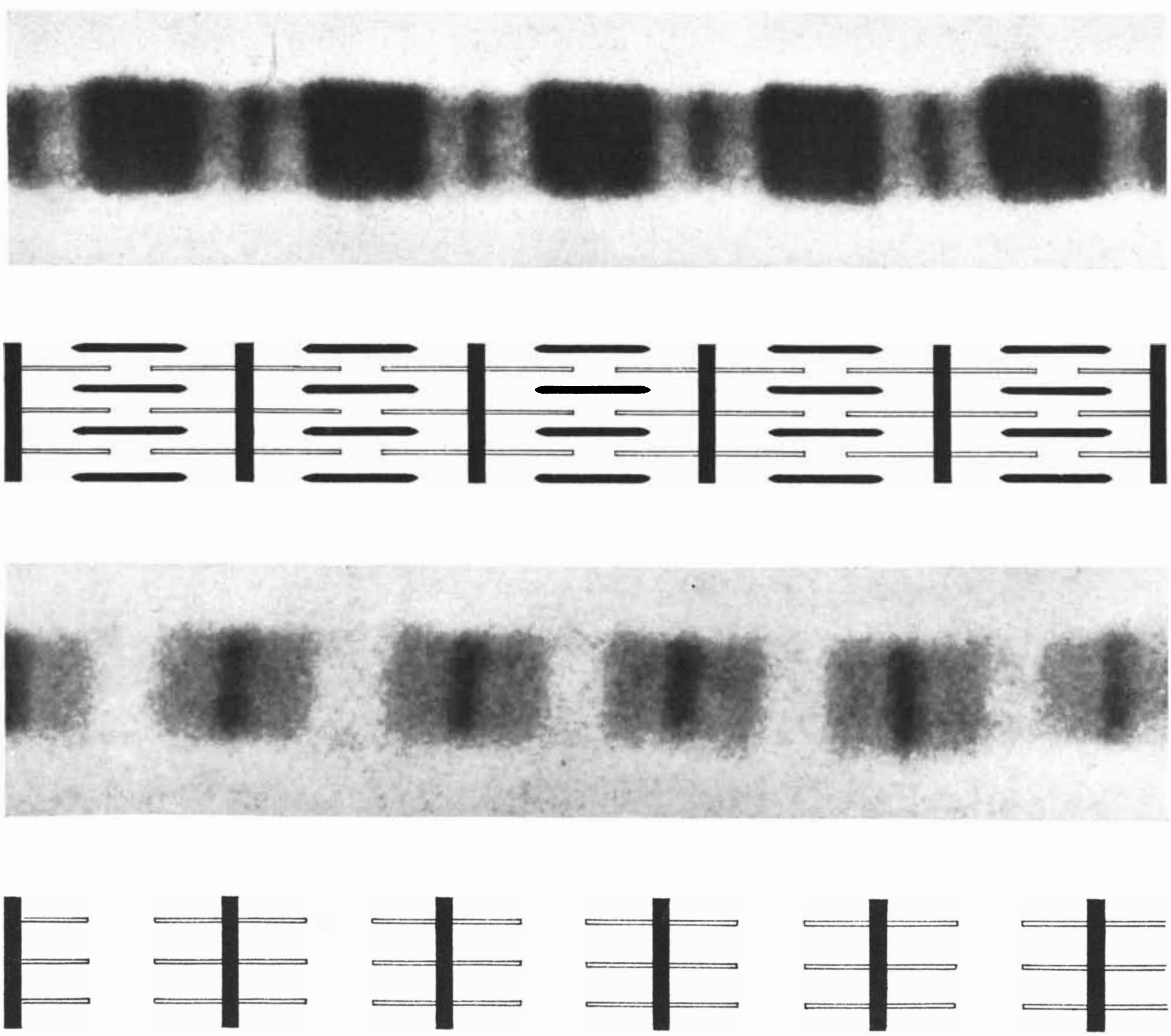
tron microscope. Indeed, many of these features were originally predicted on the basis of X-ray diffraction patterns alone.

The Sliding-Filament Model

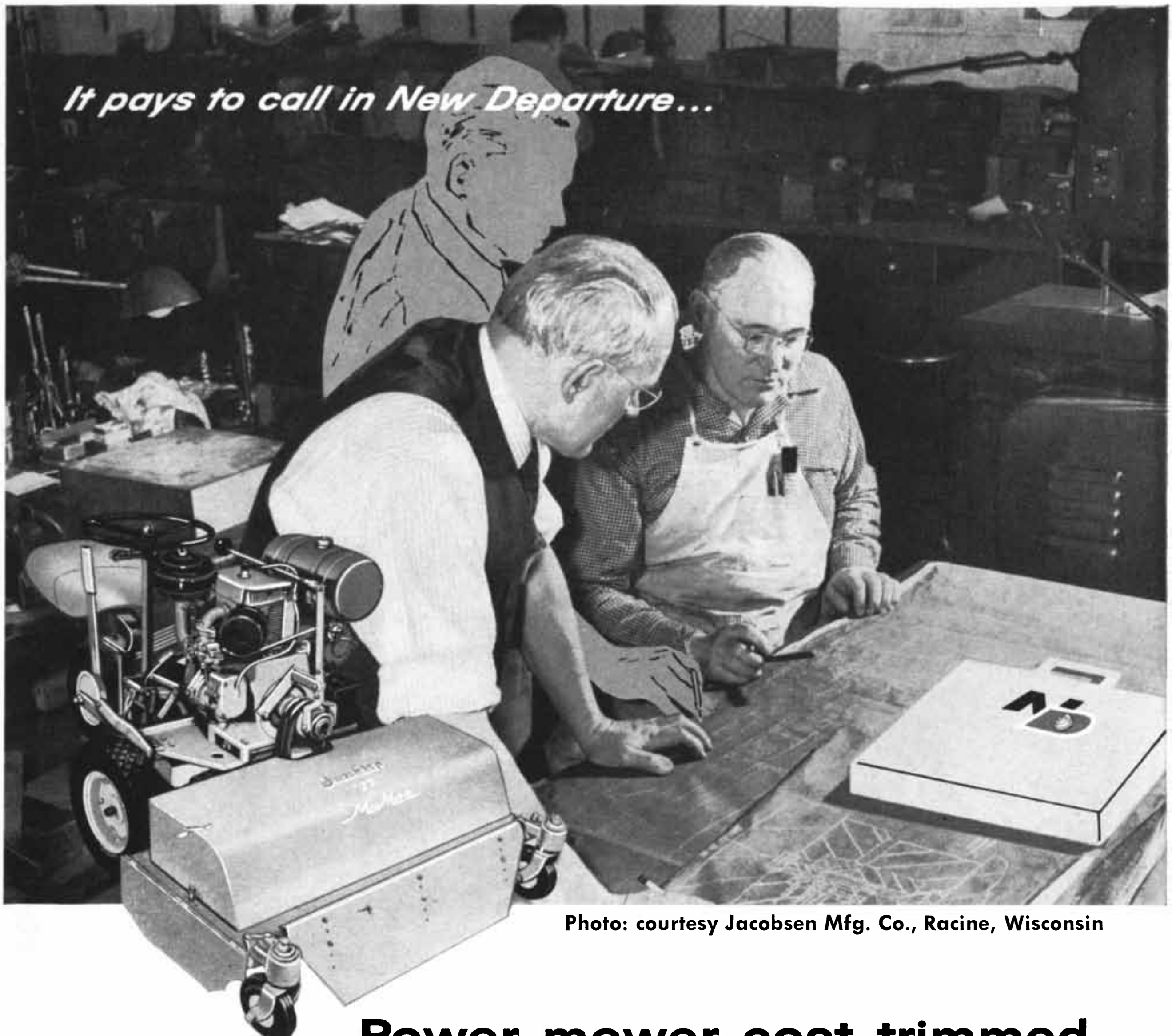
As soon as the meaning of the band pattern of striated muscle became apparent, it was obvious that changes in the pattern during contraction should give us new insight into the molecular nature of the process. Such changes can be unambiguously observed in modern light microscopes, notably the phase-contrast microscope and the interference microscope. They can be studied in living muscle fibers (as they were by A. F. Huxley and R. Niedergerke at the University of Cambridge) or in isolated myofibrils contracting in a solution of ATP (as they were by Jean Hanson and myself at M.I.T.). We all came to the same conclusions.

It has been found that over a wide range of muscle lengths, during both contraction and stretching, the length of the A-bands remains constant. The length of the I-bands, on the other hand, changes in accord with the length of the muscle. Now the length of the A-band is equal to the length of the thick filaments, so we can assume that the length of these filaments is also constant. But the length of the H-zone—the lighter region in the middle of the A-band—increases and decreases with the length of the I-band, so that the distance from the end of one H-zone through the Z-line to the beginning of the next H-zone remains approximately the same. This distance is equal to the length of the thin filaments, so they too do not alter their length by any large amount.

The only conclusion one can draw from these observations is that, when the muscle changes length, the two sets of filaments slide past each other. Of course when the muscle shortens enough,



DIFFERENT CHEMICAL COMPOSITION of the thick and thin filaments is demonstrated. At top is a myofibril photographed in the phase-contrast light microscope. The wide dark regions are A-bands; between them are I-bands bisected by Z-lines. Second from top is a simplified schematic drawing of how the thick and thin filaments give rise to this pattern. Third from top is a photomicrograph of a myofibril from which the protein myosin has been chemically removed. The A-bands have disappeared, leaving only the I-bands and Z-lines. At bottom is a drawing which shows how this pattern is explained on the assumption that the thick filaments have been removed. Thus it appears that the thick filaments are composed of myosin, and the thin filaments of other material.



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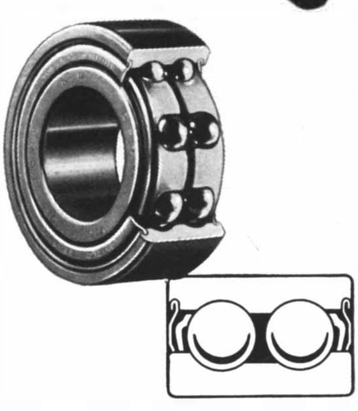
Perhaps the man from New Departure can recommend an N/D production bearing that will give *your* product the cost savings and added sales appeal you're looking for. For more information, write Department B-11.

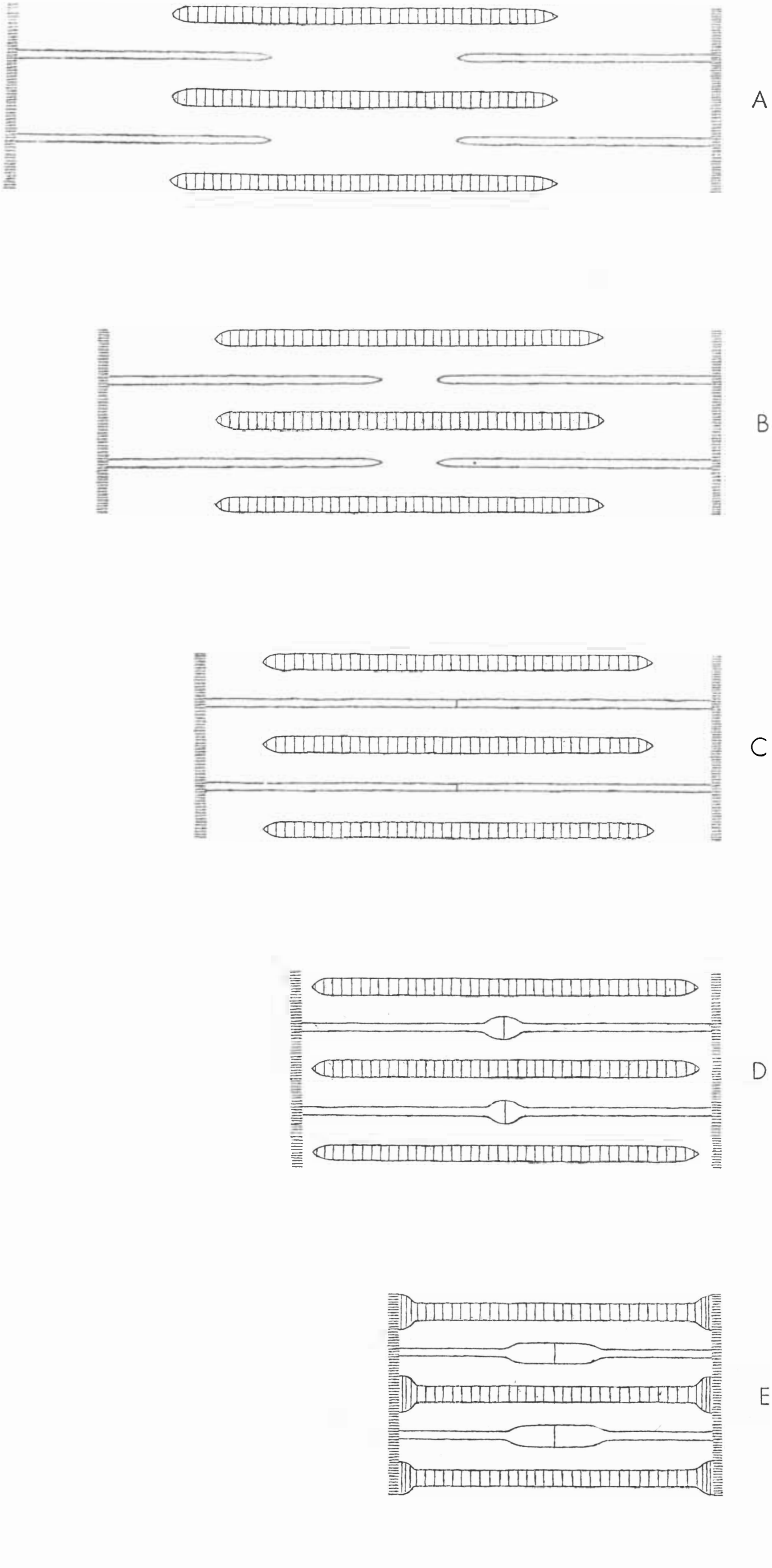


An efficient double row, pre-loaded, ball bearing for use where combined loads must be resisted by a single bearing. Both radial and axial deflections are controlled within very close limits.

NEW DEPARTURE

DIVISION OF GENERAL MOTORS, BRISTOL, CONN.

NOTHING ROLLS LIKE A BALL



CHANGE IN LENGTH of the muscle changes the arrangement of the filaments. In A the muscle is stretched; in B it is at its resting length; in C, D and E it is contracted. In C the thin filaments meet; in D and E they crumple up. In E the thick filaments also meet adjacent thick filaments (*not shown*) and crumple. The crumpling gives rise to new band patterns.

the ends of filaments will meet; this happens first with the thin filaments, and then with the thick [*see illustration at left*]. Under such conditions, in fact, new bands are observed which suggest that the ends of the filaments crumple or overlap. But these effects seem to occur as a *result* of the shortening process, and not as causes of contraction.

It has often been suggested that the contraction of muscle results from the extensive folding or coiling of the filaments. The new observations compel us to discard this idea. Instead we are obliged to look for processes which could cause the filaments to slide past one another. Although this search is only beginning, it is already apparent that the sliding concept places us in a much more favorable position with respect to what we might call the intermediate levels of explanation: the description of the behavior of muscle in terms of molecular changes whose detailed nature we do not know, but whose consequences we can now compute.

There is more to be said about such matters, but first let us return to the chemical structure of muscle. If a muscle is treated with an appropriate salt solution, and then examined under the light microscope, it is observed that the A-bands are no longer present. It is also known that such a salt solution will remove myosin from muscle. This demonstrates that the thick filaments of the A-band are composed of myosin, a conclusion which has been quantitatively confirmed by comparing measurements made by chemical methods with those made by the interference microscope. Moreover, when myofibrils which have been treated with salt solution are examined in the electron microscope, they lack the thick filaments. The "ghost" myofibril that remains consists of segments of material which correspond to the arrays of thin filaments in the I-bands. If the myofibril is treated so as to extract its actin, a large part of the material in these segments is removed. This indicates that the thin filaments of the I-band are composed of actin and (probably) tropomyosin.

Thus the two main structural proteins of muscle are separated in the two kinds of filaments. As noted earlier, actin and myosin can be made to contract in a solution of ATP, but only when they are combined. We therefore conclude that the physical expression of the combination of actin and myosin is to be found in the bridges between the two kinds of filaments. It should also be said that the thick and thin filaments are too far apart for any plausible "action at a distance,"

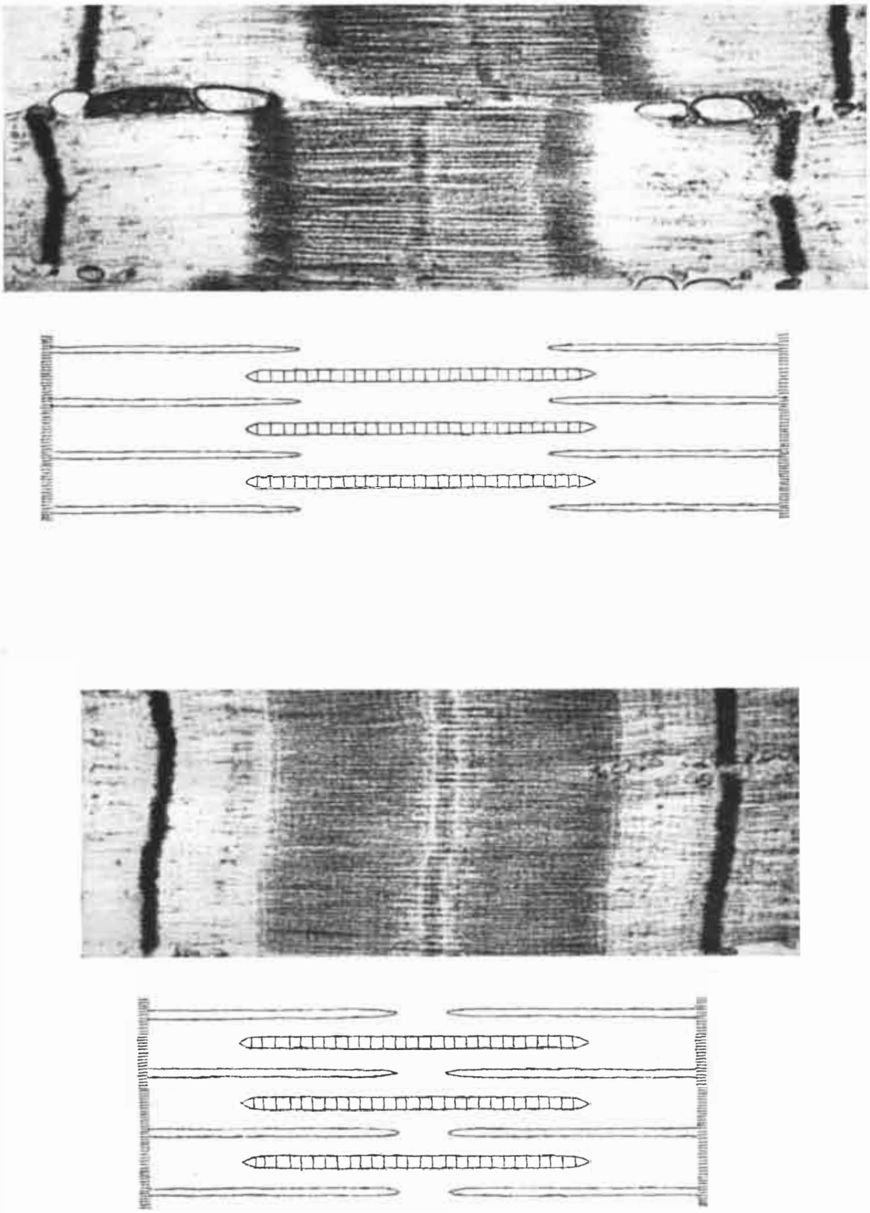
so it would seem likely that the sliding movement is mediated by the bridges.

The Cross-Bridges

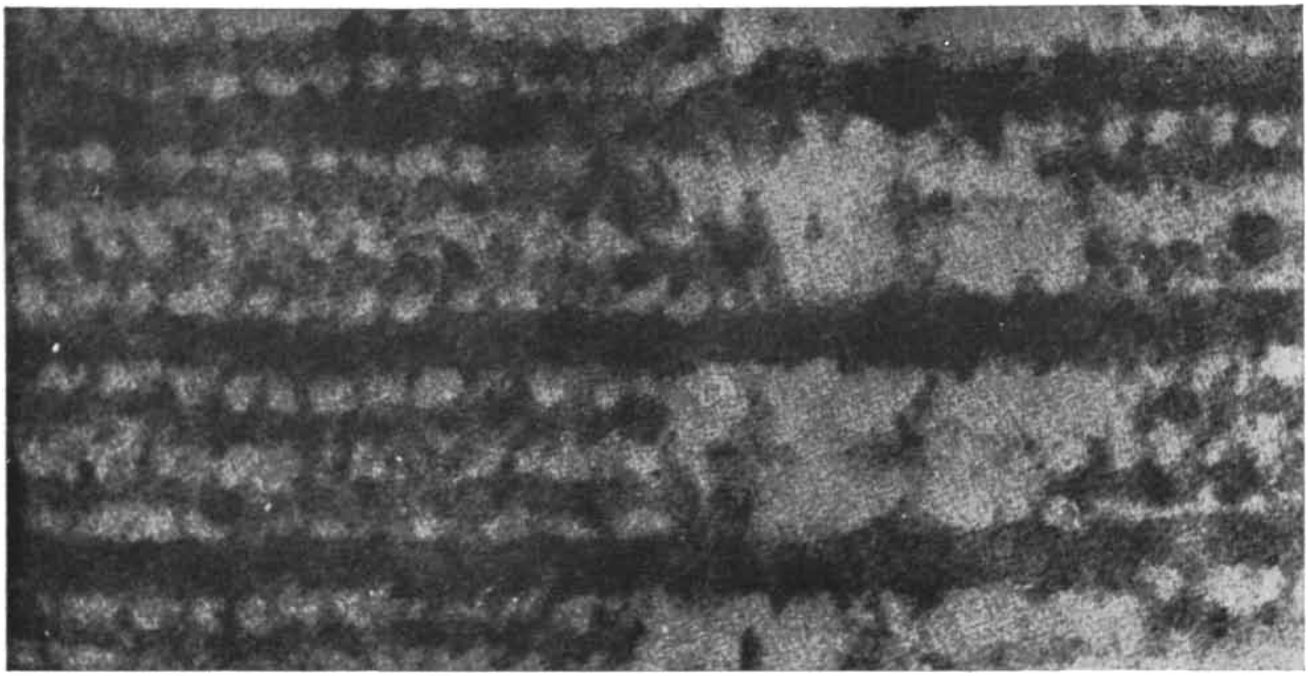
The bridges seem to form a permanent part of the myosin filaments; presumably they are those parts of myosin molecules which are directly involved in the combination with actin. In fact, when we calculate the number of myosin molecules in a given volume of muscle, we find that it is surprisingly close to the number of bridges in the same volume. This suggests that each bridge is part of a single myosin molecule.

How could the bridges cause contraction? One can imagine that they are able to oscillate back and forth, and to hook up with specific sites on the actin filament. Then they could pull the filament a short distance (say 100 angstroms) and return to their original configuration, ready for another pull. One would expect that each time a bridge went through such a cycle, a phosphate group would be split from a single molecule of ATP; this reaction would provide the energy for the cycle.

To account for the rate of shortening and of energy liberation in the psoas muscle of a rabbit, each bridge would have to go through 50 to 100 cycles of operation a second. This figure is compatible with the rate at which myosin catalyzes the removal of phosphate



STRETCHING of muscle changes its band pattern. At top is an electron micrograph showing two myofibrils in a stretched muscle. Second is a drawing of the position of their filaments. The thick and thin filaments overlap only at their ends. Third is a micrograph of a myofibril at its resting length. At bottom is a drawing showing the position of the filaments.

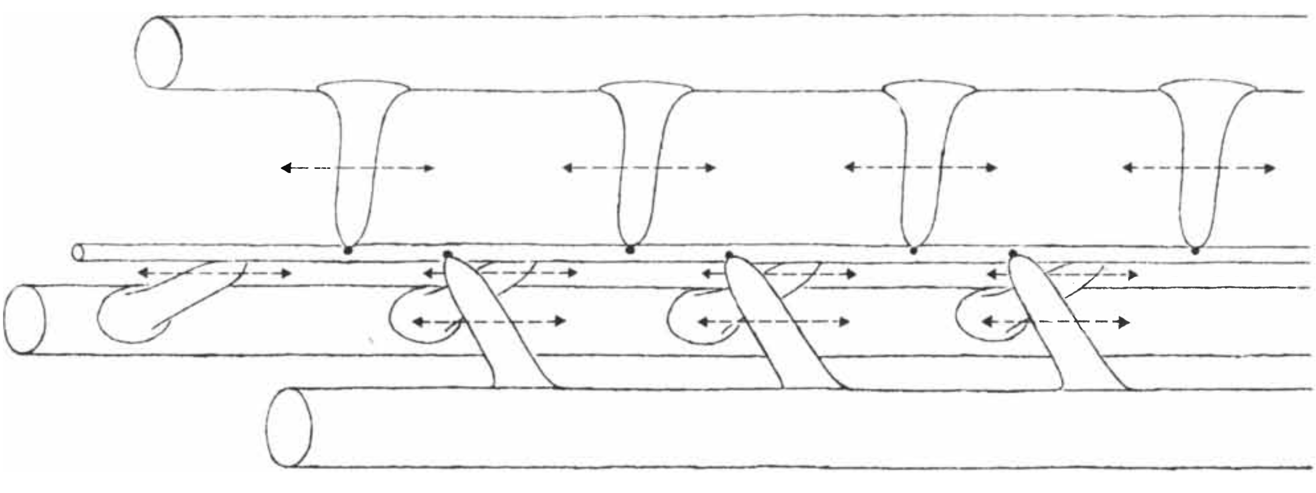


CROSS-BRIDGES between thick and thin filaments may be seen in this electron micrograph of the central region of an A-band. The micrograph enlarges the filaments 600,000 diameters. Three thick filaments are seen; between each pair are two thin filaments.

groups from ATP. When the muscle has relaxed, we suppose that the removal of phosphate groups from ATP has stopped, and that the myosin bridges can no longer combine with the actin filaments; the muscle can then return to its uncontracted length. Indeed, there is evidence from various experiments that ATP from which phosphate has *not* been split can break the combination of actin and myosin. The reverse effect—the formation of permanent links between the actin and myosin filaments in the total absence of ATP—would explain the rigidity of muscles in *rigor mortis:* when the muscles' supply of ATP has been used up, they "seize" like a piston which has been deprived of lubrication.

The system I have described is sharply distinguished from most other suggested muscle mechanisms by one significant feature: a ratchet device in the linkage between the detailed molecular changes and the contraction of the muscle. This makes it possible for a movement at the molecular level to reverse direction without reversing the contraction. Thus during each contraction the molecular events responsible for the contraction can occur repeatedly at each active site in the muscle. As a result the muscle can do much more work during a single contraction than it could if only one event could occur at each active site.

Earlier in this article I mentioned that the tension exerted by a muscle falls off as its speed of shortening increases. This phenomenon can now be explained quite simply if we assume that the process by which a cross-bridge is attached to an active site on the actin filament occurs at a definite rate. There is only a certain period of time available for a bridge to become attached to an actin site moving past it, and the time de-

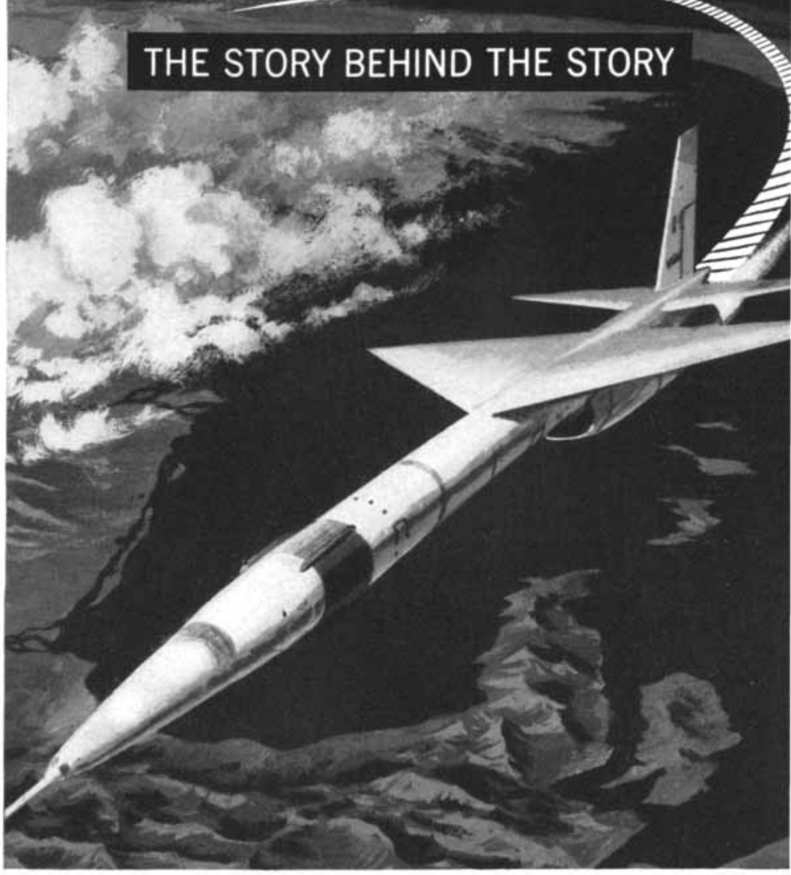


ARRANGEMENT OF CROSS-BRIDGES suggests that they enable the thick filaments to pull the thin filaments by a kind of ratchet action. In this schematic drawing one thin filament lies among three thick ones. Each bridge is a part of a thick filament, but it is able to hook onto a thin filament at an active site (*dot*). Presumably the bridges are able to bend back and forth (*arrows*). A single bridge might thus hook onto an active site, pull the thin filament a short distance, then release it and hook onto the next active site.

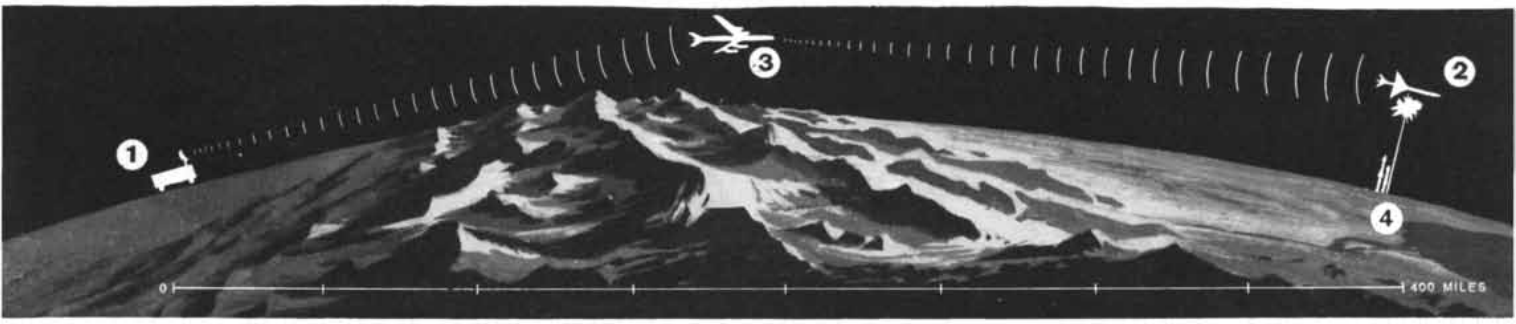
GROUND CONTROL of target drone centers in air-portable van. Men at console maintain control through flight instruments. Path of drone is traced automatically on plotting board at right.

AIR CONTROL relays commands from ground station to drone where distance or terrain block direct beam. Air director may also originate control since it has complete microwave system.

THE STORY BEHIND THE STORY



PROBING ANTI-MISSILE DEFENSES, remotely-controlled drone flies at supersonic speed toward target area. Test measures alertness of defense system and speed in launching ground-to-air missile.



GREAT RANGE of Sperry microwave command guidance system is shown in diagram. Ground station (1) controls target drone (2) either directly or through air director (3). Drone draws fire of defense system which launches ground-to-air interceptor missile (4).

RADAR SYSTEM WILL ENABLE USAF TO TEST ANTI-MISSILE DEFENSES

Can guide "attacking" drones 400 miles at supersonic speeds

How good are our anti-missile defenses? A new Sperry Microwave Command Guidance System recently demonstrated for the Air Force will help military officials find the answer. Applied to supersonic target drones used to simulate a missile attack, the system will aid in testing the readiness of air defense units and ground-to-air missile defenses.

With a range of 400 miles, the Sperry system can guide a drone along a preset course with precise accuracy from a mobile ground control station. It displays a drone's path automatically on a plotting board, receives information continuously from the drone on its speed and other flight conditions, and commands the drone's engine and flight controls. When the earth's curvature or obstructions block the ground signal, the system operates through a director aircraft which is a flying duplicate of the master ground control station.

In working with the Air Force to develop the new system, Sperry made use of its broad experience in gyroscopics and electronics as well as its mastery of microwave radar for guidance and control of missiles and aircraft. Since 1946 Sperry has been designing and producing complete long-range control systems for drones and unmanned aircraft—including the first to fly directly through an atomic cloud.

SPERRY GYROSCOPE COMPANY
Great Neck, New York
DIVISION OF SPERRY RAND CORPORATION

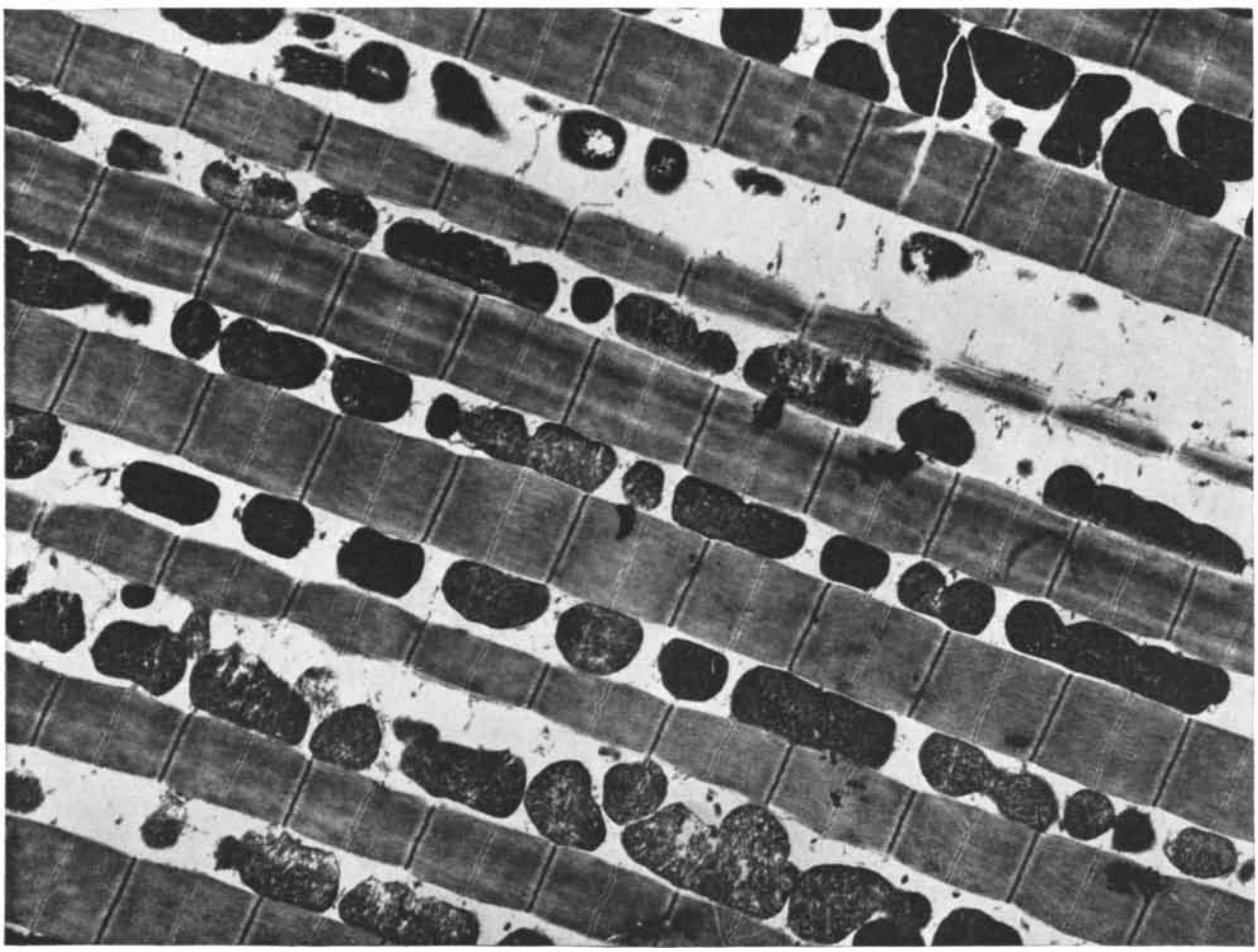
creases as the speed of shortening increases. Thus during shortening not all the bridges are attached at a given moment; the number of ineffective bridges increases with increasing speed of shortening, and the tension consequently decreases. A. F. Huxley has worked out a detailed scheme of this general nature, and has shown that it can account for many features of contraction.

It was also indicated earlier that the total energy (heat plus work) developed by a muscle contracting over a given distance increases with the tension or load placed on the muscle. This can be explained by our mechanism if the chemical reaction which delivers the energy—say the removal of phosphate groups from ATP—proceeds slowly at bridges which are not attached to an actin filament, and rapidly at bridges which are attached. Since the number of bridges attached at any moment is determined by the load on the muscle, the amount of energy released in a given distance of shortening is automatically varied according to the amount of external work done. This assumption of a difference in the reaction rate at unattached bridges and at attached bridges is plausible: when myosin is placed in a solution approximating the environment of muscle, it splits ATP rather slowly; when the myosin is allowed to combine with actin, the splitting is greatly accelerated.

There are other reasons, with which I shall not burden the general reader, for believing that the sliding-filament model of muscle accords rather well with our chemical and physiological knowledge of striated muscle. The model provides a frame of reference in which we can relate to one another many different kinds of information: about muscle itself, about artificial contractile systems and about muscle proteins. The situation is promising and stimulating, and we seem to be on the right track, but we are still far from being able to describe the contraction of muscle in detailed molecular terms—perhaps farther than we think!

There remains the most fundamental question of all: Exactly how does a chemical reaction provide the motive force for the molecular movements of contraction? We have made little progress toward answering the question; indeed, the recent studies have made the problem more difficult by seeming to require that a movement of 100 angstroms in part of the muscle structure be the consequence of a single chemical event. But it may be that the sliding process is effected by a more subtle mechanism than the one described here; perhaps a caterpillar-like action, in which one kind of filament crawls past the other by small repetitive changes of length, will be closer to the truth.

Two things are certain. The problem of muscular contraction will not be solved independently of other modern biological problems—those of the structure of proteins, of the action of enzymes, and of energy transfer in biological systems. And muscle itself provides as promising a system for attacking these problems as any we know.



FLIGHT MUSCLE of a blow fly has broad A-bands and narrow I-bands. This is consistent with the sliding-filament hypothesis because the flight muscle of the blow fly contracts only a few per cent of its length (though it must do so several hundred times a second). The dense bodies between the myofibrils are mitochondria, in which foodstuff is oxidized to provide the energy for contraction.

THIS IS GLASS

a bulletin of practical new ideas from Corning

It's cooler inside!

Sitting behind the controls of this crane in a steel mill used to be a hot job. But now cab windows are made of ¼″ polished plate that's fashioned from PYREX brand *infrared reflecting* glass.

This glass *bounces* heat away—transmission of IRR (infrared) being as low as 7%, depending on wave length. Yet you can see through these windows since about 75% of visible light is passed. These IRR windows are strong, chemically resistant, and very durable. You can get them in sizes up to 30″ x 60″. For details (along with data on blue observation glass, PYREX brand glass No. 7740, and VYCOR brand glass No. 7900) ask for PE-34, a 4-page data sheet covering flat glass properties, specifications, and applications.

Hot rod

This has *nothing* whatsoever to do with motor cars. Rather our concern here is a piece of *glass* rod that conducts electricity and produces heat.

The rod is ¼″ O.D., made of heat-resistant glass coated with a metallic oxide that's fired in for permanence. Ends are silvered so you can use clip contacts.

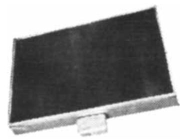
NEW, low-watt density heater from Corning consists of glass rod, coated with a metallic conductor, and having silvered ends for attaching clip contacts.

