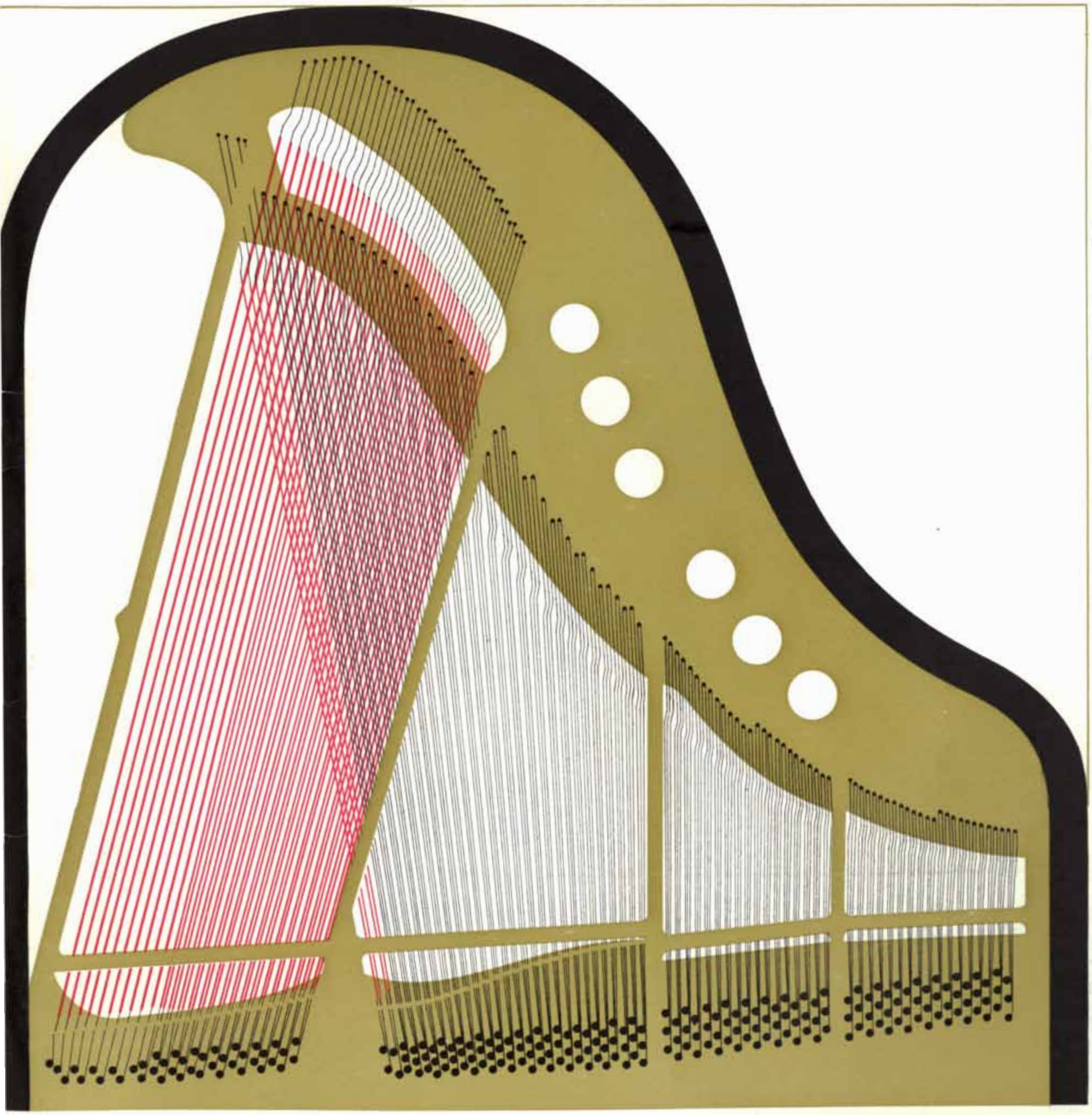
SCIENTIFIC AMERICAN



PHYSICS OF THE PIANO

SIXTY CENTS

December 1965

Rust, barnacle, stain, stress...old enemies meet new defenses

Problems that have bothered men for decades are being solved by engineers and scientists at M&T.

Barnacles, for example. In coping with this problem, copper-based antifouling paints can create another... galvanic corrosion. With paints containing organometallic bioMeT* antifoulant from M&T, though, there's neither corrosion nor barnacles.

Corrosion has been a lifelong enemy for metal water pipes. Now coming into increasing use is noncorrosive vinyl plastic pipe produced with a Thermolite* stabilizer to protect it against degradation from heat and light, both during manufacture and in actual use.

Physical working of metal sets up internal stress. Not with M&T's electro-chemical machining process. It removes metal, however hard, cleanly and without residual stress.

Some organic finishes succumb to a simple thing like food stain. Not M&T-created vinyl plastisols which resist food acids, alkalies, alcohols and other chemicals.

For more information, write M&T Chemicals Inc., General Offices: Rahway, New Jersey 07065.

M&T Chemicals Inc.

*Trademark of M&T Chemicals Inc.

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

An Investigation of the Sense of Smell Through Examination of Individual Olfactory Cells

The olfactory cell can detect odors of a very few molecules per sensing cell. New studies of olfactory tissue and of individual cells hopefully will lead to an understanding of the transducer mechanism used by this highly specific chemical sensor.

New advances in the field of instrumentation and control will come from the development of new, accurate sensors. It is interesting to note that after hundreds of years of invention and development, nature's sensors still outperform machines by a wide degree in several senses such as smelling, tasting and color perception.

This has led scientists into the field of bionics on the assumption that if they could understand how animal biosensors work they might simulate the mechanism.

One badly needed sensor that has defied invention is an adequate odor detector. For over 100 years scientists have been trying to determine the mechanism behind the incredibly sensitive sense of smell in animals.

Several theories have been proposed but none have prevailed. One theory suggests that the hairs on the olfactory cell sense the vibrations of the molecules of the odoriferous gas. Another suggests that there is a chemical reaction between the hairs and the gas. A third theory suggests that the seven or eight basic odors each have a distinctive molecular structure, with each structure fitting an appropriate receptor site on the hairs of the olfactory cell.

The olfactory bipolar sensing cell and its supporting sustentacular cells have been described in various ways. However, the mechanism whereby a gas molecule triggers a signal which passes through the membrane and is then converted to electrical energy is still completely unknown.

Honeywell scientists in probing for the answer to this have chosen to visually and cytochemically examine the individual cell itself while carrying on biochemical analyses of the cellular contents at the same time.

For their observations, they have chosen the cells of the rabbit.

Individual cells are separated by two methods. In the first, a gentle mechanical action is used and the suspended cells settle out on specially treated slides or are placed in a Rose Chamber for isolation in tissue culture. In the second method, a one millimeter square of olfactory tissue is explanted directly from the animal to the Rose Chamber, where some of the cells migrate and separate. Thus the cells are never touched and are presumed to be undamaged. Such cells can be exposed to various odors and compared visually with control cells.

In their studies, Honeywell scientists have maintained these single cells for weeks at a time.

Prior to electron microscopy, the individual cells are imbedded in an epoxy resin block for sectioning. Using an ultramicrotome, sections of 500 angstrom thickness are prepared for study with the electron microscope. Sections of 1 micron thickness are also prepared for correlated light microscopy.

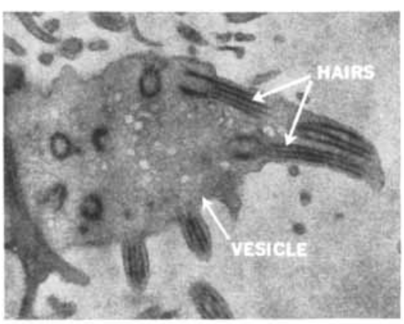


FIGURE 1. (X12,500)
Olfactory vesicle and hairs

From their observations Honeywell scientists theorize that the olfactory hair senses the odor in some unknown fashion and the hair or the olfactory vesicle (*see Figure 1*) is the probable site of a transducer process that initiates the impulse carried directly to the olfactory bulb of the brain via the olfactory rod, cell body and nerve fiber.

The bipolar cell presents a picture of a highly specialized cell characterized by a small amount of cytoplasm in contrast to the supporting cell.

The electron micrographs are revealing concentrated areas of particular intracellular structures such as mitochondria and endoplasmic reticula in certain locations in the cell body. The arrangement pattern and structural relationship of the sensing cells to the supporting cells are also being revealed.

It would seem that to understand the unique mechanism involved the most promising parts for further study would be the hairs themselves and the olfactory vesicle.

The scientists, therefore, are first concentrating their work on the olfactory hairs to determine the exact nature of the outer membrane of the hair and the exact structure of the hair, seeking highly biologically active areas.