With either a 120 or 240 volt source, you have a power *output* rate of roughly 50 watts for every 6 inches of rod.

Someone described this low-watt density heater as "a non-crystalline, rigid wire made of glass." The big question: What can you do with it? So far the project development people at Corning have come up with hot rods ranging in size from 6 to 24 inches. Larger sizes are being looked into.

Seems like a compact heater like this should be good for lots of things. We await your suggestions and inquiries.

Working on the same principle of a metallic coating that conducts electricity to produce heat are panels like this.



These panels are called PYREX brand industrial radiant heaters. You'll find them in use in plants 'round the country for drying, heating, baking, curing.

Main reason for the popularity of these heaters is the kind of heat you get. It's *uniform*, and *long wave*—5 microns and over.

And long wave heat is very readily *absorbed*. For example, here's comparable performance for a white surface.

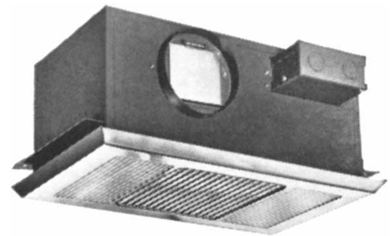
Source	Temperature °K	% radiant energy absorbed
infrared lamp	2500	30
sheathed wire unit	1000	70
"PYREX" heater	600	90

With the long wave heat from PYREX® heaters, color is of *little* importance—heating speed is almost constant.

PYREX industrial radiant heating panels are mounted in an aluminized steel frame and come complete with built-in reflector, mounting hangers, junction box, and leads.

All the facts about this efficient way to get heat are spelled out in Bulletin PE-60. Use the coupon if you'd like a copy.

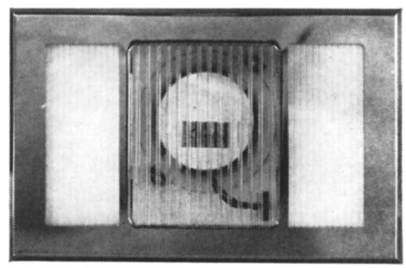
Inside job



This combination ventilator and lighting fixture is compact and smart looking. It's made by Fasco Industries, Inc., a Rochester, N. Y., firm.

Mounted in the ceiling, this fixture exhausts stale air and provides illumination for bath and/or utility rooms.

Where do we enter the picture? The grille is made of 7½″-long pieces of *glass* rod. Glass makes for smooth air flow, looks good, and stays that way.



And the 4″x7″ lighting panels are Corning No. 66 Alba-lite—an opal glass in an attractive fluted pattern. Alba-lite diffuses; it stands up to the heat from the 60-watt lamps. It, too, looks good, and is easy to keep clean.

Suggestion: If anything you make (or contemplate making) uses glass parts, try Corning. You'll get *what* you want, *when* you want it, in the *quantities* you need, at a *price* that makes sense.

Or as a starter, ask for "This Is Glass." In its 64 pages you'll probably find something you can use. Remember: *Corning can do almost anything with glass.*

Corning means research in Glass

CORNING GLASS WORKS, 49-11 Crystal Street, Corning, New York

Please send me: ☐ PE-34 "Corning Flat Glasses"; ☐ PE-60 "PYREX brand industrial radiant heater catalog"; ☐ "This Is Glass"

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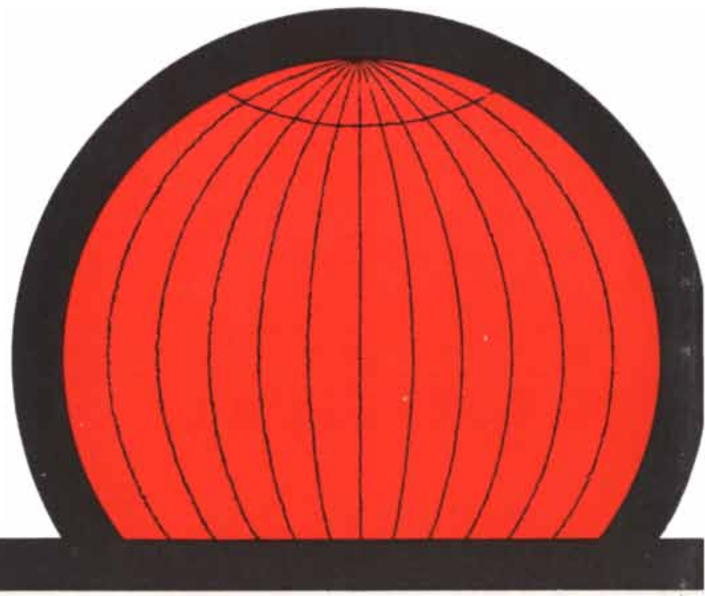
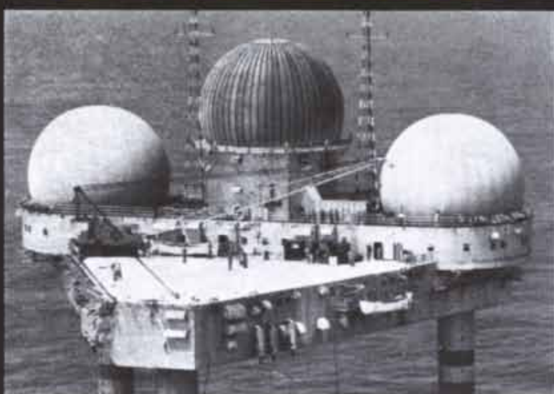


Burroughs Digital Computers Even in 'Texas Tower' Outposts

FIRM'S VITAL DATA PROCESSING ROLE IS MANY-SIDED

WASHINGTON, D.C.—Another vital link in defense, 'Texas Towers' now extend our SAGE defense system lonely miles off America's shores. Here, as well as from its chain of bases across the continental U.S., SAGE supersensitively searches for the faintest hint of airborne attack.

In these installations helping to defend 173 million Americans, the Burroughs electronic computers almost instantaneously compute and process radar data for alerting U.S. defense.



THE FACTS ABOUT MAGNESIUM AVAILABILITY

Prospect: Abundant, readily obtainable quantities in the U. S. of the lightest structural metal . . . in every usable form for both military and civilian use.

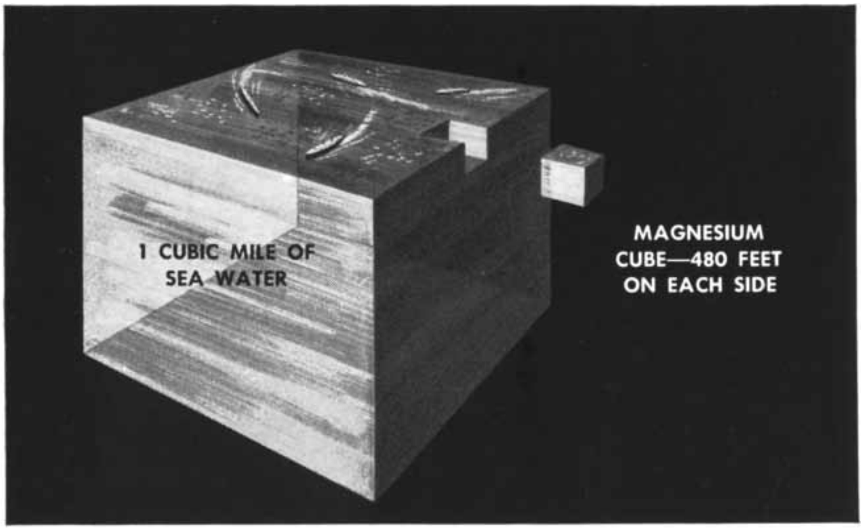
MAGNESIUM, the lightweight metal from the sea, lends itself to a host of structural and non-structural applications. The future indicates an ever increasing usage of magnesium and its alloys as more and more industries become aware of its many desirable characteristics.

In addition to being lightweight, magnesium has a high stiffness-to-weight ratio, unexcelled machinability, the ability to be worked by all common methods, and stability in many atmospheres. There are conventional alloys for use at normal temperatures and special alloys for use in the missile and aircraft field at temperatures up to 700°F. and above. Many types of casting, extrusions, and rolled products can be produced from magnesium alloys.

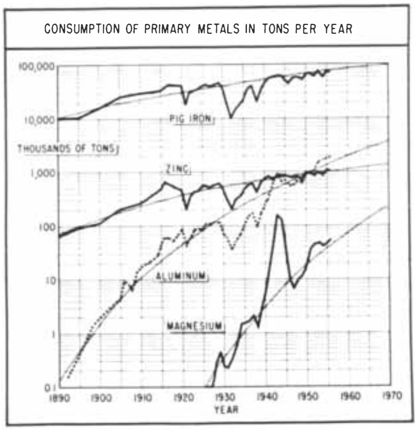
What about the availability of magnesium? Is there raw material in sufficient quantities to satisfy foreseeable requirements? Are producing capacities ample for increased demand?

The answer to these questions is an emphatic "yes"! The sources of magnesium are, by any standard of measure, inexhaustible. From the standpoint of accessibility, as well as quantity, magnesium is the most readily available of all metals.

As you know, magnesium is "mined" from the ocean, as well as the earth. One cubic mile of sea water contains about six million tons of the metal. There are approximately 320,000,000 cubic miles of sea water in the world, and the entire coast line of the continental United States can be considered as one immense source of supply. Easy to see why magnesium supply is termed "inexhaustible" in the most conservative quarters. And it is quite practical and economical to recover magnesium from sea water. Dow has been doing it for seventeen years.



ONE CUBIC MILE of sea water contains enough magnesium to build a solid cube 480 feet on each side, or, a bar one foot by one foot over 20,000 miles in length, enough to circle the earth at the latitude of San Francisco.



MAGNESIUM CONSUMPTION in the U. S. has increased at a rapid rate since the Twenties.

Perhaps less dramatic, but just as important, is the fact that more than adequate supplies of magnesium are to be found in dolomite, magnesite and other magnesium mineral deposits. These are widely distributed in nature's storehouse, a large quantity being found on the North American continent.

And what about manufactured forms of the world's lightest structural metal? Magnesium is available today in every usable form: ingot, sheet, plate, castings, forgings, and extrusions. There are some seventy sand and permanent mold foundries in all parts of the nation. Over one hundred metal working plants fabricate magnesium products and parts.

Looking toward future needs, Dow's production facilities can supply quantities of ingot and fabricated magnesium well in excess of present demand. The ingot producing plants in Texas and the mill products plant at Madison, Illinois, have a capacity of thousands of tons of magnesium products per year.

FOR MORE INFORMATION about magnesium, contact the nearest Dow Sales Office or, write THE DOW CHEMICAL COMPANY, Midland, Michigan, Department MA1481AA.

YOU CAN DEPEND ON DOW

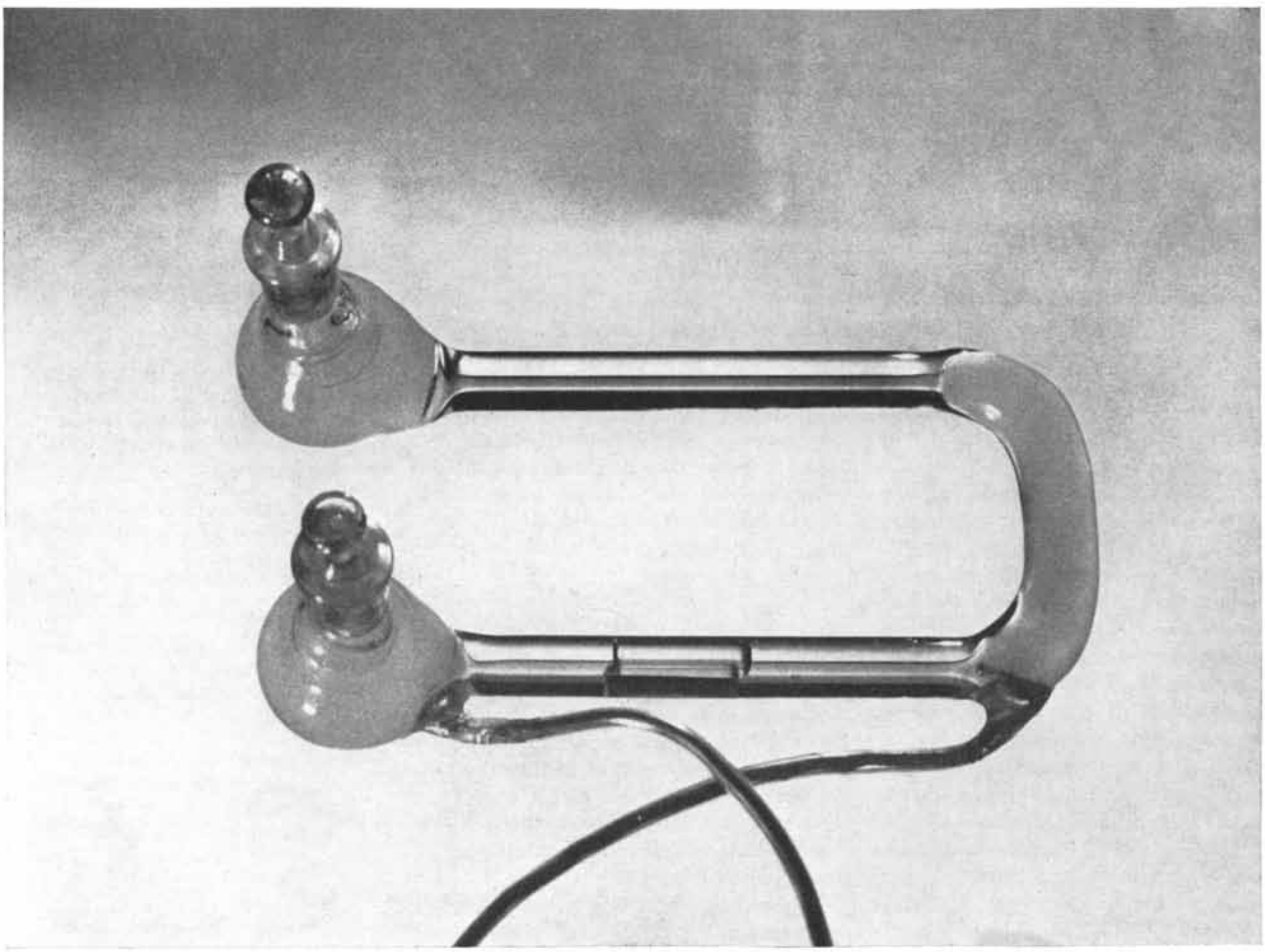
THE CONTROL OF SEX

If sperm cells from a rabbit are placed in an electric field, they separate into two groups. One group, when it is used to inseminate female rabbits, tends to produce male offspring; the other, female

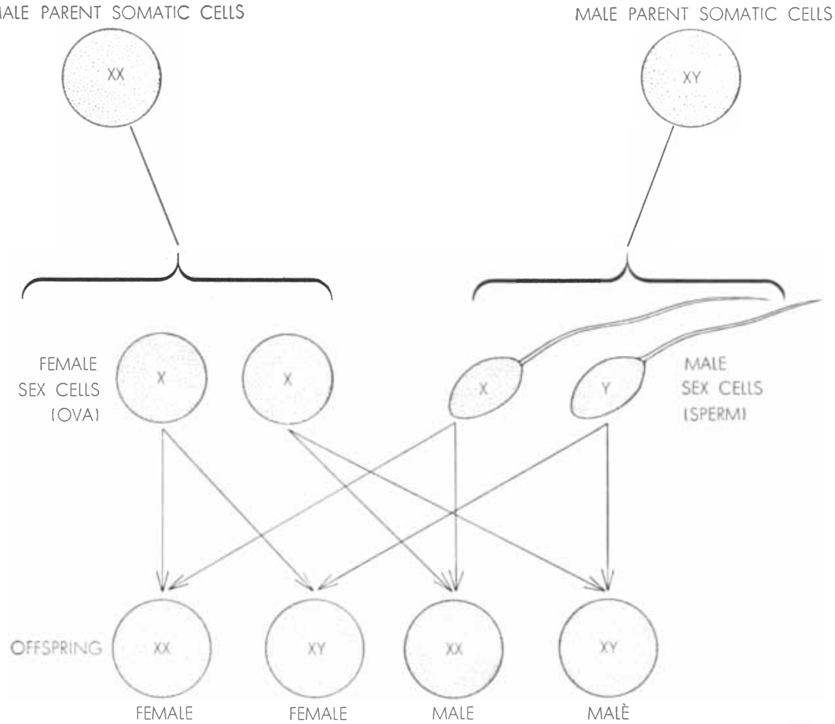
by Manuel J. Gordon

For thousands of years men have been trying to predict or control the sex of their offspring. The subject is discussed in a Chinese manuscript thought to be 4,400 years old. An Egyptian papyrus of about 2,200 B.C. observes that a pregnant woman with a face of greenish cast is certain to bear a son. According to Aristotle, and also the Talmud, placing the marriage bed in a north-south direction favors the conception of boys. (This idea was suggested by shepherds, who noticed that if ewes face north during conception, many of them bear males. Of course the shepherds were quite right; about half of the offspring of ewes were males.)

The list of old wives' tales could be extended almost without end. Fantastic though they are, the impulse to invent them was often thoroughly practical. In many societies a male heir who could carry on the family name was an economic and social asset. Today this mo-



ELECTROPHORESIS APPARATUS used to separate rabbit sperm is of a special design. One pole of the apparatus is represented by the wire attached to its left side; the other pole, by the wire attached to its right side. The entire apparatus is filled with a solution containing sperm cells. When the current is turned on, the cells migrate toward one pole or the other through the narrow bore of the thick-walled horizontal tube at bottom. The process is observed with a microscope through flat section in middle of tube.



GENETIC BASIS of sex determination is outlined in this chart. Each female somatic, or body, cell (*upper left*) contains two X chromosomes; each male somatic cell (*upper right*), an X chromosome and a Y chromosome. Ova, which result from the division of female somatic cells, all contain one X chromosome; sperm, which result from the division of male somatic cells, contain either one X chromosome or one Y chromosome. The organism resulting from the fertilization of an ovum by a sperm thus has an even chance of having somatic cells with two X chromosomes, or with one X chromosome and one Y chromosome.

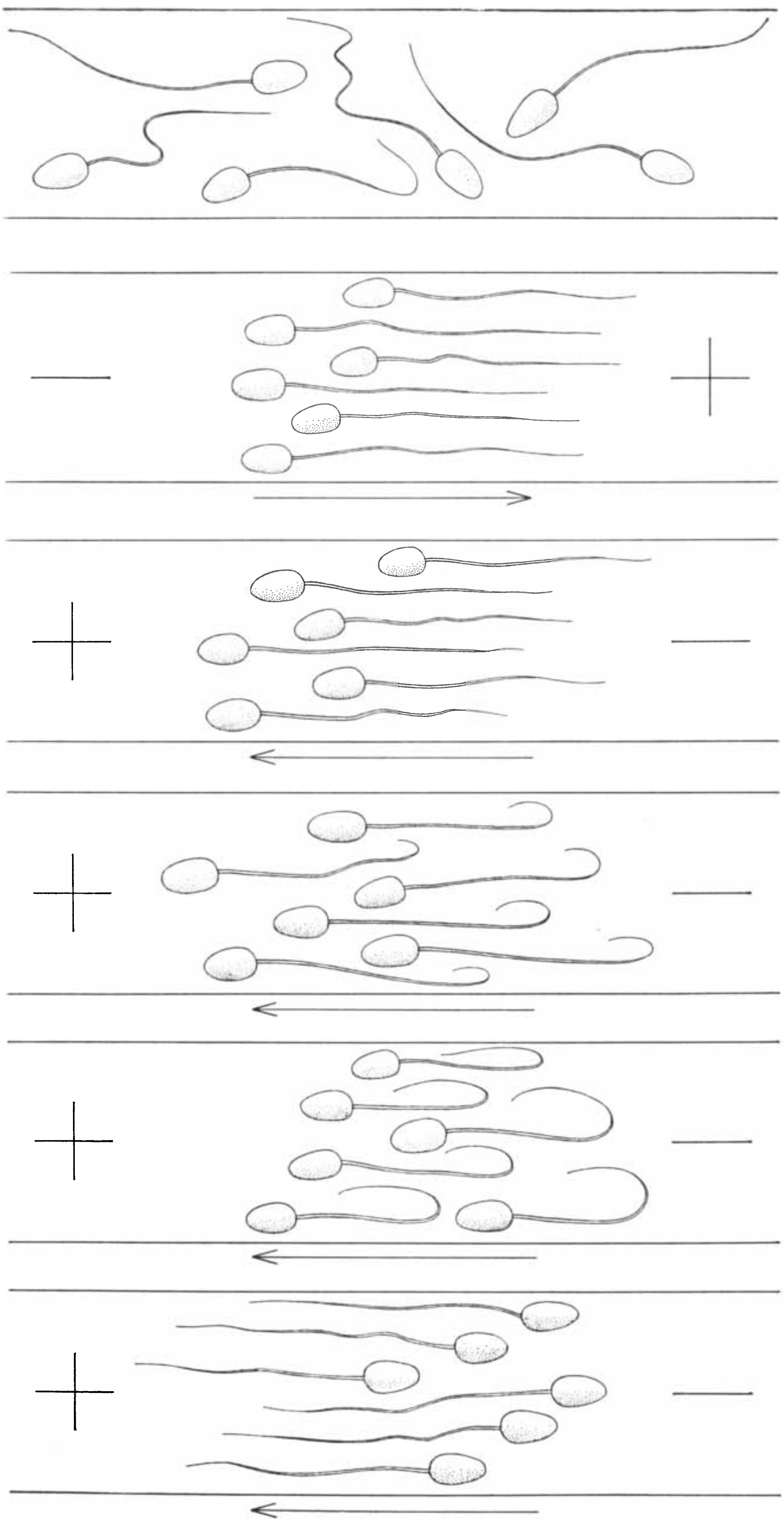
tive is not particularly pressing for most of us. However, if sex control could be accomplished safely and easily, it might relieve mankind of its burden of "sex-linked" hereditary defects such as hemophilia and color blindness. And animal breeders would find it of great and immediate value. As we shall see, it now seems likely that this ancient aspiration will be realized.

The scientific history of the subject begins with the discovery of the genetic mechanism by which sex is determined. As most of us recall from high-school biology, among the pairs of chromosomes in the cells of mammals there is a special pair which differs in males and females. In females the pair consists of two identical members known as X chromosomes; in males the pair is made up of one X chromosome and one so-called Y chromosome. When gametes (egg and sperm cells) are formed, the chromosome pairs split, so that each ovum or sperm contains only half the usual number of chromosomes, one from each pair. Egg cells obviously must all have X chromosomes; sperm cells, on the other hand, contain either an X or a Y, the two types of cell presumably being produced in equal numbers [*see illustration at top of this page*]. Thus the sex of a newly conceived animal depends simply on the type of sperm cell that happens to fertilize the egg. The expected proportion is 50-50.

As soon as this was understood, sex control became a reasonable possibility. At the very least, male- and female-producing sperm differ in their sex chromosomes. Possibly they might also be different in other ways. In any case, the obvious line of attack was to look for a physical or chemical method of distinguishing the two.

A number of methods have been tried. One idea was to find a selective poison which would inactivate one type of sperm cell and not the other. No such material has been discovered. The chemistry of the sperm cell is so delicate, and the differences between the X and Y types so subtle, it seems likely that anything which would poison one type would poison the other.

A second approach, which was widely publicized in the 1930s, was concerned with the acidity or alkalinity of the vaginal secretions at the time of the entry of the sperm. The theory, based on observations of a German physician who



MIGRATION OF SPERM CELLS toward the anode is depicted in this series of schematic cross sections of the electrophoresis tube. At top the current is turned off; the cells move at random. Second from the top the current is turned on; the cells migrate toward the anode (+) tail first. Third the current is reversed; the cells begin to migrate toward the new anode head first. Fourth, fifth and sixth their tails bend until they move tail first again.

had been treating women for sterility, was that an alkaline environment favored the conception of males; and an acid environment, the conception of females. A number of workers performed experiments on a variety of animals, administering acid and alkaline douches before intercourse. Some claimed success, but the results as a whole were conflicting. By the early 1940s interest in the method had died out.

There have been many attempts to separate the two kinds of sperm physically, by means of the centrifuge. Here the hope is that the X type and Y type differ sufficiently in size or in weight to move outward at different speeds in a rapidly rotating vessel. If so, they can be collected in separate batches and used to fertilize females by artificial insemination. Most of the centrifuge experiments have failed. Recently a Swedish investigator, Per Eric Lindahl, reported that he has partially separated X and Y sperm cells with an especially sensitive centrifuge. Thus far he has dealt only with a rather small sample, and his work has not been confirmed.

As early as 1932 V. N. Schröder, a woman biochemist in the U.S.S.R., began to publish a series of papers about a physical method of separation which did seem to work. As so often happens, her discovery was accidental. In the course of a general investigation of the chemistry of rabbit spermatozoa, Dr. Schröder was using electrophoresis to study their mobility in solutions of varying acidity and alkalinity. In this technique [see "Electrophoresis," by George W. Gray; SCIENTIFIC AMERICAN, December, 1951] the cells are placed in a vessel which has a positive electrode at one end and a negative electrode at the other. The solution in which they are suspended can be adjusted to different values of "pH," or hydrogen-ion concentration. As the pH is changed they move with different speeds toward one of the poles. Or, rather, that is what they were expected to do. To her surprise Dr. Schröder found that, at certain values of pH, sperm moved in both directions, some traveling toward the positive pole, some toward the negative, and some remaining stationary in the middle.

Obviously there was something different about the two migrating groups. Could it be the long-sought distinction between the X and Y types? To test the idea Dr. Schröder and her colleague N. K. Koltsov collected three batches of rabbit sperm from an electrophoresis vessel, one from the positive pole (anode), one from the negative pole (cath-


RESERVATIONS
DEPARTUR

LITTER NUMBER	TYPE OF SPERM INSEMINATED	SEX EXPECTED	OFFSPRING BORN		
			MALES	FEMALES	TOTAL
1	CATHODE	MALE	6	0	6
2	CATHODE	MALE	7	0	7
3	ANODE	FEMALE	0	2	2
4	ANODE	FEMALE	1	3	4
5	ANODE	FEMALE	1	3	4
6	ANODE	FEMALE	1	4	5
7	CATHODE	MALE	5	0	5
8	CATHODE	MALE	2	2	4
9	ANODE	FEMALE	2	1	3
10	CATHODE	MALE	1	1	2
11	CATHODE	MALE	3	2	5
12	ANODE	FEMALE	1	3	4
13	CATHODE	MALE	4	0	4
14	ANODE	FEMALE	1	3	4
15	ANODE	FEMALE	2	3	5
16	ANODE	FEMALE	0	4	4
17	ANODE	FEMALE	0	7	7
18	CATHODE	MALE	6	2	8
19	ANODE	FEMALE	1	0	1
20	CATHODE	MALE	1	1	2
21	CATHODE	MALE	3	5	8
22	ANODE	FEMALE	1	7	8
23	ANODE	FEMALE	4	6	10
24	ANODE	FEMALE	2	3	5
25	CATHODE	MALE	3	5	8
26	CATHODE	MALE	3	4	7
27	ANODE	FEMALE	5	3	8
28	CATHODE	MALE	4	3	7
29	ANODE	FEMALE	2	5	7
30	ANODE	FEMALE	1	5	6
31	CATHODE	MALE	3	4	7

RESULTS OF EXPERIMENTS on rabbits in the author's laboratory are tabulated. The sex of the offspring of the rabbit was successfully predicted in 67.7 per cent of the cases.

ode) and one from the middle of the vessel. They inseminated three does, one with each batch. Anode sperm produced six offspring, all females. Cathode sperm produced four males and one female. Central sperm gave a litter of two males and two females.

Encouraged by these results, Dr. Schröder repeated the experiment many times in the next 10 years, with an overall rate of success of 80 per cent in controlling the sex of rabbits. Later she refined the technique and extended her experiments to other mammals.

Several investigators have tried to duplicate the Soviet work. Some were unable to do so; others have had varying degrees of success. The most promising experiments were done by Sherry Lewin, of the South-West Essex Technical College in London, and by the present author at the University of California and Michigan State University. Our work thus far has been rather crude, and we have not achieved as high an average of control as Dr. Schröder did, but the results definitely seem to bear out hers.

We begin by collecting rabbit semen, using an artificial vagina. At first the buck rabbit must be stimulated by a female, but soon he becomes conditioned to the device itself. The ejaculate is examined to determine its sperm concentration, then diluted and placed in the electrophoresis apparatus [*see illustration on page* 87]. With no voltage on the electrodes the sperm move about at random. As soon as a voltage is applied, their active motion ceases almost entirely; they line up with their tails pointing toward one or the other electrode and begin to move toward it. If the current is reversed, the sperm also reverse, moving head first toward the opposite electrode. Soon, however, their tails bend around and they eventually line up as before, with the tails pointing toward the electrode they are approaching.

Sperm collected at the anode or cathode are then introduced into the uterus of the female. First, however, the doe must be mated to a sterilized male, because she ovulates only after copulation. In about 30 days the litter is born. It is difficult to determine the sex of newborn rabbits by simple inspection, so the offspring are killed and their gonad tissue examined microscopically.

All told we have had 167 births in 31 litters. We predicted the sex of the offspring correctly in 113 cases, for an average of 67.7 per cent [*see table on this page*]. Considering the sexes separately, there were 62 successes out of 87 for females (71.3 per cent) and 51 out of 80 for males (63.7 per cent). Anode

sperm produced a ratio of 62 females to 25 males; cathode sperm a ratio of 29 females to 51 males. The probability that these ratios were the result of chance is much less than one in 1,000. Some of our trials are known to have been spoiled by errors of technique or equipment failure, but these results are all included in the tabulation. Seven of the litters consisted of one sex only, and in each case it was the sex predicted.

On the whole the evidence that the two types of rabbit sperm can be separated by electrophoresis is convincing. What makes this possible? Probably it is due to differences in the protein content of the cells. All protein molecules carry both positive and negative charges. Their net charge depends on the pH of their environment. When the pH is low, they act as positive ions; when it is high, as negative ions. In between there is a value of the pH for which they are neutral. This value, known as the isoelectric point, differs with different proteins.

Suppose that the proteins in sperm cells containing X chromosomes are somewhat different from those in sperm with Y chromosomes. Then their isoelectric points would also be different. If they are placed in a solution whose pH lies between the two points, one type will be negatively charged and move toward the anode; the other will be positively charged and move toward the cathode. We have analyzed ground-up sperm collected at anode and cathode and found that their proteins are in fact different.

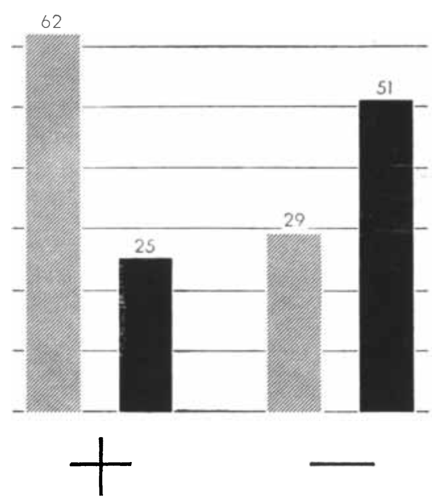
Assuming that our explanation is correct, why should the sex-control experiments not work 100 per cent of the time? Perhaps the isoelectric points of X- and Y-type sperm extend over ranges of values that overlap slightly. If so, some cells will move the "wrong" way. On the other hand, an examination of our results indicates that the experiments work either quite well or not at all. It may be that some unknown factors are influencing the efficiency of separation.

For practical purposes it may be possible to sidestep these questions entirely. In our present apparatus sperm can be collected only from one electrode. The direction of the applied voltage determines whether it is the cathode or the anode. A new apparatus has been designed in which sperm can be collected from both electrodes during the same run. If we take only the first cells to arrive at the poles, we may very well get pure samples of each type.

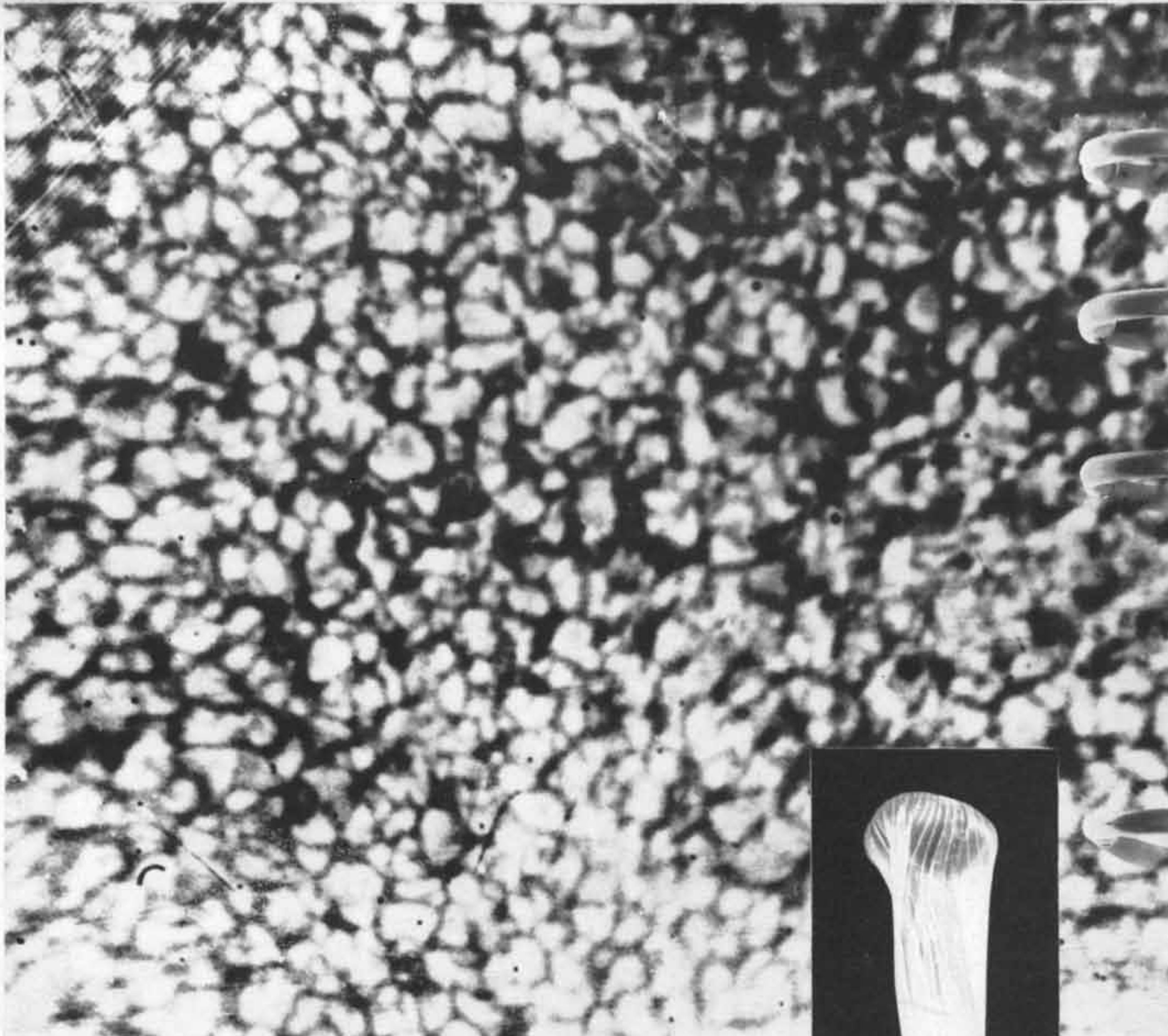
But in any case we shall want to satisfy our curiosity about the fundamental processes involved. A number of new investigations are now under way in our laboratory at Michigan State University. We are examining the electrophoretic motions of individual spermatozoa to see whether their isoelectric points are distributed in overlapping ranges. Do the sperm tails, which respond so dramatically to reversals of current, have the same kind of charge distribution as the whole sperm cell? An experiment on isolated tails should provide the answer. Again, electrophoresis is a surface phenomenon; the charges which control the motions of the sperm must in some way make themselves felt at the outer covering. But whether the difference lies in the surface proteins, or in internal proteins which induce a surface charge through the covering membrane, is not yet known. A chemical analysis of membranes separated from sperm cells will give us this information.

We have also begun to work with other animals. At the moment we are trying to separate cattle sperm. (Lewin has already reported some success with human sperm.)

Our experiments have aroused great interest among dairy-cattle breeders. They would gain an obvious economic advantage by producing mostly heifer calves, raising only enough bulls for purposes of reproduction. Furthermore, sex control would be an efficient tool in breed improvement. Although a good deal of work is still to be done, we are hopeful that livestock breeders will have a workable method of sex control in the not-too-distant future.



SEX RATIO of offspring produced by anode-migrating sperm cells (*left*) was 62 females (*hatched bar*) and 25 males (*black bar*). Sex ratio of the cathode-migrating cells (*right*) was 29 females and 51 males.



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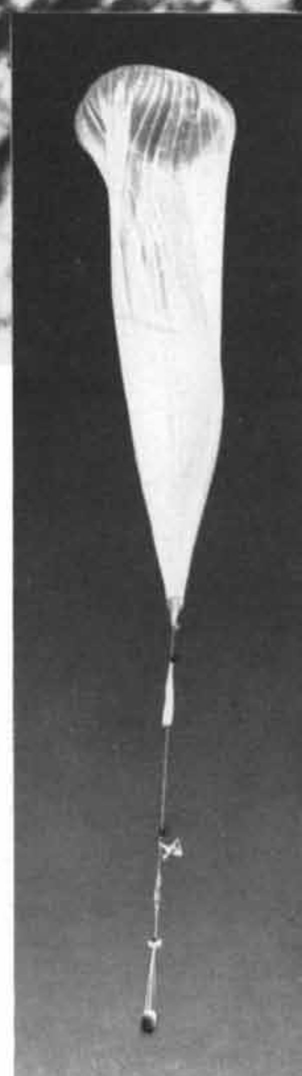

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Dr. Henry Hurwitz, Jr., Ph.D., Harvard (1941), is a former faculty member at Cornell University and was a theoretical physicist at the Los Alamos Scientific Laboratory during World War II. He joined General Electric in 1946, worked for ten years in the field of fission power at the Knolls Atomic Power Laboratory, and now serves as manager of the *Nucleonics and Radiation Section* at the General Electric Research Laboratory.

Forward toward fusion

General Electric's Dr. Henry Hurwitz, Jr., leads a long-range program in thermonuclear research

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At the General Electric Research Laboratory, Dr. Henry Hurwitz, Jr., is leading a group of scientists who are giving their undivided attention to the problems of achieving and holding the fantastic temperatures — in the range of 100 million degrees — required to sustain a thermonuclear reaction. Using large and complex research equipment which they have designed, Dr. Hurwitz and his associates are exploring the properties of plasma and the physics of magnetic containment.