The scientists have observed that in the rabbit there is an average of 6 to 12 olfactory hairs per cell. The olfactory hairs show a structure similar to that of cilia found on other types of cells throughout the animal kingdom displaying the conventional 9-plus-2 pattern of fibers at their proximal ends. (*see Figure 2*)

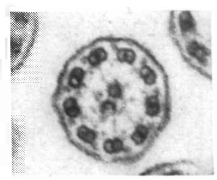


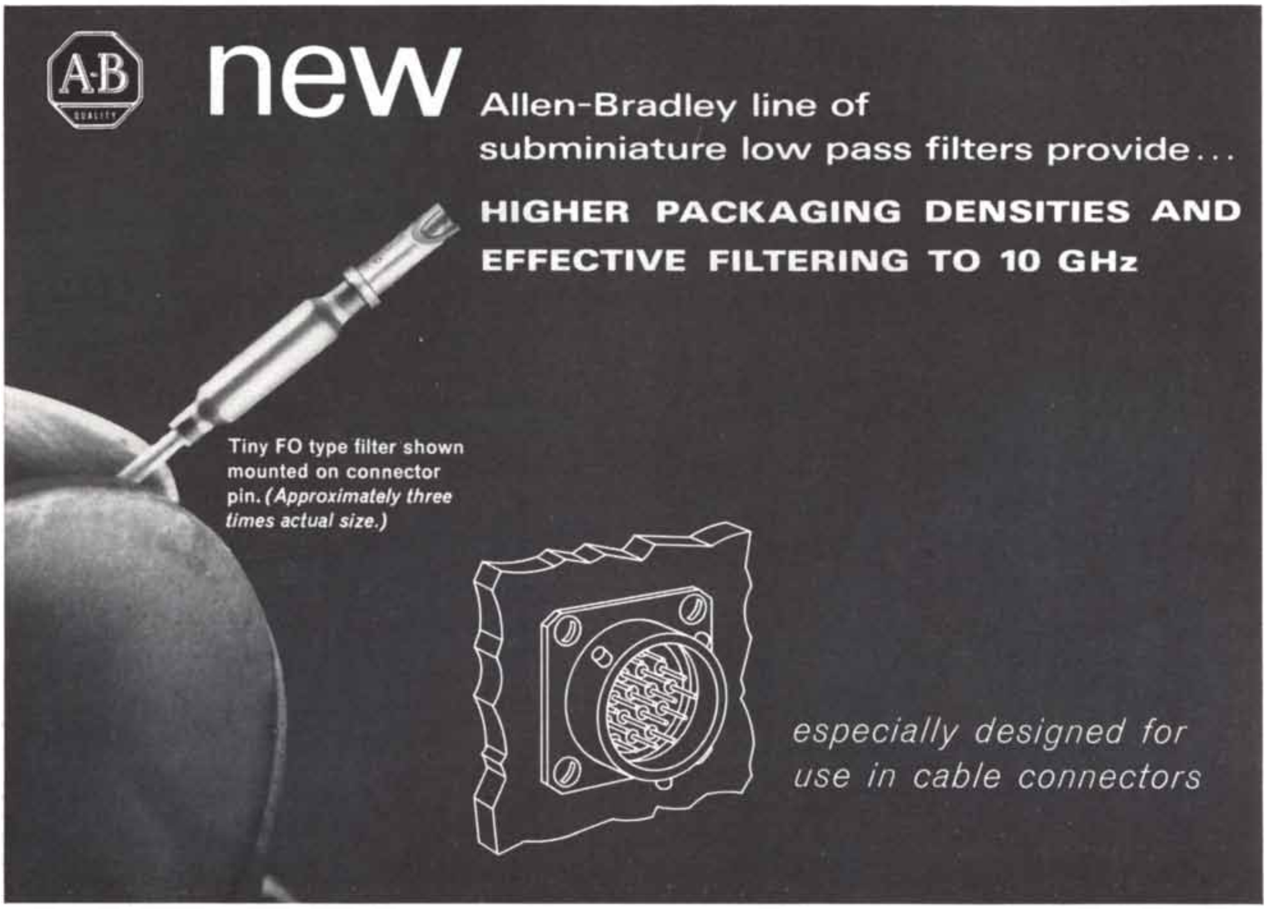
FIG. 2 (X90,000)
Cross section
olfactory hair

They also display an intricate pattern of fibrous connections between the central and outer fibers and the outer membrane.

Obviously much further investigation is needed but hopefully a more complete understanding will lead to new concepts for electronic sensing applicable to detecting and identifying odors in many problem areas including air pollution control, engine performance analysis and military detection procedures.

If you are engaged in biological research of olfaction and wish to know more of Honeywell's activities in this area, you are invited to write Dr. Herbert Heist, Honeywell Research Center, Hopkins, Minnesota. If you are interested in a career at Honeywell and hold an advanced degree write to Dr. John Dempsey, Director of Research at this same address.

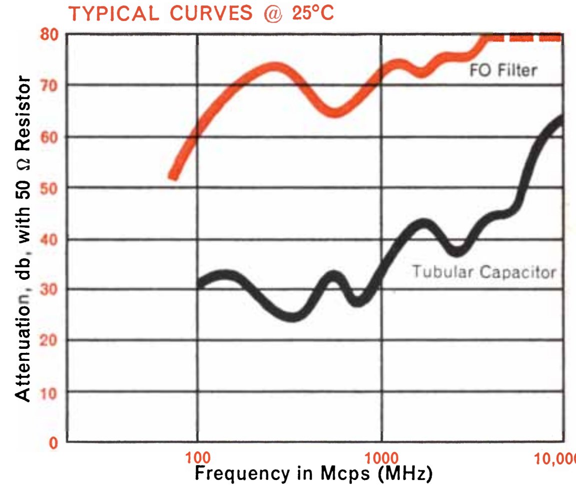
Honeywell



TYPICAL SPECIFICATIONS

	A  ACTUAL SIZE	B  ACTUAL SIZE	C  ACTUAL SIZE
Pin Size	#16 (0.062″ dia.)	#20 (0.040″ dia.)	#24 (0.030″ dia.)
Max. O.D.	0.160″	0.100″	0.075″
Approx. Length	0.625″	0.450″	0.350″
Voltage Rating (V.D.C. max.)	500 v	200 v	100 v
Feed-thru current rating	25 amp	10 amp	5 amp
Attenuation, min. (at max. operating temp.)	50 DB	50 DB	50 DB
Temp. Range	−55°C to +125°C	−55°C to +125°C	−55°C to +85°C

TYPICAL CURVES @ 25°C



■ This new line of FO type subminiature low pass filters is designed to provide maximum reduction of RFI *in a minimum of space*—attenuation is greater than 50DB over the frequency range from 100 MHz to 10 GHz.

The exclusive Allen-Bradley design allows unusually close spacing. The filters can be introduced into connectors with no reduction in the number of terminals, still providing the possibility of individual replacement of filters if desired.

With these filters mounted through a ground plane in the connector, there's complete shielding to prevent the possibility of rf coupling between input and output.

A-B engineers will be pleased to cooperate with you in the application of these new subminiature filters. For more details, please write: Allen-Bradley Co., 1204 South Third Street, Milwaukee, Wisconsin 53204.

Export Office: 630 Third Ave., N.Y., N.Y., U.S.A. 10017.

ALLEN-BRADLEY
QUALITY ELECTRONIC COMPONENTS

Established 1845 SCIENTIFIC AMERICAN December 1965 Volume 213 Number 6

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. COPYRIGHT © 1965 BY SCIENTIFIC AMERICAN, INC. ALL RIGHTS RESERVED. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $7 PER YEAR.

THE COVER

The design on the cover is a somewhat schematic representation of the interior of a modern "baby grand" piano (see "The Physics of the Piano," page 88). Many details of the piano's construction have been omitted in order to emphasize the essential sound-producing component of the instrument: the strings. Thus the small bends that appear in the path of each string are caused by undepicted pins, which change the string's direction. Also included in the design is the cast-iron frame (*gold*), which sustains the tremendous tension exerted by the strings. The strings themselves are made of steel wire (*black*). In order to make the bass strings vibrate slower and thus produce a lower pitch, they are wrapped in copper or iron wire (*red*); two such wrappings are often used in the extreme bass. The bass strings are "overstrung" in order to conserve space and to bring them more nearly over the center of the soundboard. In this particular piano 226 strings are provided for playing the 88 notes of the standard keyboard. The design was made with the kind cooperation of Steinway and Sons.

THE ILLUSTRATIONS

Cover drawing by Jerome Kühl

Page	Source
14	Joan Starwood
15	Jo Ann Beechel
16–17	Joan Starwood
18	H. E. Huxley, Medical Research Council, Cambridge (*top*); Joan Starwood (*bottom*)
19	Joan Starwood
20	H. E. Huxley, Medical Research Council, Cambridge
21	H. E. Huxley, Medical Research Council, Cambridge
22	H. E. Huxley, Medical Research Council, Cambridge (*left and center*); Joan Starwood (*right*)
23–25	H. E. Huxley, Medical Research Council, Cambridge
26	Joan Starwood
27	H. E. Huxley, Medical Research Council, Cambridge
29	Joan Starwood (*top*); Brookhaven National Laboratory (*bottom*)
30–36	Allen Beechel
45–47	Thomas Prentiss
48	Miriam Rothschild (*top*); A. V. Grimstone, University of Cambridge (*bottom*)
49–52	Miriam Rothschild
54	Syun-Ichi Akasofu, University of Alaska
56–62	Irving Geis
66	Earl H. Freimer and John Zabriskie, Rockefeller University
68	Eric Mose
69	Earl H. Freimer, Richard M. Krause and Maclyn McCarty, Rockefeller University
70–72	Eric Mose
74	George E. Murphy, Cornell University Medical College
77	David M. Gates and C. M. Benedict
78	Bunji Tagawa
79	Cam Tibbals
80	Bunji Tagawa
81	David M. Gates and C. M. Benedict
82–84	Bunji Tagawa
88–89	James Egleson
90	Dan Todd
91	E. Donnell Blackham
92–93	James Egleson
94–99	Hatti Sauer
100–102	Joan Starwood
103	Alex Semenoick
104–105	Joan Starwood
107–109	Robert Little
110–112	Roger Hayward

LETTERS

Sirs:

Perhaps you will permit a minor cavil with regard to Victor A. McKusick's interesting account "The Royal Hemophilia" [SCIENTIFIC AMERICAN, August]. It is suggested in the final paragraph that the probability of the three surviving fourth-generation females' having all escaped the bad seed is only 1/8. Although such was certainly the case during these ladies' childhood, it seems to me that we can now utilize the evidence provided by their progeny to figure *a posteriori* probabilities.