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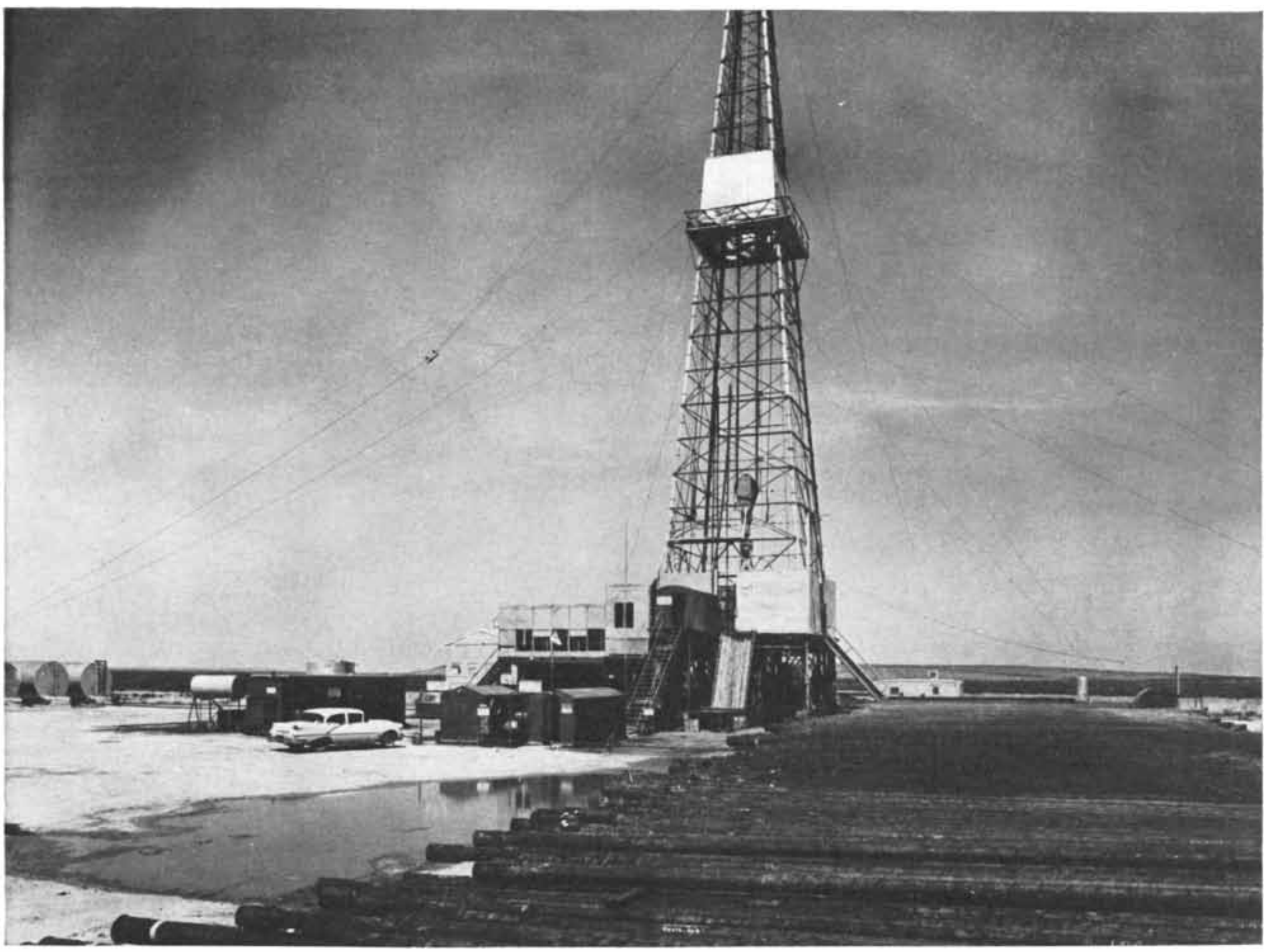
Drilling for Petroleum

As man's consumption of oil increases and old sources are depleted, he must sink more and deeper wells to find it. This necessity has stimulated the development of ingenious new techniques of drilling

by Sullivan S. Marsden, Jr.

Oil prospectors drilling an exploratory well in western Texas recently reached a depth of 25,000 feet, and are going even deeper [*see photograph below*]. They have drilled the world's deepest well, but they have thus far found no oil. The episode is symbolic. As the consumption of oil rises and the supply below ground diminishes, prospecting must go wider and deeper. Prospecting means, above all, drilling. The sensitive tools and techniques of the geologist and geophysicist can tell where oil is likely to be found. But only the drilling crew can determine whether it is there or not. As prospecting goes on to less likely sites, drillers must sink greater numbers of deeper wells to discover the same amount of oil. In the U. S., as compared to 20 years ago, they are drilling seven times as many wells



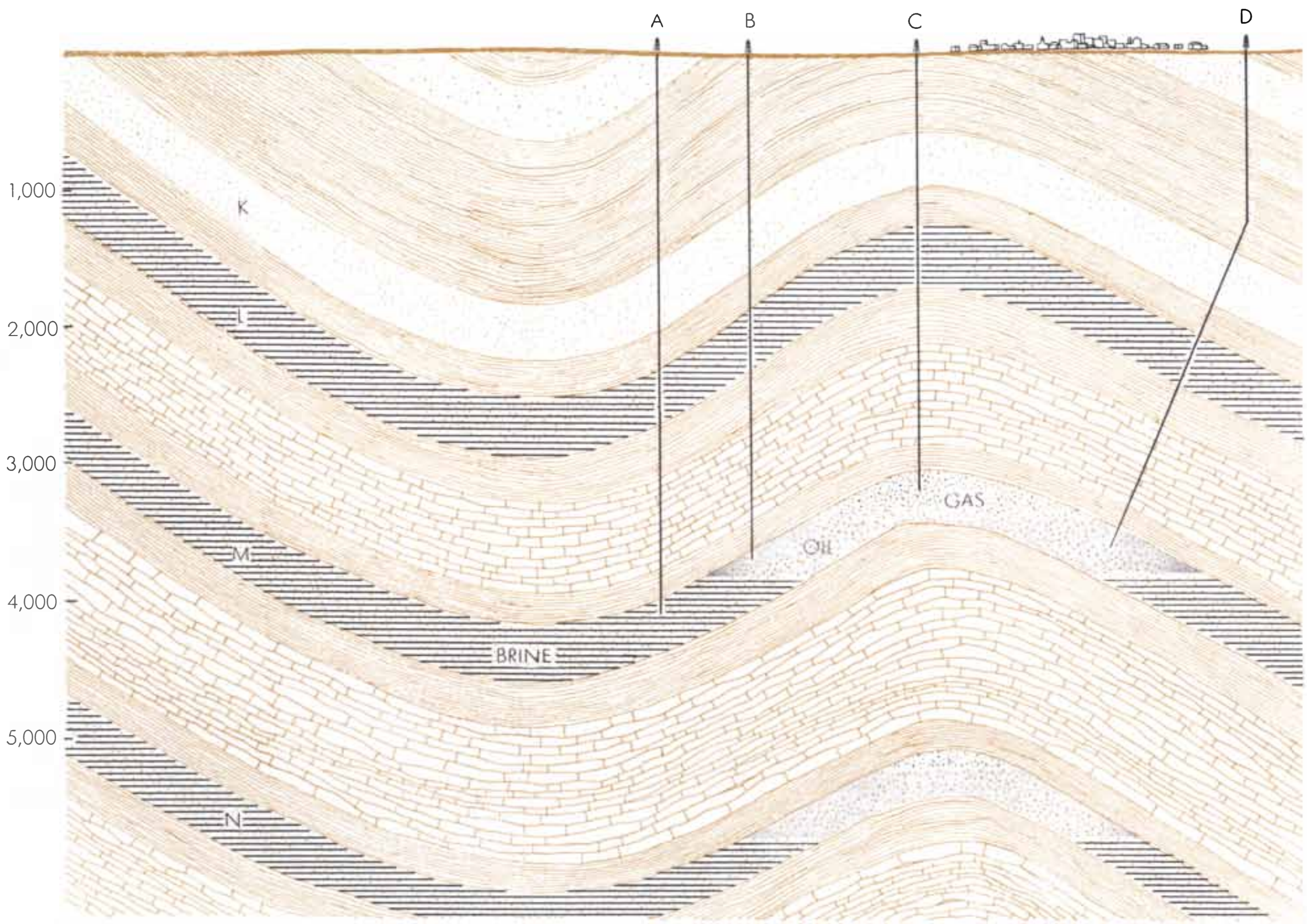
WORLD'S DEEPEST WELL, in western Texas, has passed 25,000 feet and is going still deeper. The many pipes in the foreground symbolize the problems of conventional drilling at these great depths. They must be lifted from the hole, disconnected, reassembled and lowered again every time a drill bit is changed. Friction between the turning pipe and the hole causes enormous power losses.

and are drilling them on the average nearly half again as deep. Yet they have not increased at all the amount of oil discovered [*see illustration on page 102*].

The cost of prospecting thus becomes an ever larger element in the cost of oil. The ingenuity of drillers, however, has kept the direct costs of drilling constant, though the cost of every other element in the operation has risen with inflation. What is more, drilling technology has now entered a phase of innovation that promises to reduce costs and to drive wells faster and deeper than ever before. Some of the most significant innovations coming into use are the product of Soviet technology. They involve the simple but radical stratagem of moving the engine that drives the drill from the surface of the ground to the bottom of the hole along with the drill itself. This "Russian revolution" in drilling will open up the crust of the earth to exploration thousands of feet downward to strata which can now be drilled only at prohibitive cost, and beyond these to deeper strata that cannot be reached by conventional equipment.

The oil prospector has a fair idea of what his drill bit will encounter as it works its way down into the earth. The oil he seeks (and the natural gas often found with it) originated in the debris of life in ancient seas; together with the silt in the ooze on the sea floor it was transformed by time and pressure into oil-bearing shales. From the shales the oil seeps upward into overlying sedimentary strata, saturating the pores and larger openings in the rock. There it may be trapped in "reservoirs" beneath an impervious layer of "cap rock." Frequently the oil and its entrapped gas "float" upon a layer of brine, a vestige of the original ocean waters, which saturates the lower levels of the porous stratum [*see illustration below*]. Prospecting in the beds of ancient seas, the driller can expect to find sedimentary rock—chiefly limestone, sandstone, shale and dolomite—between the surface and the oil he seeks. When he drills a "development well" near existing wells to tap other parts of the same reservoir, he knows what sequence of strata he will find. But when he sinks a "wildcat" in regions not previously drilled, he has to depend upon indirect evidence and must be prepared for anything.

His drilling bit will sink quickly through shales and some sandstones that are so soft they can be "drilled" by a jet of water; it will inch its way through dolomites and other sandstones that are so hard that they rapidly wear away bits tipped with diamond or tungsten carbide. In some porous strata the rock may contain brine or water under artesian pressure, and the well is flooded. In dry porous strata the drilling fluid pumped down to promote the action of the bit may leak away into the rock. A deposit of rock salt may dissolve in the drilling fluid, creating a troublesome bulge in the bore of the well; the swelling and



TYPICAL DRILLING PROBLEMS are shown in this cross section of an oil field; the vertical scale, somewhat exaggerated, is in feet. Oil (*light gray*) in porous rock strata often floats on brine and is overlaid with natural gas; artesian or gas pressure may produce a dangerous "gusher." A poorly located well (A) may strike brine instead of oil (B) or gas (C). Directional drilling (D) is used to reach oil under urban areas or bodies of water. Wells drilled through water-bearing strata (L) may be flooded; dry, porous strata (K) may absorb drilling fluids. Oil fields often contain deeper oil-bearing strata (N) which are more expensive to explore.

sloughing-off of some shales may cause a similar irregularity of bore.

At 15,000 feet, under normal conditions, the driller must contend with temperatures above the boiling point of water; under abnormal geological conditions he may run into even higher temperatures, such as the 460 degrees Fahrenheit recently measured in a 15,000-foot well in Texas. High temperatures speed up the corrosion of drilling tools and change the properties of drilling fluids. But the high temperature in a deep well also reduces the viscosity of the oil, if it is there, and makes it flow more readily. The driller must also be ready to deal with high pressure as he approaches his goal. It can deliver the oil without the necessity of pumping, but it can also produce a wasteful and dangerous gusher.

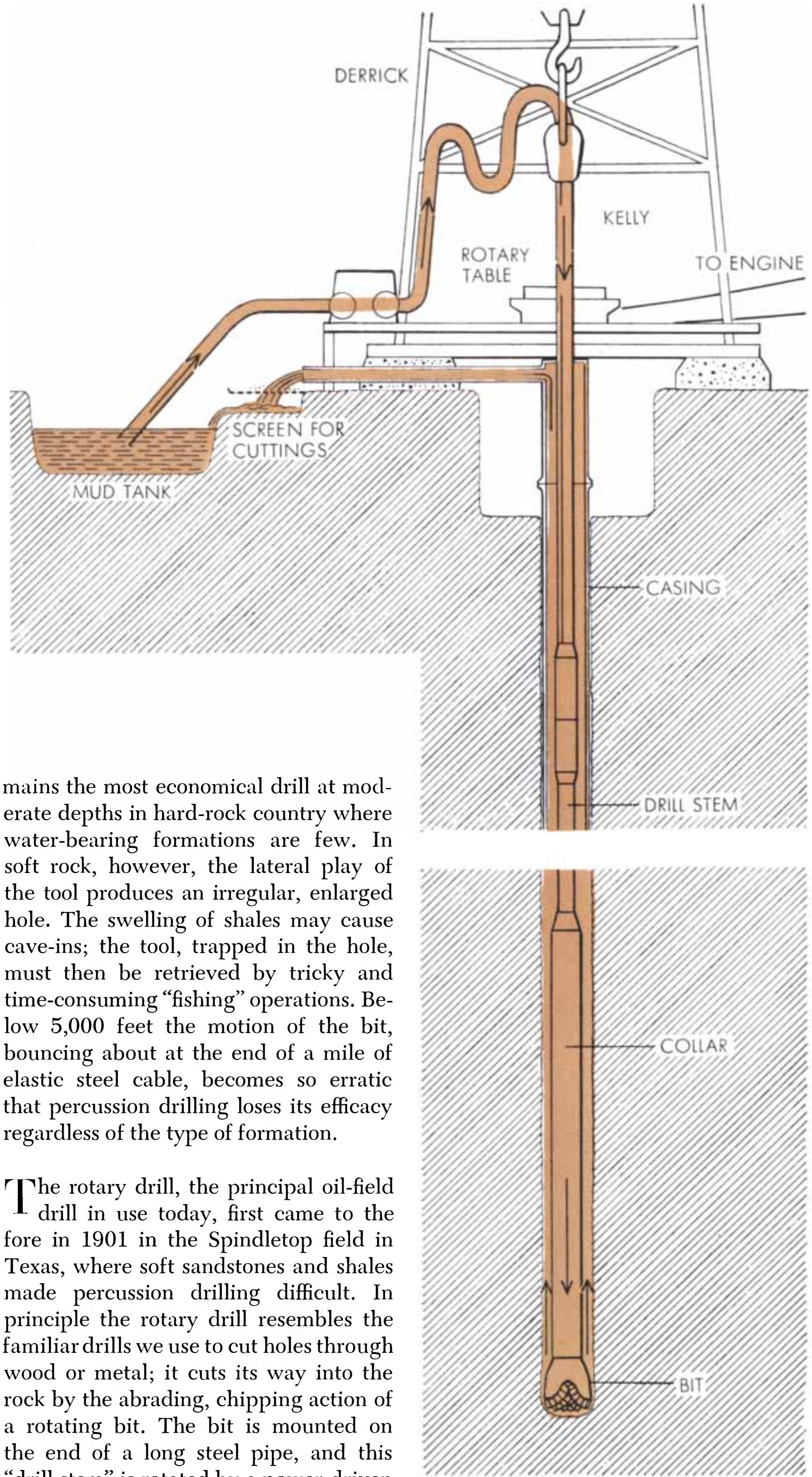
The first U. S. oil well was drilled in 1859 by a technique devised centuries before in China to drill salt wells to depths of 1,500 feet or more. This technique employs a heavy, chisel-edged tool to pound a hole in the rock, much as a mason hammers a star chisel into brick or mortar. In modern percussion drilling the free fall of a heavy drill bit, six to eight feet long, cuts away the rock. The tool is suspended in the hole by a cable and is alternately lifted several feet and dropped by the action of a walking beam. Water poured into the hole (or seeping in from wet formations) forms a slurry with the cuttings. Periodically the drilling must be halted and the tool reeled up to permit the bailing of the slurry from the hole.

If water from a wet formation fills the well to too great a depth, it will check the fall of the bit and make drilling slower. On these occasions a steel casing must be lowered into the hole and cemented in place to seal off the water-bearing strata, and drilling continues with a bit of smaller diameter. If the hole passes through several wet strata, each stratum may have to be walled off in turn with casing of progressively smaller diameter. Thus a hole with a diameter of more than a foot at the surface may narrow to less than six inches at the bottom.

Percussion-drilling equipment is relatively light, portable, and inexpensive to buy and operate. Bits can be reeled up and changed in a few minutes, a significant virtue, because even a moderately deep well may wear out dozens of bits. The "cable tool" rig still does most of the drilling in the Appalachian area it opened up nearly a century ago; it remains the most economical drill at moderate depths in hard-rock country where water-bearing formations are few. In soft rock, however, the lateral play of the tool produces an irregular, enlarged hole. The swelling of shales may cause cave-ins; the tool, trapped in the hole, must then be retrieved by tricky and time-consuming "fishing" operations. Below 5,000 feet the motion of the bit, bouncing about at the end of a mile of elastic steel cable, becomes so erratic that percussion drilling loses its efficacy regardless of the type of formation.

The rotary drill, the principal oil-field drill in use today, first came to the fore in 1901 in the Spindletop field in Texas, where soft sandstones and shales made percussion drilling difficult. In principle the rotary drill resembles the familiar drills we use to cut holes through wood or metal; it cuts its way into the rock by the abrading, chipping action of a rotating bit. The bit is mounted on the end of a long steel pipe, and this "drill stem" is rotated by a power-driven turntable on the derrick floor [*see illustration on this page*]. At the bottom of the hole, just above the bit, a number of heavy pieces of pipe called drill collars, weighing as much as 50 tons, increase the pressure of the bit against the rock. The combination of bit, collars and drill stem is called the drill string.

The operation of a rotary drill depends

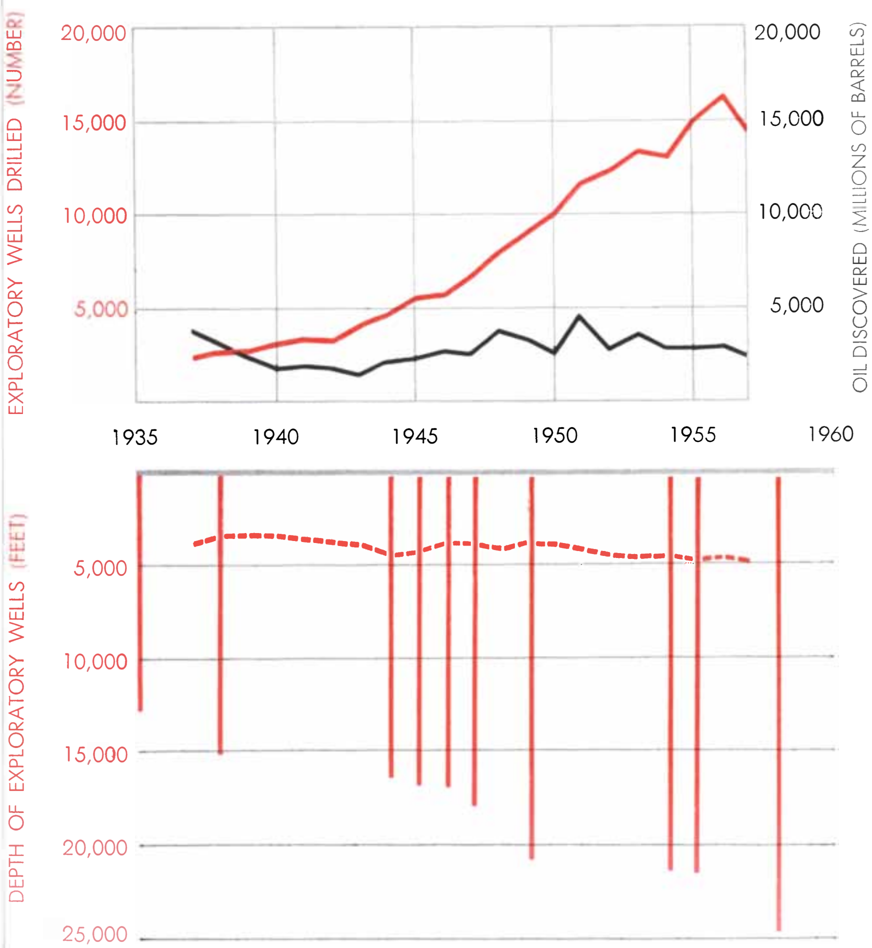


ROTARY DRILL, the commonest type in this country, owes much of its success to the use of drilling "mud" (*shown in color here and on page 110*). This carries cuttings to the surface, lubricates and cools the rotating bit and drill pipe and normally prevents intrusion of water from "wet" porous strata.

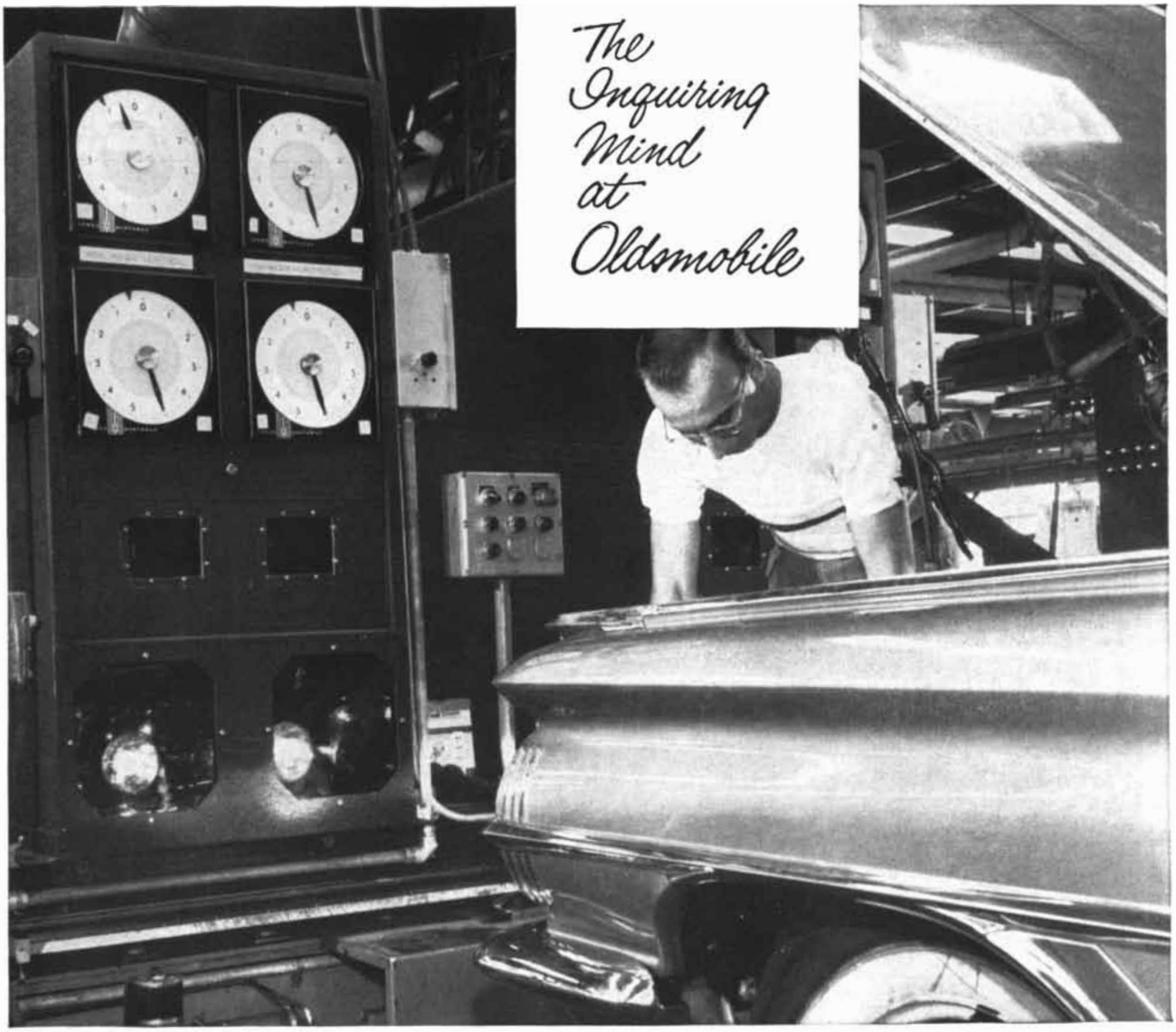
heavily upon the role of the drilling fluid known as "mud." Made of water, colloidal clay and various chemical additives, this viscous fluid is pumped down the drill stem and forced through holes in the bit just above the cutting elements. There it lubricates the moving parts of the bit and cools both bit and rock. It returns to the surface through the space between the drill stem and the wall of the hole, bearing with it the rock cuttings. When not in motion, the mud tends to thicken slightly; thus it keeps the cuttings from settling to the bottom. Its principal function, however, is to provide hydrostatic pressure to counterbalance gas, oil or water pressure in the formations being drilled. The mud thus eliminates the need for casing (except in extreme situations) while the hole is being drilled. If the well strikes oil, however, it is almost always "cased off" from top to bottom to prevent the oil from leaking away or picking up water on its way to the surface.

The driller must carefully adjust the properties of his mud to deal with the variety of difficulties met in different formations. To offset high pressures he may load the mud with some high-density material, raising the weight of the mud to twice that of water. In highly permeable formations, which may literally suck the mud from the hole, the driller will add hay, cottonseed hulls, small strips of cellophane, ground up sugar-cane fiber, wood, feathers or walnut shells to block the openings in the rock. In shales the mud often picks up additional colloidal matter and becomes too viscous; in gypsum, anhydrite or salt it may develop other idiosyncrasies. The driller corrects each of these with an appropriate additive.

In a few special situations drillers have been finding that they can get along better without mud. At great depths in soft rock the pressure of the mud column tends to support the rock against the chipping of the bit. This problem can be



MORE AND DEEPER WELLS must now be drilled to discover the same amount of oil. Number of wells drilled (*colored curve*) has risen sharply since 1935 (figures for previous years are not available). Average depth (*broken curve*) and maximum depth reached (*vertical lines*) have also increased. Oil discovered (*black curve*) has not increased at all.



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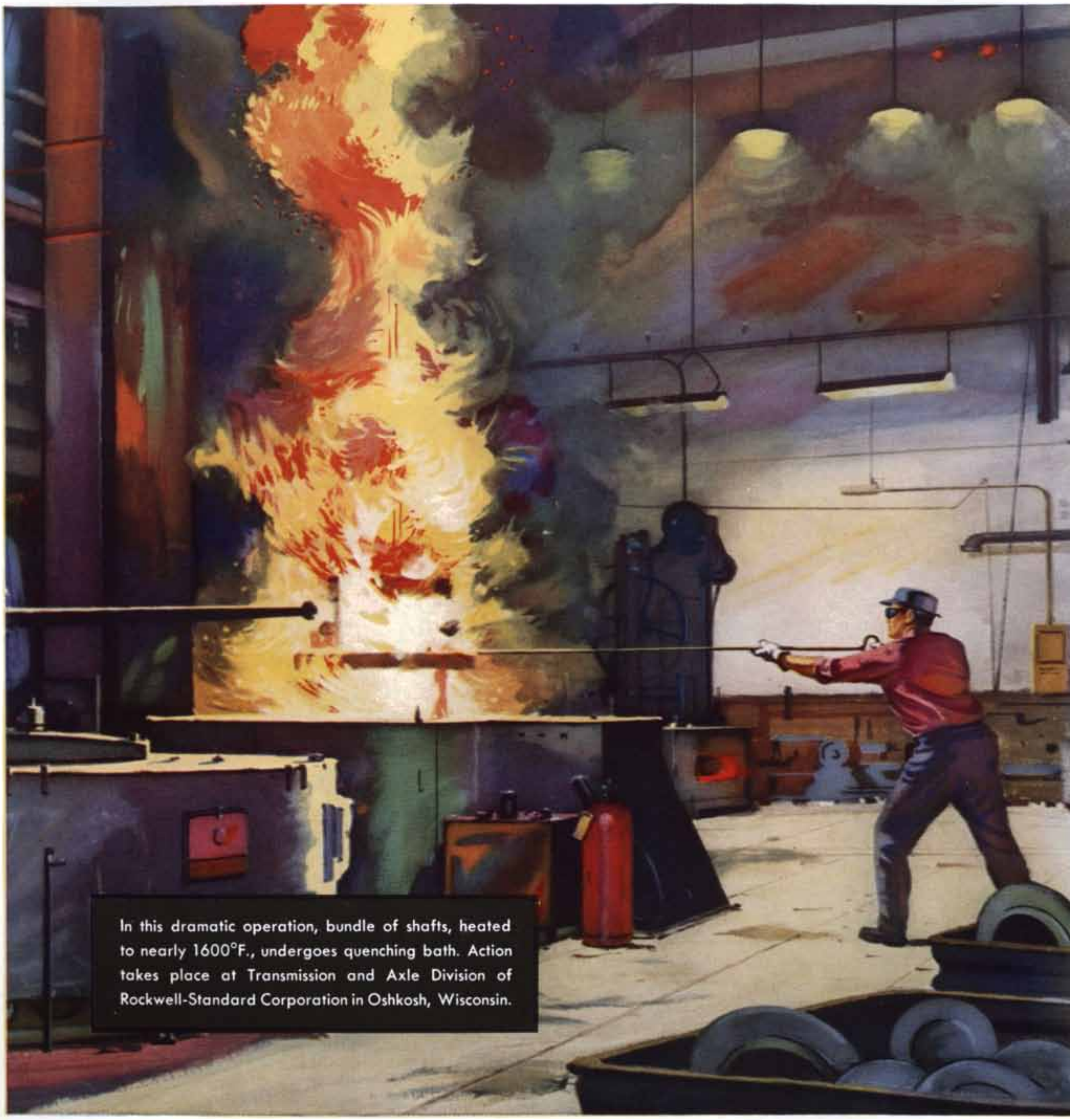

In this dramatic operation, bundle of shafts, heated to nearly 1600°F., undergoes quenching bath. Action takes place at Transmission and Axle Division of Rockwell-Standard Corporation in Oshkosh, Wisconsin.

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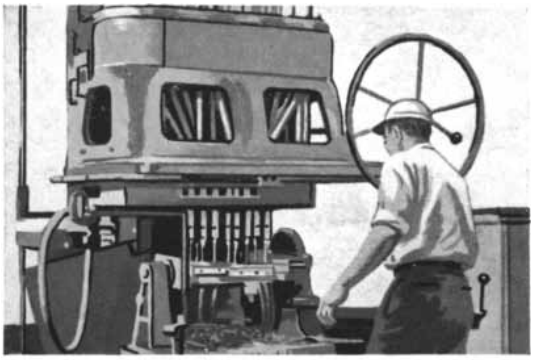
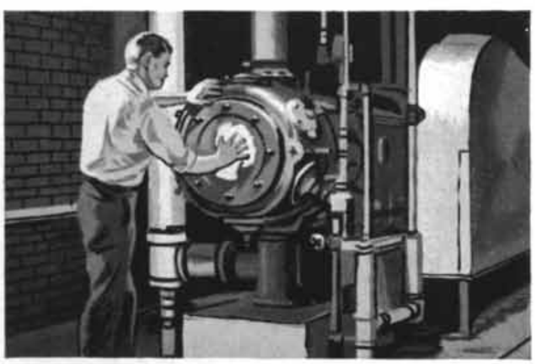
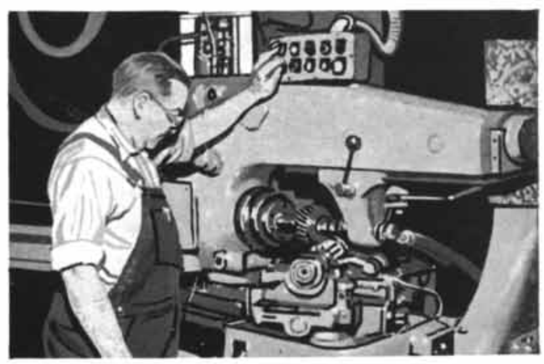


$19,520 saved on hydraulic-system maintenance. Valve failures caused severe production loss on multiple-spindle drills, boring machines and grinders. Mobil product solved problem . . . increased production by 4,000 hours per annum.

New storage and mixing tanks with automatic controls were installed as part of Mobil program. This system increased soluble-oil storage capacity . . . simplified oil purchasing . . . eliminated manual mixing of oil and water . . . saved $1,075 per year.



$3,000 air-compressor shutdown and overhaul avoided. Severe scoring was occurring in cylinder of vitally needed compressor. Mobil recommended oil that has kept compressor operating efficiently for past two years.



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Correct Lubrication

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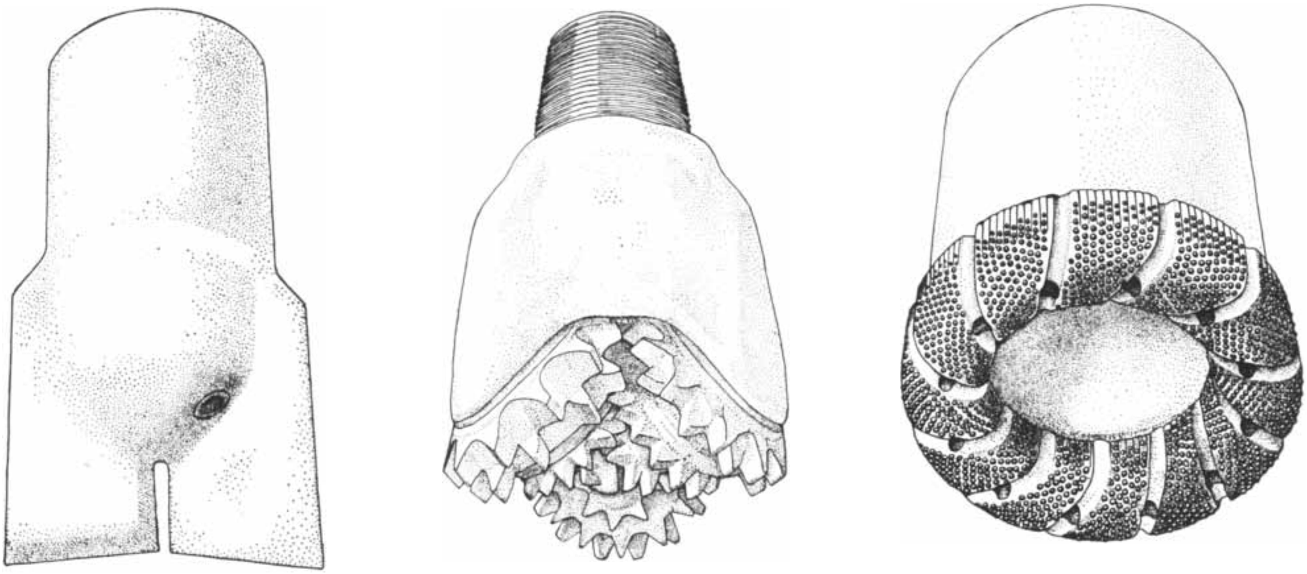


DRILL BITS of many different types are used to solve various drilling problems. Shown at left is a fishtail bit. Once widely used, it has now been largely replaced by the tricone bit (*center*), the toothed cones of which chip away the rock with a shearing action. The core bit (*right*), set with industrial diamonds, is used to cut out solid cylinders of rock needed for geological examination.

solved in dry formations by dispensing with mud and blowing the cuttings out of the hole with compressed air as a cloud of fine dust. Natural gas, if it is available under pressure, is sometimes used instead of air, but it creates a fire hazard. Air or gas drilling can triple the rate of progress in soft rock, and more than double it in hard rock.

When clouds of dust no longer come out of the hole, the air or gas driller knows that he has hit a wet formation and is in for trouble. Water may cause the cuttings to stick to the drill, lowering the drilling rate sharply and freezing the drill string in the hole. Where water seepage is slow, the driller can add a foaming agent to the air stream and bring the cuttings to the surface in the foam. With more rapid seepage he may have to compromise between air and mud drilling by using "aerated mud."

The principal working part of the rotary drill is, of course, the bit. From several dozen highly specialized types the driller can select the one best suited to a particular formation [*see illustration above*]. The tricone bit, with its three rotating cones studded with rows of hardened teeth, is perhaps the most widely used. The cones rotate on ball or roller bearings in such a manner that the inner and outer rows of teeth turn at a speed slightly different from that of the middle rows. This difference in rotation adds a shearing action to the chipping. The mud stream, squirted at the teeth through a number of small holes, prevents accumulation of clay and cuttings.

The "jet bit" directs a jet of mud through one large central hole to cut soft rock; the cones on this bit serve merely to enlarge the hole and keep it at a uniform size. A similar bit has a special application in the drilling of wells at an angle to reach oil reservoirs under urban areas or under water. In this operation the jet is set at an angle to the vertical, and the drill string is not rotated until the hole is headed in the direction desired.

At times the driller must bring samples of rock to the surface. For this purpose he uses a core bit with a hollow center and a ring-shaped cutting edge, usually set with industrial diamonds, which cuts out cylinders of solid rock.

The overwhelming predominance of rotary drilling in recent years has tended to overshadow the superiority of percussion drilling in hard, dry formations at moderate depths. Some drillers, working in hard formations, have sought to combine the advantages of the two methods by starting their hole with a cable-tool rig and shifting to a rotary rig for the deeper sections. The hammer drill, a recent invention, brings the principles of percussion and rotary drilling together in one rig. The hammer mechanism, installed in a conventional rotary drill string between collar and bit, resembles the familiar pneumatic hammer of street excavators, but is driven by the mud stream instead of by compressed air. It pounds the bit at 400 to 1,000 strokes per minute as the drill string rotates 50 to 100 times per minute. In some hard formations hammer drilling penetrates 10 times as fast as ordinary rotary drilling.

The percussion principle is advanced even further in two other drills now in the development stage. In the sonic drill, a mud-driven sonic generator causes a heavy drill collar to vibrate vertically up to 300 cycles per second to hammer a special bit. The drill string is rotated at low speed to make a symmetrical hole. The magnetostriction drill causes its bit to hammer at high rates of speed by taking advantage of the tendency of certain metals to change their dimensions when subjected to an intense magnetic field.

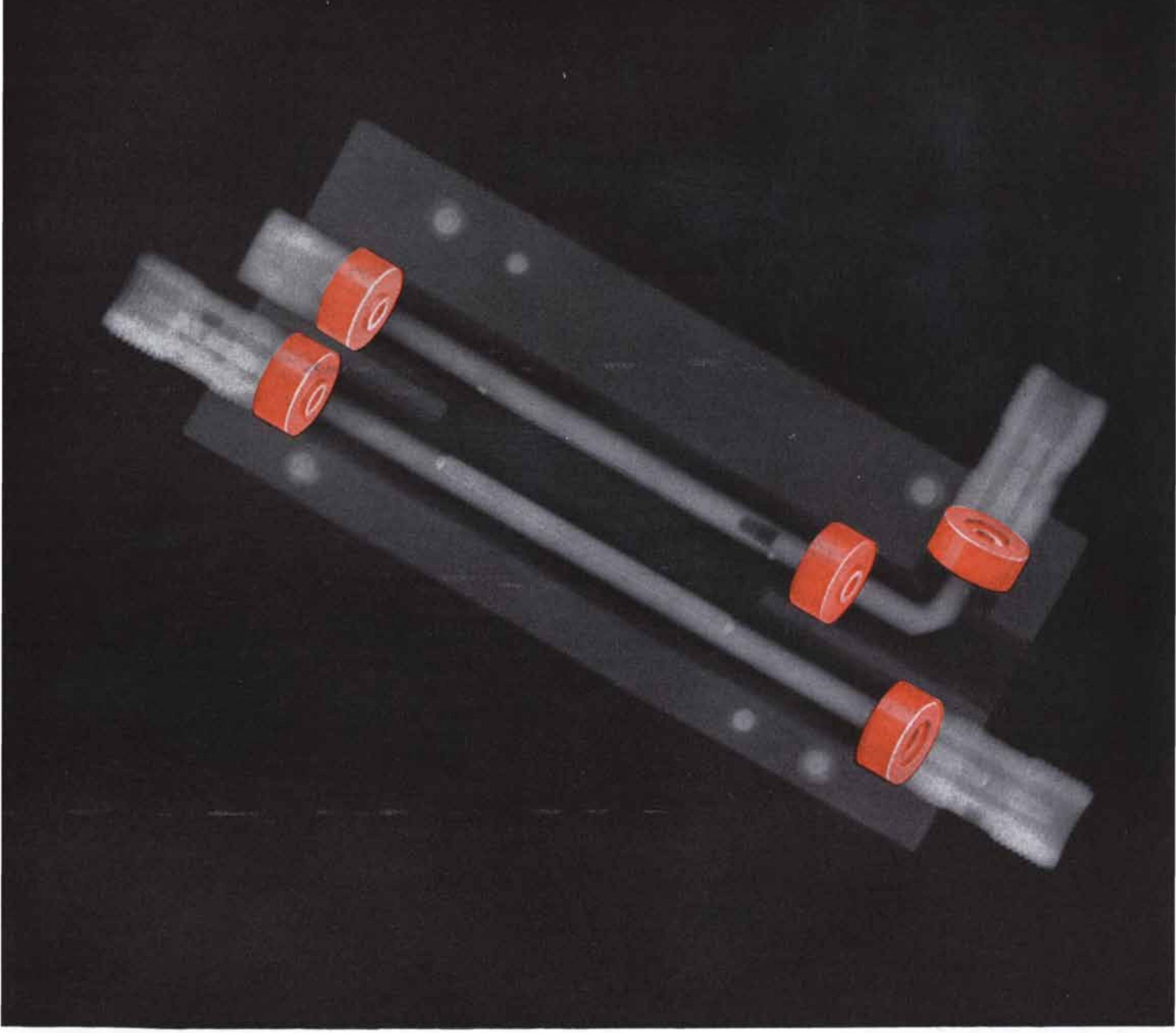
As rotary drillers adapt the percussion principle to their own style of drilling they cannot help contemplating another virtue inherent in the cable rig. This is the ease with which it is possible to hoist the tool from the well for the changing of bits. In the rotary drill the same procedure requires that the entire drill string be "pulled" from the hole, disassembled into manageable lengths (usually 90 feet), stacked vertically in a corner of the derrick, then reassembled and lowered into the hole again. A single well may wear out 100 bits; the lifting and lowering of several miles of pipe takes hours and also takes longer as the well gets deeper. Drillers are trying a retractable bit which can be lowered through the drill pipe on a cable, then expanded and fastened to the bottom of the drill string, then retracted and hauled up when it wears out. A more radical attack dispenses with bits entirely, using instead steel pellets which are blasted against the bottom of the hole by a mud jet [*see illustration at right on page 110*].