Using Bayes's theorem one finds, for example, that the probability of Lady Mary's being a carrier is only 9/41, given her healthy son and three grandsons. Likewise Princess Beatriz has a carrier probability of 3/11. Since Princess Maria has no male descendants yet to demonstrate the definite presence or possible absence of the gene, her probability remains unchanged at 1/2. At the moment, then, the probability that the gene was never sent to any of them is $(1 - 9/41) \times (1 - 3/11) \times (1 - 1/2)$, or 128/451—somewhat better than 1/8 but still not good.

It is easy enough to calculate the probability of carrierdom for each of the females in the genealogy. Of more interest to outsiders, however, is the probability that the gene is now effectively extinct. If we discount the pretender Anastasia, and if we consider Mary, Beatriz and Maria all out of the running for producing any more offspring, then the only possible carriers are the fifth- and sixth-generation females. We obtain the following probabilities for the three clans: Neither Anne nor Elizabeth a carrier, 36/41; neither Sandra nor Olympia, 9/11; none of Princess Maria's four daughters (nor little Victoria), 17/32. The three groups are independent and so the probability of the queen's gene having already met ruin is the product of the above numbers, which comes to about .38. Of course the figures are subject to revision each time another male child is born. An unafflicted boy raises the probability of extinction, whereas a hemophilic boy would shatter all hopes. New girls provide no new information.

The usual objection could be raised to all of this that it is improper to speak of probabilities in connection with events whose outcome is already perfectly definite, although unknown. Quite so. A clever enough man with a clever enough microscope could change all the probabilities mentioned to zeros and ones. Meanwhile the calculated figures remain of potential significance to insurance companies, bookmakers and any eugenically minded members of the families of the female descendants of Queen Victoria.

ANDREW L. GRAM

W. M. Keck Laboratory
of Environmental Health
Engineering
California Institute of Technology
Pasadena, Calif.

Sirs:

Dr. Gram is perfectly correct in pointing out the error in stating the probability of the carrier state in Lady May Abel Smith (not Lady Mary, as written in the article) and the two Spanish princesses. The figure given is the prior probability. As Gram has pointed out, the figure is reduced by the "progeny test."

VICTOR A. MCKUSICK

Johns Hopkins Hospital
Baltimore, Md.

Scientific American, December, 1965; Vol. 213, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Martin M. Davidson, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 20 cents.

Microfilm correspondence and orders should be addressed to Department SA, University Microfilms, Ann Arbor, Mich. 48107.

Subscription rates: one year, $7; two years, $13; three years, $18. These rates apply throughout the world. Subscribers in the United Kingdom may remit to Midland Bank Limited, 69 Pall Mall, London SW 1, England, for the account of Scientific American, Inc.: one year, two pounds 11 shillings; two years, four pounds 14 shillings; three years, six pounds 10 shillings.

Change of address: please notify us four weeks in advance of change. If available, kindly furnish an address imprint from a recent issue. Be sure to give both old and new addresses, including ZIP-code numbers, if any.

Fuel cell A-OK after 1800 hours running time

An Allis-Chalmers 2-kw, 28-volt fuel cell functionally identical to the one shown here, has successfully completed 1800 hours of operation under simulated space power conditions. During the test it efficiently supplied power outputs ranging from 800 to 2300 watts. This hydrogen-oxygen fuel-cell power system additionally yielded drinking water as a by-product.

Built under NASA contract, the system has the capacity for ten round trips to the moon, or could supply power to an orbiting space station for up to sixty days.

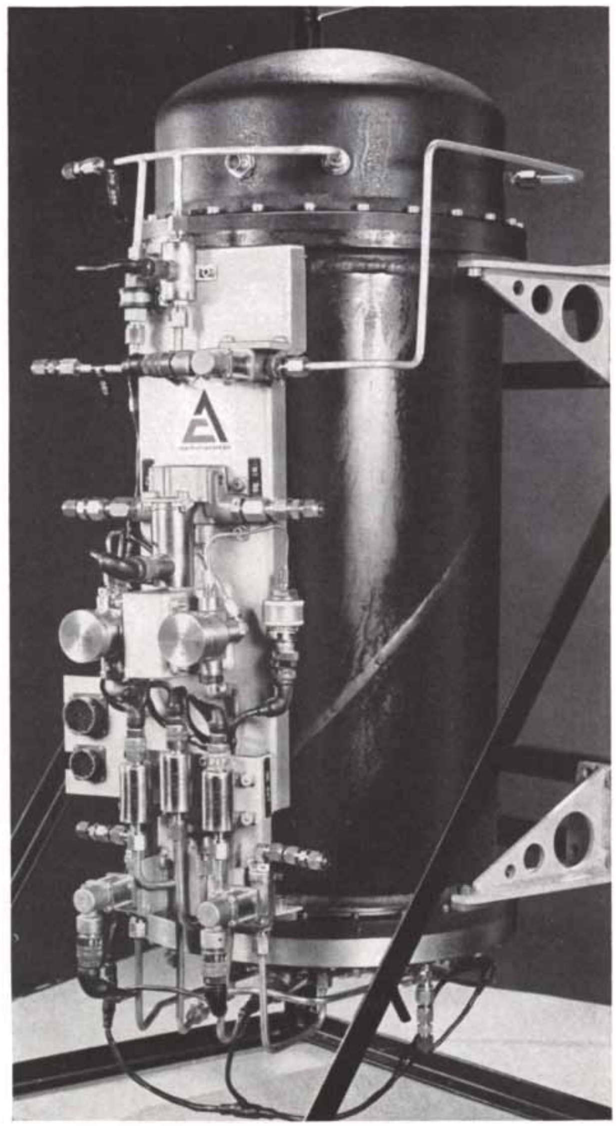
The 2-kw aerospace fuel cell illustrated is a completely automated and self-sustaining version that allows quick restarts at aerospace temperatures. (Allis-Chalmers fuel cells have been restarted at a unit temperature of −10°C, and −40°C environment.) It also produces 2½ to 3 gallons of drinkable water per day — enough for two astronauts. Purity of water is assured by the simple distillation process inherent in the Allis-Chalmers fuel cell.

May we discuss your aerospace and defense fuel-cell application? Write: Marketing, Space and Defense Sciences Department, ALLIS-CHALMERS, Box 512, Milwaukee, Wisconsin 53201.

FUEL-CELL design for Aerospace and Hydrospace applications is but one of the opportunities open today for qualified scientists and engineers at Allis-Chalmers. For information concerning employment write to: Manager of Professional Placement, Allis-Chalmers, Milwaukee, Wisconsin 53201.

An Equal Opportunity Employer

ALLIS-CHALMERS



Advanced 2-kw, fully automated and self-sustaining aerospace fuel cell power system similar to the 1800-hour test system described.

6513-R

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1915: "French scientists find that tobacco, even when denicotinized, has a marked and deleterious effect upon the heart. For some time past such effect was noticed upon the large blood vessels such as the aorta, but the present researches concern the heart proper, and it also appears that the action is not, as might be supposed, due to the nicotine proper, for smoke from other sources appears to have the same bad effect, and even in tobacco this does not depend on the proportion of nicotine. The present work was carried out at the physiological laboratories of the Paris Medical College and the results were presented before the Biological Society."

"Recently a navy seaplane was successfully launched from the American cruiser *North Carolina* while the latter was under way, the event representing the culmination of a series of experiments which started in 1912. The launching device used is in the form of a car propelled along a track, the aircraft being held on the car until it reaches the end of the track. When the car stops, the seaplane is released and proceeds under its own power through the air. To give the seaplane the necessary momentum, the car is propelled along the track at a gradually increasing speed up to about 50 miles an hour."

"On November 29th a radio operator of the Federal Wireless Telegraph Company, stationed at Honolulu, succeeded in intercepting messages sent out by the high-power station at Nauen near Berlin, Germany. At the time the German station was sending war dispatches, and so perfect was the reception of the signals that the Honolulu operator 'copied' the messages without difficulty. The distance traversed by the signals was about 9,000 miles, establishing a new world's record in radio transmission."

"A further step has been accomplished in the development of the marine aeroplane. There is building in the aircraft yards of the Curtiss Aeroplane Company at Buffalo a huge flying boat, whose size and power exceed any craft aloft. This machine, which can properly be called the first battleship-aeroplane, is a direct development of the *America*, a twin-engine flying boat which was to cross the Atlantic in the summer of 1914, when the outbreak of the war stopped the attempt. The battleship-aeroplane that is building at the yards of the Curtiss Company is a triple-screw triplane flying boat, which will weigh, fully equipped, 21,450 lbs. Altogether there is no exaggeration in saying that the Curtiss triple-screw flying boat opens a new epoch in aircraft construction, and while far from being an aerial battleship such as may be seen in the future, she certainly represents the embryo of such an idea. In the present war she should prove immensely valuable; in view of her superior armament, cruising radius and sufficient speed there does not seem to be anything aloft that could meet her on even terms."

Scientific American.

DECEMBER, 1865: "In the report of the Secretary of War a general summary is given of the military campaigns of 1864 and 1865, ending in the suppression of armed resistance to the national authority in the insurgent States. The national military force on the 1st of May, 1865, numbered 1,000,516 men. It is proposed to reduce the military establishment to a peace footing, comprehending 50,000 troops of all arms, organized so as to admit of an enlargement by filling up the ranks to 82,000, if the circumstances of the country should require an augmentation of the Army. The volunteer force has already been reduced by the discharge of more than 800,000 troops, and the department is proceeding rapidly in the work of further reduction. The war estimates are reduced from $516,240,131 to $33,814,461, which amount in the opinion of the department is adequate for a peace establishment."