The effort to reach greater and greater depths, however, exposes an even more fundamental weakness in the drill string. In a 9,000-foot hole the rotation of the drill pipe dissipates in friction with the sides of the hole about 90 per cent of the power applied at the turntable; in deeper holes it wastes even more power.

This loss of efficiency shows up clearly in drilling-costs. For a 4,000-foot well the average direct drilling-cost in 1957 was about $4.50 a foot (total costs, which include casing and many other items of equipment, were about $14 a foot). In the deeper sections of a 20,000-foot well direct drilling-costs increase to more than $100 a foot. The total cost of such a well now exceeds $1 million; with crude oil at $3 a barrel, the well must be a good producer to pay for itself. When it comes to exploratory drilling, these costs look even more forbidding. Even in known oil-bearing regions more than two exploratory wells out of three are worthless "dusters"; the ratio is eight out of nine for wildcat wells in previously undrilled regions.

Improvements in drilling technology, competition among drilling contractors, and rising oil prices have made wells of 15,000 feet and deeper economically feasible. Such wells, however, are still the exception. The world-record 25,000-foot well may be close to the economic limit of present drilling methods. Yet sedimentary rock deposits in some areas are more than 40,000 feet thick, and there seems to be no geologic reason why oil should not be found at these enormous depths. The history of many rich fields, in fact, reveals a sequence of discoveries

IMPROVED DRILLING TECHNIQUES are typified by the "turbodrill," whose motive power is located in the drill hole rather than on the surface (*see diagram on next page*).



Insulators made of TFE-fluorocarbon resins are used in coaxial couplers which sample RF power in radar-jamming equipment. (By Narda Microwave Corporation, Mineola, New York.)

THE INSIDE STORY: parts that help misguide enemy missiles

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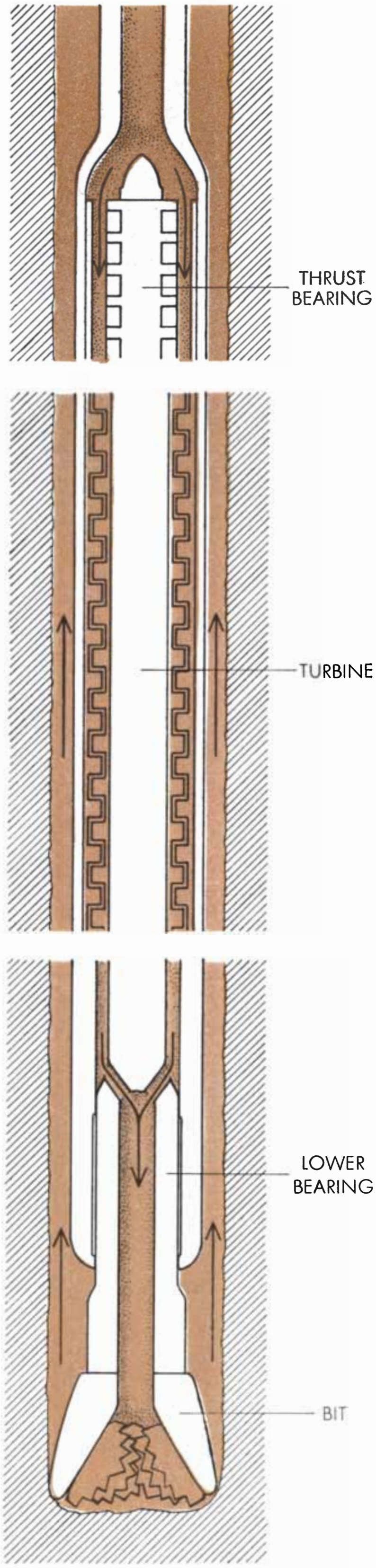
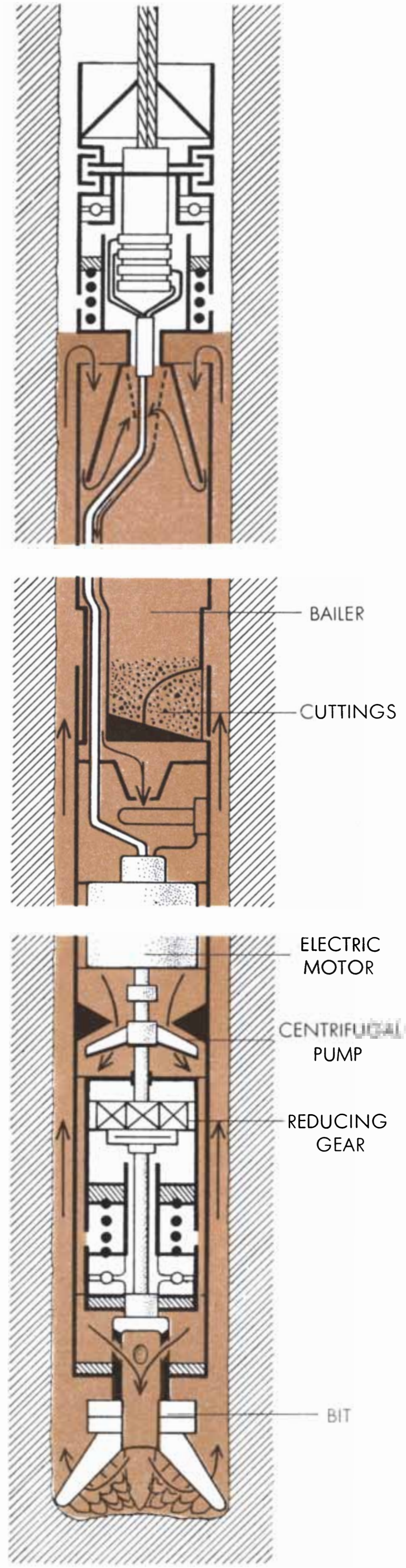
in successively deeper layers. If the rapidly increasing demand for petroleum products is to be satisfied, we must find ways of exploring and tapping these deep formations.

It is now clear that the way to bring these depths within practical and economical drilling range is to place the power source that drives the drill at the bottom of the hole instead of at the surface. The most successful effort in this direction is represented by the turbodrill. To drive the bit it employs a long, thin turbine mounted on the end of a nonrotating drill stem [*see illustration at far left*]. The turbine is driven by mud (or sometimes water) pumped down from above; the exhaust mud from the turbine goes through the bit and carries the cuttings to the surface in the usual way.

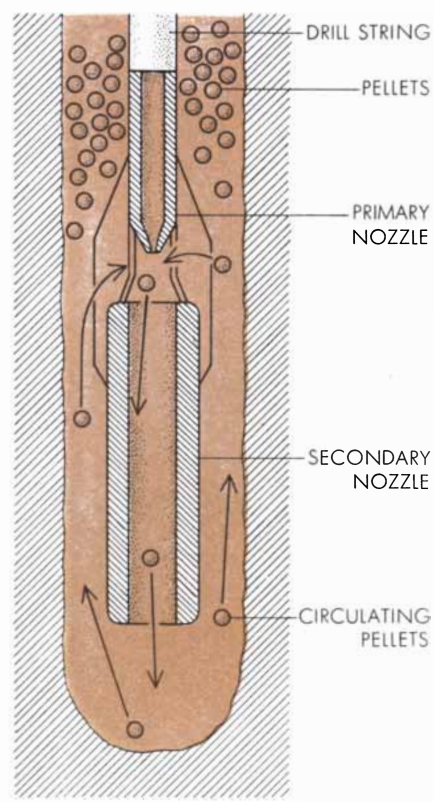
While the turbodrill seems to have been invented at about the same time by a number of engineers in several countries, it has attained its greatest success in the U.S.S.R. In that country it is drilling five out of six wells. Its devel-



TURBODRILL is driven by the descending stream of mud; its drill pipe does not rotate. By avoiding friction with the sides of the hole, it prevents the enormous loss of power which cuts down the efficiency of conventional rotary drilling in deep wells.



ELECTRODRILL circulates mud only at the bottom of the hole, thus lowering pumping costs. It can be easily hauled up on its cable to change bits or empty the bailer. At great depths these advantages overcome its lightness and consequent slow drilling rate.

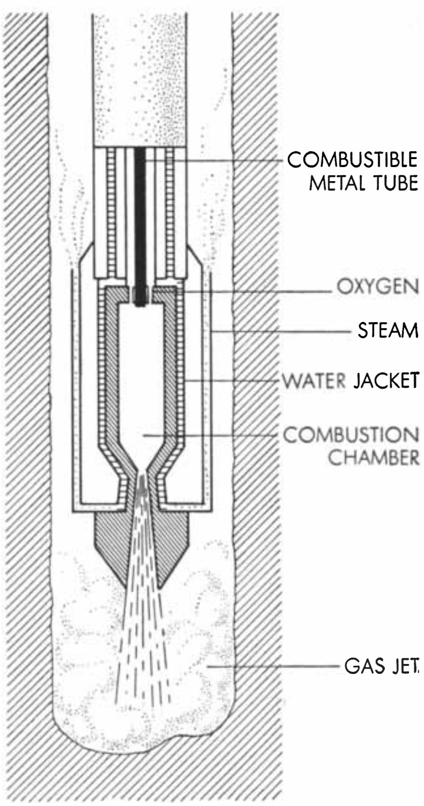


PELLET DRILL uses steel balls driven by a mud jet to blast away the rock. The mud returns to the surface but the balls do not. Pellet drilling is still in the experimental stage; so far it has shown itself no more efficient than conventional, rotary drilling.

opment in the U. S. has been intermittent; however, an oil equipment manufacturer in Texas has undertaken a large development program. A similar device under development in this country, the dynadrill, is powered by a different sort of mud engine.

Another Soviet development is the electrodrill—a long, thin electric motor which turns the bit through reduction gears. The motor also turns a centrifugal pump to circulate the mud through a bailer and strain out the cuttings. Suspension of the entire apparatus on a cable makes for maximum speed in bit-changing and bailing. Since it must be kept comparatively light in weight, however, the electrodrill does not exert sufficient pressure to achieve adequate drilling speed. At great depths its virtues seem to offset its slower speed. Russian drillers sometimes start their hole with a turbodrill and shift to an electrodrill at the 10,000- or 15,000-foot level.

The most striking Soviet innovations set aside drill strings, bits and mud in favor of "flame drilling." Soviet journals have described one drill which burns a metal tube in an oxygen stream to produce temperatures of 2,000 degrees centigrade—hot enough to melt granite. Another burns kerosene and oxygen in a 3,500-degree jet which not only melts rock but partially burns it. So far as we know these systems are still in the development stage.



FLAME DRILL, now being experimented with in the U.S.S.R., uses a rocket-like jet of gas at 2,000 degrees centigrade to melt and blast away rock. A similar device, also experimental, produces a 3,500-degree jet by means of a mixture of oxygen and kerosene.

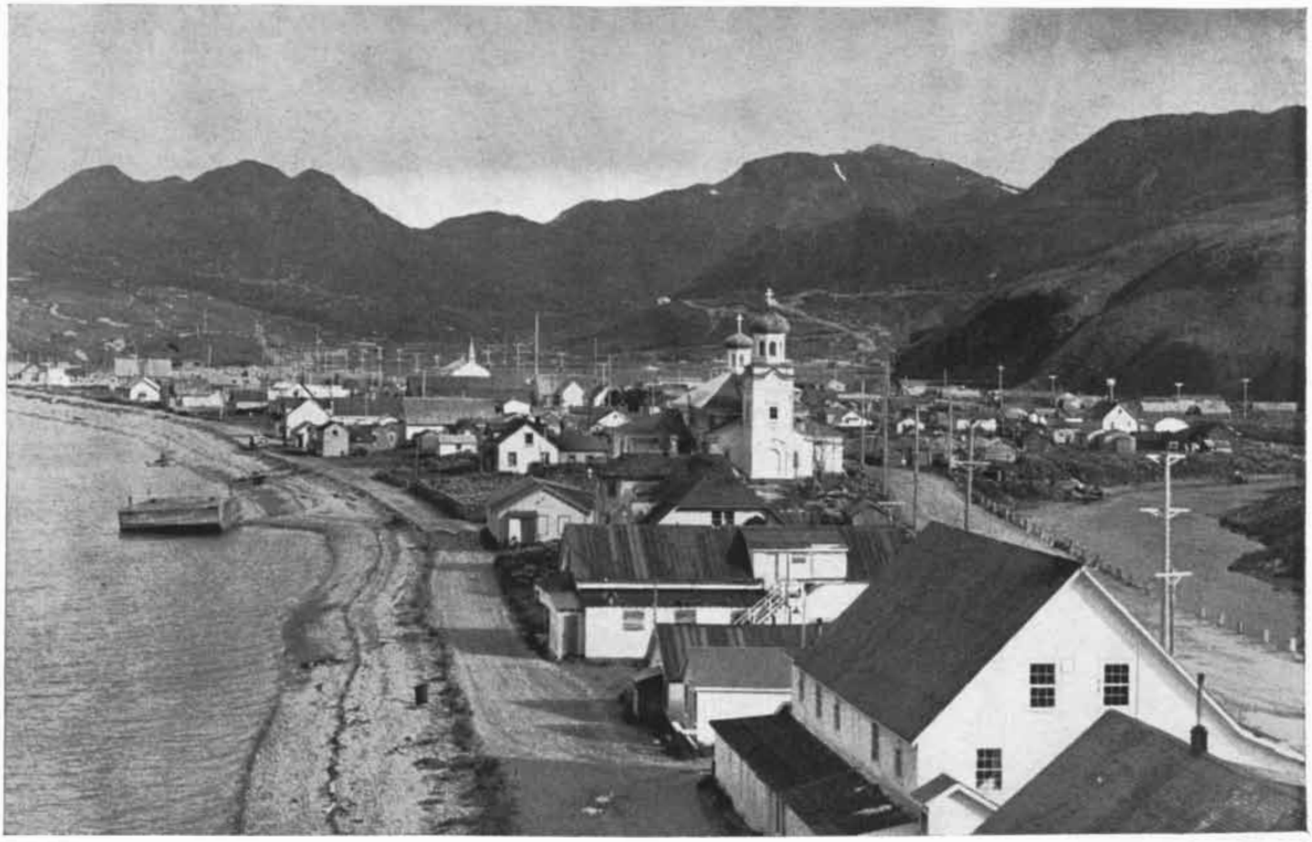
The turbodrill or dynadrill will probably come into more general use outside the U.S.S.R., at least for deep, hard formations; the same may eventually be true of the electrodrill and flame drills. But no one drill is likely to monopolize the field; one or another type of drill will always prove best in each combination of circumstances. The wide use of rotary drilling in the U. S. exerts a certain bias in this country toward such modifications of that method as the hammer drill and retractable bits.

Recently Soviet publications claimed that their engineers have developed the equipment to drill a 50,000-foot hole —twice the U. S. record and three times the Soviet record. Presumably they figured in terms of turbodrilling followed by electrodrilling. A panel of U. S. experts was accordingly moved to discuss whether we, using rotary equipment, could do the same.

They concluded that a 50,000-foot hole would need to have a diameter of two feet for the first 2,000 feet, decreasing thereafter to six inches at the bottom. Casing and drilling pipe of sufficient strength are available, but a more powerful turntable would be needed to turn a 9½-mile drill string. The most serious problems would be temperature and pressure. Depending on local conditions, temperatures at the bottom of the hole would range from 450 to 875 degrees F. Special bits would have to be made from heat-resistant alloys, and since present drilling muds are stable only to 500 degrees, new muds would have to be formulated. Pressures at 50,000 feet might reach 60,000 pounds per square inch, enough to make some rocks flow in plastic deformation. This would introduce the driller to an entirely new order of problems.

The panel did not take up the question of cost, but this would probably run into the tens of millions of dollars. Even if such a hole struck oil, it could not pay for itself. It would, however, supply a good deal of valuable information on temperatures, radioactivity, and rock structures at extreme depths. The scientific value of a 50,000-foot hole might make it worthwhile for the Government to sponsor it.

ALEUTIAN ISLANDS, west of Alaska, once supported 20,000 aboriginal Aleuts in their mist-shrouded harbors. The photograph at top shows Mount Makushin, an active volcano, towering above the cliffs and meadows of Unalaska, second largest of the Aleutians.



ALEUTIAN VILLAGE of Unalaska has a population of 150, three fourths of them native Aleuts. Once the center of the Russians' Aleutian trade (note the Russian Orthodox church), it typifies the seaside towns in which the surviving Aleuts were consolidated.

THE ALEUTS

These hardy seafarers have lived in the Aleutian Islands for 3,000 years, but their numbers are rapidly dwindling. They are now known to be a southern branch of the Eskimo

by T. P. Bank

Schoolbooks have given us a stereotyped view of the Eskimos as a fur-swathed people who live in igloos and share a perennially frozen Arctic wasteland with polar bears and sled dogs. Actually this is an entirely atypical picture that fits only a small minority of the Eskimo population. More than two thirds of the Eskimos live not in the ice-locked Far North, but well below the Arctic Circle in western and southern Alaska, and these people never saw an igloo until white men introduced it from northern Canada. The Eskimos are in fact a far-flung folk who inhabit the broadest stretch of land of any people on earth—from Greenland to the western tip of the Aleutian Islands, a distance of more than 6,000 miles. Because they are so widely dispersed, they have developed cultural patterns as diverse as the vast territory they occupy.

Perhaps the most highly individualistic of all the Eskimos were the Aleuts (pronounced "Al-ee-oots"), whose descendants still inhabit the Aleutian Islands. Until two centuries ago they were the largest single Eskimo group, with a population about 20,000 strong. They were a vigorous, inventive people who mastered beautifully their stern but rich environment. Putting together recent archaeological studies and the accounts of the Russian explorers who first discovered them, we can draw a fairly complete picture of this extraordinary people as they were before the white man came and almost wiped them out.

The home of the Aleuts is an archipelago of volcanic islands—the tops of submerged mountains. The more than 70 islands of the archipelago lie like giant steppingstones in an arc between North America and Asia. Indeed, they were used as steppingstones by the Aleuts, who in prehistoric times made their way from island to island almost across the North Pacific. Looking at the Aleutians on a map, we are immediately impressed by two things: the great length of the arc (more than 1,000 miles), and its symmetrical formation—like a gigantic sieve between the stormy North Pacific on one side and the cold Bering Sea on the other. Present-day mariners know the islands as a dangerous stretch of jagged coasts, windswept rocky headlands, active volcanoes and treacherous offshore reefs. U. S. soldiers who were stationed there during World War II were perhaps more impressed by the weather, which is almost invariably wet, windy and raw. In summer the islands are enveloped in heavy fogs; in fall and winter they are lashed by squalls and violent storms called williwaws.

Yet in spite of the storms and perennial fogs, the Aleutians have a Temperate

ALEUTS who have survived civilization now number less than 1,000. This Umnak Island family has a government-built house and wears rubber boots instead of gut "mukluks."

SALMON CATCH, to be dried and smoked for winter eating, is hauled in at dawn by an Aleut family on Unalaska Island. The Aleuts eat sea-lion meat, shellfish, salmon, cod, halibut and porgies, and formerly used animal skin and bones for clothing and tools.

WEDDING of an Aleut couple takes place in the Russian Orthodox church whose exterior may be seen in the photograph at the bottom of page 112. The crowns, symbols of the sanctity of marriage, are held so they do not touch the head of the bride or groom. Orthodox liturgy and U. S. popular dance music have replaced traditional chants and story-telling dances throughout the Aleutian Islands.

Zone climate. The most southerly part of the chain lies only a few degrees north of Seattle. The Japan Current that is responsible for California's celebrated weather also warms the Aleutians. The temperature at sea level rarely drops below 25 degrees Fahrenheit, even in winter. It is an excellent climate for plant and animal life. The broad valleys and mountain slopes of the islands are covered in summer with luxuriant grasses and colorful wildflowers. The rocky sea cliffs are home for some of the largest colonies of sea birds in the world. And the turbulent waters around the islands abound in fish, clams, crabs and sea mammals. In short, the Aleutians are far more habitable than their storms and rocky terrain would suggest.

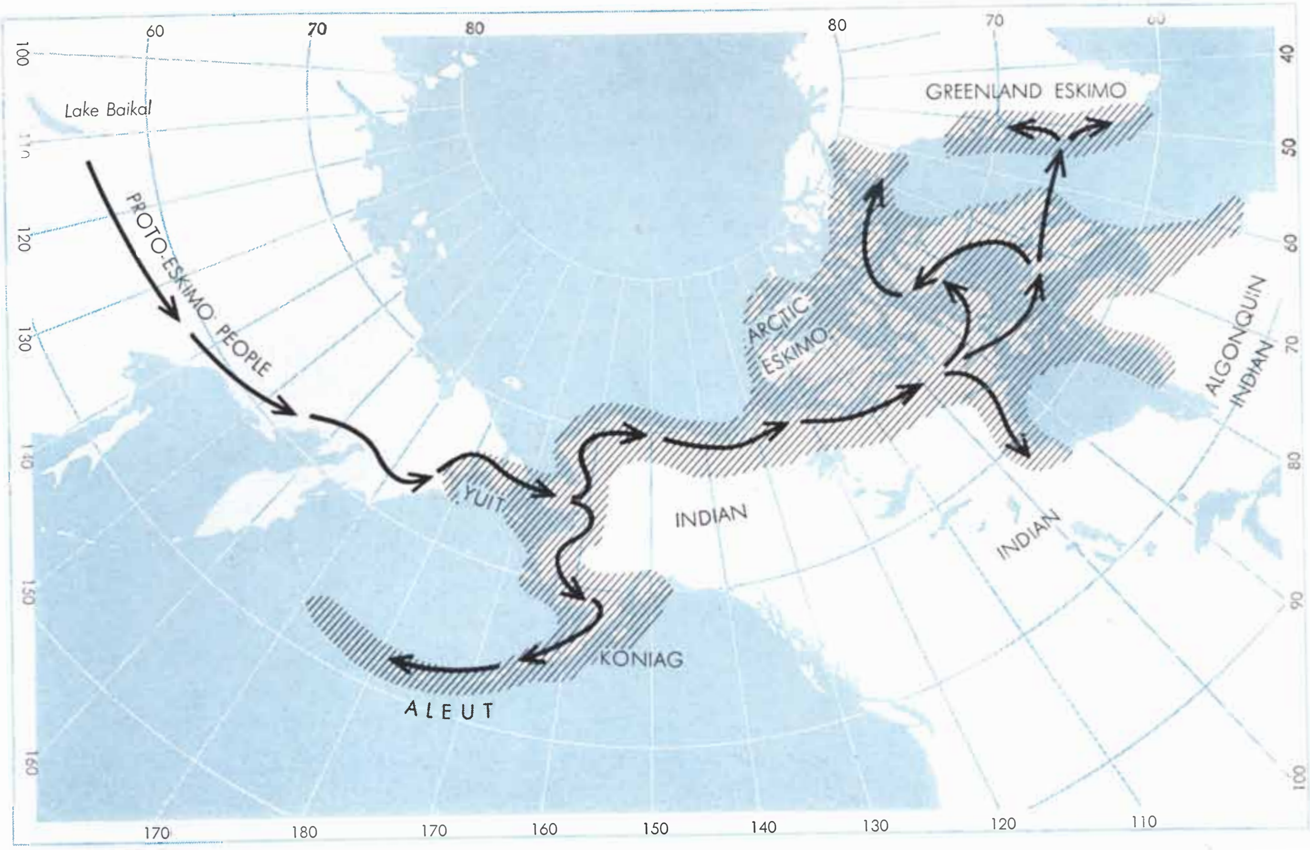
According to recent dates obtained by the radiocarbon method, the Aleuts first settled in the islands at least 3,000 years ago. Just where they came from has been a matter of much speculation. Because they are unlike other Eskimos in many ways, it was thought for a long time that the two groups were not related at all. Some scholars believed that the Aleuts came directly from Asia by way of Kamchatka. Others thought that they were descended from American Indians, and one bizarre theory had them coming from the so-called lost continent of Mu in the Pacific. But recent studies have established that the Aleuts are without doubt a branch of the Eskimo stock, and that they reached the Aleutians from the Alaskan mainland. Their language, although superficially different, stems from proto-Eskimo roots. Physically the Aleuts resemble other Bering Sea Eskimos, though when they are compared with groups living farther away, the similarity is less pronounced. Many features of their culture—notably their kayak-like skin boats, toggle harpoons and stone lamps—are typically Eskimo. To clinch the matter, recent serological tests have shown that the Aleuts and other Eskimos have an almost identical distribution of blood factors.

If the Aleuts are Eskimos, the question arises: Where did the Eskimos originate? It is generally agreed that they probably came from northwest Asia via the Bering Strait many centuries after the ancestors of the American Indian passed through this same gateway. The ancestral Eskimos, or proto-Eskimos, probably followed the coast after crossing the Bering Strait, one wave of people wandering north and east along the Arctic Ocean and another wave going south along the Bering Sea. The southerly migration eventually reached the Aleutians and became the first Aleuts.

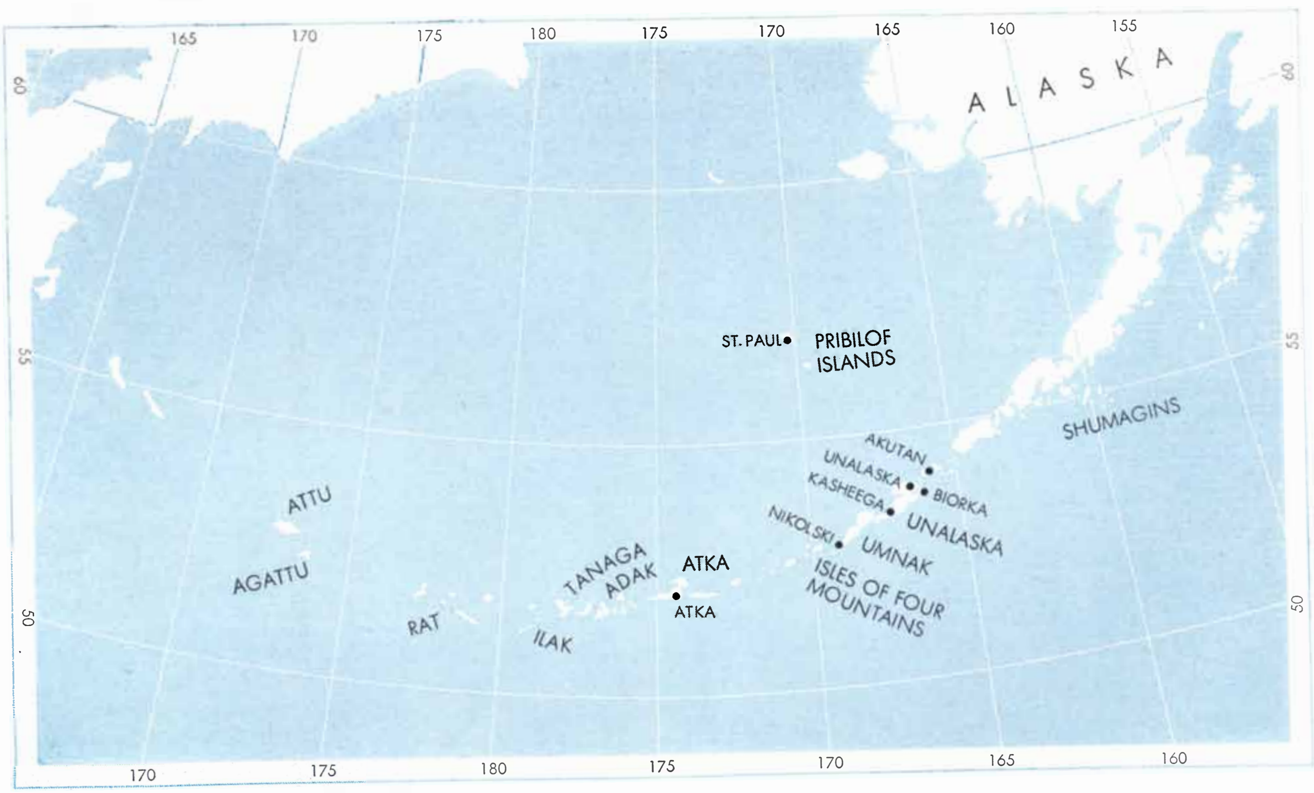
Anthropologists have long puzzled over the fact that certain cultural traits found in Kamchatka, the Kuriles and northern Japan bear a remarkable resemblance to parts of Aleut culture. This would seem to indicate direct cultural exchanges between the Aleuts and peoples on the Asiatic mainland. If so, then either the Aleuts or the Asiatics had to cross more than 400 miles of rough, open sea in small boats—no mean feat even for skilled seafarers like the Aleuts. Some interesting clues to the mystery were discovered recently when Japanese archaeologists digging in northern Hokkaido uncovered the remains of an Eskimo-like people who briefly inhabited the shores of the Sea of Okhotsk 1,000 years ago. Accompanying artifacts indicate that these Sea-of-Okhotsk Eskimoids may have stemmed from northeastern Siberia, possibly from the same proto-Eskimo source that gave rise to the ancestors of the Aleuts. If this is true, it would explain many of the cultural similarities found in southwestern Alaska, Kamchatka, the Kurile Islands and northern Japan. They are remnants of the common cultural heritage of two groups of southern Eskimos who inhabited different continents.

Our most direct information about what the Aleutian Eskimos were like before they were touched by the white man's civilization comes from accounts by Russian explorers who visited them soon after the Aleutians were discovered by Vitus Bering and Aleksei Chirikov in 1741. Unhappily the Aleuts' flourishing culture and economy did not long survive this discovery. When the Bering expedition returned to Russia and told of the vast herds of fur animals in the North Pacific, fortune hunters started a stampede almost equal to the great Klondike gold rush that came some 150 years later. Adventurers, thieves, exiles, murderers and princes alike set out to plunder this remote region of its treasure. A tide of greed, cruelty and bloodshed swept over the Aleutian Islands. The Aleuts fought back, but they were overwhelmed by the superior weapons of the Russian hunters. Whole villages were wiped out; the population was decimated not only by guns but also by smallpox, measles, tuberculosis and pneumonia.

In the 1870s the U. S. naturalist William Healey Dall, a student of the famous Louis Agassiz, conducted the first systematic excavation of abandoned Aleut village sites, some of whose remains form mounds as high as 30 feet or more. Later the Swedish anthropologist



MIGRATION ROUTES show how the Eskimos and Aleuts of today derive from a common stock, the "Proto-Eskimos," who may possibly have come from the Lake Baikal region in Siberia. It is believed that the Eskimos and Aleuts diverged more than 3,000 years ago.



THE ALEUTIAN ARCHIPELAGO stretches about 1,000 miles westward from the Alaskan Peninsula across the North Pacific. The western islands were geographically, genetically and culturally the most isolated. Dots indicate the present Aleut villages. There are also a few Aleuts now living in the Shumagins, on the Alaskan Peninsula and in Komandorski Islands near Kamchatka.

Waldemar Jochelson also dug into the Aleuts' past. The most extensive archaeological work in the islands was done in the 1930s by the late Ales Hrdlicka of the Smithsonian Institution. He brought back and studied hundreds of Aleut skeletons. Unfortunately his failure to keep exact field notes made his collections of Aleutian materials less useful than they might have been.

Since World War II studies of the Aleuts have been made by William S. Laughlin, now at the University of Wisconsin, and by the writer of this article. Both studies have had the help of modern techniques such as blood-typing, radiocarbon dating and pollen analysis. In addition to showing that the Aleuts arrived in the islands at least 3,000 years ago, the new studies indicate that when they arrived the Aleutian climate may have been somewhat colder. The subsequent change to a Temperate Zone climate, plus the isolation of the islands, undoubtedly had a profound effect on the Aleuts' way of life. This is manifested by their later culture, which diverged in many ways from that of the Eskimos and the Indians on the North American continent. For example, the Aleuts did not depend for clothing on the furs of animals. Their primary concern was keeping dry: they wore rain parkas (*kamleikas*) made of bird skins or the gut of sea mammals. Lacking flint and having mainly beach pebbles or boulders to work with, the Aleuts made comparatively crude stone tools; for want of clay they made no pottery. Since the walrus seldom ventures into the southern Bering Sea, the Aleuts could not easily collect ivory for carvings and for weapons, as did the northern Eskimos. Because the Aleutians are treeless, and driftwood is the only source of wood, the Aleuts never built large wooden structures, as did some Indian tribes. On the other hand, the Aleuts learned to exploit the luxuriant plant life of their islands for food, for medicines and for poisons which are unknown to the northern Eskimos, and they attained great skill and artistry in basketwork and weaving. Living on the edge of a sea that remains open all winter, they developed not dog sleds but marvelously seaworthy skin boats.

The Aleuts were primarily hunters of sea mammals—seals, sea lions and whales. They wasted nothing of their quarry that was edible or usable. When a dead whale was brought ashore, the Aleuts carved up its meat and fat for food. They burned its fat for heat and light. They used its ribs and jawbones for building; turned its shoulder blades into tables or seats, its small vertebrae

ANCIENT VILLAGE of the Aleuts is shown in the course of excavation by the University of Michigan expedition of 1951. The lighter-colored streaks are strata of shells and fishbones which were left by the inhabitants. This site is on Dutch Harbor Island.

ANCIENT BURIAL of two adults and a child was found in the same site on Dutch Harbor Island, which is in Unalaska Bay in the eastern Aleutians. Because the bodies were buried under heavy, flat stones, all three of the skulls have been completely crushed.

into chairs and its bone ends into plates; fashioned other bones into harpoon heads and daggers; converted the intestines to rain parkas, waterproof bags and translucent windows for their semi-subterranean houses; used the sinews for thread and cord; and carved the teeth and dense pieces of bone into ornaments, needles and arrowheads.

Warriors as well as hunters, the Aleuts equipped themselves with formidable and ingenious weapons. They had stone axes, and from bone they made clubs, poniards, knives and spears. Their most ingenious military weapon was a compound lance. The barbed head, made of bone with a stone point, was exactly as long as the depth of a man's body from chest to spine; it was mounted on the wooden staff in such a fashion that once it was driven home it would detach itself and lodge irremovably in its victim. For protection in combat the Aleut warrior often bore a wooden shield or body armor made of wooden slats tied together with sinews.

Among their peaceful tools and implements were spoons made from the breastbone of the duck, bone wedges for splitting driftwood, carved bone fishhooks, stone axes, scrapers, drills and lamps. The artistic talent of the Aleuts is best displayed in their basketry. They wove exquisite grass mats, colorful baskets, intricately fashioned grass capes and grass burial shrouds. To give color to their designs they used octopus "ink," ochres and vegetable stains as dyes, or wove into them small feathers and colored strings of gut.

Perhaps the Aleuts' highest attainment was their skill and prowess as seamen and navigators. In this respect they surpassed all other Eskimos. It was not uncommon for Aleut hunters to rove the turbulent seas for hundreds of miles, paddling for days on end, resting seated erect in their skin boats when tired and lashing their small craft together to ride out storms. Russian explorers reported that Aleut hunters at sea "blazed a trail" with whitened sea-lion bladders, weighted with long ropes and stone sea anchors, which they set afloat at intervals to mark the route home through the fog.

The Aleuts put their faith in sunlight as the potent source of all life. They therefore habitually arose with the dawn to make the most of the daylight. Water, particularly sea water, was thought to be a great source of vitality. Before any special event or during some kind of crisis an Aleut took a ceremonial bath in the sea; to insure their stamina new-born babies were dipped in the surf no matter what the time of year.

As a warlike people, the Aleuts usually built their villages on a narrow isthmus, a neck of land or a promontory between two bays, apparently so that they could quickly transfer their skin boats from one body of water to the other in case of attack from the sea. Their dwellings were built underground, with only a narrow opening in the sod roof as an exit. Near every village was a lookout hill (*agi'sax'*). Here sentries watched for enemies, hunters scanned the sea for game, and women and children searched the horizon for their seafaring men, whose return they greeted with songs and dances.

Though ocean hunting was the livelihood of all the Aleuts and gave their scattered communities a basic cultural identity, their customs nonetheless differed from one island group to another. For instance, some Aleuts hunted whales and others did not. People on the western islands made their fish-line sinkers of round beach cobbles which they grooved around the middle, while elsewhere the Aleuts used flat cobbles. Ornaments worn by the Aleuts varied considerably, and there were many different styles of weapons and dress. Apparently isolation from one another, plus a demanding environment, stimulated the Aleuts' genius for developing new ideas. In time certain islands became centers of regional culture and of separate dialects. As we might expect, differences were most marked at opposite ends of the 1,000-mile chain of islands. This is because the chain, together with its linearly dispersed population, acted very much like a filter. New ideas originating in the eastern Aleutians or on the Alaskan mainland had to pass from island to island through this filter before reaching the westernmost Aleuts. On the way the innovations were often modified or blocked by the existence of local culture centers, dialects and military leagues that broke the flow into eddies.

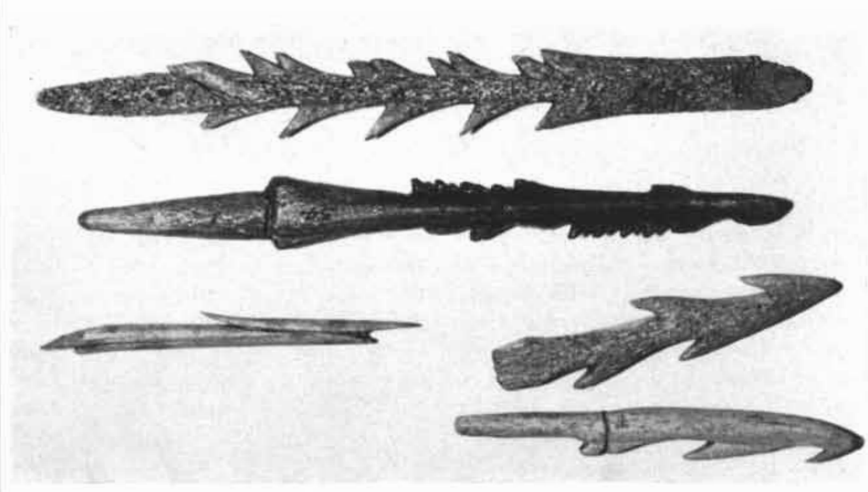
The eastern Aleuts, but apparently not the westerners, developed the practice of mummifying their dead. They removed the viscera and other internal organs through the pubic region or through a hole in the chest and stuffed the body cavity with dry sphagnum moss. The corpse of a dead chief or of a wealthy person was preserved by specially treating it with fat rendered from human brains. It was then tightly bound and clothed in bird skins, furs or elaborately decorated grass mats. It was secreted in a cave or a sheltered place among the rocks, often in a lifelike position: for example, seated in a skin boat and looking out to sea. Frequently the dead man's possessions were buried with him, and sometimes slaves were killed and immured with their masters. Less revered mummies were strung up on cave walls with thongs. Some Aleutian mummies are over 1,000 years old, yet the bodies are well preserved today. This practice developed into an important cult that played a profound role in the life of some of the eastern Aleuts. It spread to the middle Aleutians, but apparently was unknown in the western islands.

The Aleuts differed also in physical type. Hrdlicka sorted the skeletons which he brought back from the Aleutians into two types—broad-headed ("brachycephalic") and comparatively long-headed ("dolichocephalic"). He decided that the long-headed skeletons represented a people entirely different from the broad-headed ones. Hrdlicka called the long heads "Pre-Aleuts." He held that the Aleutians were populated in two migration waves, and that the Pre-Aleuts reached the islands about 1,000 years ahead of the broad-headed Aleuts. No one has found any evidence, however, that links the supposedly earlier long heads and the later broad heads to the remains of different cultures. Recently William Laughlin was able to show that long heads as well as broad occur in the living population. The long heads are found mostly in the western Aleutians, the broad heads mostly in the east. Laughlin concludes that the later migration of broad heads never reached the western islands.

There is, however, another explanation for the two physical types. In my opinion, the Aleutians were populated in a single, slow-moving wave of migration. It reached the Aleutians at least 3,000 years ago; the Aleuts are in fact one of the oldest Eskimo peoples in the New World. This migration was never a mass movement of large numbers of people, but rather consisted of sporadic movements by small family groups over a long period of time. Islands may sometimes have been populated by members of a single family with a genetic make-up very different from that of the over-all Aleut norm. Gradually the Aleut population spread itself thinly across the whole Aleutian archipelago. It became separated, like a human chain whose links were not all joined. Under such conditions, and considering the isolation of some island groups, it is easy to see how gene drift or the genetic eccentricity of local strains could lead to considerable variation. This was enhanced in the eastern part of the chain in recent times by more frequent mixing between eastern Aleuts and mainland Eskimos; the western Aleuts had far fewer opportunities to marry outside their own island groups.

We shall have very little chance to learn much more from the Aleuts themselves. Today they live in a few scattered villages at river mouths, where we and the Russians before us have herded them. Their number has dwindled to less than 1,000. Despite efforts by the U. S. Indian Service, the decline continues.

It is a picture all too familiar to anthropologists: a once-thriving, independent people, admirably disciplined for life in a rigorous environment, now impoverished, diseased and spiritually weakened, its ancient culture all but destroyed. The story might serve as a lesson to us. But it is probably too late to save the southernmost of our Eskimos.



WEAPON POINTS used by the Aleuts are shown in this photograph. The three at bottom are darts for hunting. At top are detachable war lance heads described in the text.

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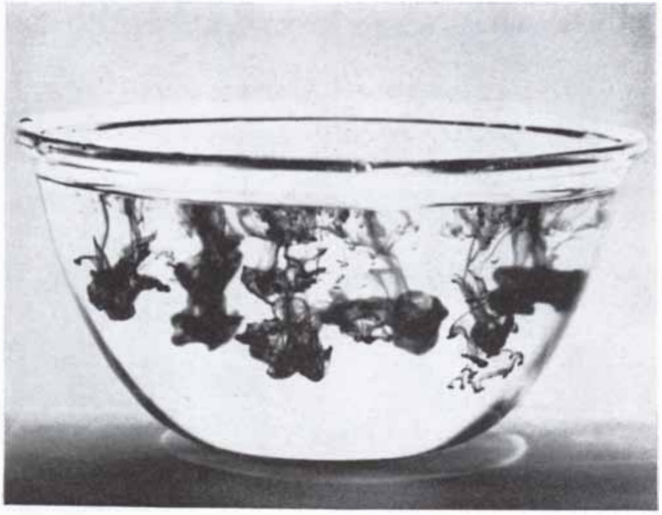
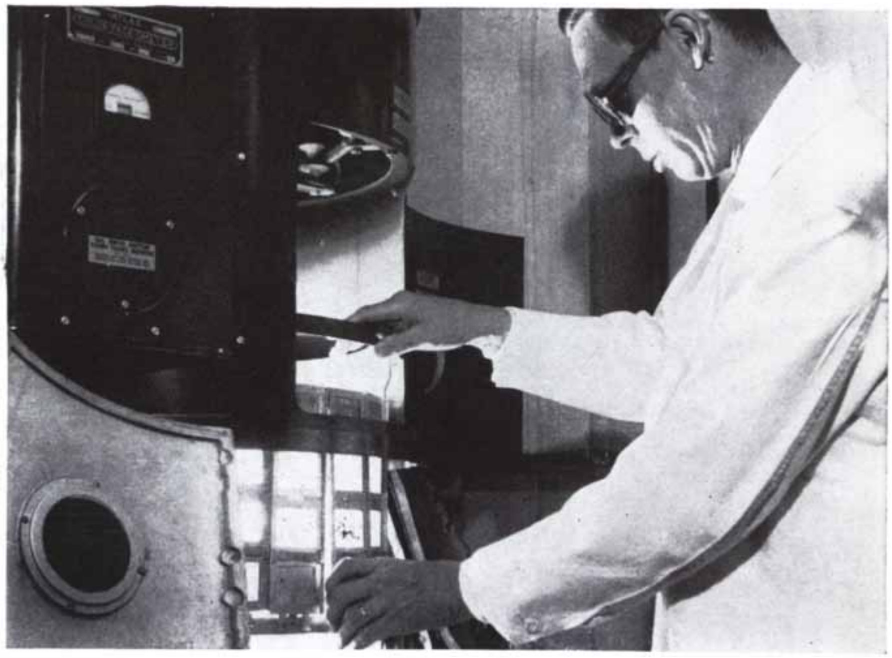
Life on the Chemical Newsfront

LEATHER COLORS OF UNUSUAL LIGHTFASTNESS are produced by CALCOFAST* *dyes*, which are also outstanding for levelness, clarity and transparency. Termed "metallized dyes" because of the introduction of a metal into the molecule, CALCOFAST dyes produce a full range of medium and pastel shades on leathers tanned with basic chrome sulfate or a combination of the chrome compound and synthetic tanning materials. Applied in the same manner as acid and direct dyes, CALCOFAST dyes are soluble in water and compatible with commonly used anionic and non-ionic wetting agents and water-soluble finishes.
(Organic Chemicals Division)

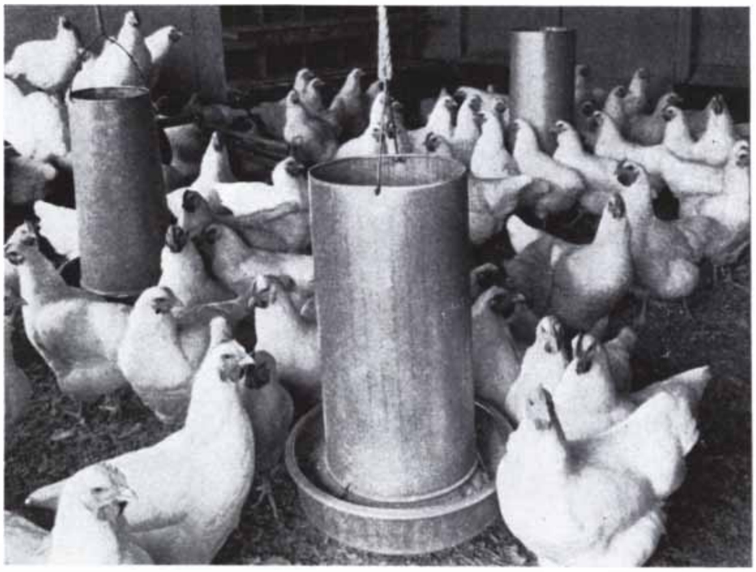


WHEN METALLIC IONS CLOUD YOUR PRODUCT, the trouble can often be cleared up with CYQUEST® 40 *sequestering agents*. Metal ions, present in only a few parts per million, can spoil color, cause turbidity, catalyze degradation reactions and otherwise affect product quality. CYQUEST 40 sequestering agent seeks out such di- and tri-valent metal ions and binds them securely as stable, soluble chelates. By isolating these ions, CYQUEST 40 eliminates problems in processing, shipping, storage and use of chemical products. (Industrial Chemical Division)

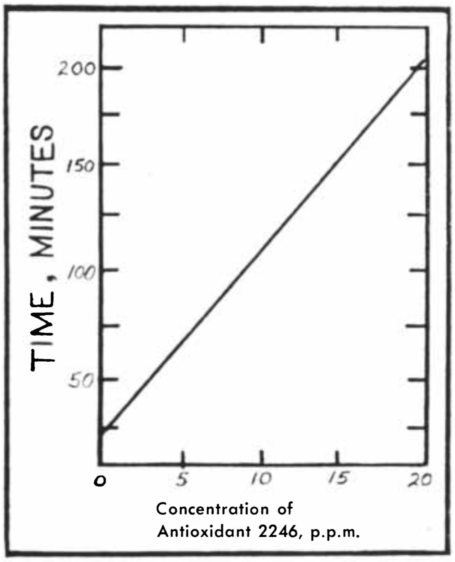


FADE-OMETER TESTS of polyvinyl chloride, as well as exposure tests conducted in Florida and Arizona, demonstrate the effectiveness of Cyanamid's CYASORB* *light absorbers.* Use of small percentages of CYASORB UV 24 in PVC, for example, prevents discoloration, embrittlement and other forms of degradation usually caused by outdoor exposure. Because CYASORB UV 24 absorbs strongly in the ultraviolet range and is unaffected by the absorption process, it gives long-lasting protection to UV-sensitive materials.

(Organic Chemicals Division)



NEW PROTECTION FOR LAYING HENS is provided by ARZENE* arsenosobenzene, the first coccidiostat to be accepted by the U. S. Food and Drug Administration for use with laying hens as well as broilers. ARZENE is being marketed by Cyanamid to feed manufacturers as a stable premix which is especially effective against the parasites that cause coccidiosis. Continuous feeding of ARZENE enables birds to develop immunity against troublesome species of coccidia. Extensive trial work shows the compound also stimulates growth and improves feed efficiency. (Agricultural Division)



GRAPH SHOWS EFFECTIVENESS of Cyanamid's ANTIOXIDANT 2246® as an oxidation inhibitor. Tests were conducted with 200-gram samples of α-pinene at 70° C with a continuous stream of oxygen bubbling through them. The induction period required before oxidation begins varies linearly with the concentration of antioxidant. Similar data indicate the usefulness of ANTIOXIDANT 2246 in other fats and oils, paraffin wax, petroleum products and as a polymerization inhibitor in chemical processes. Further data on chemical and physical properties and test results are available on request.

(Market Development Dept.)

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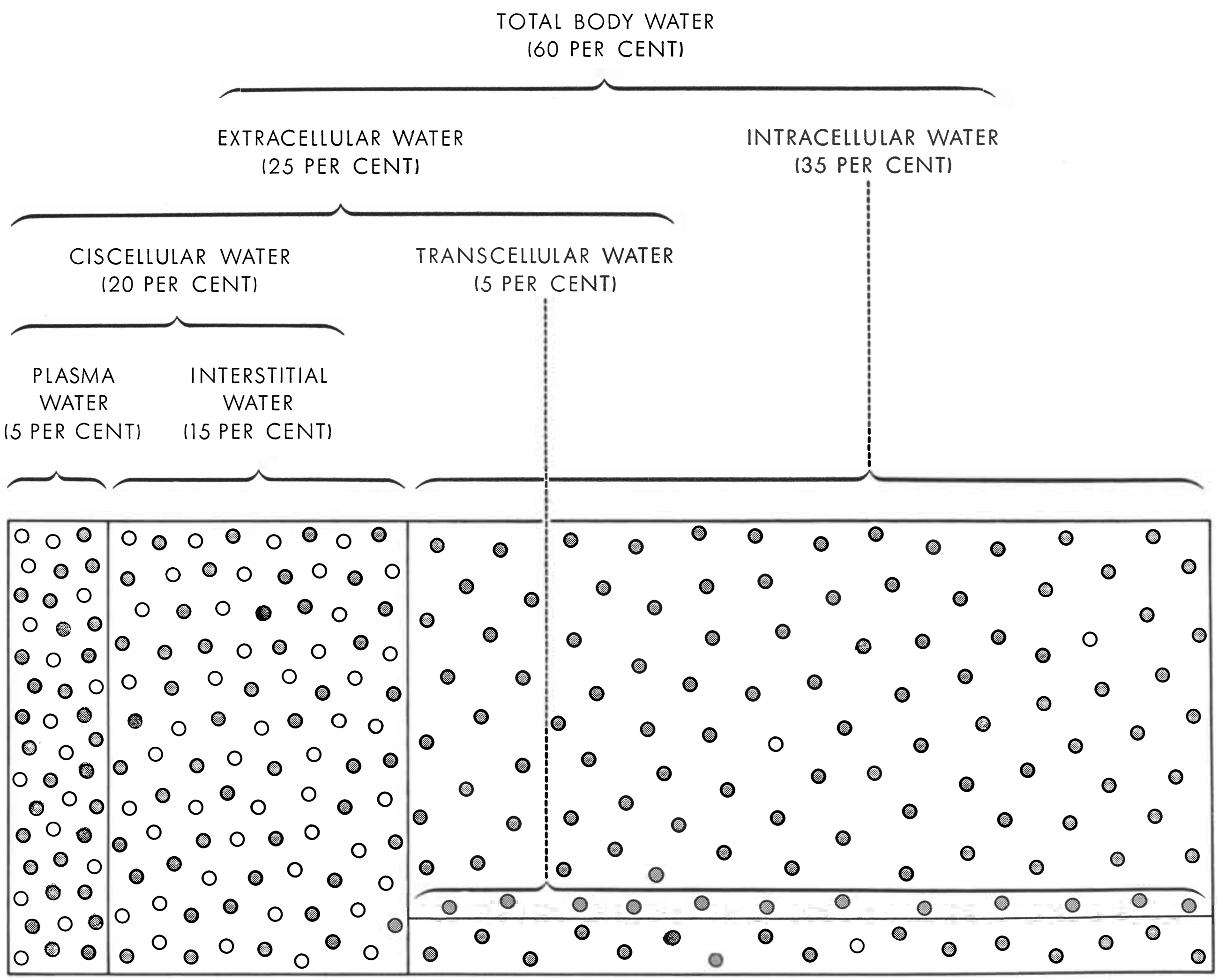
Body Water

Water accounts for 60 per cent of the weight of an adult man. The proportion decreases slowly with age, but it is maintained within narrow limits from one day to the next

by A. V. Wolf

What part of the weight of an animal is represented by water? The answer depends upon, among other things, whether the animal is fat or lean. Water accounts for two thirds of a thin cat, but only one third of a fat pig. Young animals are more watery than old ones. On the average an early human embryo is 97 per cent water; a newborn baby, 77 per cent; an adult man, 60 per cent. The water content of the human body falls rather sharply from birth to an age of about four years, when it levels off. Indeed, among mammals in general, the proportion of water in the body drops in this manner until "chemical maturity," or relatively constant composition, is attained after about a 20th of the life span. Still, body water continues to diminish slowly with age. As the body dries out,



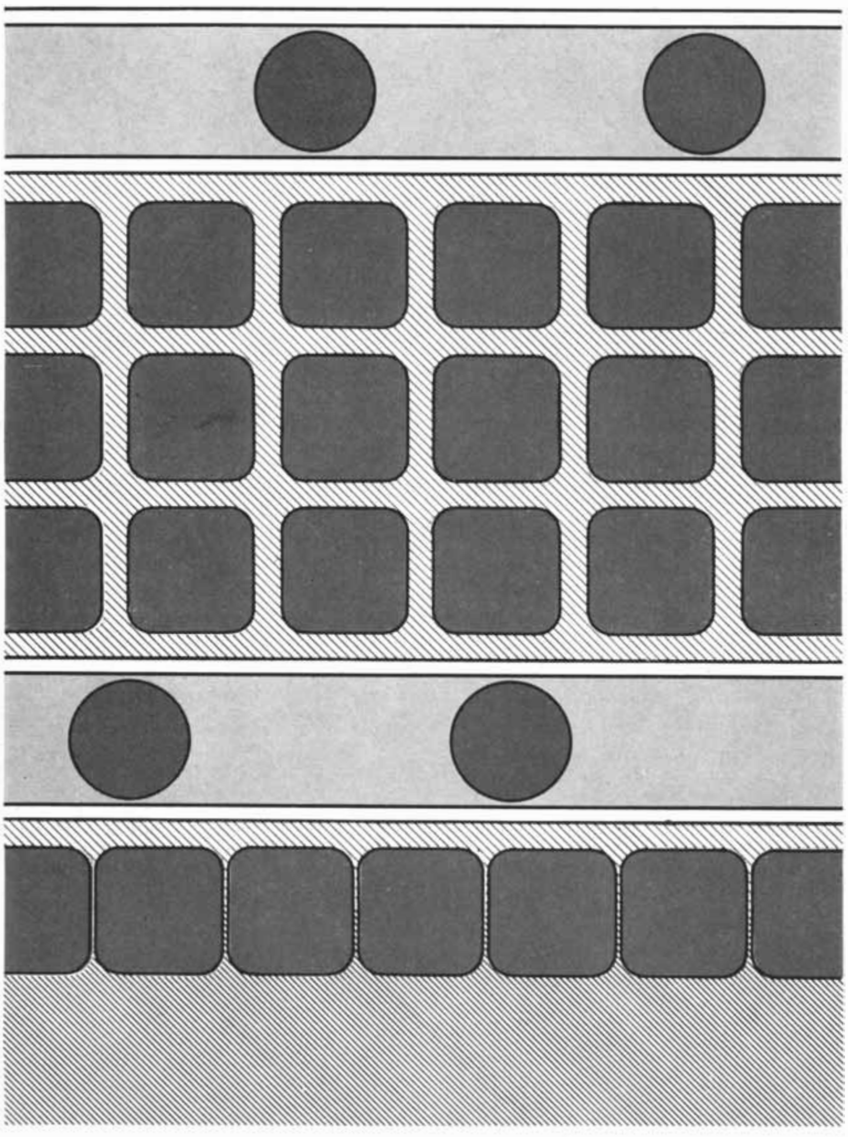
TOTAL BODY WATER is divided into compartments for the convenience of the physiologist. The percentages in this chart are fractions of the total body weight. Extracellular water is outside the cells; intracellular water, inside. Some of the extracellular water (*ciscellular*) is in the blood plasma and the interstices between cells; some (*transcellular*) is inside hollow organs. Dots indicate distribution of substances used to study body water: heavy water (*gray*), radioactive sodium (*white*) and Evans blue (*colored*).

its metabolism, as measured by its rate of oxygen consumption, slows down. In an adult human being oxygen consumption per unit of body water does not change with age, as though the water content of the body were a measure of its vital activity. It would appear that the flame of life is sustained by water.

This dependence on water may be conveniently observed in an earthworm. A healthy worm, when it is stimulated, wriggles in a way which makes it attractive both to anglers and to fish. Exposed to air, it loses both water and liveliness; before half of its fluid is gone it is quiescent. At this point it may still be revived by water. But if it is dried still more, its chances of recovery will diminish. Only certain simpler organisms can survive extreme desiccation.

This fact underlies one of the defects in a World War II plan to provide for all the needs of U. S. troops abroad. To prevent spoilage and conserve precious space, vast quantities of food were being shipped in dehydrated form. It was suggested that wives and sweethearts could also be transported in this way. At the happy destination, it would only be necessary to add water. For better or worse, however, neither women nor men can stand much drying out; they have large water requirements which must be regularly met.

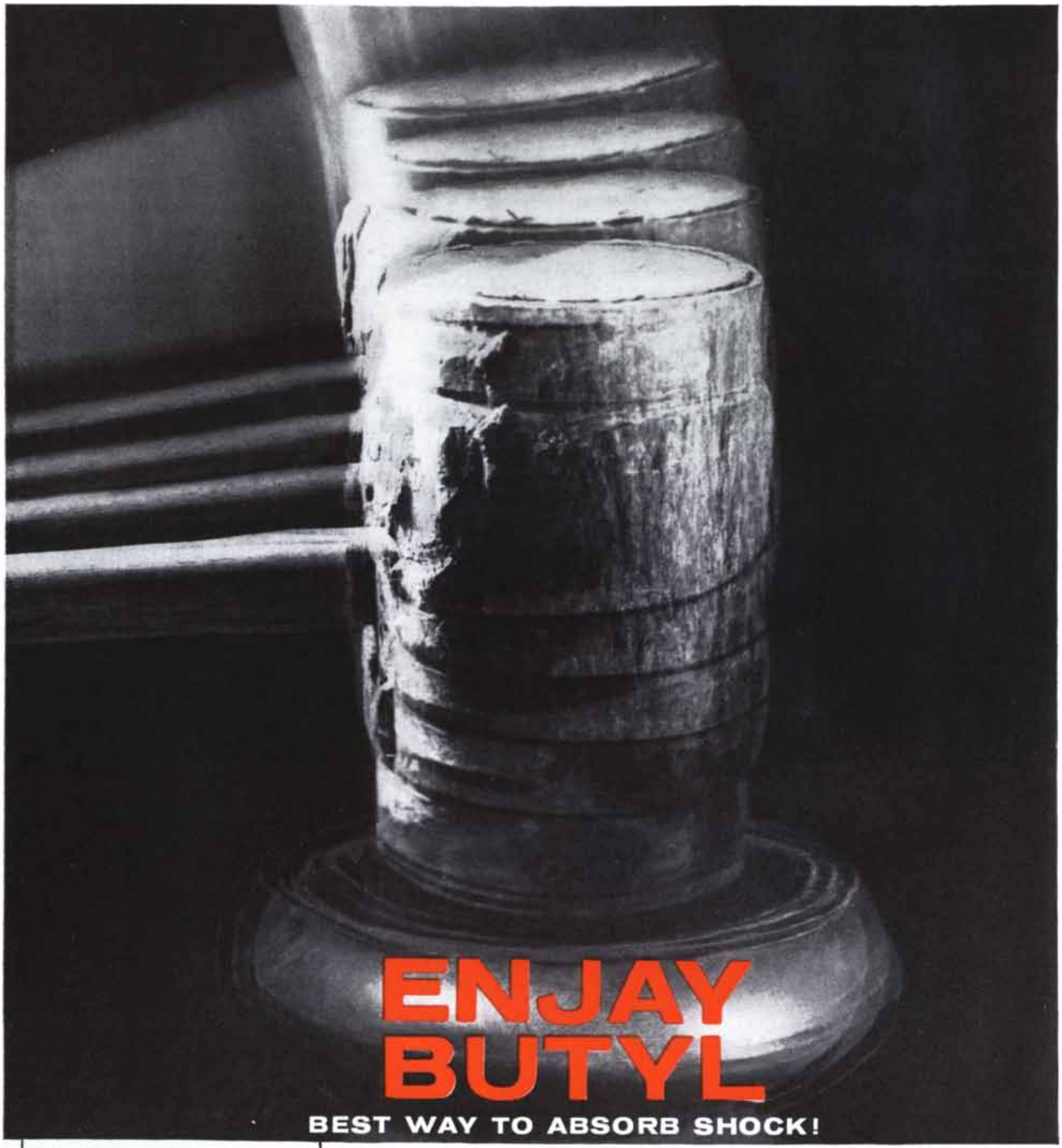
This is not the case with all animals. Grain weevils and the larvae of the clothes moth get along without liquids in their diet and live on air-dried foods usually containing less than 10 per cent water. The kangaroo rat may ingest no free fluid after weaning; the desert antelope of North Africa and the wild ass of the Gobi Desert, appear to do without drinking water. Curiously, certain animals maintain almost a constant percentage of water in their bodies regardless of access to water. Deprived of fluid, rats and mice stop eating food that is too dry and die after losing one third of their original body weight. Both solids and water disappear in the same proportion from their tissues, and their bodies contain a constant 70 per cent of water.

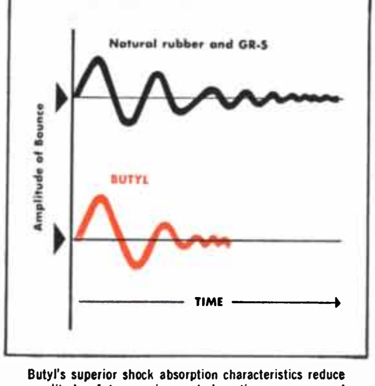


WATER COMPARTMENTS are more realistically illustrated in this still highly schematic drawing. The round shapes are blood cells; the square shapes with rounded corners are tissue cells. The intracellular water is indicated by the dark gray tone. The light gray tone represents the plasma water within the blood vessels; the lighter hatched areas, the interstitial water; the darker hatched areas at bottom, the transcellular water in a hollow organ.

Water pervades all tissues and organs, but physiologists maintain the convenient fiction that body water is compartmentalized: part of it is in the bloodstream, part is inside the cells, and part fills the spaces in the body cavities and between the tissue cells [*see illustration on preceding page*]. Actually body water scarcely recognizes anatomical boundaries—it diffuses, percolates, and otherwise migrates about the body. The water in the bloodstream, for instance, passes continuously and rapidly across the enormous collective surface of the capillaries; if we could suddenly label all the water molecules in the blood, perhaps only half the labeled molecules would remain in the bloodstream one minute later. At any one moment, however, about 8 per cent of the body water appears to be confined to the blood plasma; 25 per cent is accounted for by the fluid other than blood which lies among the cells of tissues; 60 per cent lies within the cells. In addition there is a disconcerting fraction of the body water which behaves in some ways as though it were inside the cells, but is strictly speaking a part of the extracellular fluid. This "transcellular" water mainly occupies the cavities of hollow organs such as the gut. Its functions are diverse. It lubricates the joints and other areas where organs rub and slide past each other; it acts as a protective distributor of pressures on various structures, including the developing fetus; it distends the eyeballs at the pressure needed to maintain their form and function. On occasion it serves as an emergency source of water; the feces then become drier and the eyeballs soften as they lose fluid.

To measure the quantity of water in the body it is possible to chop an animal into small pieces, dry the pieces in an oven at 100 degrees centigrade for a week or so, and note the loss of weight due to the evaporation of water. This





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Akron • Boston • Charlotte • Chicago • Detroit • Los Angeles • New Orleans • Tulsa procedure is not convenient with men or horses, and it has the additional drawback that it cannot be repeated with the same animal. But the body can be considered a sort of container, and there are several ways of measuring water in a flask or vessel. One method is to add a known amount of some freely soluble and identifiable substance, mix it thoroughly, remove a small sample of the solution and analyze it for the concentration of the substance. The volume of fluid in the container can then be calculated by dividing the concentration of the test substance into the known amount of it dissolved in the fluid. The substance used to measure body water, however, must not only be freely soluble in water; it must also be readily distinguishable from other substances in the body, nontoxic and able to diffuse quickly throughout all the body water. In addition it should not be destroyed by the body's metabolism, and should not become more concentrated in some parts of the body than in others. No one will be surprised to learn that few substances meet all these conditions.

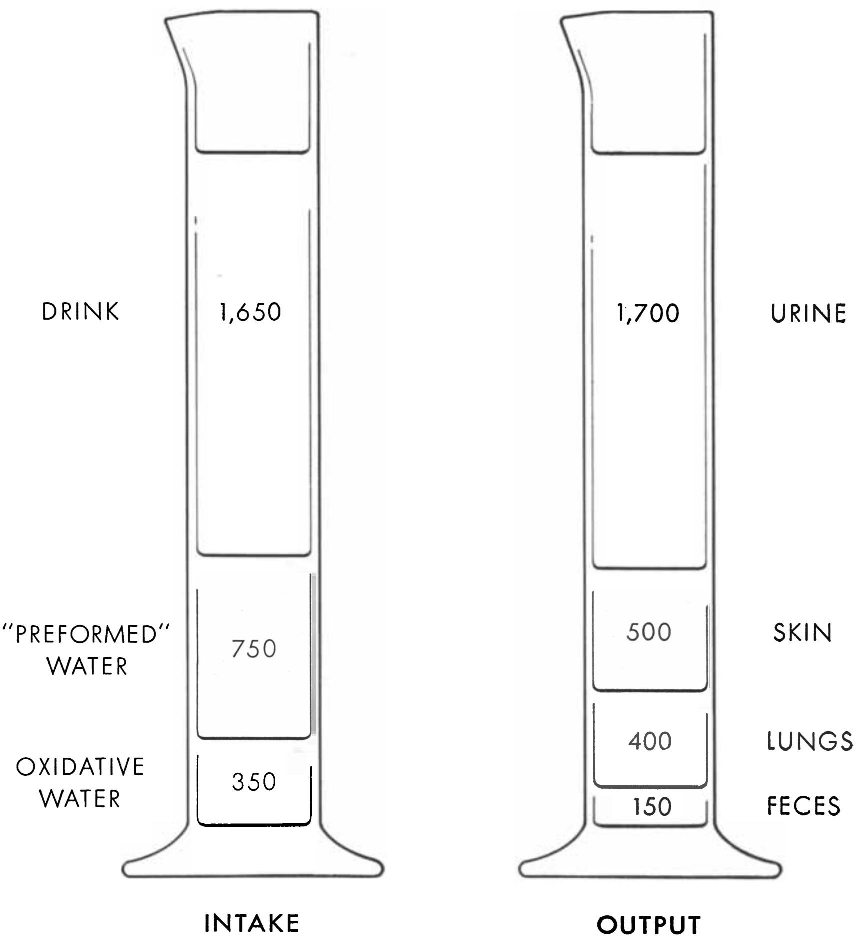
Urea, antipyrine and its derivatives, and water labeled with hydrogen isotopes (deuterium or tritium) have all been employed to measure the total body water. Within an hour after they have been injected into the bloodstream or swallowed, these substances diffuse through the body water. Their diffusion is so complete that analysis of their concentration in the blood yields a reliable measurement of total body water.

To measure the water contained in the several compartments of the body calls for variations of the same strategy. The ideal substance for measuring the "extracellular" compartments must diffuse in and out of the circulatory system readily and work its way into all the interstices among cells, but must not cross the cell membranes. Actually no known substance quite fills these specifications, although cane sugar, ions such as thiocyanate, and radioactive chloride, sulfate and sodium are frequently used. There are, however, other ways of measuring extracellular volume. One ingenious approach, applicable to isolated organs, was employed by the late Frederick L. Truax of the University of Rochester to determine the extracellular space of rat liver. First he made a photomicrograph of a thin section of the organ and weighed the photographic print. Then he carefully cut out the spaces between the images of the cells and reweighed the print. Since this organ has a sufficiently uniform structure throughout, simple arithmetic yielded the ratio of extracellular space to total liver volume.

Having measured the total body water and the extracellular water, then by subtraction one can obtain the intracellular water. Unfortunately materials which diffuse into all of the extracellular space in an isolated organ such as a muscle may not work so well in the organism as a whole, and they may particularly fail to find their way into the transcellular water pockets. Such a substance will give a low value for extracellular volume; instead the figure will approach the "ciscellular" volume [*see illustration on page 125*]. Thus the transcellular water will end up incorrectly counted as intracellular water. Mathematicians who insist, on topological grounds, that the water inside the gut cavity is outside the body do not make matters easier.

The portion of the ciscellular water in blood plasma can be determined in a somewhat roundabout way by the use of a dye known as Evans blue. Then, by subtracting the water in the plasma from the ciscellular fluid, we can estimate the volume of water contained in the interstitial spaces of the tissues.

The amount of water in the body is regulated with noteworthy precision. At 24-hour intervals the weight of a man may vary little more than one third of a pound, which sets an order of magnitude for the variation of his body water. The body normally maintains a balance between water intake and water loss. If the body loses much water—as a consequence of exercise, say—it acts to reduce the deficit. The urine excreted decreases (but does not entirely cease); thirst develops, and as a result water is drunk more rapidly than it is lost by evaporation and excretion. Conversely, if there is an excess of water, the body speeds up its elimination of water. The rate of urine formation accelerates and exceeds the relatively constant gain of water from the oxidation of foodstuff in the body;



WATER BALANCE is maintained by taking in water in an amount equal to that lost each day. In a typical day, a man may gain about 2,750 cubic centimeters of water by drinking fluids, by eating foods containing "preformed" water, and by the oxidation of food. This balances losses by excretion of urine and feces and by evaporation through skin and lungs.

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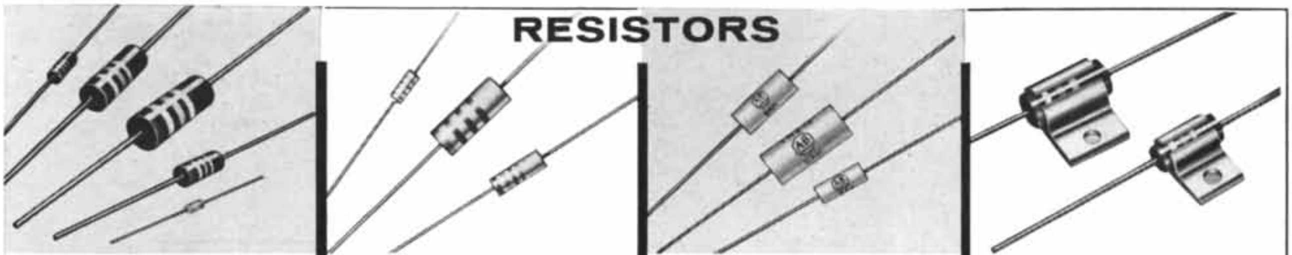

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COPPER CLAD—Metal panel mounting, insulated composition resistor supplied in two ratings: 3 and 4 watts at 70°C, and 4 and 5 watts respectively at 40°C.

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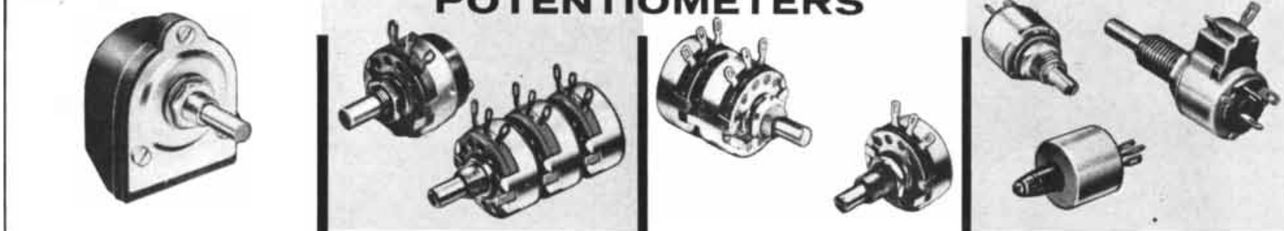

INDUSTRIAL—Type H with solid, hot molded resistor element. Quiet, improves with use. Life over 100,000 cycles. Rated 5 watts, 40°C; and 3 watts, 70°C.

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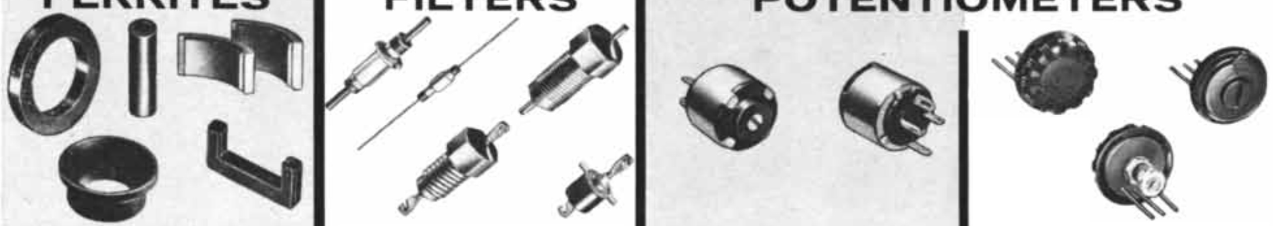
POTENTIOMETERS



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PRINTED CIRCUIT TYPE—Solid molded element. Rated 1/4 watt at 70°C. Type F is only 1/2" in diam. Screwdriver adjustment. Total resistance values to 5 meg.

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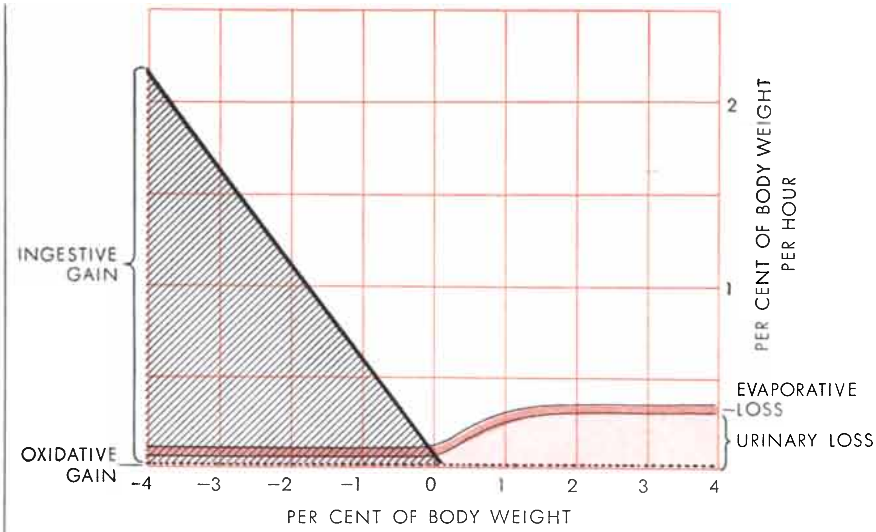


HOW WATER BALANCE IS MAINTAINED is shown in this diagram devised by E. F. Adolph of the University of Rochester. When the body is dehydrated (*left of zero water load*), gain by drinking (*hatched*) exceeds water loss via urine excretion (*light color*) and evaporation from lungs and skin (*dark color*). When there is an excess of water in the body (*right of zero water load*), urine output increases and drinking stops so that water loss exceeds the small gain from the oxidation of the hydrogen of foodstuff (*broken line*). These regulatory processes compensate for deficits or excesses of water and tend to bring the body to a zero water load, where the curves of total gain (*black line*) and loss (*colored area*) cross.

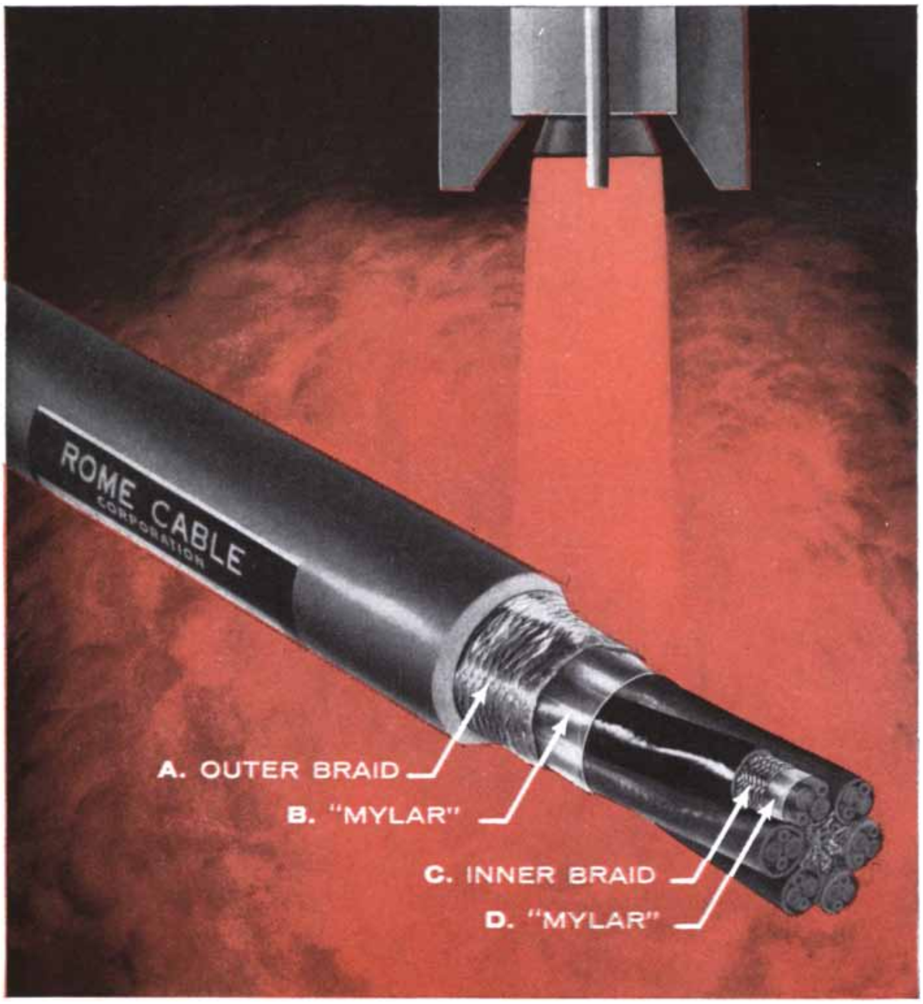
the loss of water by evaporation through the skin and lungs is added to that lost in the urine. Thirst is absent at such a time, so that water is not drunk. In both water-excess and water-deficiency the rate at which the fluid content returns to normal is nearly proportional to the amount of water which the body must lose or gain. To obtain a concrete idea of how gain and loss factors operate in the water balance of the human body, the reader may consult the illustration on the next page.

It is remarkably difficult for a human being voluntarily to achieve a large change in his body water. Ordinarily a man becomes thirsty when he has lost 1 per cent of his normal water content, and will take steps to restore the deficiency. If circumstances enforce increasing water losses, the gentle tickle of thirst becomes a burning discomfort which seems to increase without limit [see "Thirst," by A. V. Wolf; Scientific American, January, 1956]. Shortly before dehydration results in death, however, thirst abates.

D. J. Larrey, surgeon-in-chief of Napoleon's army in Egypt and Syria, described this paradoxical phenomenon in his account of how in 1798 the French crossed part of the Libyan Desert without food or water. Broiled by the sun as they crossed a fearsome terrain, the most vigorous soldiers suffered excruciating thirst. "Called too late for some of them," wrote Larrey, "my help was useless and they died as if snuffed out. This death seemed to me sweet and peaceful; as one of them told me in his last living moment, he experienced an inexpressible comfort. . . ."