"Our man in Washington writes:—'The man most envied and most to be pitied in this city is Andrew Johnson, President of these United States. Though possessed of an iron constitution, capable of great endurance, he has not that elastic element in his nature, which afforded so much relief to his lamented predecessor, who, like William, Prince of Orange, bore the sorrows of a nation upon his shoulders with a smile upon his face. On three different occasions I went to the old White House to see the President for a few minutes upon some important business connected with the Patent Office. Each time I found the halls and ante-rooms adjoining his private office thronged with anxious men and women, who either wished to look at, or to get an interview with, His Excellency. The President, though appearing quite well, nevertheless exhibits a care-worn and anxious expression. His labors are excessive, and, from motives of mere curiosity, visitors ought not to force their attentions upon him, and just now especially, while he has so many burdens to bear; besides, the White House is a dirty old place and is not fit for his residence.' "

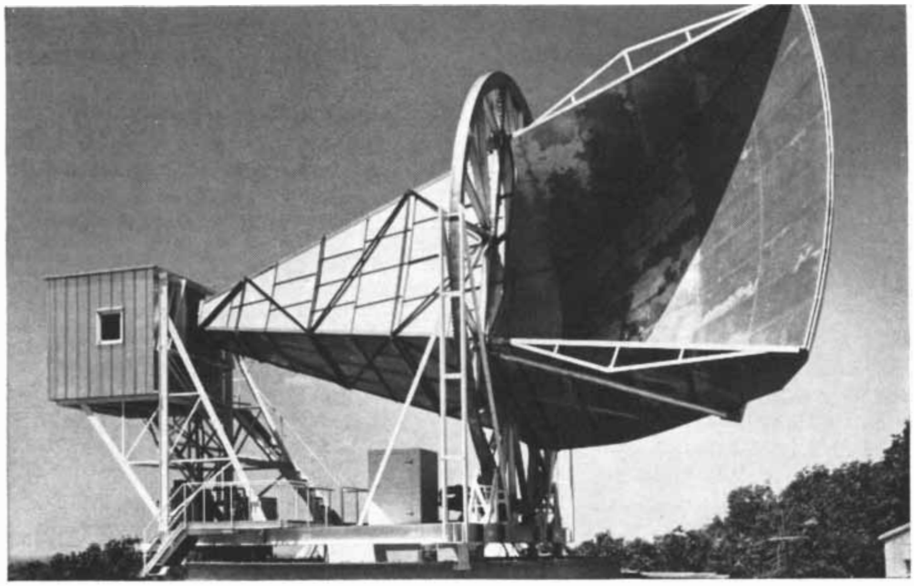
"Some interesting facts respecting yeast have been brought before the Academy of Sciences by M. Bechamp in a note 'On the Physiological Exhaustion and Vitality of Beer Yeast.' The author washed and washed globules of yeast until they appeared to be mere envelopes of cellules and found that they still retain the power of changing cane sugar into glucose and setting up the alcoholic fermentation, which proves, he considers, that the property of setting up fermentation resides in the properties of the living cellule and is a consequence of the act of nutrition of this cellule."

"At the last meeting of the Literary and Philosophical Society of Manchester, Mr. George Greaves read a paper embodying the suggestion that the 'internal heat of the earth,' which he supposes will render it impossible for us to raise coal from below a depth of 4,000 feet, should itself be employed in place of the fuel of which he thinks it will one day cut off our supply. He considers that the heat of the fiery ocean which he believes lies under our feet might supply us with all the mechanical power we want, and that one method of causing it to do this 'might be by the direct production of steam power by bringing a supply of water from the surface in contact with sufficiently heated strata, by means of artesian borings or otherwise.' "

"Prof. Agassiz is following the upward course of the Amazon River and has already discovered 60 new species of fish."

Report from

BELL LABORATORIES



Bell Laboratories' horn-reflector antenna located at Holmdel, New Jersey. It is coupled to a traveling-wave maser receiver through a waveguide switch which permits comparison of received noises and noise from a reference source.

A radio problem that may have a ten-billion-year-old solution

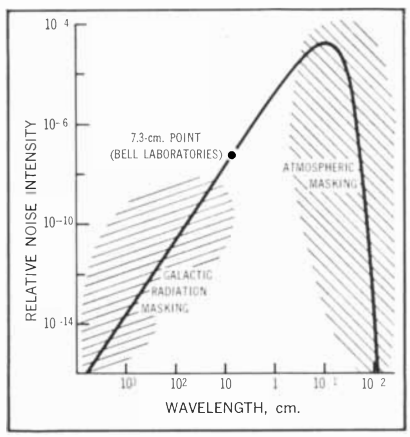
Activities in technology sometimes have surprising implications. For example, recent antenna tests conducted by Bell Telephone Laboratories at Holmdel, New Jersey, have apparently produced evidence about the early history of the universe.

In their radio communications studies, Bell Laboratories scientists had been using a horn-reflector antenna (employed on Project Echo and Telstar® experiments) to measure the radio noise emitted by Cassiopeia A, an exploded star now surrounded by fiery gas. This and other similar measurements require accurate knowledge about or elimination of noise produced by the atmosphere, the ground, and the components of the antenna system itself. Now, noise from the Earth's atmosphere can be accurately measured and the antenna is so directional that ground noise is negligible (verified through a series of tests with a mobile transmitter). The electrical joints in the antenna system and waveguide were reworked and sealed to eliminate any possible noise due to leakage. And, an extremely accurate noise-level reference source—the best produced so far—was designed and built especially for this project.

But there was some noise which could not be explained. It was stronger than that radiated by the distant fixed stars. It showed none of the patterns typical of man-made interference. Drs. A. A. Penzias and R. W. Wilson were frankly puzzled. Strangely enough, similar unexplained noise, of the same order of magnitude, had been suspected by Bell scientists during the Project Echo and Telstar experiments. At that time, though, measurement techniques were not sufficiently perfected to allow them to be certain of their suspicions.

Not far away, however, at Princeton University, an explanation was being devised without knowledge of the Bell experiments. A group under Prof. R. H. Dicke was seeking information about the relationship between gravity and the recession of distant galaxies from us and from each other. The original composition of our galaxy (inferred from spectral lines of "old" stars) and the belief—held by many astronomers—that all matter was once compressed into a vastly smaller volume than at present suggested to the group that the universe was at that time much hotter—a veritable fireball. Such a fireball would emit a characteristic "black-body" radiation which—after cooling through billions of years of expansion—would have fallen in frequency from about 10^{20} cps. to about 10^{10} cps. It would thus lie in the radio spectrum, at wavelengths of a few centimeters. This was very much like the noise which was puzzling the men at Bell Laboratories.

A mutual acquaintance saw a possible connection and put Bell in touch with Princeton. Result: the signal received at Bell Laboratories has enabled Prof. P. J. Peebles of Princeton to draw the hypothetical radiation spectrum shown in the figure. Future measurements at other wavelengths within this spectrum are planned at both Bell and Princeton to determine whether there was a primordial fireball. If so, it will be the first reliable view man has had of events 10 billion years ago.



Virtually all of the "black-body" radiation which might have come from the supposed primordial fireball is concentrated between wavelengths of 7500 cm. and 0.01 cm. However, the long-wave end of the spectrum is masked by the galactic radiation to which radio astronomers listen and the short-wave end is masked by the Earth's warm-air atmosphere. Therefore, only the portion of the curve between about 20 cm. and 1 cm. can be studied. Bell Laboratories has supplied a point at the Telstar wavelength (7.3 cm.). Bell and Princeton scientists will next look for other points along the same curve. If these points are found, they will be powerful evidence of such radiation and, in turn, of the former existence of the fireball itself.

Bell Telephone Laboratories

Research and Development Unit of the Bell System

THE AUTHORS

M. N. SRINIVAS and ANDRÉ BÉTEILLE ("The 'Untouchables' of India") are respectively professor of sociology and reader in sociology at the University of Delhi. Srinivas, a graduate of the University of Mysore, received doctorates at the University of Bombay and the University of Oxford. He has taught in India, Britain and the U.S. For the past year he has been a fellow at the Center for Advanced Study in the Behavioral Sciences in Stanford, Calif. During that time he has completed a book, *Social Change in Modern India,* and begun work on another concerning Rampura, a multicaste village in the state of Mysore. Béteille was graduated from the University of Calcutta and obtained a Ph.D. at the University of Delhi. His book, *Caste, Class and Power: Changing Patterns of Stratification in a Tanjore Village,* will be published in the near future. In October he began a year's appointment as a visiting fellow at the University of Manchester.

H. E. HUXLEY ("The Mechanism of Muscular Contraction") is an investigator in the Medical Research Council's Laboratory of Molecular Biology at the Postgraduate Medical School of the University of Cambridge. "I had originally intended to become a nuclear physicist," he says, "but when I finished off my undergraduate degree [at Cambridge] it seemed a more attractive proposition to think of applying the ideas and methods of the physicist to the biological field." He has done that in extensive research with the electron microscope, the phase-contrast microscope and the interference microscope, first in the laboratory where he now works and then at University College London, where he spent six years before returning to Cambridge in 1962. Huxley was elected a Fellow of the Royal Society in 1960.

EUGENE P. WIGNER ("Violations of Symmetry in Physics") is Jones Professor of Theoretical Physics at Princeton University. Winner in 1963 of the Nobel prize in physics, which he shared with Maria Goeppert Mayer and J. H. D. Jensen, he has made major contributions to quantum mechanics, the theory of solids and the theory of nuclear chain reactions. In 1927 he introduced into quantum mechanics the concept of parity, or reflection invariance, which he discusses in the present article. Among the many other awards he has won are the Enrico Fermi Award of the U.S. Atomic Energy Commission in 1958 and the Atoms for Peace award in 1960. Early in World War II he helped to bring the discovery of uranium fission to the attention of President Roosevelt; later he had an important role in the design of nuclear reactors for producing plutonium. Wigner was born in Hungary, received his college degrees in Berlin and came to the U.S. in 1930. For six years, beginning in 1931, he was part-time professor of mathematical physics at Princeton; he took up his present appointment in 1938, after a year at the University of Wisconsin.