So much for water-lack. The reverse condition of water-excess provokes difficulties hardly less formidable. The man who sets out to drink a considerable quantity of water must overcome a growing disgust for it; indeed, enforced drinking (the "water cure") was early recognized as a method of torture. The drinker's kidneys tend to eliminate the water in a flood of urine; but if he persists in his guzzling, perhaps because of some pathological compulsion, a peculiar condition known as "water intoxication" may develop. Headache, nausea, weakness, confusion, lack of coordination, staggering gait, tremors and muscle twitches, shouting delirium, convulsions, coma and even death supervene. These symptoms are produced not primarily by the water, but by a relative lack of salt, for the concentration of salt in the body fluids diminishes as its water volume increases. Taking salt thus relieves the disease of water intoxication, just as drinking water relieves the disease of thirst created by an increase in salt intake.

Related to water intoxication is the "heat cramp" which afflicts coal miners, stokers, steel workers and others who labor in a hot environment, sweat profusely and then unfortunately drink water too copiously. Heat cramp consists of a localized muscular contraction



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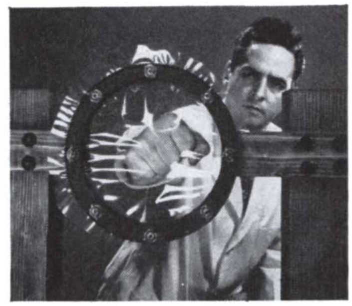

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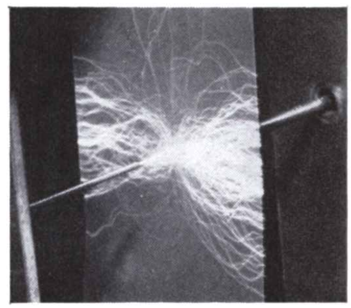

HIGH DIELECTRIC STRENGTH. Average of 4,000 volts per mil . . . average power factor of 0.003 at 60 cycles.

Rome Cable reports . . .

Du Pont Mylar® helps eliminate reject problem in manufacture of cable for "Titan" ICBM

PROBLEM: In designing its instrumentation cable for the "Titan" ICBM project, Rome Cable Corporation wanted a thin, abrasion-resistant tape to protect the insulated conductors from possible puncture by loose strands of the tin-copper braid (See C in illustration). They were also searching for a thin, heat-resistant core binder tape to prevent possible puncture from the outer braid (See A) during extrusion of the cable jacket.

SOLUTION: A tape of Du Pont "Mylar" polyester film for both applications (See B&D). Reason: "Mylar" has the desired balance of mechanical and electrical properties . . . it's tough, abrasion- and puncture-resistant, even in thin gauges. "Mylar" has a high melting point . . . runs well on existing machinery.

RESULTS: The two tapes of "Mylar" eliminated shorted cables due to puncture from loose strands of metal. Solving this problem has helped Rome Cable stabilize production, save money on time and materials and produce a cable that assures better performance and greater reliability in the ICBM.

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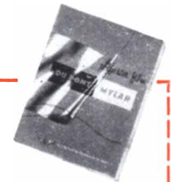

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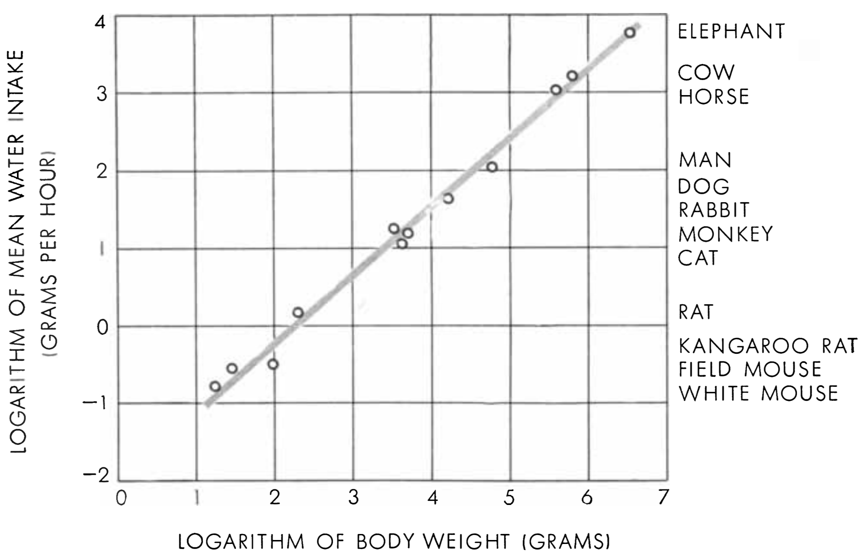
which produces a hard knot. It affects only a few bundles of muscle at a time; never an entire mass of muscle. But as one group of muscle bundles relaxes, an adjacent group contracts; the cramp thus wanders painfully through the muscle. If a man gets an attack while lifting a heavy weight, cramp may occur in the arms, legs or abdomen. In severe attacks it has taken half a dozen men to hold down the victim and straighten out the affected limb.

Heat cramp tends to occur in contracted muscles, in which the cells contain more than the normal amount of water, and in which the salt content of the extracellular fluid is low. Since sweating causes the loss of salt, a man drinking water in moderate amounts, but without ingesting salt, may dilute the salts of his body fluids somewhat as in water intoxication. Even if he drinks no more than he needs to restore his normal water content, relatively speaking he overdrinks; his body fluids become as dilute in salt as they would if he had been drinking water in excess. A sweating man usually practices "voluntary dehydration"; usually he unconsciously refrains from drinking enough to completely replace his lost fluids until he has had an opportunity to regain salt at mealtime. This voluntary dehydration is a physiologically charted course between the Scylla of water deficit and the Charybdis of abnormally low salt concentration in the body fluids. As in the case of water intoxication, the administration of salt rapidly relieves or prevents heat cramp. The ritual of taking salt tablets in hot weather, however, is for most people usually unnecessary.

A comparison of the water requirements of various animals reveals some interesting, though tantalizingly obscure, relationships. In animals ranging in weight from a fraction of an ounce (for a mouse) to several tons (for an elephant), the logarithm of the average rate of water intake plotted against the logarithm of the body weight results in a straight line [*see illustration below*]. This indicates that water intake in dissimilar animals varies according to the .88 power of body weight. An amazing assortment of biological variables (*e.g.*, heart rate, urine flow, blood volume, nitrogen excretion) is similarly governed by a characteristic power of the body weight.

Also intriguing is the time required for an organism to turn over a weight of water equal to its body weight. To achieve this feat a microscopic freshwater amoeba requires seven hours, a mouse five days, a dog or a cow two weeks, a man or a horse four weeks, and a camel three months. The animals having the lowest known requirement for water per unit of surface area are the meal-worm larva and the tortoise. The meal worm turns over its weight in water in five months, and the tortoise does so in a year; the rate in both cases is .0003 gram per square centimeter per hour. A cactus, as might be expected, outdoes all animals, and can live for 29 years on an amount of water which weighs only as much as it does.



WATER INTAKE of mammals from mouse to elephant shows a constant relationship to weight. When the logarithms of weight and water intake are plotted, the values fall close to a straight line whose slope indicates that water intake varies as the .88 power of the weight.

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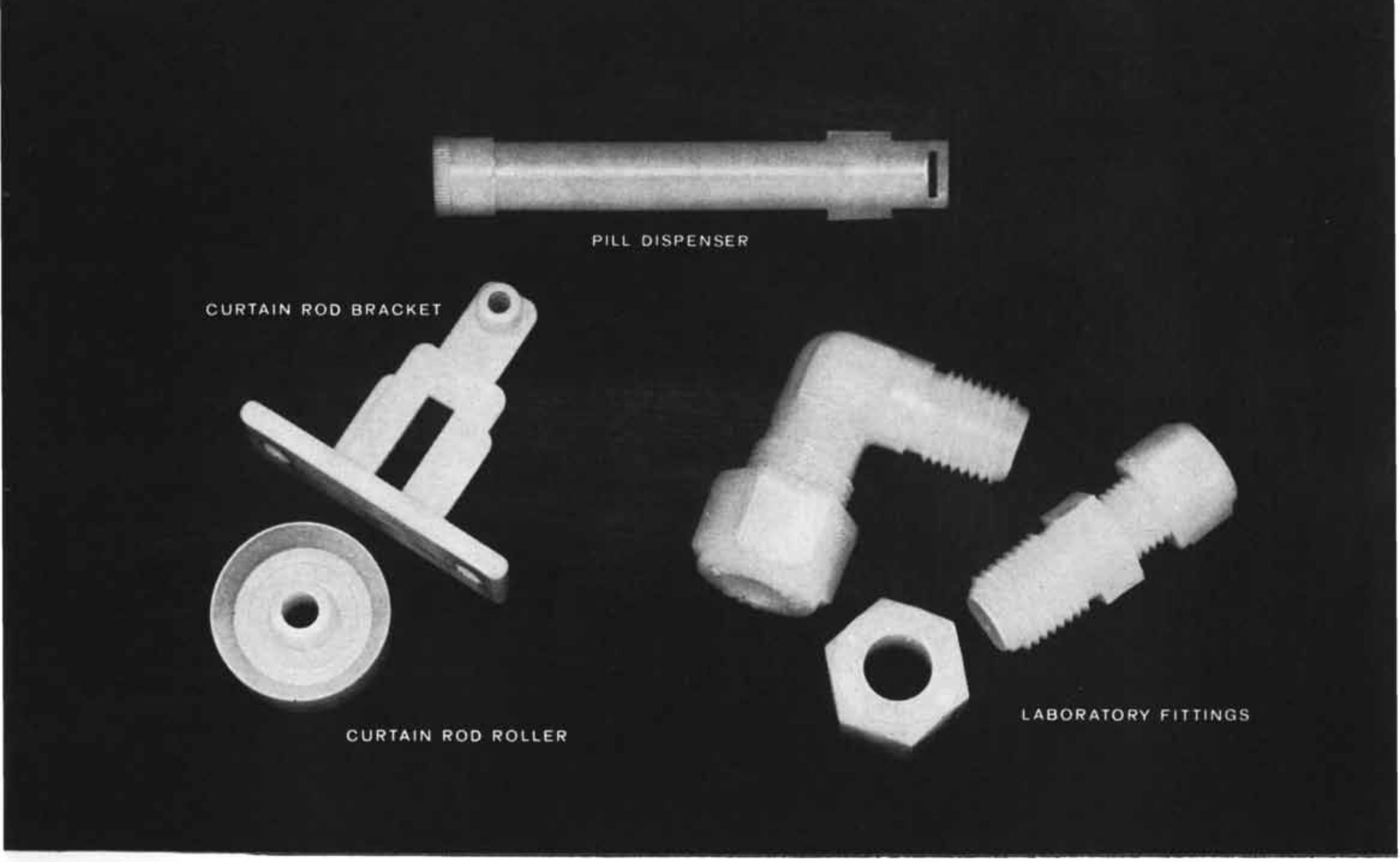

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Properties of Fortiflex "A" Related to Melt Index

PHYSICAL PROPERTIES	ASTM METHOD	UNITS	FORTIFLEX RESINS A-20	A-70	A-250	A-500
Melt Index	D-1238-52T	—	0.2	0.7	2.5	5.0
Heat Distortion Temp. (66 psi)	D-648-45T	°F.	185	185	180	180
Brittleness Temp.	D-764-52T	°F.	—200	—180	—160	—100
Impact Strength, izod (⅛" x ½" injection-molded bars)	D-256-54T	ft. lb./in. notch	23	18	13	3
Tensile Strength, Max., 0.2 in./min.	D-638-52T	psi	3700	3600	3500	3300
Elongation, First Tensile Yield Point	D-638-52T	%	25	25	25	25

Properties of Fortiflex "A" Not Affected by Melt Index

PHYSICAL PROPERTIES	ASTM METHOD	UNITS	VALUE
Density		g/cc.	0.96
Refractive Index	D-542-50	n_D^{25}	1.54
Hardness, Shore D	D-676-49 T		65
Stiffness	D-747-50	psi	150,000
Water Absorption (⅛" specimen, 24 hr. immersion @ room temp.)	D-570-54T	%, wgt. gain	<0.01
Flammability	D-635-44	in./min.	1.0
*Mold Shrinkage, length		in./in.	0.03 to 0.05
width		in./in.	0.02 to 0.04

*Measured on injection molded tensile bar. Mold shrinkage depends on part design and molding conditions.

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CREATING A NEW WORLD WITH ELECTRONICS . . . NO. 8

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MATHEMATICAL GAMES

How rectangles, including squares, can be divided into squares of unequal size

by Martin Gardner

Can a square be subdivided into smaller squares of which no two are alike? This enormously difficult problem was long thought to be unsolvable, but now it has been defeated by translating it into electrical-network theory and back into plane geometry. Here William T. Tutte, assistant professor of mathematics at the University of Toronto, presents a fascinating account of how he and three fellow students at the University of Cambridge finally squared the square.

"This is the story of a mathematical research conducted by four students of Trinity College, Cambridge, in the years 1936-38. One was the author of this article. Another was C. A. B. Smith, now a statistical geneticist at University College London. He is also well known as a writer on the theory of games and the counterfeit-coin problem. Another was Arthur H. Stone, now researching recondite regions of point-set topology. He is one of the inventors of the flexagons described in an earlier issue of *Scientific American*. The fourth was R. L. Brooks. He has now left the academic world for the British Civil Service. But he retains an enthusiasm for mathematical recreations, and an important theorem in the theory of graph colorings bears his name. These four students referred to themselves with characteristic modesty as the 'Important Members' of the Trinity Mathematical Society.

"In 1936 there were a few references in the literature on the problem of cutting up a rectangle into squares of unequal size. Thus it was known that a rectangle of which one side was 32 units long and the other 33 units could be dissected into nine squares with sides of 1, 4, 7, 8, 9, 10, 14, 15 and 18 units (*Figure 1*). Stone was intrigued by a statement in Henry Ernest Dudeney's *The Canterbury Puzzles* which seemed to imply that it was impossible to cut up a *square* into unequal smaller squares. He tried to prove the impossibility, without success. He did, however, discover a dissection of the rectangle of sides 176 and 177 into 11 squares.

"This partial success fired the imagination of Stone and his three friends, and soon they were spending much time on the problem. The construction of 'perfect rectangles' (the term used by the group to denote any rectangle cut up into unequal squares) proved to be quite easy. The method used was as follows. First we sketch a rectangle cut up into rectangles, as in Figure 2. We then think of the diagram as a bad drawing of a squared rectangle in which the small rectangles are really squares, and we work out by elementary algebra what the relative sizes of the squares must be on this assumption. Thus in Figure 2 we denote the sides of two adjacent small squares by x and y. We can say that the side of the square immediately below them is x plus y, and then that the side of the square next on the left is x plus $2y$, and so on. Proceeding in this way we get the formulas shown in Figure 2 for the sides of the 11 small squares. These formulas make the squares fit together exactly except along the one segment AB. But we can make them fit on AB too by choosing x and y to satisfy the equation: $(3x + y) + (3x - 3y) = (14y - 3x)$. This reduces to $16y = 9x$. Accordingly we write down $x = 16$ and $y = 9$. This gives the perfect rectangle of Figure 3, which is the one first found by Stone.

"Sometimes this method gave negative values for the sides of small squares. It was found, however, that such negative squares could always be converted into positive ones by minor modifications of the original diagram. In some of the more complicated diagrams it proved necessary to start with three unknown squares of sides x, y and z, and to solve two linear equations instead of one. Sometimes the squared rectangles obtained proved not to be perfect, and the attempt was considered a failure. Fortunately this did not happen very often. We recorded only 'simple' perfect rectangles, that is, perfect rectangles containing no smaller perfect rectangles.

"In this first stage of the research large numbers of perfect rectangles were constructed, their 'order' or number of component squares ranging from nine to 26. In the final form of each rectangle the sides of the squares were represented as integers without a common factor. Of course we all hoped that if we constructed enough perfect rectangles by this method we would eventually obtain one which was a perfect square. But as the list of perfect rectangles lengthened, this hope faded.

"In the next stage of the research we abandoned experiment for theory. We tried to represent squared rectangles by diagrams of different kinds. The last of these diagrams, introduced by Smith, suddenly made our problem part of the theory of electrical networks.

"Figure 4 shows a perfect rectangle together with its Smith diagram. Each horizontal line in the rectangle is represented by a dot, or 'terminal,' in the diagram. In the figure the terminal is placed so that it lies on a continuation to the right of its corresponding horizontal line. Any square in the rectangle is bounded above and below by two of the horizontal lines. Accordingly it is represented by a line, or 'wire,' that joins the two corresponding terminals. We imagine that an electric current can flow in each wire. The magnitude of the current is numerically equal to the side of the corresponding square, and its direction is from the terminal representing the upper horizontal line to the terminal representing the lower one.

"Surprisingly enough, the electric currents assigned by the above rule do obey Kirchhoff's laws for the flow of current in a network, provided we take each wire to be of unit resistance. Kirchhoff's first law states that, except at the poles, the algebraic sum of the currents flowing to any terminal is zero. This corresponds to the fact that the sum of the sides of the squares bounded below by a given horizontal line is equal to the sum of the sides of the squares bounded above the same line, provided of course that the line is not one of the horizontal sides of the rectangle. The second law says that the algebraic sum of the currents in any circuit is zero. This is equivalent to saying that when we describe the circuit, the net corresponding change of level in the rectangle must be zero.

"The total current entering the network at the positive pole, or leaving it at the negative pole, is evidently equal to the horizontal side of the rectangle, and

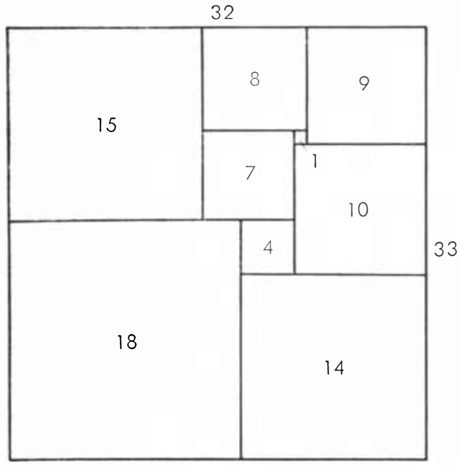


Figure 1

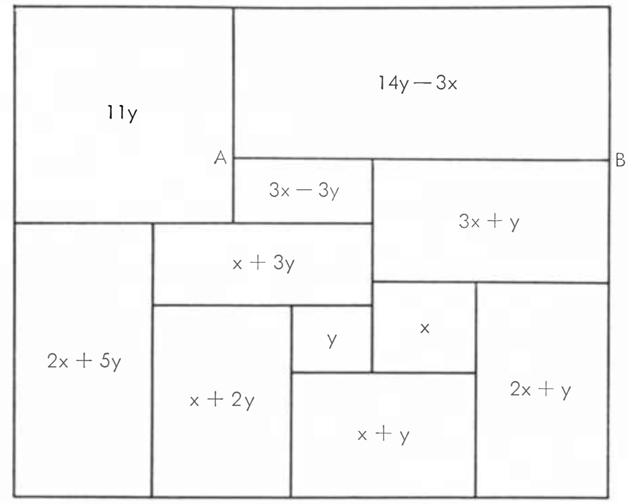


Figure 2

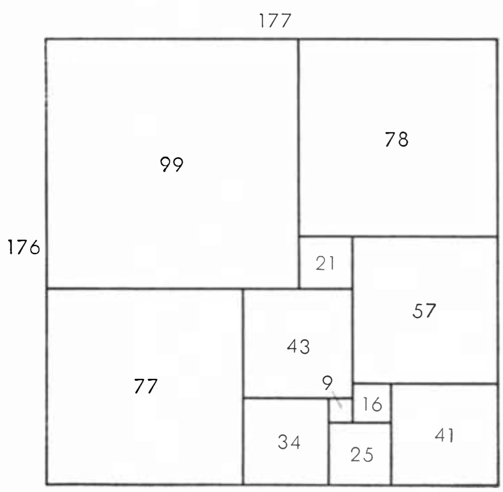


Figure 3

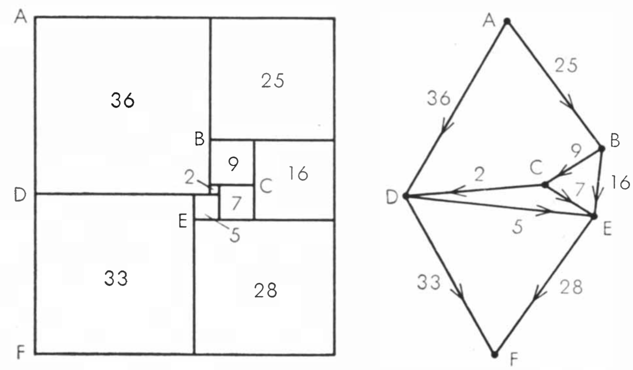


Figure 4

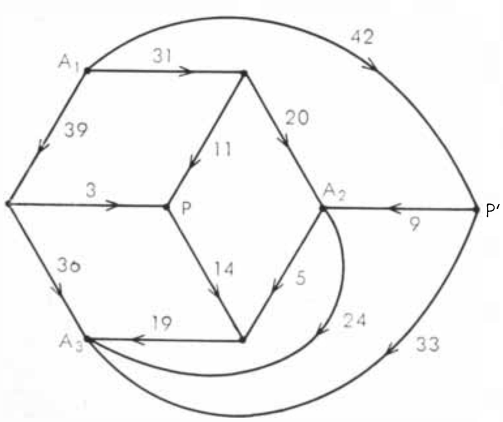


Figure 5

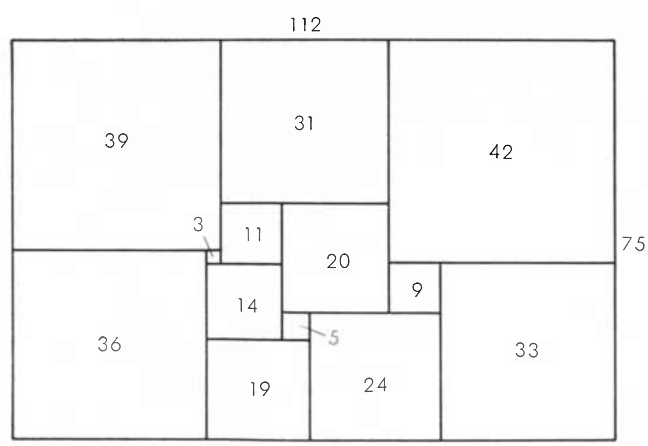


Figure 6

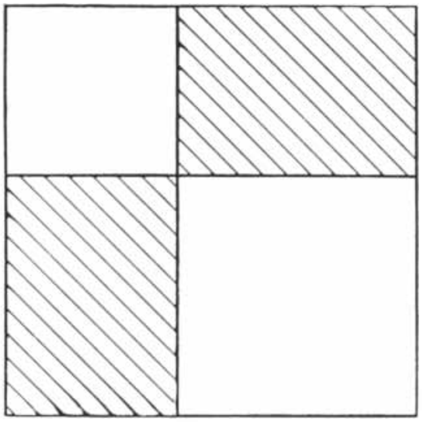


Figure 7

the potential difference between the two poles is equal to the vertical side.

"The discovery of this electrical analogy was important to us because it linked our problem with an established theory. We could now borrow from the theory of electrical networks and obtain formulas for the currents in a general Smith diagram and the sizes of the corresponding components squares. The main results of this borrowing can be summarized as follows. With each electrical network there is associated a number calculated from the structure of the network, without any reference to which particular pair of terminals is chosen as poles. We called this number the complexity of the network. If the units of measurement for the corresponding rectangle are chosen so that the horizontal side is equal to the complexity, then the sides of the component squares are all whole numbers. Moreover, the vertical side is equal to the complexity of another network obtained from the first by identifying the two poles.

"The numbers giving the side of the rectangle and its component squares in this system of measurement were respectively called the 'full' sides and the 'full' elements of the rectangle. For some rectangles the full elements have a common factor greater than unity. In such cases, dividing by the common factor gives the 'reduced' sides and elements. It was the reduced sides and elements that had been recorded in our catalog.

"The discovery of the Smith diagram simplified the procedure for producing and classifying simple squared rectangles. It was an easy matter to list all the permissible electrical networks up to 11 wires, and to calculate all the corresponding squared rectangles. We then found that there were no perfect rectangles below the ninth order, and only two of the ninth (*Figures 1 and 4*). There were six simple ones of the 10th order and 22 of the 11th. The catalog then advanced, though more slowly, through the 12th order (67 simple perfect rectangles) and into the 13th.

"It was a pleasing recreation to work out perfect rectangles corresponding to networks with a high degree of symmetry. We considered, for example, the network defined by a cube, with corners for terminals and edges for wires. This failed to yield any perfect rectangles. However, when complicated by a diagonal wire across one face, and flattened into a plane, it gave the Smith diagram of Figure 5 and the corresponding perfect rectangle of Figure 6. This rectangle is especially interesting because its reduced elements are unusually small for the 13th order. The common factor of the full elements is six. Brooks was so pleased with the rectangle that he made a jigsaw puzzle out of it, in which each piece was one of the squares.

"It was at this stage that Brooks's mother made the key discovery of the whole investigation. She tackled Brooks's puzzle and eventually succeeded in putting the pieces together to form a rectangle. But it was not the squared rectangle which Brooks had cut up! The Important Members met in emergency session.

"We had sometimes wondered whether it was possible for two different perfect rectangles to have the same shape. We would have liked to obtain two such rectangles with no common reduced element, and thus to get a perfect square by the construction shown in Figure 7. The hatched regions in this diagram represent the two perfect rectangles. Two unequal squares are added to make the large perfect square. But no rectangles of the same shape had hitherto appeared in our catalog, and we had reluctantly come to believe that the phenomenon was impossible. Mrs. Brooks's discovery renewed our hopes, despite the fact that her rectangles failed in the worst possible way to have no common reduced element.

"There was much excited discussion at the emergency session. Eventually the Important Members calmed down sufficiently to draw the Smith diagrams of the two rectangles. Inspection of these soon made clear the relationship between them.

"The second rectangle is shown in Figure 8, and its Smith diagram in Figure 9. It is evident that the network of Figure 9 can be obtained from that of Figure 5 by placing the terminals P and P' at the same point. As P and P' happen to have the same electrical potential in Figure 5, this operation causes no change in the currents in the individual wires, no change in the total current, and no change in the potential difference between the poles. We thus have

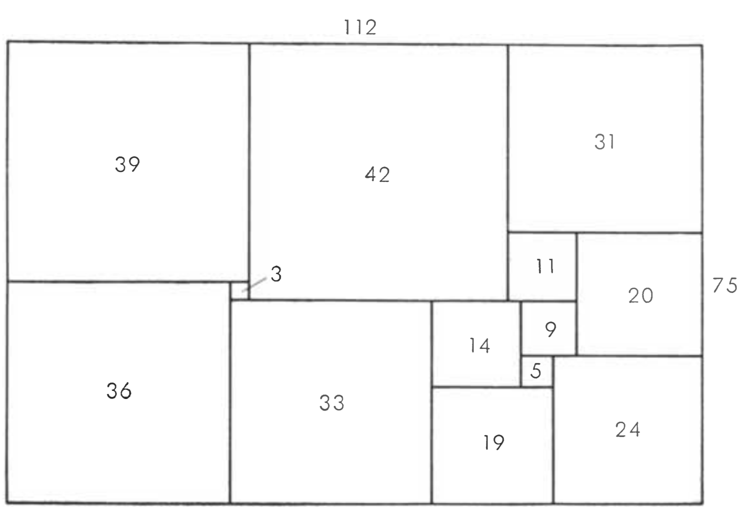


Figure 8

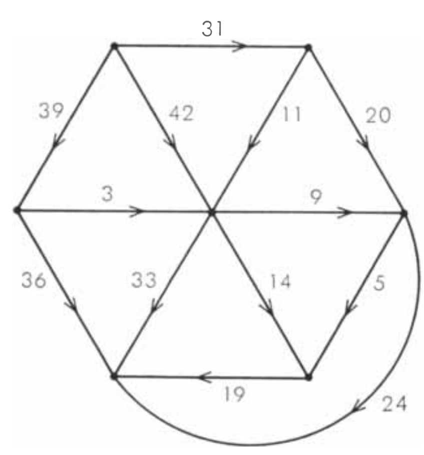
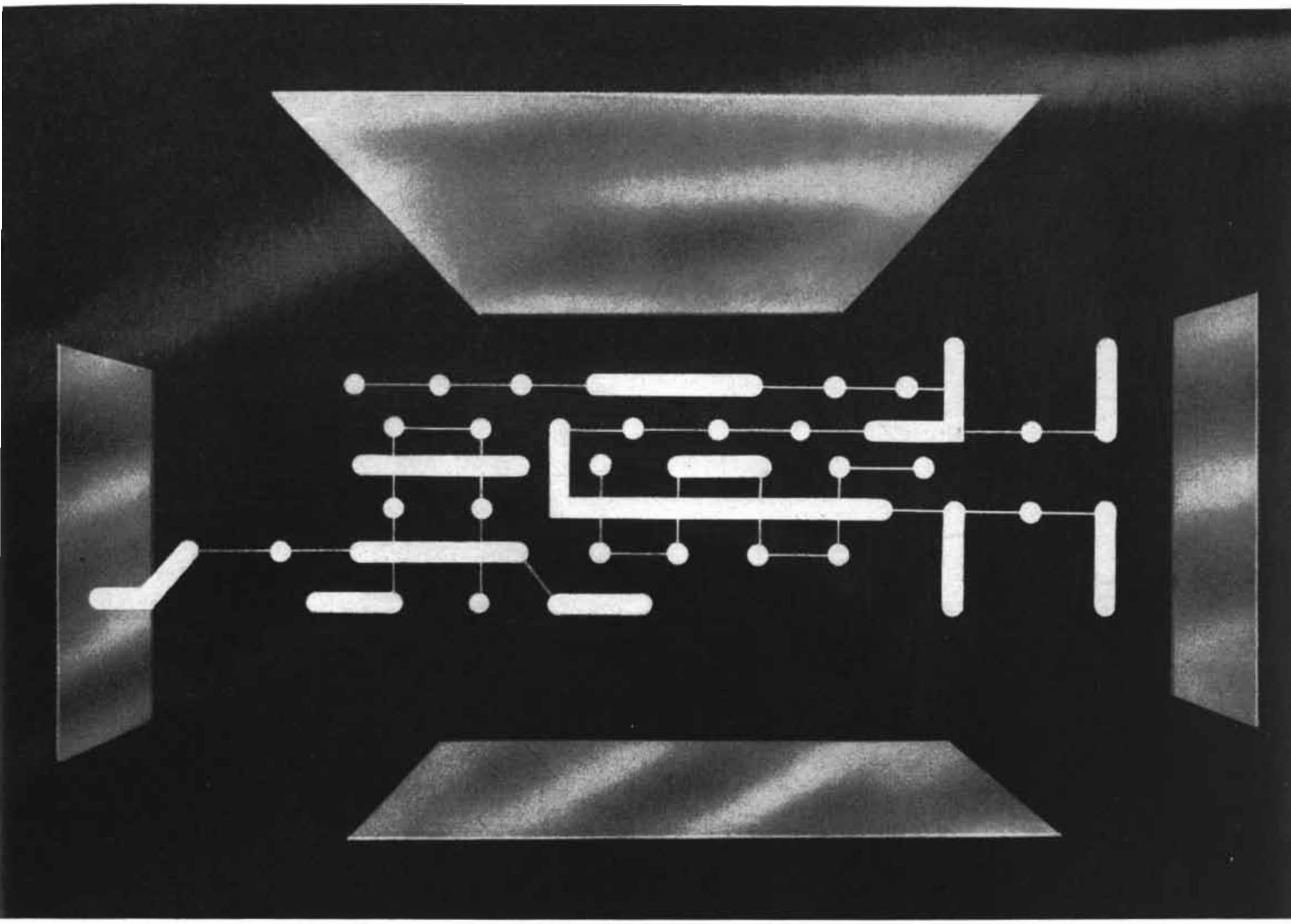


Figure 9



Low temperatures for high-speed circuitry

Certain metals and alloys lose their resistance to electricity at temperatures close to absolute zero. They become "super-conductors." Investigations by Dr. D. R. Young and others at the IBM Yorktown Research Center are directed toward the utilization of this unique property in the development of small-size, high-speed switches with increased logical capacities.

Interestingly, when a "super-conductor" is exposed to certain magnetic fields, it reverts instantly to an ordinary conductor. One experimental switching device that takes advantage of this property has been constructed at IBM. In essence, it is a "sandwich" of glass, tin, silicon monoxide and lead. The device is immersed in liquid helium to bring it close to absolute zero. The tin strip becomes a "super-conductor," so current flows readily through it. When a current is applied to the lead strip it creates a magnetic field. As a result, the tin strip is no longer a "super-conductor" and now has electrical resistance . . . it is "off." Remove the magnetic field and it is "on" again. This then is an "on-off" device, or switch, that is expected to work at speeds much greater than present switch capacities. There are no moving parts to wear out and 1,000 such devices can be mounted on a bit of glass only a few inches square.

In addition to these experiments, the study of matter at very low temperatures is being applied to other areas at IBM. The immediate objective is to apply the results to the development of device formulations which will greatly accelerate arithmetic speed and increase the logical capacity in electronic computers of greatly reduced size.

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International Business Machines Corporation, Dept. 659Y, 590 Madison Avenue, New York 22, New York a simple electrical explanation for the fact that the two rectangles have the same reduced sides and elements.

"But why do P and P' have the same potential in Figure 5? Before the emergency session had broken up it had also obtained an answer to this question. The explanation depends on the fact that the network can be decomposed into three parts meeting only at poles A_1 and A_2 and the terminal A_3. One of these parts consists solely of the wire joining A_2 and A_3. A second part is made up of the three wires meeting at P', and a third is constituted by the remaining nine wires. Now the third part has threefold rotational symmetry, with P as the center of rotation. Moreover, current enters or leaves this part of the network only at A_1, A_2 and A_3, which are equivalent under the symmetry. This is enough to insure that if any potentials whatever are applied to A_1, A_2 and A_3, the potential of P will be their average. The same argument applied to the second part of the network shows that the potential of P' must also be the average of the potentials of A_1, A_2 and A_3. Hence P and P' have the same potential, whatever potentials are applied to A_1, A_2 and A_3; and in particular they have the same potential when A_1 and A_2 are taken as poles in the complete network and the potential of A_3 is fixed by Kirchhoff's laws.

"The next advance was accidentally made by the present writer. We had just seen Mrs. Brooks's discovery completely explained in terms of a simple property of symmetrical networks. It seemed to me that it should be possible to use this property to construct other examples of pairs of perfect rectangles with the same reduced elements. The obvious thing to do was to replace the third part of the network in Figure 5 by another network having threefold rotational symmetry about a central terminal. But this could be done only under severe limitations which should now be explained.

"It can be shown that the Smith diagram of a squared rectangle is always planar, that is, it can be drawn in a plane with no crossing wires. Moreover, the drawing can always be made so that no circuit separates the two poles. There is also a converse theorem which states that if an electrical network of unit resistances can be drawn in a plane in this way, then it is the Smith diagram of some squared rectangle.

"My problem was to replace the third part of the network shown in Figure 5 by a new symmetrical network with center P, in such a way that the complete network would not only be planar, but remain planar when P and P' were coalesced. After a few trials I found two closely related networks satisfying these conditions (*Figures 10 and 11*). As was expected, each diagram allowed of the coalescence of P and P', and so gave rise to two squared rectangles with the same reduced elements. But all four rectangles had the same reduced sides, and this result was quite unexpected.

"Essentially the new discovery was that the rectangles corresponding to Figures 10 and 11 have the same shape, although their reduced elements are not all the same. A simple theoretical explanation of this was soon found. The two networks have the same structure, apart from the choice of poles, and therefore the rectangles have the same full horizontal side. Moreover, the networks remain identical when poles are coalesced, and therefore the two rectangles have the same vertical side. We felt, however, that this explanation did not probe deep enough, since it made no reference to rotational symmetry.

"We agreed to refer to the new phenomenon as 'rotor-stator' equivalence. It was always associated with a network which could be decomposed into two parts, the 'rotor' and the 'stator,' with

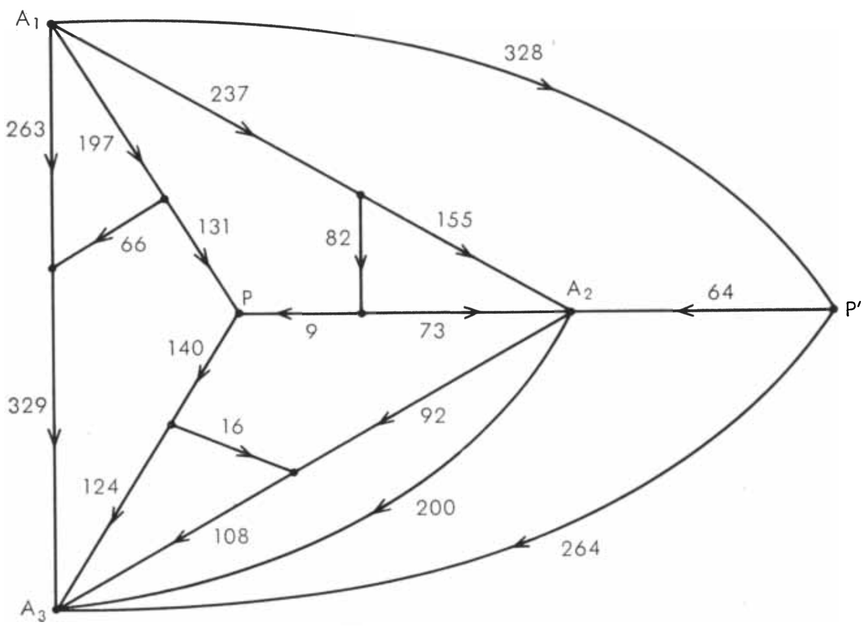


Figure 10

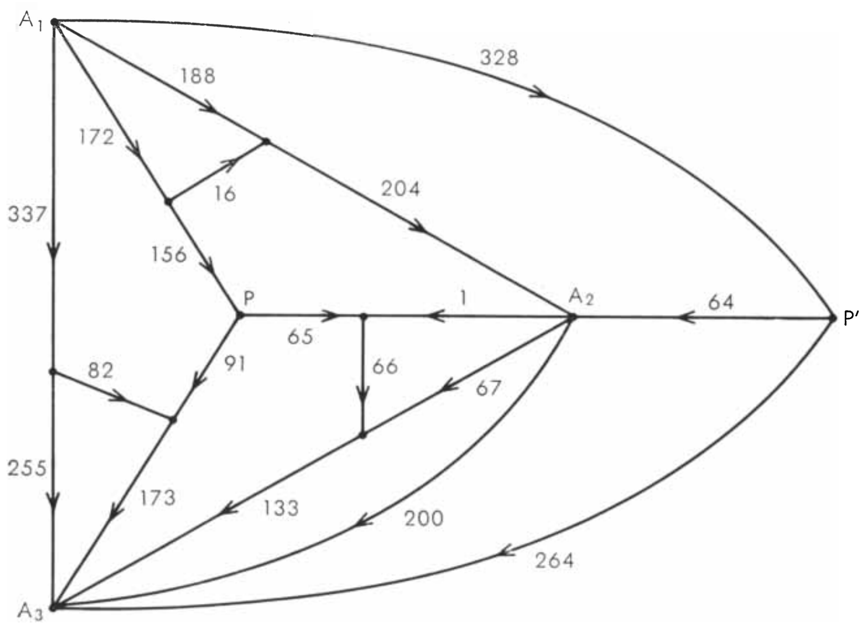


Figure 11

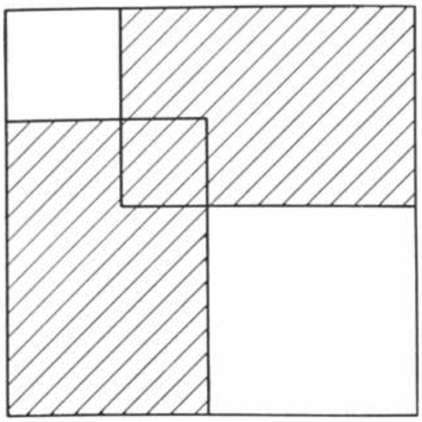


Figure 12

the following properties. The rotor had rotational symmetry, the terminals common to the rotor and stator were all equivalent under the symmetry of the rotor, and the poles were terminals of the stator. In Figure 10, for example, the stator is made up of the three wires joining P' to A_1, A_2 and A_3, and the wire linking A_2 with A_3. A second network could then be obtained by an operation called 'reversing' the rotor. With a properly drawn figure this could be explained as a reflection of the rotor in a straight line passing through its center. Thus starting with Figure 10 we can reflect the rotor in the line PA_3, and so obtain the network of Figure 11.

"After studying a few examples of rotor-stator equivalence the researchers convinced themselves that reversing the rotor made no difference to the full sides of the rectangle, and no difference to the currents in the wires of the stator. But the currents in the rotor might change. We were able to obtain satisfactory proofs of these results only at a much later stage.

"A tantalizing question now arose. What was the least possible number of common elements in a rotor-stator pair of perfect rectangles? Those of Figures 10 and 11 had seven common elements, three of which corresponded to currents in the rotor. The same rotor with a stator consisting of a single wire A_2A_3 and the extra terminal A_1 gave two perfect rectangles of the 16th order with four common elements. Using a one-wire stator there seemed no theoretical reason why we should not obtain a pair of perfect rectangles having only one element, corresponding to the stator, in common. But we saw that if we could do this we could also obtain a perfect square. For with the rotors of threefold symmetry which we were studying, a one-wire stator always respresented a corner element of each corresponding rectangle. From two perfect rectangles with only a corner element in common we could expect to obtain a perfect square by the construction illustrated in Figure 12. Here the hatched regions represent the two rectangles. The square in which they overlap is the common corner element.

"Naturally we got to work at once calculating rotor-stator pairs. So it came to pass that Smith and Stone sat down one day to compute one complicated pair while Brooks, unknown to them, worked on another in a different part of the College. After some hours Smith and Stone burst into Brooks's room crying, 'We have a perfect square!', to which Brooks replied, 'So have I.' Both squares were of the 69th order. But Brooks went on to experiment with simpler rotors, and so obtained a perfect square of the 39th order.

"There are three more episodes worth mentioning in the history of the perfect square, though each may seem like an anticlimax. To begin with we kept adding to the list of simple perfect rectangles of the 13th order. One day we found that two of these rectangles had the same shape and no common element. They gave rise to a perfect square of the 28th order by the construction of Figure 7. Later we found a 13th-order perfect rectangle which could be combined with one of the 12th order and one extra component square to give a perfect square of the 26th order. If the merit of a perfect square is measured by the smallness of its order, then the empirical method of cataloging perfect rectangles had proved superior to our beautiful theoretical method.

"Other researchers have used the empirical method with spectacular results. R. Sprague of Berlin fitted a number of perfect rectangles together in a most ingenious way to produce a perfect square of the 55th order. This was the first perfect square to be published (1939). More recently T. H. Willcocks of Bristol obtained a perfect square of the 24th order (*Figure 13*). This still holds the low-order record.

"In case any reader would like to work on perfect rectangles, here are two unsolved problems. What is the smallest possible order for a perfect square? Is there a simple perfect rectangle twice as long as it is high? Simple perfect squares have already been obtained by extensions of the theoretical method."

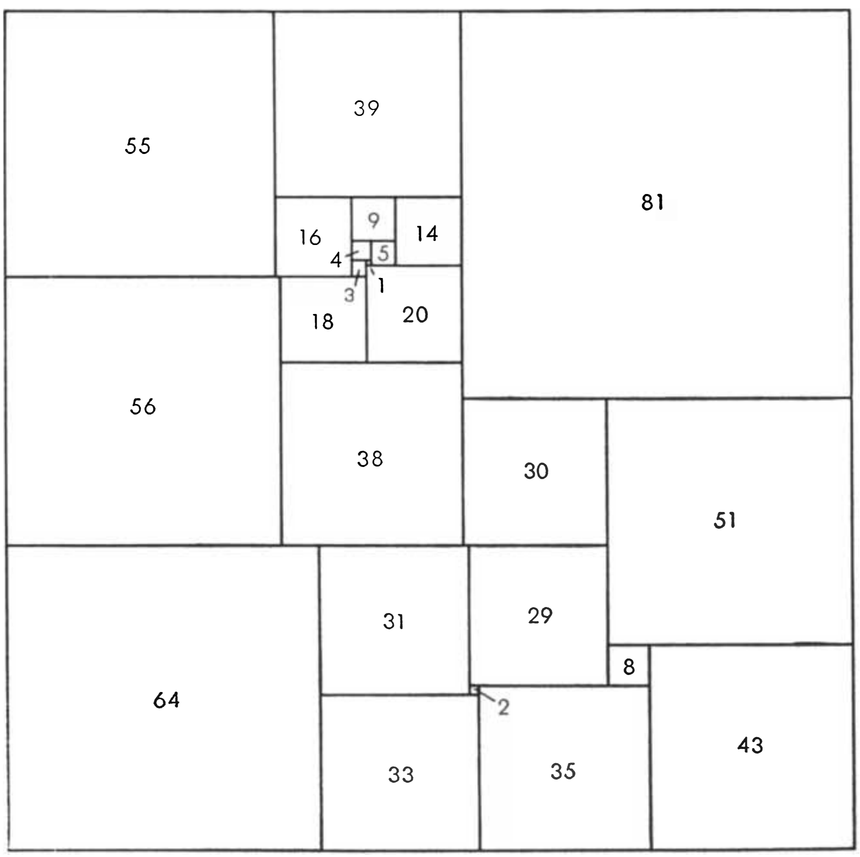


Figure 13

Last month's figure-tracing puzzle can be solved with as few as 13 corner turns. Start at the second node from the left on the large triangle. Move up and to the right as far as possible, then left, then down and right to the base of the triangle, up and right, left as far as possible, down and right, right to the corner of the large triangle, up to the top of the triangle, down to the triangle's left corner, all the way around the circle, right to the third node on the triangle's base, up and left as far as possible, right as far as possible, then down and left to the base.

The cord-and-ring puzzle is solved as follows. Loosen the center loop enough so that the ring can be pushed up through it. Hold the ring against the front side of the panel while you seize the double cord where it emerges from the center hole. Pull the double cord toward you. This will drag a double loop out of the central hole. Pass the ring through this double loop. Now reach behind the panel and pull the double loop back through the hole so that the cord is restored to starting position. It only remains to slide the ring down through the center loop and the puzzle is solved.

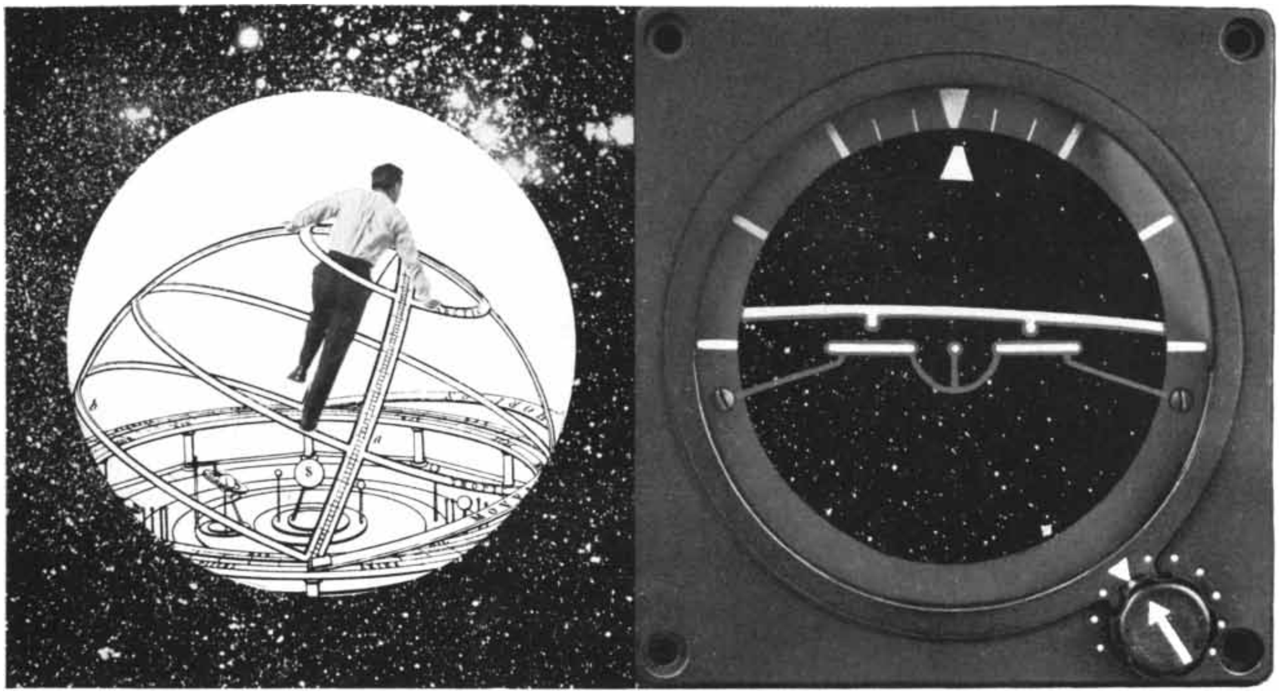
Many readers have pointed out an error in the answer in September to problem No. 2. Three airplanes are quite sufficient to insure the flight of one plane around the world. There are many ways this can be done, but the following seems to be the most efficient. It uses only five tanks of fuel, allows the pilots of two planes sufficient time for a cup of coffee and a sandwich before refueling at the base, and there is a pleasing symmetry in the procedure.

Planes A, B and C take off together. After going 1/8 of the distance, C transfers 1/4 tank to A and 1/4 to B. This leaves C with 1/4 tank; just enough to get back home.

Planes A and B continue another 1/8 of the way, then B transfers 1/4 tank to A. B now has 1/2 tank left, which is sufficient to get him back to the base where he arrives with an empty tank.

Plane A, with a full tank, continues until it runs out of fuel 1/4 of the way from the base. It is met by C which has been refueled at the base. C transfers 1/4 tank to A, and both planes head for home.

The two planes run out of fuel 1/8 of the way from the base, where they are met by refueled plane B. Plane B transfers 1/4 tank to each of the other two planes. The three planes now have just enough fuel to reach the base with empty tanks.



THE AMATEUR SCIENTIST

About a remarkably simple device to attain low temperatures, and various other matters

Conducted by C. L. Stong

Shortly after the end of World War II word came to the U. S. that the Germans had developed a remarkably simple device with which one could reach temperatures as low as the freezing point of mercury. The device, which was said to consist only of an air compressor and three pipes, immediately attracted the interest of amateurs who had dreamed of performing experiments requiring moderately low temperatures. The details of construction were not available, but it was reported that the device had in effect realized "Maxwell's demon," a fanciful means of separating heat from cold without work.

Among those intrigued by the demon's alleged capture was George O. Smith of Highlands, N.J. Smith writes: "The 19th-century British physicist James Clerk Maxwell made many deep contributions to physics, and among the most significant was his law of random distribution. Considering the case of a closed box containing a gas, Maxwell started off by saying that the temperature of the gas was due to the motion of the individual gas molecules within the box. But since the box was standing still, it stood to reason that the summation of the velocity and direction of the individual gas molecules must come to zero. In essence Maxwell's law of random distribution says that for every gas molecule headed east at 20 miles per hour, there must be another headed west at the same speed. Furthermore, if the heat of the gas indicates that the average velocity of the molecules is 20 miles per hour, the number of molecules moving slower than this speed must be equaled by the number of molecules moving faster.

"After a serious analysis of the consequences of his law, Maxwell permitted himself a touch of humor. He suggested that there was a statistical probability that, at some time in the future, all the molecules in a box of gas or a glass of hot water might be moving in the same direction. This would cause the water to rise out of the glass. Next Maxwell suggested that a system of drawing both hot and cold water out of a single pipe might be devised if we could capture a small demon and train him to open and close a tiny valve. The demon would open the valve only when a fast molecule approached it, and close the valve against slow molecules. The water coming out of the valve would thus be hot. To produce a stream of cold water the demon would open the valve only for slow molecules.

"Maxwell's demon would circumvent the law of thermodynamics which says in essence: 'You can't get something for nothing.' That is to say, one cannot separate cold water from hot without doing work. Thus when physicists heard that the Germans had developed a device which could achieve low temperatures by utilizing Maxwell's demon, they were intrigued, though obviously skeptical. One physicist, Robert M. Milton, investigated the matter at first hand for the U. S. Navy.

"Milton discovered that the device was most ingenious, though not quite as miraculous as had been rumored. It consists of a T-shaped assembly of pipe joined by a novel fitting, as depicted in the accompanying illustration [*next page*]. When compressed air is admitted to the 'leg' of the T, hot air comes out of one arm of the T and cold air out of the other arm! Obviously, however, work must be done to compress the air.

"The origin of the device is obscure. The principle is said to have been discovered by a Frenchman who left some early experimental models in the path of the German Army when France was occupied. These were turned over to a German physicist named Rudolf Hilsch, who was working on low-temperature refrigerating devices for the German war effort. Hilsch made some improvements on the Frenchman's design, but found that it was no more efficient than conventional methods of refrigeration in achieving fairly low temperatures. Subsequently the device became known as the Hilsch tube.

"The Hilsch tube in the illustration is constructed as follows. The horizontal arm of the T-shaped fitting contains a specially machined piece, the outside of which fits inside the arm. The inside of the piece, however, has a cross section which is spiral with respect to the outside. In the 'step' of the spiral is a small opening which is connected to the leg of the T. Thus air admitted to the leg comes out of the opening and spins around the one-turn spiral. The 'hot' pipe is about 14 inches long and has an inside diameter of half an inch. The far end of this pipe is fitted with a stopcock which can be used to control the pressure in the system. The 'cold' pipe is about four inches long and also has an inside diameter of half an inch. The end of the pipe which butts up against the spiral piece is fitted with a washer, the central hole of which is about a quarter of an inch in diameter. Washers with larger or smaller holes can also be inserted to adjust the system.

"Three factors determine the performance of the Hilsch tube: the setting of the stopcock, the pressure at which air is admitted to the nozzle, and the size of the hole in the washer. For each value of air pressure and washer opening there is a setting of the stopcock which results in a maximum difference in the temperature of the hot and cold pipes. When the device is properly adjusted, the hot pipe will deliver air at about 100 degrees Fahrenheit and the cold pipe air at about −70 degrees (a temperature substantially below the freezing point of mercury and approaching that of 'dry ice'). When the tube is adjusted for maximum temperature on the hot side, air is delivered at about 350 degrees F.

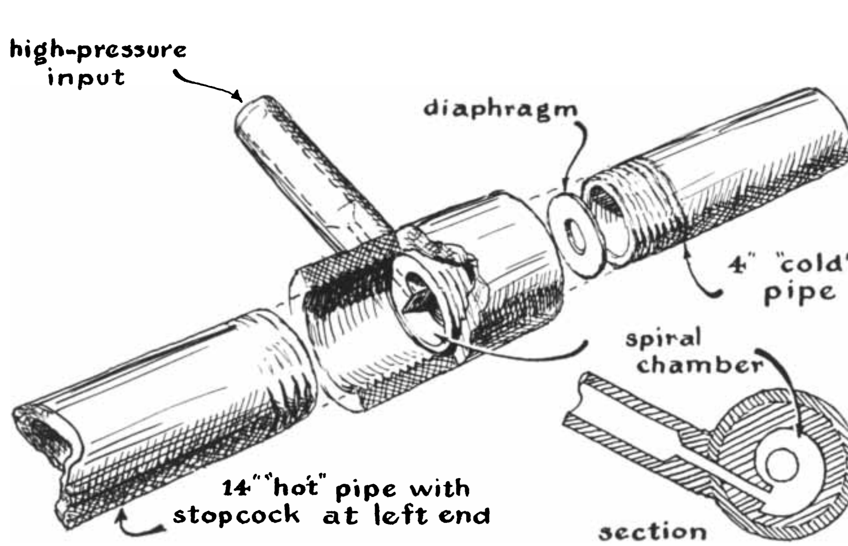
"Despite its impressive performance, the efficiency of the Hilsch tube leaves much to be desired. This perhaps explains why no one has mathematically analyzed its operation. Indeed, there is still disagreement as to how it works.

"According to one explanation, the compressed air shoots around the spiral and forms a high-velocity vortex of air. Molecules of air at the outside of the vortex are slowed by friction with the wall of the spiral. Because these slow-moving molecules are subject to the rules of centrifugal force, they tend to fall toward the center of the vortex. The fast-moving molecules just inside the outer layer of the vortex transfer some of their energy to this layer by bombarding some of its slow-moving molecules and speeding them up. The net result of this process is the accumulation of *slow-moving*, *low-energy* molecules in the center of the whirling mass, and of *high-energy*, *fast-moving* molecules around the outside. In the thermodynamics of gases the terms 'high energy' and 'high velocity' mean 'high temperature.' So the vortex consists of a core of cold air surrounded by a rim of hot air.

"The difference between the temperature of the core and that of the rim is increased by a secondary effect which takes advantage of the fact that the temperature of a given quantity of gas at a given level of thermal energy is higher when the gas is confined in a small space than in a large one; accordingly when gas is allowed to expand, its temperature drops. In the case of the Hilsch tube the action of centrifugal force compresses the hot rim of gas into a compact mass which can escape only by flowing along the inner wall of the 'hot' pipe in a compressed state, because its flow into the cold tube is blocked by the rim of the washer. The amount of the compression is determined by the adjustment of the stopcock at the end of the hot pipe. In contrast, the relatively cold inner core of the vortex, which is also considerably above atmospheric pressure, flows through the hole in the washer and drops to still lower temperature as it expands to atmospheric pressure obtaining inside the cold pipe.

"Apparently the inefficiency of the Hilsch tube as a refrigerating device has barred its commercial application. Nonetheless amateurs who would like to have a means of attaining relatively low temperatures, and who do not have access to a supply of dry ice, may find the tube useful. It will deliver a blast of air 20 times colder than air which has been chilled by permitting it simply to expand through a Venturi tube from a high-pressure source. Thus the Hilsch tube could be used to quick-freeze tissues for microscopy, to chill photomultiplier tubes, or to operate diffusion cloud-chambers. But quite apart from the tube's potential application, what could be more fun than to trap Maxwell's demon and make him explain in detail how he manages to blow hot and cold at the same time?"

In August it was stated in this department that if a rectangle is cut into strips, its area, as found by multiplying its length by its width, is not changed when the strips are pushed over to make a parallelogram. Many readers have asked why this should be so. The explanation is that the strips merely slide over one another and the pushing does not alter the sum of their widths [*see illustration on page 148*]. Some readers were also puzzled by the fact that the resulting parallelogram was shown in the August issue with straight sides instead of the stepped edges depicted here. When the rectangle is sliced into strips of infinitesimal thickness, and has been pushed over, the ends of the strips form a row of mathematical points, which by

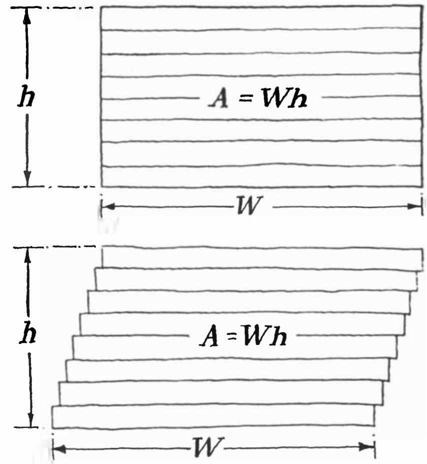


Cutaway views of the Hilsch tube

definition constitutes a straight line. The notion of angular edges changing into straight lines when the number of strips reaches infinity appears to offend common sense, and has baffled generations of students. But once the concept is grasped the battle with the calculus is half won.

Larry Simpson of West Lafayette, Ind., submits a simple method of using the pocket-knife planimeter, also described in the August issue. One first draws a straight reference line from the center of the unknown area. The rounded edge of the big blade, fully opened, is put on the line. The point of the small blade at the other end of the knife is opened to make a right angle with the handle, and is placed on the end of the reference line inside the unknown area. The point of the small blade is used to trace the reference line to its intersection with the boundary, around the boundary, and back to the starting point. This action causes the big blade to take a zigzag path over the paper. It comes to rest at a perpendicular distance from the reference line which depends on the size of the unknown area. The handle of the knife then makes an angle with the reference line. Instead of computing the unknown area in terms of this angle, as described in the August issue, Simpson achieves substantially the same result by multiplying two lengths. "The area," he writes, "is approximately equal to the distance between the point of the little blade and the point at which the big blade touches the paper, multiplied by the perpendicular distance between the reference line and the point at which the big blade touches the paper after the figure has been traced. For relatively small angles between the knife handle and the reference line the error introduced by this additional approximation is small enough to neglect."

Most novices who set out to build a telescope select an instrument of the Newtonian type for their first project because of its simplicity and ease of construction. The Newtonian employs only three optical parts: the parabolic objective mirror which brings celestial objects to focus, a small diagonal mirror (or prism) which bends the converging rays at a right angle so the image can be viewed without obstructing the objective, and an eyepiece for examining the image. The performance of all telescopes depends primarily on the quality of the optical parts, particularly of the objective, which should not depart more than a fraction of a wavelength of light from



About the rectangle and the parallelogram

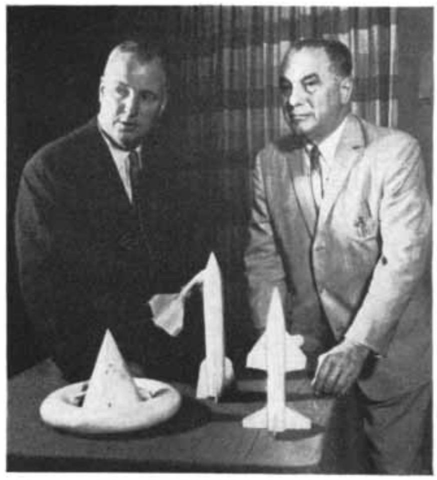
the desired curvature. But performance is also affected by the design of the mounting—the structure which holds the optical elements in alignment and keeps them trained on the stars.

Every part of the mounting contributes to one or more aspects of the instrument's performance: the ease with which a desired star can be brought into the field of view and kept there, the steadiness of the image and its sharpness and freedom from distortion. It is relatively easy to design a mounting to maximize a given aspect of performance, such as steadiness of the image. Steadiness, for example, can be achieved by using heavy parts. But usually a gain in one aspect of performance is bought at some cost to another aspect, such as portability. As a consequence no two amateur instruments are precisely alike.

One disadvantage of nearly all reflecting telescopes is the necessity of supporting the diagonal mirror or prism in the aperture of the telescope. In this position the diagonal blocks part of the light entering the telescope. Moreover, rays which graze the diagonal *en route* to the objective are diffracted, or bent slightly, an effect which detracts from the sharpness of the image. It is possible to tilt the objective mirror somewhat and thus move its focal point outside the aperture without introducing a diagonal mirror into the optical system, but even a small tilt introduces serious distortion. Thus most amateurs use a diagonal, as Isaac Newton did, and support it by an assembly of sheet-metal arms attached to the inner wall of the telescope's main tube. The supporting arms, frequently assembled as a three-legged "spider," are set edgewise with respect to the entering rays to minimize the loss of light.

The spider arrangement leaves much

An invitation
to
senior scientists
and
engineers



A $14,000,000 R & D Center, housing 9 new laboratories, was revealed as core of Republic's $35,000,000 Research and Development Program at recent announcement by Mundy I. Peale, President, and Alexander Kartveli, Vice-President for Research and Development.

....To join Republic Aviation's new $35 million Research and Development Program for spacecraft, missiles and advanced aircraft

In announcing Republic's $35 million research and development program, designed to arrive at major breakthroughs in the aviation industry's transition to astronautics, Mundy I. Peale, President, set the following objectives:

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>
> "...RADICAL NEW FAMILIES OF LONG-RANGE AIR-TO-AIR MISSILES AND AIR-TO-SURFACE BALLISTIC MISSILES FOR STRATEGIC AND TACTICAL AIRCRAFT."
>
> "...VERTICAL TAKE-OFF FIGHTER-BOMBERS, HIGH-MACH FIGHTER-BOMBERS, AND SUPERSONIC TRANSPORTS."

Alexander Kartveli, Vice-President for Research and Development, emphasized that Republic's program "will not duplicate in any way investigatory work currently in progress elsewhere, but will stress novel concepts and new approaches to basic problems of missiles and space technology."

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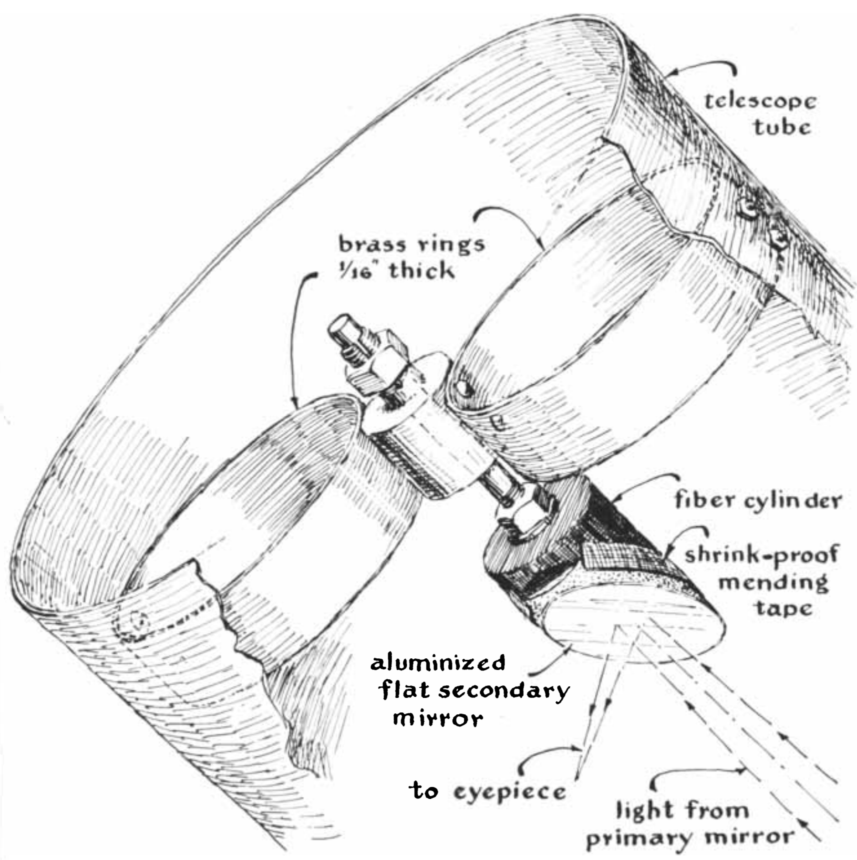
to be desired as a support for the diagonal, however. Any bar which sticks into the aperture introduces diffraction and causes a streak of light to cross all bright star images. Three bars make three streaks. When these are spaced 120 degrees apart, as in the conventional spider, bright stars have six long points. A spider of four bars set at right angles makes only four points, which might seem preferable to six. But the streaks of opposite pairs of bars fall on top of each other and reinforce the total light. Hence the designer must make a choice between six relatively dim streaks and four bright ones.

Under certain circumstances the presence of the streaks can prove useful. Brilliant stars appear as relatively large, diffuse disks on a photographic plate made with the unobstructed refracting telescope, and their centers are difficult to establish accurately. The streaks provide the astronomer with a convenient set of coordinates which aid in locating the star. But more often than not the streaks are a nuisance, as when one wishes to view the faint companion of a bright star such as Sirius or Polaris, and discovers that the position of the telescope is such that the faint star is lost in a bright streak. To solve the difficulty, the French astronomer A. Couder devised a set of specially shaped masks to cover the four bars of his spider. They had the effect of dividing the telescope into four proportionately smaller instruments, each with an unobstructed aperture. This expedient eliminated the streaks, but at some cost in the sharpness of the images. Photographs made with the masks showed star images slightly more diffuse than those made without the masks.

René A. Wurgel of Union City, N.J., submits a diagonal support which also minimizes diffraction effects as well as the amount of light blocked off by the diagonal. "Neither reading the literature on telescope-making nor experimenting on one's own account assures that this is the best way to support a diagonal," he writes, "but in my experience it is clearly superior to the conventional three-arm spider.

"The support substitutes a short brass cylinder sandwiched between a pair of rings for the conventional spider arms [*see illustration on page 150*]. The rings are rigidly attached to the main tube by screws. Another set of screws fastens the inner side of the rings to the cylinder. One end of the cylinder is turned down, split and threaded to clamp a quarter-



A novel diagonal mounting for a small reflecting telescope

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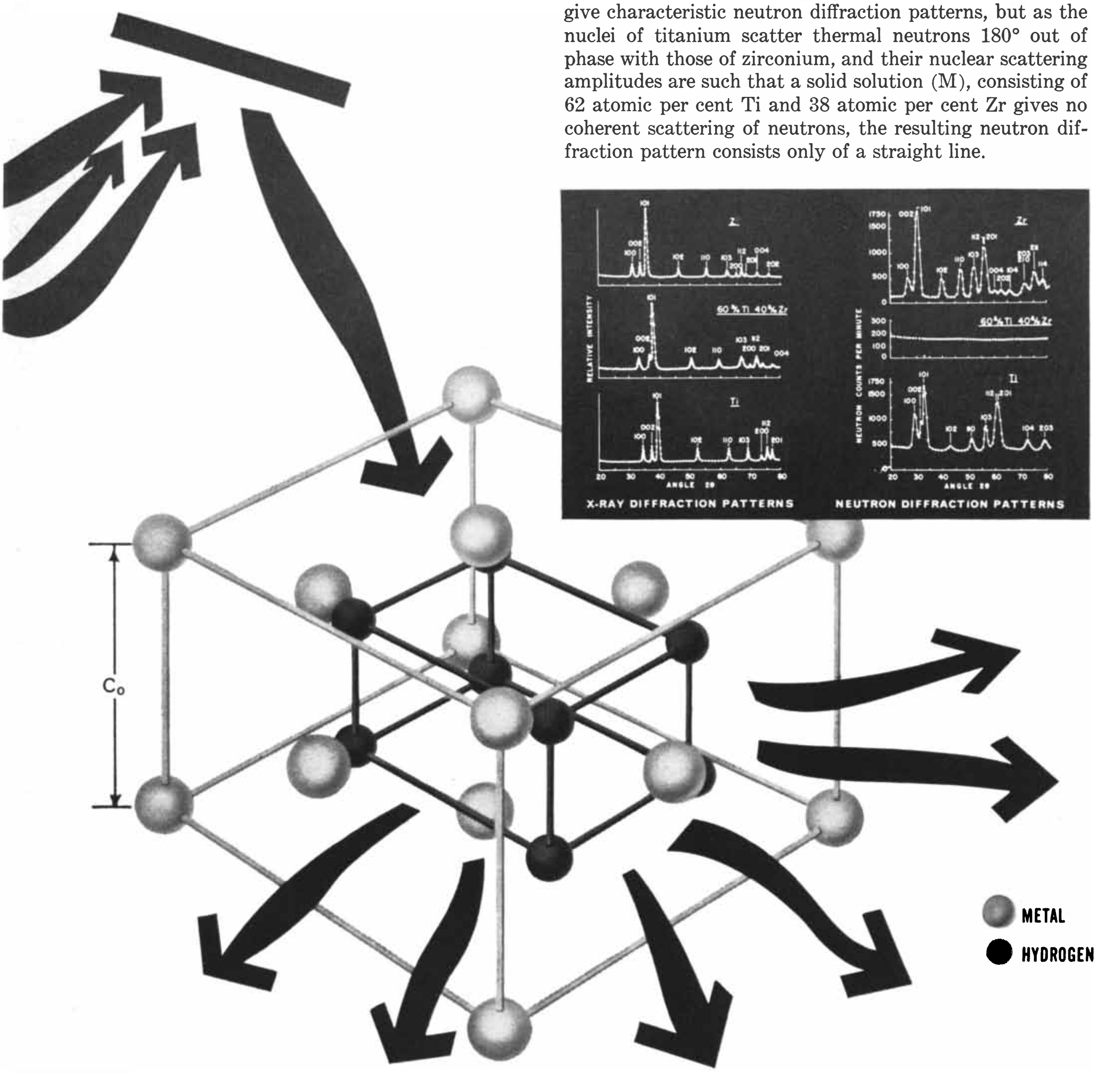

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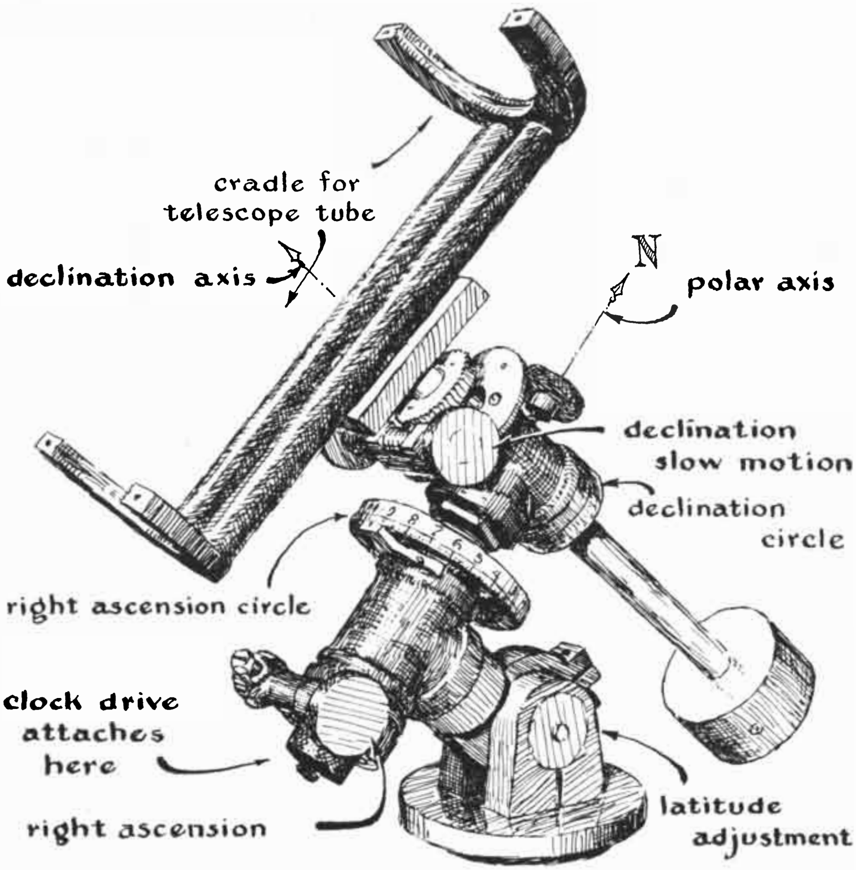

A telescope mounting assembled from war-surplus parts

inch shaft which passes through the center. The lower end of the shaft screws into one end of a fiber cylinder, the other end of which is cut off at an angle of 45 degrees as a backing for the diagonal. The threaded portion of the shaft is locked into the fiber cylinder with a nut as shown. All adjustments of the mirror are made by means of sliding or rotating the shaft.

"The support includes no obstruction with a diameter greater than the minor axis of the diagonal mirror. This was achieved by the unorthodox method of taping the diagonal to the fiber cylinder. I used No. 810 Permanent Mending Tape, sold by the Minnesota Mining and Manufacturing Company. Do not try this with Scotch tape, or attempt to cement or glue the diagonal in place. Repeated trials proved to me that cement warps the mirror when it sets.

"Although the amount of light conserved by this arrangement is doubtless negligible, it is still satisfying to know that maximum light reaches the objective. The real advantage of the system becomes apparent during the observation of double stars. With a run-of-the-mine eyepiece, a diagonal corrected to 1/8 wavelength, and a six-inch objective corrected to 1/12 wavelength, my instrument easily splits double stars with a separation of 7/10 second of arc and a difference in brightness amounting to one magnitude."

In these days of inexpensive surplus parts amateurs without access to machine tools can still have telescope mountings with most of the features found in professional instruments. Such a mounting was built by Charles N. Fallier, Jr., of Hicksville, N.Y. [*see illustration above*]. "As mountings go," writes Fallier, "this one boasts nothing particularly noteworthy with the possible exception of the mechanism for driving the telescope in right ascension. This portion of the assembly is from a surplus panoramic telescope which had a 360-degree rotation and a 32 to 1 worm-and-gear drive with an attached circle calibrated in 100-mil divisions, all totally enclosed. For a clock drive a 48 to 1 reduction gear is substituted for the right-ascension knob and driven by a one-revolution-per-minute motor. The driving rate is not quite sidereal but close enough for casual observation. The gears came from the tuner of a surplus radio transmitter."

7 *ways to satisfy a scientific curiosity*

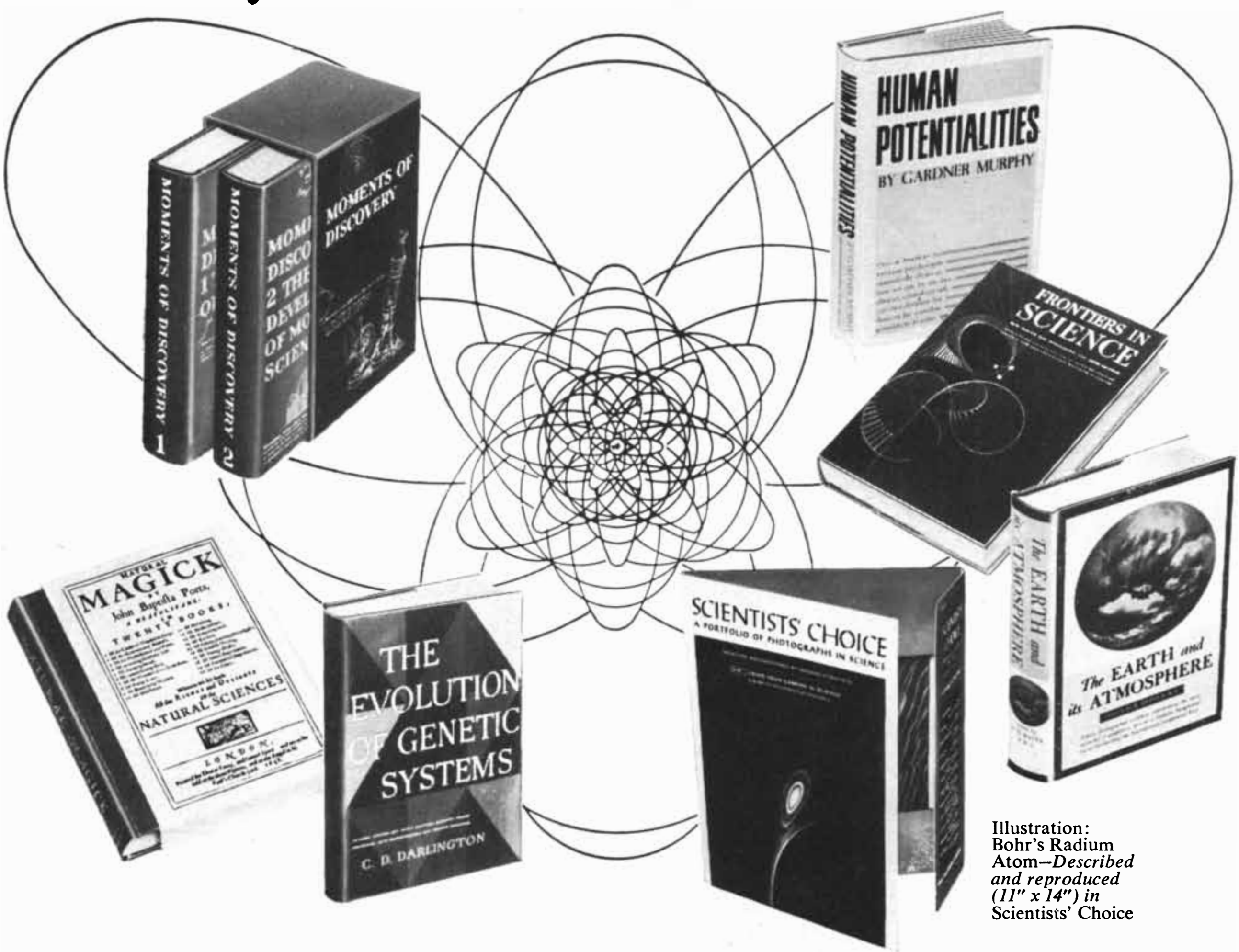

Illustration:
Bohr's Radium Atom—*Described and reproduced (11" x 14") in* Scientists' Choice

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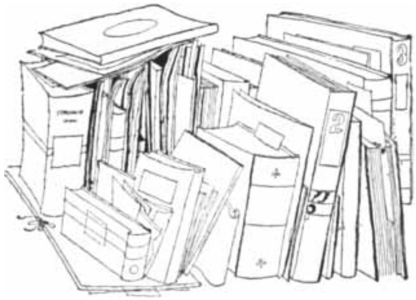

BOOKS

A disturbing study of the relationship between social class and mental disease

by Robert W. White

Social Class and Mental Illness: A Community Study, by August B. Hollingshead and Fredrick C. Redlich. John Wiley & Sons, Inc. ($7.50).