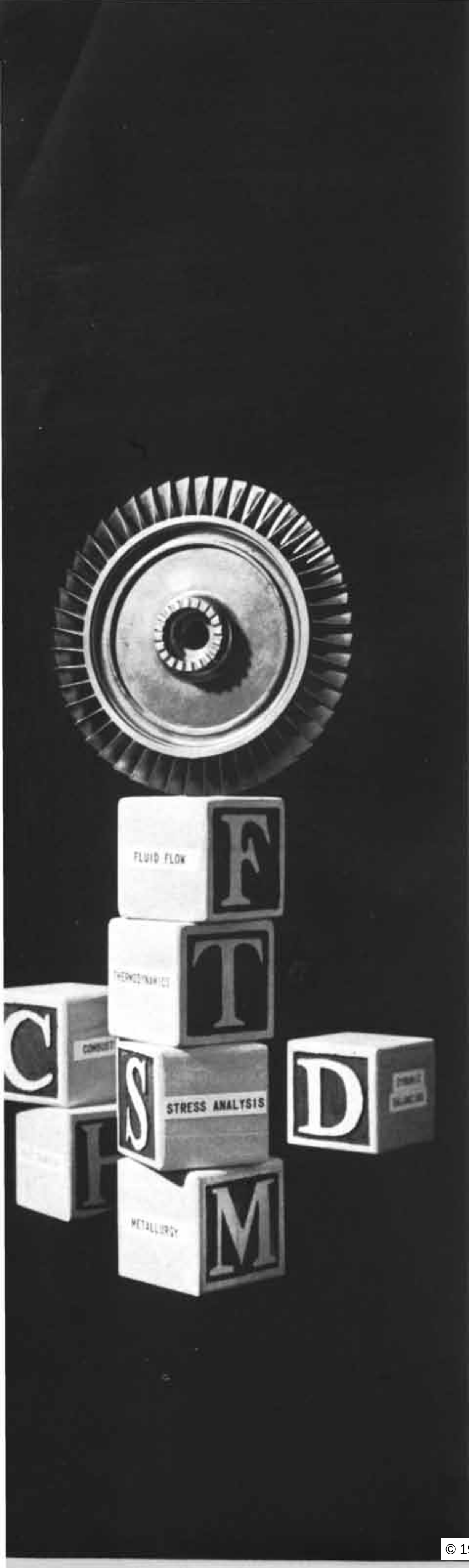
MIRIAM ROTHSCHILD ("Fleas") is a naturalist who was educated at home, took no public examinations and holds no university degrees. Her chief interest is parasitology, but—in the tradition of the amateur—she has also investigated and published papers on such subjects as gigantism in winkles, the behavior of sea gulls, the defensive poisons of moths and butterflies, mimicry in insect smells, the life cycle of intestinal worms and the conservation of natural resources. Her recent work has been mainly on fleas; she explains that she has "found a study of these insects is relatively easy to combine with rearing a family of six children." She and G. H. E. Hopkins in collaboration have produced so far about half a million words on fleas, describing the collection made by her father, Charles Rothschild. Working with another amateur, Bob Ford, she has discovered a phenomenon described in her article: the only known example of a parasitic insect with a reproductive cycle controlled by the hormones of its vertebrate host.

SYUN-ICHI AKASOFU ("The Aurora") is professor of geophysics at the University of Alaska. Born in Japan, he took undergraduate and master's degrees at Tohoku University, receiving a Ph.D. at the University of Alaska in 1961. His article summarizes investigations that he and his colleagues have made at the university's Geophysical Institute. The work was particularly inspired, he says, by Sydney Chapman and C. T. Elvey at the institute. Akasofu is spending the current academic year at the University of Iowa working with James A. Van Allen and his colleagues on relations between auroras and the magnetosphere.

EARL H. FREIMER and MACLYN McCARTY ("Rheumatic Fever") work at Rockefeller University: Freimer is assistant professor and associate physician and McCarty is professor, physician-in-chief and vice-president. Freimer, a graduate of the University of Michigan, took his medical degree at Syracuse University and joined the Rockefeller Institute (which was the name of Rockefeller University until recently) in 1957. McCarty, a graduate of Stanford University, received medical training at Johns Hopkins University and joined the institute in 1941. With Colin MacLeod and the late Oswald T. Avery he showed that deoxyribonucleic acid was responsible for transformation in pneumococci.

DAVID M. GATES ("Heat Transfer in Plants") is director of the Missouri Botanical Garden in St. Louis and professor of botany at Washington University. "As a boy," he writes, "I walked in the footsteps of my father, an eminent ecologist and botanist, as we studied the forests, dunes, bogs and beaches of northern Michigan." He found, however, that "biology then was not sufficiently quantitative or analytical, and physics captured my imagination." He obtained bachelor's, master's and doctor's degrees at the University of Michigan, thereafter teaching physics and doing research in atmospheric physics for several years. But he "could not forget biology" and eventually returned to it because "to understand the natural ecosystems is the greatest challenge to man today," since "we are rapidly eroding the natural ecosystem from the surface of the earth and soon it will be too late to understand."

E. DONNELL BLACKHAM ("The Physics of the Piano") is instructor in music at Brigham Young University. He did his undergraduate and graduate work at that university, obtaining a master's degree in music theory and organ performance. Simultaneously he pursued a long-standing interest in scientific subjects by taking several courses in science and mathematics. Recently he received an associate degree in electronics engineering technology. For three years he served as an assistant to Harvey Fletcher, the prominent acoustical engineer who is now at Brigham Young University. Their investigations involved the piano, the organ and a variety of stringed instruments.



One of a series briefly describing GM's research in depth

Automotive Turbine Research —from the beginning

Thermodynamics. Fluid flow. Heat transfer. Metallurgy. Stress analysis. Dynamic balancing. Combustion.

A mechanical engineering syllabus? No. An outline of a gas turbine engine research program.

It started about 20 years ago when GM Research began studying all aspects of gas turbines and their operation. Turbines were successful in aircraft, but automotive vehicles presented an entirely new challenge. We had to go clear back to fundamentals.

Research on fluid flow characteristics led to new methods for designing compressors, turbines, and diffusers.

To learn more about combustion and to measure combustion efficiency, we had to sample and analyze elusive dynamic gases. A chromatographic gas analyzer was developed to do it.

There was no reliable way to measure temperatures of moving gases. We developed the techniques to do so. Further heat-transfer research produced a new parameter for describing conduction-convection processes.

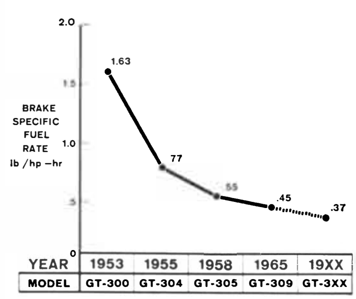
Materials research yielded the first castable nickel-aluminum-titanium turbine bucket material—forerunner of many of today's high temperature alloys.

Engines evolved too. In 1953, our GT-302 powered the XP-21 Firebird, the first gas-turbine automobile built in the United States. It provided baseline data for further research. Improvements in efficiency, performance, and engine braking followed. Latest experimental installations: GT-309's—in Chevrolet's Turbo-Titan III, a heavy-duty truck; and GMC's Turbo-Cruiser II, a transit bus.

Out of research . . . the scientific advances of today, the engineering for tomorrow.

General Motors Research Laboratories

Warren, Michigan



Turbine Engine Progress—
from a recent paper.

Established 1845 SCIENTIFIC AMERICAN December 1965 Volume 213 Number 6

The "Untouchables" of India

The members of India's lowest castes have traditionally suffered harsh social and economic discrimination. Such discrimination is now prohibited by statute and is slowly beginning to give way

by M. N. Srinivas and André Béteille

Without violence or much notice from the outside world India is undergoing a profound social revolution. Its traditional caste system is slowly but surely disintegrating. Whether or not the revolution will proceed fast enough to satisfy the emancipated castes or India's needs as a developing nation remains to be seen. Like the Negroes of the U.S., the former "untouchables" of India are increasingly restless about their condition. Most of them are not yet able to exercise in practice the rights with which they have now been endowed by law. In India religious sanctions as well as economic, social and legal ones have traditionally enforced the inferior position of the lower castes. Today the nation's new constitution and its government are firmly committed to the overthrow of those traditions.

For understandable reasons the people of India themselves have always avoided the term "untouchables." In the new constitution adopted in 1950 the castes formerly considered untouchable are referred to as "scheduled castes," because the Government of India Act of 1935 listed them in a separate schedule. Various other names have been attached to them, but most people in India now call the former untouchables by the name Mahatma Gandhi gave them: Harijans, or "children of God."

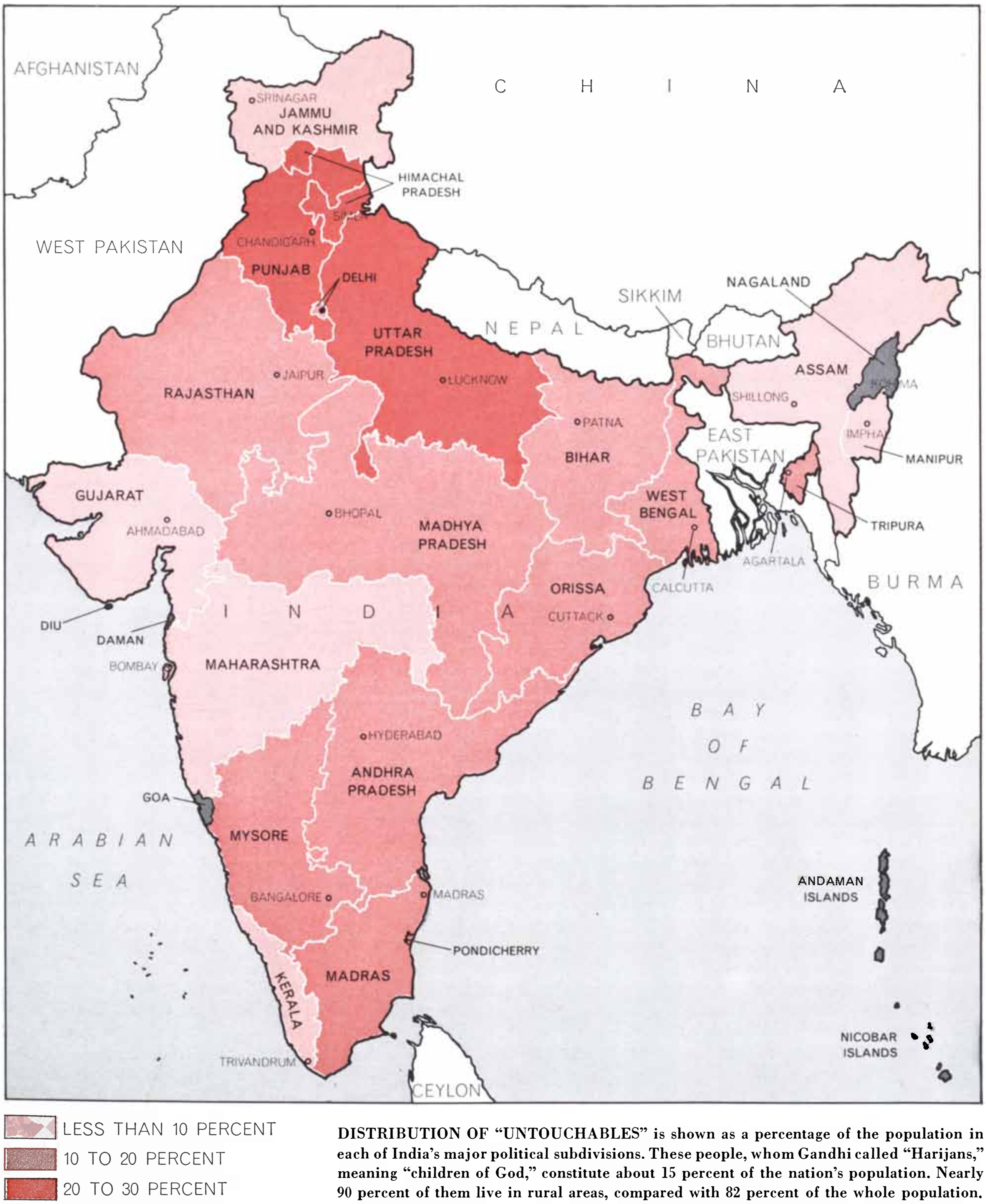
The Harijans, traditionally ranked at the very bottom of Indian society, make up a substantial section of the so-called "backward classes" that are the Indian government's chief concern. In the 1961 census the Harijans numbered 64,504,113 persons. They are divided into a large number of castes (Palla, Paraiya, Mala, Madiga, Mahar, Bhangi, Cheruman, Pulayan, Holeya and so on) that differ considerably from one another in culture and other respects. The Harijans are not distinguished from the rest of Indian society by any common language, physical type or special culture. They have been set apart, however, and most of them continue to be set apart, in three basic respects: occupation, style of living and housing segregation. The Harijans are mainly manual workers, predominantly farm laborers: 89 percent of them are rural, compared with a figure of 82 percent for the entire population. In most cases they live in segregated settlements outside the villages to which they are attached. Their style of living is the heritage of a ritualized culture pattern that for centuries has kept them at the bottom of the society.

The caste system of India rests on a dual foundation: philosophical and economic. The Hindu ideal of a model society, as developed by Brahmanic scholars and authorities, divided the population into a hierarchy of castes (varnas), each of which was associated with certain occupations. The Brahmans at the top pursued the most exalted callings; the "untouchables" at the bottom (known as panchamas and by other names) did the most menial work. Each person was bound for life to the caste in which he was born, and his caste pursued a distinctive style of life in matters of dress, diet, religious ritual and so forth. The lower castes were forbidden to imitate the dress or customs of the upper ones. Moreover, the very lowest groups, the "untouchables," were considered to be in a permanent state of pollution and hence were barred from contact with their superiors.

Perhaps foremost among the customs that mark a caste as "unclean" are its eating habits. Hindus regard meat-eating as a mark of low status, and the eating of beef as putting a caste beyond the pale. Because Hindu villagers will never slaughter a cow, the only cattle available for eating are those that die a natural death; eating beef therefore amounts to eating carrion. The Harijans are assigned the lowest social rank partly because they are beef-eaters. Giving up beef would not, however, free them from the stigma that tradition has attached to them.

The stigma and taboos are strongest in southern India. In the state of Madras, Harijans must live in separate settlements, called *cheris,* which are half a mile or more away from the main village and often lie in paddy fields. No orthodox Brahman will enter a *cheri,* regarding it as ritually polluted. The residential segregation of Harijans is general throughout rural India, and even in the cities there tend to be Harijan ghettos. Keeping Harijans at a distance also applies to religious life. They are not admitted to the major Hindu temples, and a Brahman priest will not perform services for a Harijan. Traditionally a Harijan may not enter a temple used by the upper castes. He is forbidden to draw water from the village well. In southern India until recently a Harijan was not permitted to build a brick and tile house, to wear an upper garment or to put on any garment made of silk. He was not allowed to wear clothes or jewelry such as were worn by the high castes. In some villages he is still forbidden to wear a dhoti (loincloth) extending below the knees. Traditionally the Harijans have been required to live in huts with thatch roofs and to show proper deference to the upper castes in manners and speech.

Although the Harijans have been virtual outcasts socially, they are certain-



DISTRIBUTION OF "UNTOUCHABLES" is shown as a percentage of the population in each of India's major political subdivisions. These people, whom Gandhi called "Harijans," meaning "children of God," constitute about 15 percent of the nation's population. Nearly 90 percent of them live in rural areas, compared with 82 percent of the whole population.

ly not so economically. India depends heavily on them as a basic agricultural labor force. In addition they do other essential and distasteful jobs: the removal of dead cattle and other scavenging tasks, the skinning and tanning of hides, the making of sandals and other leather goods, basketmaking, work as watchmen and messengers. In short, the social structure of the village, and the economy of India as a whole, could hardly exist without the services of the Harijans.

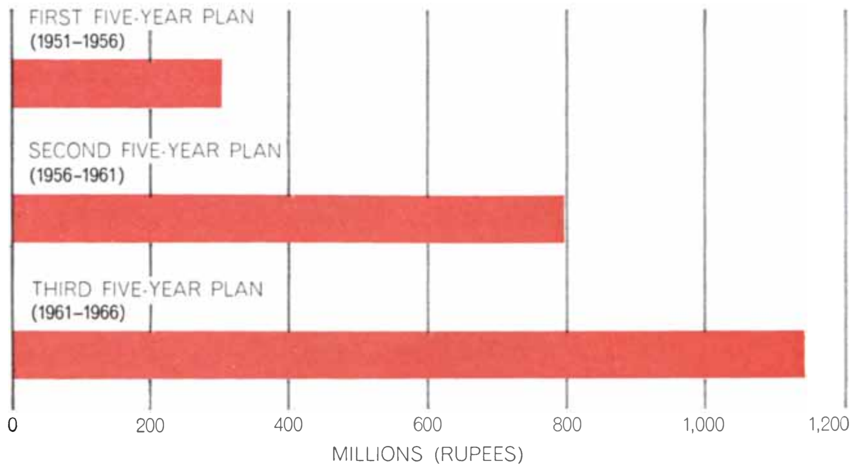
In times gone by the Harijans were literally serfs of the dominant castes and rulers of the villages. They were forced to supply free labor whenever it was demanded of them. In the 19th century the British governors of the country abolished their slavery. This step alone did little to improve their economic position. To this day comparatively few Harijans own any land, and those who do farm their own land have holdings so small that their condition is hardly better than that of agricultural laborers. For a century or more, however, the new political and social forces at work in India as well as in the rest of the world have been tending to bring about both a formal and a *de facto* liberation of the Harijans.

For one thing, the growing urbanization and industrialization of India have gradually undermined the doctrine of untouchability. The notions of purity and pollution that could be maintained in a simple village society lose all significance in the city, where Harijans may work shoulder to shoulder with members of the higher castes in factories and rub elbows even with Brahmans in buses, restaurants and motion-picture theaters.