One way to learn more about a form of illness is to study the frequency with which it occurs in different parts of the human habitat. Medical science knows this method as epidemiology. It is generally less spectacular than clinical or experimental research, but it has often provided substantial help in understanding the nature of disease. This book reports the results of a highly original study in epidemiology. As their medical topic the authors have taken mental illness, and as their area the city of New Haven, Conn., with its surrounding suburbs. At first glance the area might seem too small for a full-scale epidemiological study, but the most striking feature of the research is its analysis of the community into social classes which can be treated almost as if they were separate cultures, with differing outlooks and values. If we had been asked beforehand to predict the relationships between social class and mental illness, we might have imagined a few possibilities, but we would hardly have anticipated the firm and extensive correlations brought to light in this impressive research project.

On an early page the authors warn us that we are likely to be shocked by their disclosures. One reason for shock may be that most of us do not like to think about either social class or mental illness. In the U. S. we aspire to the democratic ideal of a classless society. We would like to believe that existing social class differences are not substantial handicaps to equality of opportunity. We are thus professed enemies of snobbishness, and it is disquieting to be reminded of how extensively we practice what we do not preach. We also want to believe that mental illness, with its threat to rationality and self-direction, is a remote and restricted problem that will never strike close to our personal lives. It has taken years to convince even a small part of the public that mental disorder is our greatest national health problem, whether the reckoning be made in money, efficiency or personal suffering. Yet in this book we must face both these disturbing facts, and we must face the evidence that mental illness and its treatment are distinctly related to social class and position. Whether or not we are shocked by these relationships may depend upon how we interpret the statistical findings. But surely those for whom the psychiatrist has become a sort of folk hero, an embodiment of sensitivity and wisdom, will be disappointed to find him caught in the web of social stratification and slow to grasp the outlook of patients who come from strata remote from his own.

The authors of this book share the uncommon virtue of being able to see over the fences that separate one scientific discipline from another. Hollingshead is a sociologist who came to Yale University in 1947 with a record of important research elsewhere on social stratification. He had just completed the work published under the title *Elmtown's Youth*, in which he examined the effects of social class membership on the behavior of high-school pupils and of their teachers in a community in the Middle West. In this study he gathered evidence that lower-class children drop out of school early on account of disapproving attitudes by middle-class teachers, who insist upon standards of behavior which are foreign to the lower-class home. Redlich is a psychiatrist who came to Yale's School of Medicine in 1942 after training and several years of practice in Vienna. He is favorably inclined toward Freud's account of human nature, including the view that early life experiences are of great importance in shaping personality toward later mental health or illness. We know how often it happens that distinguished men in different fields work side by side on the same campus for years without ever realizing that they have anything to learn from one another. It is our good fortune that a spark was struck between Hollingshead and Redlich, even though some cherished illusions be scorched in the resulting heat.

The central questions of the research are expressed as follows by the authors: "(1) Is mental illness related to class in our society? (2) Does a psychiatric patient's position in the status system affect how he is treated for his illness?"

To answer such questions it is necessary to know a great deal about the community and about its population of psychiatric patients. One of the most important research operations was the taking of a psychiatric census. This was accomplished by asking all psychiatric agencies in the area—state and federal hospitals, private hospitals, community clinics and private practitioners—to make available the records of all patients undergoing care and treatment during a period of six months (June to December, 1950). Victims of mental illness who were not in treatment at recognized agencies or with qualified psychiatrists obviously escaped this net, but evidence is given that very few others were missed. This operation yielded a total of 1,891 psychiatric patients being treated in a community with a total population of not quite 237,000. The second major operation was to study by means of interviews a 5-per-cent sample of the New Haven population, selected by taking every 20th address in the city directory, with a view to establishing the existing lines of social stratification. These two formidable bodies of data were supplemented by interviews with psychiatrists, whose position in the status system was an essential aspect of the study. Obviously a large team of trained investigators was necessary to assemble and interpret such a mass of material.

The 5-per-cent sample showed that the people of the New Haven community could be stratified into five main classes. Three indicators of status were used to determine class position: the residential address of a household, the occupational position of its head and the years of schooling the head had completed. If these criteria seem arbitrary and rather too external, it should be pointed out that much past work testifies to their approximate correctness and therefore justifies their use in large-scale research. The true stuff of class membership lies in willingness to associate on an intimate basis; class lines appear at the points where visiting, inviting to meals and intermarriage begin to be felt as not appropriate. Fortunately for research there is a rather high correlation between these intimate facts and the more accessible criteria of residential area, occupation and education. Furthermore, the five classes detected in New Haven have much in common with those found in Elmtown, and they do not differ greatly from the stratifications observed by W. Lloyd Warner in Newburyport, Mass., and by Allison Davis and John Dollard among Negroes in the South. Much can be learned by examining these social classes, which seem to represent a common American pattern.

In Class I we find the business and professional leaders of the community. The membership comprises 3.4 per cent of the population; the median years of school completed by the male head of the family is 17.6; and the median annual income in 1950, calculated on the basis of what the male head earns or owns, was $10,000. The members live in the best areas, send their children to private schools and Ivy League colleges, and constitute the clientele of the private clubs which provide for their leisure time. Within this single small horizontal stratum there are vertical cleavages resulting from recency of wealth and ethnic differences. The greatest power and prestige are enjoyed by a core group of old families which are mostly descended from early settlers in New England and have been wealthy for several generations. This group is distinctly inhospitable toward "social climbers" from Class II with newly acquired wealth, especially when these newcomers have the ethnic roots of the more recent immigrants from southern or eastern Europe. As a result there tend to be several subgroups which nurse considerable bitterness over the exclusive tactics of the core group. Taken as a whole the families in Class I are stable, secure, active in the community and concerned with community welfare.

Class II is made up of people in managerial positions in the lesser-ranking professions. They represent 9 per cent of the population, with 15.5 years of schooling and a median income of $6,500. As a whole these people are highly sensitive to status and much concerned about success and upward mobility. Three quarters of them have risen to Class II from lower status in the previous generation. They believe strongly in education and urge it upon their children, but good grades and scholarships have to be part of the plan if private schools and Ivy League colleges are to be reached. About a fifth are of older American stock, a fifth are Irish, and a quarter are Russian and Polish Jews. Members of Class II are great "joiners" and take an active part in neighborhood and community organizations. They experience a good deal of tension over their social and economic limitations, but the pain of exclusion from Class I does not prevent them from erecting barriers against Class III.

In Class III (21.4 per cent, 12.4 years of schooling, median income $4,929) the typical occupation is that of salaried employee, though a quarter of the household-heads own small businesses. Occupations include section heads in large offices, chain-store managers, bank tellers and bookkeepers, and there are also semiprofessional pursuits such as photography and drafting. About a third of this class is of Irish origin and another third is drawn from the more recent immigration from southern and eastern Europe. Typically the residence is a small single-family house on a small lot, but importance is attached to its being in a good neighborhood. Outside of home ownership and life insurance, only a little money can be saved. There is some distress in Class III, especially among its older members, about not advancing more rapidly to a better home and a more leisurely way of life, but on the whole the tone is relatively optimistic.

In Class IV (48.5 per cent, 9.4 years of school, median income $3,812) the majority of household-heads are skilled or semiskilled employees. The meager income is almost always supplemented by the wife's earnings. About a third of this class is Italian, and a great many of the families are still in process of acculturation to American life. Members of Class IV usually occupy two-family or three-family houses, and if they have title to their homes, they are still in the process of making the necessary payments. Some of their leisure time has to be spent working around the house to keep the property in repair. Radio and television are in practically every home, and are heavily used. Reading does not get much beyond the daily newspaper, and there is little participation in neighborhood or community affairs. The labor union provides the most common opportunity for social participation, but even this is viewed as an impersonal and distant organization.

Class V (17.7 per cent, six years of school, median income $2,659) is the stratum of semiskilled and unskilled labor. The home is apt to be a few rooms in a crowded old tenement, bare and unsanitary, or perhaps a tarpaper shack in the suburbs. No money is saved, major purchases such as refrigerators and television must be made on the installment plan, and only half the families own cars, these cars having a median age of 12 years. It is worth pausing to compare this picture with that of the poorest classes in most parts of the world today, to say nothing of times past. The poorest class in New Haven makes up only about a sixth of the population, and if the electric icebox and television are its only luxuries, they at least proclaim a level of existence far above that of the traditional destitute masses. But the position of Class V is far from satisfactory. Its members are, in the words of the authors, "individualistic, self-centered, suspicious, and hostile to formal institutional controls." They tend to feel that everyone is against them, denying them a fair chance; even with respect to neighbors they believe that everybody has to look out for himself. Of all strata, Class V has the least amount of social cohesiveness and neighborly support.

This, then, is the social class background upon which the authors project their study of the prevalence of mental illness. Their statistical findings—which are given at great length and with much pains to control for factors such as age, sex, race, marital status and religious affiliation—show consistent relationships which can be summarized very briefly. The most general finding is that the five classes do not contribute proportionately to the total of psychiatric patients being treated at a given time. The relationship is an inverse one, with Class I contributing only 1 per cent; Class II, 7 per cent; Class III, 13.7 per cent; Class IV, 40.1 per cent; and Class V, 38.2 per cent. Comparing these figures with the proportion of each class in the general population, it is apparent that Class V, representing only 17.7 per cent, has overwhelmingly the highest prevalence of mental illness.

An interesting point comes to light when the patients are divided into neurotics and psychotics. Psychosis is the more serious form of disorder, producing a degree of incapacity that generally re-

quires hospitalization, and it accounts for three quarters of the patients in the New Haven sample. Neurosis, defined here as "a condition of subjective malaise and disturbed social interaction," turns out to be related not inversely but directly to class status: Classes I and II have more than their share, so to speak, of neurotic patients, and Class V has less than its share. With psychotics the relationship is inverse and so strong that it swamps the neurotic figures in the general total. As a whole, mental illness has its lowest relative frequency at the top of the social ladder and its highest frequency at the bottom.

Similar relationships exist between class status and methods of treatment. Patients from Classes I and II are given more time and seen more frequently by their psychiatrists. Hospitals and clinics spend more upon their treatment and care. Psychoanalytic therapy, which attempts a profound reorganization of personality and makes great demands upon time, is virtually restricted to the two upper classes. Shorter forms of psychotherapy—some of which are based upon psychoanalytic principles, but some of which consist mainly of encouragement, advice and direction—are likely to be chosen for patients in Classes III and IV. Physical methods, which in 1950, before the use of tranquilizing drugs, consisted chiefly of electroshock and insulin coma, had their most frequent use in the lower half of the status hierarchy. Members of Class V receive merely custodial care, without treatment, far more often than other classes and considerably more often than is warranted by the nature of their illness. The authors consider it one of the outstanding findings of their study that Class V schizophrenic patients, untreated at the hospitals and unwanted at home, simply stay on in custodial care, often to the ends of their lives. More energetic attempts at treatment would require a larger corps of trained workers than is available, yet lifelong custodial care is in the end anything but an economy of public funds.

The statistics concerning class differences in treatment can be put in dramatic form by concentrating on the publicly supported clinics, where payment by patients, if it occurs at all, is arranged by a nonmedical staff member rather than by the salaried psychiatrist. Here it would seem that we can rule out the economic factor and see whether or not class status has any independent effect. The results are startling. The painful truth emerges that senior psychiatrists prefer to work with patients high on the social ladder, that they turn over Class III patients to internes and Class IV's to medical students, and that class position is thus very definitely related to the amount and expertness of treatment. These findings were a resounding shock to the staff members of the clinics, who did not have the slightest conscious intention of practicing class discrimination.

What are the causes of this pervasive intrusion of social class into the prevalence and treatment of mental illness? Here we must tread carefully, for statistics do not always point unequivocally to the real causes of events. As a first possibility we have the fact that the psychiatrists in New Haven all belong either to Class I or Class II and that most of them have moved upward since the previous generation. Does this mean that they are practicing a kind of exclusion against lower-class patients? Such an interpretation is unlikely. The doctor-patient relationship is a well-defined professional one, not the kind of intimate social relationship in which class lines are really drawn. The authors point out, however, that the class status of the psychiatrist makes for very real difficulties in establishing the kind of relationship with lower-class patients that is favorable for successful treatment. The outlook and values of these patients are very different from those of the doctor, who may be disturbed by the flimsy marital relationships and crude aggression which are commonplace in Class V, by the nearly illiterate habits and restricted expectations of Class IV, or by the tight respectability of Class III. How will the psychiatrist fare with a patient who doesn't want his children to go to college, who isn't interested in altering his personality or making the best use of his potentialities, who merely wants to get well so that he can resume his humdrum life and enjoy television again? There is real point in the authors' suggestion that psychiatrists could profit by training which would help them to understand the outlook of class subcultures different from their own.

The problem is further illuminated when we look at things from the point of view of the patient. From interviews the authors discovered that the several classes have very different expectations about mental disorder and its treatment. Only in the two upper classes is there a fair grasp of the psychiatrist's functions and a knowledge that he can be helpful with emotional problems. Few members of Class V know that a psychiatrist is a medical doctor, and most of them believe that mental illness is caused by bad blood, bumps on the head or some other externally imposed condition. Most patients from the two lower classes are brought to the psychiatrist by irritated family members or by the police; they view the doctor suspiciously, resent his prying, mistrust a "talking cure" and expect to be magically cured by a pill or an injection. The idea of achieving maximal self-realization through insight into one's own behavior—the goal of psychoanalysis—is beyond the comprehension of the great majority of patients who arrive for treatment, and frequently the psychiatrist struggles in vain to secure its acceptance in even the most primitive form.

The class-bound attitudes of patients and of psychiatrists go some distance toward explaining the statistical findings of this study. Neurotic disorders appear to occur less frequently in the lower classes simply because their symptoms are not singled out from the general hardships of life and because it is not realized that such things can be helped by physicians. Psychotic disorders are recorded more frequently because the attitudes of doctors and lower-class patients combine to prevent the giving of proper treatment, with the result that the patients accumulate in hospitals. The fascinating possibility that early-life stress and family training differ from class to class, thus disposing toward the development of different types of illness, is mentioned by the authors but deferred to a volume still in preparation. The yield of this research project is substantial. It should have a strong influence toward improving the treatment of mental illness. The training of psychiatrists, the enlargement of staffs, the spreading of information and the expansion of proper facilities can all go forward more wisely as a consequence of what has come to light in this book.

For those with restless minds there are bound to be further questions. What lies behind social-class attitudes? How did they come into being? Why do people have such an interest in status and upward social mobility? Perhaps it is not unfair to say that the authors of this book, bent on demonstrating the effects of social class, in the end convey an exaggerated picture of its importance. An unwary reader might form the impression that everyone is deeply preoccupied with the status hierarchy and that having better status is a malicious end in itself rather than a means of bettering other aspects of one's life. We cannot accuse the authors of holding such views, but it is pertinent to point out their silence on the subject of differences in intelligence. Even if one shuns the idea of innate intellectual differences, in spite of much evidence in its favor, and hopes to explain all actual differences as the product of social advantages and handicaps, it is inescapable that the five social classes represent a descending order of effective intelligence. The design of the research, which used years-of-schooling as one of its three criteria of social class, makes this result inevitable. Many of the attitudes shown by lower-class patients and their families are appropriate not only to their class position but also to people who ended their mental training in grammar school and who could not read Freud with understanding even in pocket books borrowed from the public library. Psychoanalysis aims to produce emotional alterations, but it does so by means of highly sophisticated mental operations and self-observations. Perhaps it will always be limited to the higher levels of effective intelligence, and perhaps directive methods are really more appropriate at other levels.

In any event the authors' recommendations hold true. We shall never know how much can be accomplished with patients at each social level until we try, and we shall never try until we put much more time, thought, human resources and training into the task—an enterprise to which this book is certain to make a signal contribution.

Short Reviews

EVOLUTION BY NATURAL SELECTION: DARWIN AND WALLACE. Cambridge University Press ($4.75). Darwin's *Origin of Species* was published in 1859, but it was preceded by two earlier papers of his on the same subject which deserve to be as well known. The first expression of his views on the interplay of the mutability of species and the principle of natural selection is recorded in a rough *Sketch* completed in 1842; this was followed by a more finished *Essay* in 1844. The *Essay* sets forth brilliantly, and more simply and directly than the *Origin*, the reasons which led Darwin to his conclusions. Considering how little evidence he had to go on, and even recognizing (as he himself was careful to acknowledge) that others before him had asserted both the tendency of species to change and to natural selection, it is remarkable that he was able, in Sir Gavin de Beer's words, "to steer a straight course in a largely uncharted ocean of ignorance, with rocks of falsehood right across his path." Though neither the *Sketch* nor the *Essay* was published when written, Darwin was so convinced that he was on the right track that he left instructions that if, as he once feared, death overtook him before he finished his work, his wife was to publish the *Essay*. There followed the dramatic event of Alfred Russel Wallace's discovery of the same principle of evolution by natural selection 14 years later, before Darwin had made known his theory (except in a private letter to Professor Asa Gray of "Boston, U.S.A.", dated September 5, 1857). Once Wallace had imparted his discovery to Darwin, the two scientists presented the theory in a joint publication issued by the Linnaean Society of London in 1858. The *Sketch*, the *Essay* and the joint communication, all pieces of the highest possible interest to a wide variety of readers, are reprinted in this centenary commemorative volume. A long, wonderfully clear foreword by Gavin de Beer describes the development of the theories of evolution from Darwin's predecessors to the present day. It also explains the status of natural selection in modern science and the resolution of the cleavage, produced by the rediscovery at the end of the 19th century of the Mendelian laws of inheritance (first published in 1866, but unnoticed), between the Darwinian upholders of selection on the one hand and the Mendelian protagonists of evolution by sudden discrete steps on the other. An engrossing contribution to the history of scientific thinking.

THE NEUTRINO, by James S. Allen. Princeton University Press ($4.50). A progress report of the investigations through May, 1958, of this member of the proliferating family of particles of nuclear physics. Wolfgang Pauli postulated the existence of the neutrino in 1931; Enrico Fermi made immediate use of the concept in his theory of beta-decay. Then, when the theory appeared to be complete, the work of C. N. Yang and T. D. Lee in 1957 reopened it by suggesting studies of processes which involve the neutrino or antineutrino. These investigations have turned up new facts, and it is likely that research in this direction will continue to be fruitfully pursued for some time to come.

COMPUTABILITY & UNSOLVABILITY, by Martin Davis. McGraw-Hill Book Company, Inc. ($7.50). An introduction to the theory of recursive functions. The subject deals with the scope of purely mechanical procedures for solving various problems. Some problems, as Kurt Gödel and the late A. M. Turing showed, are "absolutely unsolvable." In fact, one of the basic results of the theory of computability may be interpreted as asserting the possibility of programming a given computer in such a way that it is impossible to program another computer (which is either a copy of the given computer or another machine) "so as to determine whether or not a given item will be part of the output of the given computer." In addition to their philosophic importance these conclusions are of practical relevance in information theory, algebra, number theory and mathematical logic. A clearly written, well-presented survey of an intriguing subject.

EFFECT OF RADIATION ON HUMAN HEREDITY. World Health Organization. Columbia University Press ($4). A report of a study group composed of leading geneticists convened by the World Health Organization in 1956, together with papers presented by various members of the group. The authors of the papers include H. J. Muller, T. C. Carter, Bruce Wallace, R. M. Sievert, A. J. Lejeune, W. M. Court Brown, L. S. Penrose, A. R. Gopal-Ayengar, A. C. Stevenson, James V. Neel, N. Freire-Maia, Howard B. Newcombe. It is unmistakably clear from the report that additional mutation produced in man will be harmful to individuals and to their descendants. "While there may be inherent and environmental mechanisms," the group states, "which modify the impact of these mutations over periods of many generations, the effectiveness of such mechanisms in man is not known. In essence, then, all man-made radiation must be regarded as harmful to man from the genetic point of view." This careful and sober conclusion, overwhelmingly buttressed by the best available scientific evidence, contrasts with the opinions of a well-known physicist. "The worldwide fallout," this man has written, "is as dangerous to human health as being an ounce overweight." His own views are proof of the dangers of a single misplaced ounce of fat. Anyone reading the WHO report will realize that a contemptuous dismissal of the perils of fallout betrays not only ignorance and dogmatism but a shocking lack of moral responsibility.

SOVIET EDUCATION FOR SCIENCE AND TECHNOLOGY, by Alexander G. Korol. John Wiley & Sons, Inc. ($8.50). A survey, based on researches by the author and other members of the staff of the Massachusetts Institute of Technology's Center for International Studies, of the educational system of the U.S.S.R., in particular Soviet training in physics and mechanical engineering. A considerable amount of information

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was gathered both from printed sources —curricula, examinations, textbooks, policy documents—and notes of observations made by specialists who visited educational institutions in the U.S.S.R. in 1955. The book therefore has more substance than the usual reports on Soviet life and institutions offered to the U.S. public. Korol describes the 10-year school (which is the Soviet counterpart of our 12-grade system from elementary through high school), the secondary technical schools, the general features of undergraduate and graduate higher education. In discussing curricula in physics and mechanical engineering, the author goes into detail and makes comparisons with the most nearly equivalent curricula at M.I.T. A concluding chapter offers some pertinent comments and reflections. There is no doubt, Korol says, that the U.S.S.R. has achieved impressive gains in the quality of educational training, especially in engineering. The number of students has increased enormously (there are, for example, twice as many engineering students in the U.S.S.R. as in the U. S.), facilities have been vastly enlarged and improved, teachers are better qualified and better rewarded. For various reasons—status, prestige, economic advantage, political climate—young people show a strong urge toward professional specialization in "politically safe disciplines" such as mathematics and the physical sciences. While the massive accomplishments of the U.S.S.R. in industry, technology and science demonstrate the effectiveness of their system of training, doubts arise as to whether this system fulfills the objectives of a rounded education. Unfortunately, Korol observes, the reaction of many U. S. newspapers, politicians, educators and scientists to Soviet gains has been absurdly misguided, creating the belief that there is an education "race," that education is like bomb manufacture and unless we beat the Russians in the manufacture of engineers the country will perish. That our goals in education should not be identical with Soviet goals, or, that to the extent we adopt their goals we deny the values we profess to cherish, is a truth which seems to have got lost in the fog of the Cold War.

On the Magnet, by William Gilbert. Basic Books, Inc. ($8.50). Gilbert's *De magnete*, one of the basic works of physics, was printed in London in 1600. Its author was a leading English medical practitioner with a taste for mathematics and natural science. In 1601 he reached the peak of his profession as physician to Queen Elizabeth, but for many years before this he pursued, alongside his practice, his intense interest in scientific matters, in particular in the phenomenon of magnetism. His investigations of the subject seem to date from about 1581. For about two decades he conducted exhaustive experiments on lodestones, devising new instruments, trying new specimens, making a model, among others, of a terella (little earth) to probe the magnetism of the earth. In one of his celebrated experiments he used 75 diamonds to test the belief that the diamond could act like a lodestone in magnetizing an iron needle. It is said that he spent 5,000 pounds of his own money, a very large sum for the times, on these inquiries. *De magnete* appeared in Latin in a small edition and has since become one of the very scarce books of science, rarer even than the First Folio of Shakespeare. The need was early felt for an English version, but while other Latin editions appeared, for some curious reason no translation was published until 1900, when the Chiswick Press printed an elegant vellum-bound volume in a limited edition, amplified with excellent notes by Silvanus Thompson. The translation and revision were carried out by 10 persons, including the noted physicist Joseph Larmor, under the sponsorship of a "Gilbert Club" founded in 1889, having Lord Kelvin as its president. This scholarly and attractive tercentenary volume has also become scarce, but Basic Books has now issued a facsimile for its "Collectors Series in Science." The entire production is handsomely executed and modestly priced.

H. A. Lorentz: Impressions of His Life and Work, edited by G. L. de Haas-Lorentz. North-Holland Publishing Company, Amsterdam ($2.75). No physicist had a greater influence on the advances of science brewing at the turn of the century than Hendrik Antoon Lorentz. When he came upon the scene, James Clerk Maxwell's theory of electromagnetism dominated theoretical physics; yet certain of its peculiar complexities were almost as much a barrier as a stimulus to further development. Action at a distance had been supplanted by the field concept, but in Maxwell's system the field was not so much an independent entity as an attribute of matter in motion. This feature gave rise to confusion and dilemmas, especially in the study of the electrodynamics of moving bodies. It was here, as Einstein said, that Lorentz achieved his act of "intellectual liberation." He discarded the notion that matter is the carrier of the field, and proposed instead the bold hypothesis that the seat of the field is empty space, or, as it was then called, the ether. By this stroke he simplified the vector model and evolved a theory comprehending all electromagnetic phenomena, including the electrodynamics of moving bodies. Lorentz's theory met all questions except one—the fateful Michelson-Morley result—which was not to be wholly reduced until Einstein announced the special theory of relativity. But even this famous departure depended upon another of Lorentz's discoveries, the so-called Lorentz transformation, which, by "pulling time and space askew," helped overcome the paradoxes of the Michelson-Morley experiment, and explain why no ether-wind effect was to be found. Like Henri Poincaré, Lorentz failed to generalize and draw the full conclusions from his hypothesis, thus leaving the crowning step to Einstein; but as the latter has remarked, Lorentz's insight "simply *had* to lead to the special relativity theory." The present volume, a modest tribute to so creative a man, consists of essays by relatives, friends and pupils, who discuss Lorentz's work and sketch his life. The longest contribution is by his daughter, herself a physicist, who gives revealing personal reminiscences of her father. A. D. Fokker describes Lorentz's famous dissertation on the reflection and refraction of light, his theory of electrons, the development of Maxwell's theory, his achievements in molecular theory, the evolution of the celebrated transformations. Other papers deal with the bearing of his work on modern electromagnetic telecommunication (B. Van Der Pol), his study of the effect of the enclosure of the Zuyder Zee on the tides (J. Th. Thijsse), the general influence of his ideas on modern physics (H. B. G. Casimir). In a touching tribute written especially for this volume, Einstein speaks of Lorentz's greatness as a scientist, of his kindness, sense of humor and "perfect serenity," of "his half sceptical, half humble disposition." "For me personally," he says, "[Lorentz] meant more than all the others I have met on my life's journey."

SPIDERS, SCORPIONS, CENTIPEDES AND MITES: THE ECOLOGY AND NATURAL HISTORY OF WOODLICE, MYRIAPODS AND ARACHNIDS, by J. L. Cloudsley-Thompson. Pergamon Press ($9). Six hundred thousand species of insects are known, and the total number in existence probably exceeds a million. There are more species of beetles than of all other animals in the world put together. The variety of insect shapes and sizes and their adaptability stagger the imagination. The beetle *Niptus hololeucus* can live on cayenne pepper, thrive on sal ammoniac, and dwell cosily in the corks of entomologists' cyanide killing-bottles; the fly *Psilopa petrolei* inhabits puddles of crude petroleum; the African goliath beetle measures four inches in length and two in breadth; *Ornithoptera victoriae*, a magnificent butterfly of the Solomons, has a wingspread exceeding one foot; some of the parasitic *Hymenoptera*, at the other end of the scale, are less than a hundredth of an inch in length, despite their complex structure. Less is known about other terrestrial arthropods, but it is certain they are no less interesting. This book bears out the fact. The species with which it deals face the problems of all small animals on dry land. A major problem is to escape desiccation. One solution is to avoid dry places and to dwell mostly in a humid environment (but small animals must avoid becoming waterlogged or trapped by surface tension); another is to evolve an integument which retains moisture. Arthropods have exploited both methods. Woodlice, centipedes, millipedes and their kin lack a wax covering and therefore live where it is moist, and journey abroad only at night when the temperature drops and the relative humidity rises. The author discusses the ecology and natural history of each species, provides bibliographies, a classificatory index, a glossary and 16 pages of plates. This is an attractive and readable book, but the price is prohibitive.

Notes

British Philosophy in the Mid-Century, edited by C. A. Mace. The Macmillan Company ($5.25). A University of Cambridge symposium consisting of lectures given at the university in 1953 by various philosophers and scientists, including C. D. Broad, A. C. Ewing, R. B. Braithwaite, A. J. Ayer, Gilbert Ryle, H. Bondi and the late G. E. Moore, who made one of his rare appearances.

Russian-English Glossary of Solid State Physics, edited by I. Emin. Consultant's Bureau, Inc. ($10). Four thousand terms of solid state theory, crystallography, physics of metals, metallurgy, ferromagnetism, semiconductors and related fields, taken from recent issues of Soviet physics journals.

The Cambridge Bibliography of English Literature: Vol. V, Supplement: A.D. 600-1900, edited by George Watson. Cambridge University Press ($13.50). A supplement to a noted reference work, bringing up to 1955 the lists of books in the various sections dealing with subjects ranging from Elizabethan sonneteers to philosophy and science.

Studies in the Mathematical Theory of Inventory and Production, by Kenneth J. Arrow, Samuel Karlin and Herbert Scarf. Stanford University Press ($8.75). A series of interrelated papers treating the general mathematical concepts behind efficient inventory and production control. An introductory essay by Arrow sketches the historical background of the present burgeoning study, using quite powerful tools, of optimal policies for holding inventories.

Mathematical Theory of Compressible Fluid Flow, by Richard von Mises, Hilda Geiringer and G. S. S. Ludford. Academic Press Inc. ($15). This monograph, representing the first part of an intended comprehensive work on compressible flow, was begun by von Mises, and completed after his death by Geiringer and Ludford.

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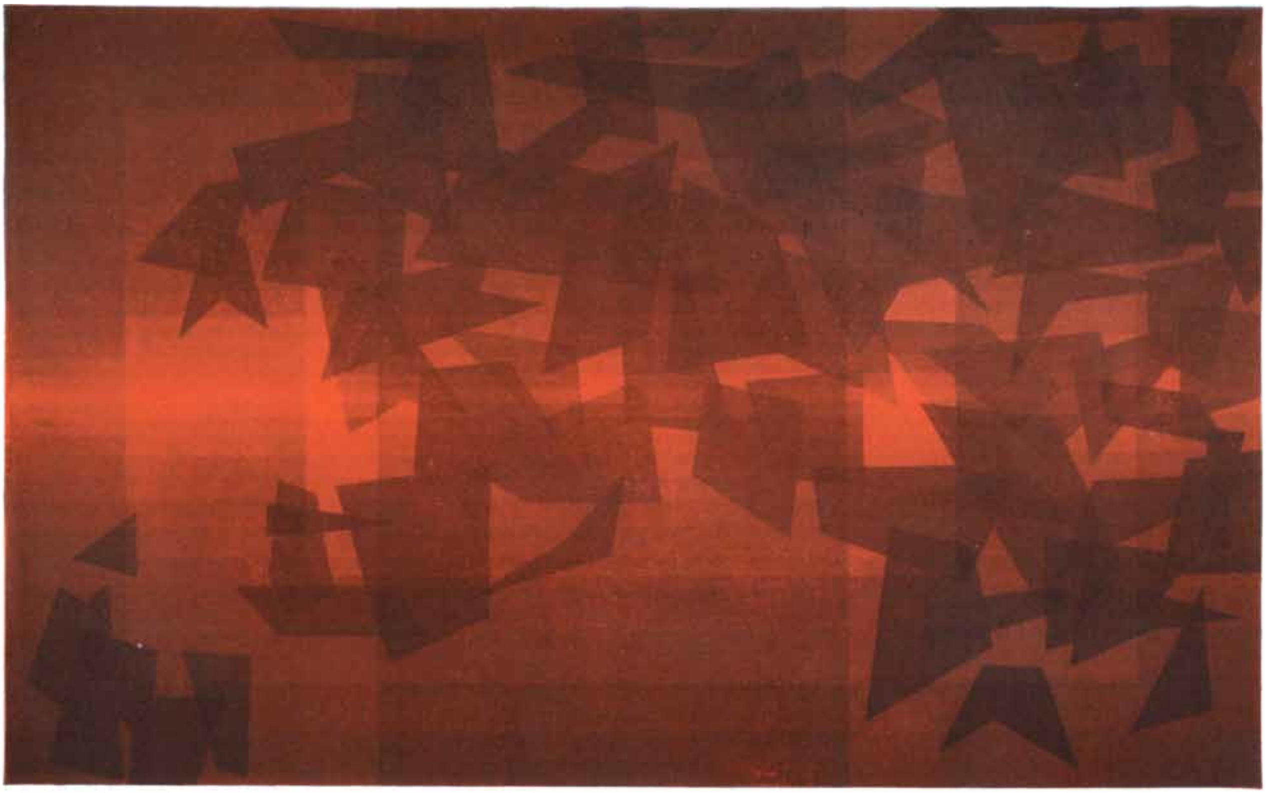

"ECLIPSE" a recent painting by Simpson-Middleman, gifted artistic interpreters of the physical sciences. About this new expression they write: "'Eclipse was painted as a result of watching an actual eclipse of the sun. We were particularly struck with the curious light that was both dim and glowing and the unusual pattern of the shadows on the leaves of the trees around us. We had never seen anything like it before." Painting courtesy of John Heller Gallery, Inc.

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Engineers and scientists at Boeing are at work on advanced projects that include a space weapon system based on a manned orbital vehicle capable of re-entry into the atmosphere and normal landing. This major contract-supported program is a result of recognition of Boeing's space-age orientation, its tremendous technical and research capability and its extensive weapon system management experience.

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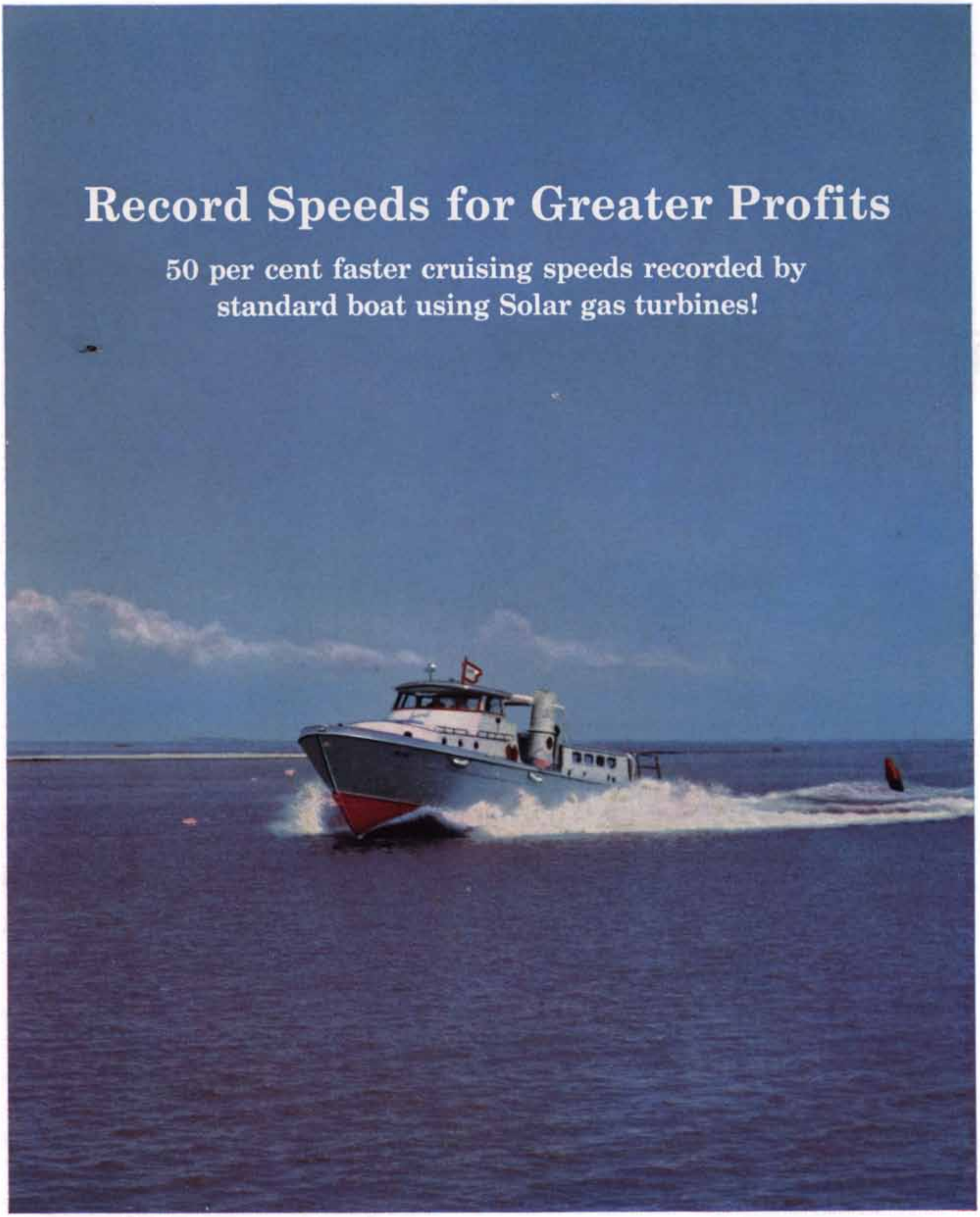

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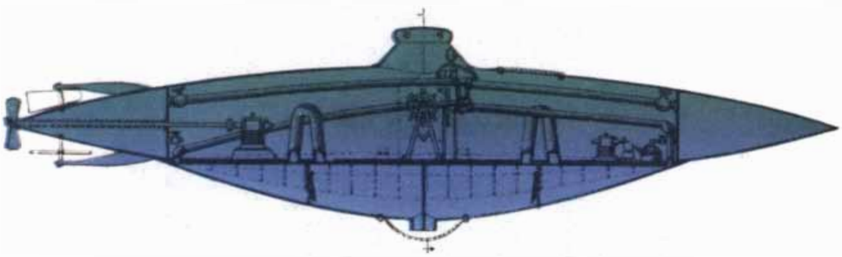

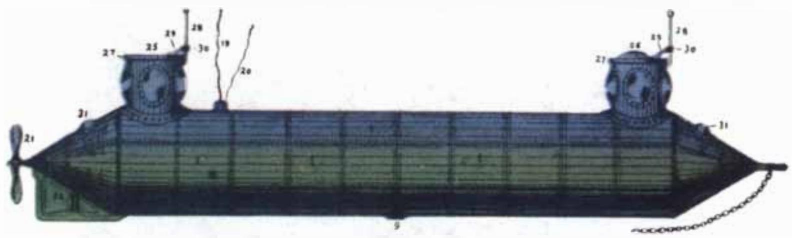

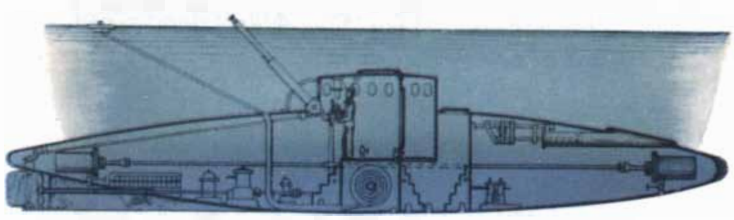

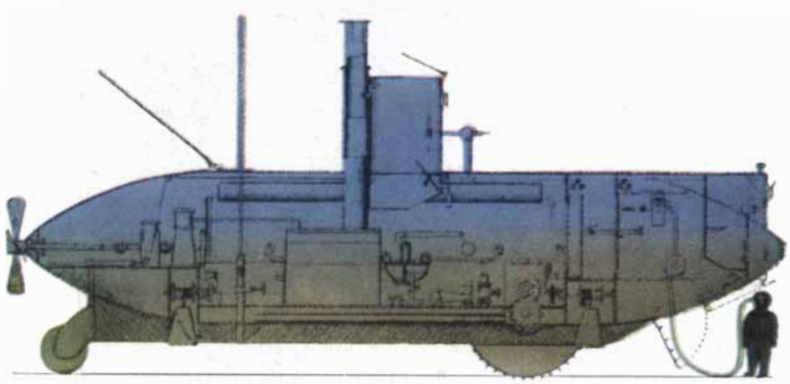

"The Crew Sang, Played Cards, Caught Clams"

Before the submarine won recognition as a naval weapon, there had been at least a hundred years of experimentation with submersibles. Bushnell's *Turtle* futilely attacked British warships during the Revolution. Robert Fulton's *Nautilus* briefly interested Napoleon. The Confederate submarine *Hunley* went down off Fort Sumter with her one victim, the frigate *Housatonic.* The Union tinkered unsuccessfully with a small, hand-cranked submarine, *The Intelligent Whale.* In 1897, Simon Lake launched his wheeled *Argonaut,* designed to sink straight down rather than to dive. The craft explored the Chesapeake Bay area while the crew sang, played cards, caught clams. But in 1897, also, John P. Holland, founder of the Holland Torpedo Company, predecessor of Electric Boat, launched the *Holland,* a "porpoise dive" boat destined to be chosen three years later as the United States Navy's first submarine and eventually the world's model.

From Chapter 2 of "Dynamic America," a history of 420 pages and 1500 illustrations to be published soon by Doubleday & Company and General Dynamics Corporation, 445 Park Avenue, New York 22, N.Y.

GENERAL DYNAMICS