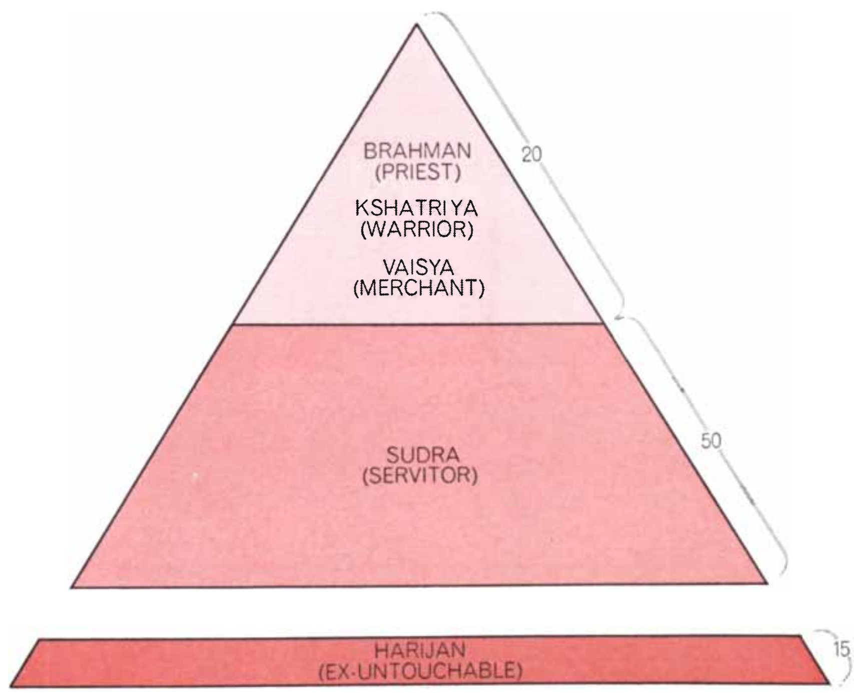
For another thing, some Harijans are discarding Hinduism. Prevented from changing their style of life and thereby moving up in the caste hierarchy, they have turned in large numbers to other religions. The late B. R. Ambedkar, a leader of the "untouchable" Mahar caste who attributed most of India's ills to orthodox Hinduism, led masses of his followers in conversion to Buddhism. Other sizable groups adopted Islam, Sikhism or Christianity. In their new faiths they were no longer willing to accept the Hindu sanctions of caste.

By far the most important liberating factor, however, has been the political democratization of India. This process began with Britain's promulgation of the Government of India Act of 1919, which can be considered the first step toward India's independence. It ushered in local self-government for the country. In doing so it raised the question of representation and protection for the depressed groups in the population, most particularly the Harijans. Two opposing points of view developed.

In the 1920's Gandhi became one of the leaders championing the Harijans' cause. He wanted to integrate them into Hindu society, and he worked on the conscience of the upper castes to break down barriers and to institute programs for improving the condition of the Harijan castes. Ambedkar, the Harijan leader, took a different view. He believed the Harijans could assert their rights only by uniting to make themselves an independent political force that would cope with the caste Hindus on their own terms. Ambedkar succeeded in persuading the British government to accept a system of "communal electorates" in which the Harijans could vote as a bloc. Gandhi, fearing that this system would pit the Harijans and the caste Hindus against each other in irreconcilable, alienating conflict, fought the idea by going on his famous fast



GOVERNMENT AID to Harijans is reflected by the increasing amounts allotted to them in India's first, second and third five-year plans. The central and state governments all provide special grants for the education, housing, health and welfare of the "untouchables."



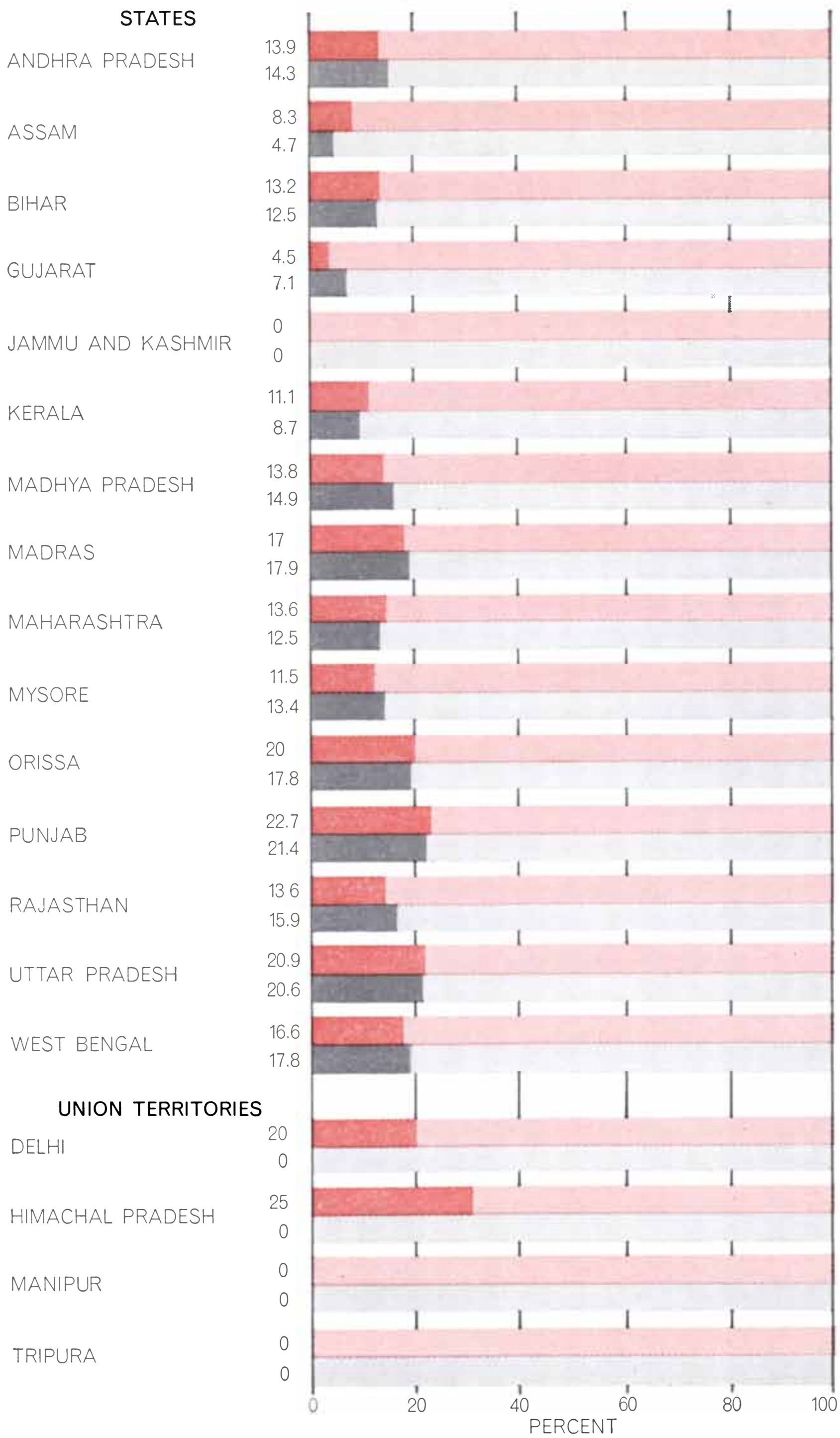
HINDU CASTE STRUCTURE is represented by this pyramid. The top three castes, making up about 20 percent of the population, were regarded as the "twice-born" and the Sudras as "once-born." Within the structure but quite apart from the other castes were the "untouchables." Not shown is the 15 percent of India's population made up of non-Hindus.

"unto death." In the end Ambedkar capitulated and entered into the Poona Pact of 1932 with Gandhi. It provided for withdrawal of the communal electorate plan and the adoption of political measures designed to protect the interests of the Harijans. These and other provisions concerning Harijans were incorporated in the Government of India Act of 1935.

Under Ambedkar's leadership the Harijans grew in influence as a separate political force. After India was finally granted full independence in 1947, Ambedkar became a chief draftsman of its constitution. This basic document of the new nation gives specific recognition to the Harijans (scheduled castes) and the tribal peoples of India (scheduled tribes). It assigns 76 of the 500 seats in the Lok Sabha ("House of the People"), or national legislature, to the scheduled castes, and it also reserves seats in the state legislatures for them in rough proportion to their population. In addition to seats in the elective bodies, the constitution assigns quotas to the Harijans for jobs in government services, which carry high social prestige and political power. And in almost every state the Harijans are assured of representation in the local governments, from the village to the district level, that India has been setting up in its ambitious program of democratic decentralization (Panchayati Raj).

Apart from the formal constitutional and legislative provisions, there is also a tacit understanding that the national cabinet will have at least one Harijan as a cabinet minister, and the same is true in most of the state cabinets. The present central cabinet has a Harijan member: D. Sanjivayya. He was formerly chief minister of the state of Andhra Pradesh and later president of the Congress Party.

The constitution outlaws the practice of untouchability, and an Act of 1955 makes its practice in any form a punishable offense. Under the law the Harijans are now free to adopt whatever style of life they choose; all the traditional taboos are legally abolished. The law says they may dress as they please, drink from any village well, enter any Hindu temple. It is a long way, of course, from a statute on the books to the enjoyment of a right in practice. The non-Harijan castes, from the dominant peasant castes in the villages to the Brahmans in high places, have not yet generally accepted the new legal order of things. Harijans are still barred from many village wells and temples; many barbers refuse to cut their hair and many laundrymen to wash their clothes; the old prohibitions as to how they may dress still prevail in many places; high castes refuse to eat food cooked by them. Untouchability has by no means come to an end. Each year about 500 alleged violators of the law are taken to court, and no doubt this is only a tiny proportion of the actual number of violations of the legal prohibitions against discrimination toward Harijans. Moreover, apart from outright discrimination, the Harijans remain under tremendous disadvantages enforced by their economic and educational condition.



LEGISLATIVE SEATS reserved for Harijans are shown for the Lok Sabha, or "House of the People," in the national parliament (*color*) and for the state legislatures (*gray*). The representation of Harijans is roughly proportional to their strength in the population of each subdivision, as can be seen in a comparison of this chart with the map on page 14.

One indication of their depressed condition is the comparatively small number of Harijans actually employed in government jobs. In 1963, out of a quota of 12.5 percent of Class I government posts allotted to the Harijans, only 1.3 percent could be filled by qualified candidates, and they also fell short of filling the quotas in Class II and Class III. On the other hand, Harijans predominated in the more menial types of government employment, such as sweeping and cleaning.

Long oppressed as an inferior people, living at the edge of subsistence, lacking any tradition of education and compelled in any case to go to work at an early age, the Harijans are hardly in a position to attain true freedom overnight. India's central and state governments are giving special attention to Harijan needs and appropriating considerable amounts for special grants to them in education, housing, health and welfare [*see top illustration on page 15*]. It is increasingly clear, however, that only slow headway is being made. In the 1961 census 90 percent of the Harijans were found to be still illiterate, compared with a figure of 78 percent for the population of India as a whole. To be sure, the literacy rate of the other rural castes is only slightly better than the Harijans'. The Harijans, however, suffer from social and psychological handicaps created by their long servitude, and their advance is opposed by stubborn social forces that are entrenched in the nation's economic and political systems.

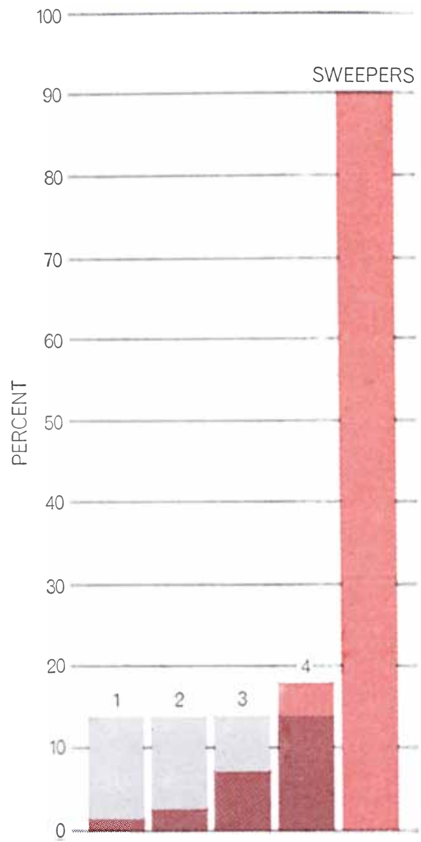
One of the most important factors standing in the way of any united effort by the Harijans to improve their lot is their own cultural diversity. They are far from being a homogeneous group; indeed, about the only thing they have in common is their poverty. The various Harijan castes often differ from one another more than they do from the upper castes with which they are associated. Each Harijan caste or group partakes of the culture of the state or region in which it lives. It knows only the language of its region, and thus it does not even speak the same language as Harijans in other areas (there are 14 different indigenous languages in India). Even within the same linguistic region there is a diversity of Harijan castes, and these may form a hierarchy that mimics the caste system as a whole. In the state of Madras, for example, the two principal Harijan castes, the Pallas and the Paraiyas, generally live in separate streets and have separate wells. Different Harijan castes do not intermarry and sometimes will not even eat together. As we have already noted, the Harijans are not united by religion. Apart from the fact that many have adopted non-Hindu creeds, the Hindu Harijans, being barred from the upper-caste temples where Sanskrit ritual is practised, focus their worship on local deities and demons.

In general it is probably a fact that the vertical cultural unity within a region, embracing the upper and the lower castes, is stronger than any national unity of interest among the Harijans as a class. This makes it very difficult to organize the Harijans for common political action at the all-India level. They have not formed a separate political party of any importance except in one state: the Republican Party founded by Ambedkar in the state of Maharashtra. Instead such political activity as the Harijans have organized in their own behalf has been devoted to working through the existing parties. In a sense the cultural crosscurrents have prevented the emergence of any sharp political cleavage between the Harijans and the upper castes and so have made for political stability in India.

This does not mean that the Harijans are a negligible political force. They are making significant gains in political power at every level from the village to the state. Even in the Tanjore district of southern India, long a citadel of Brahman orthodoxy, they now control the governing bodies of some villages and have elected Harijans as village presidents. In the state of Andhra Pradesh the Harijan legislators have used their political leverage to win representation in the state cabinet and have succeeded in elevating a Harijan to the post of chief minister.

Political activity is creating a new spirit of confidence and a higher level of aspiration among the Harijans. The older generation is still by and large submissive to the upper castes, but among young Harijans there is an increasing disposition to challenge the traditional order. This is especially noticeable in the state of Maharashtra, where the Mahar caste of Harijans has a higher rate of literacy than the landowning peasant caste. Throughout India young Harijans are beginning to imitate the styles of life of the dominant castes and to assert their civic and political rights. In many areas the caste Hindus, particularly the peasant castes in the villages, are resisting bitterly. This has produced many violent clashes, and they are likely to increase as time goes on. It seems rather unlikely, however, that there will be any organized, large-scale conflict. The Harijans are too divided, too scattered and too weak in economic and educational terms to mount an organized revolt at the state or national level. Moreover, the government and the ruling party are in general sympathetic to their needs and aspirations.

Full integration of the Harijans into Indian society quite evidently will take a long time. The social distance between the Harijans and the dominant castes—the centuries-old gulf that has divided them into separate worlds and prevented any sort of interchange, from marriage to simply eating together—is too wide to be bridged in one fell swoop. But the caste concept in India is weakening, the social system is becoming more fluid and the gulf that has separated the Harijans from the rest of society is inexorably narrowing.



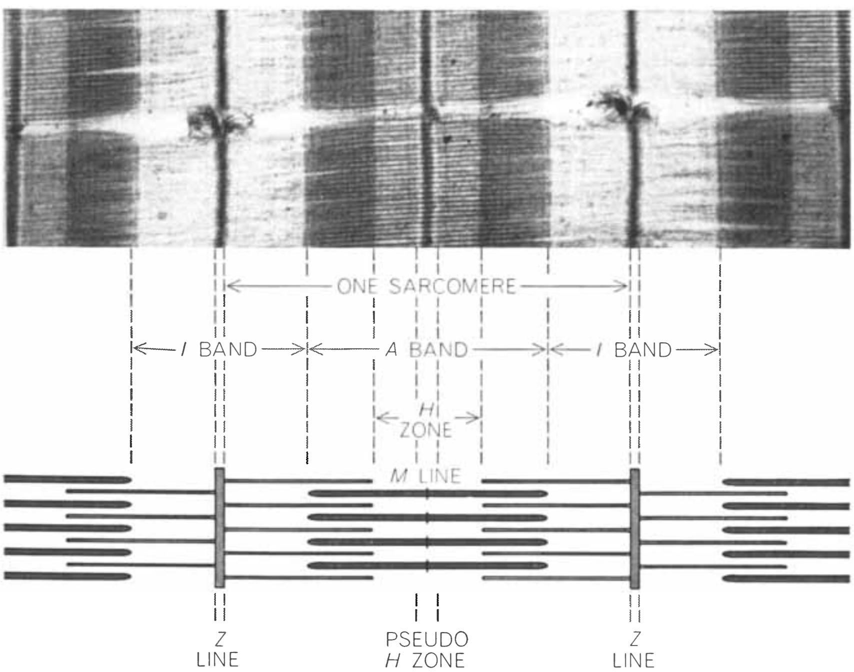
CIVIL SERVICE POSTS reserved for and held by Harijans are compared. In classes 1–3, ranging from top administrative posts to clerical work, the number of jobs occupied by Harijans (*color*) is smaller than the number reserved for them (*gray*); in class 4, "Laborers," they hold more jobs than are reserved for them. The menial and unclassified jobs lumped under the heading of "Sweepers" are nearly all held by Harijans.

The Mechanism of Muscular Contraction

When a muscle contracts, one kind of filament within it slides past another kind. Electron microscopy and other techniques have begun to disclose how the filaments exert a force on each other

by H. E. Huxley

An outstanding characteristic of all animals is their ability to move voluntarily by contracting their muscles. When I summarized our understanding of muscle contraction seven years ago [see "The Contraction of Muscle," by H. E. Huxley; SCIENTIFIC AMERICAN, November, 1958], it had already been determined that during contraction two kinds of filament in voluntary muscle—thick filaments and thin ones—slide past each other so as to produce changes in the length of the muscle. At that time one could offer only a hypothetical description of contraction at a more detailed level; it was assumed that a relative force is somehow exerted between the thick and thin filaments at sites where they are connected by tiny cross-bridges. Now, thanks to advances in electron microscopy and allied techniques, we have been able to substantiate that hypothesis and to learn considerably more about the nature of the interaction of the thick filaments (composed mainly of the protein myosin) and the thin ones (composed of another protein, actin). It appears that at each site where the proteins of the two kinds of filament are in contact one of them (probably myosin) acts as an enzyme to split a phosphate group from adenosine triphosphate (ATP) and thus provide the energy for contraction. The basic problem is to understand how the conversion of chemical into mechanical energy takes place.



STRIATED MUSCLE from the leg of a frog is shown in longitudinal section in an electron micrograph (*top*) and the overlap of filaments that gives rise to its band pattern is illustrated schematically (*bottom*). Parts of two myofibrils (long parallel strands organized into muscle fiber) are enlarged some 23,000 diameters in the micrograph. The myofibrils are separated by a gap running horizontally across the micrograph. The major features of the sarcomere (a functional unit enclosed by two membranes, the *Z* lines) are labeled. The *I* band is light because it consists only of thin filaments. The *A* band is dense (and thus dark) where it consists of overlapping thick and thin filaments; it is lighter in the *H* zone, where it consists solely of thick filaments. The *M* line is caused by a bulge in the center of each thick filament, and the pseudo *H* zone by a bare region immediately surrounding the bulge. The electron micrograph and others illustrating this article were made by the author.

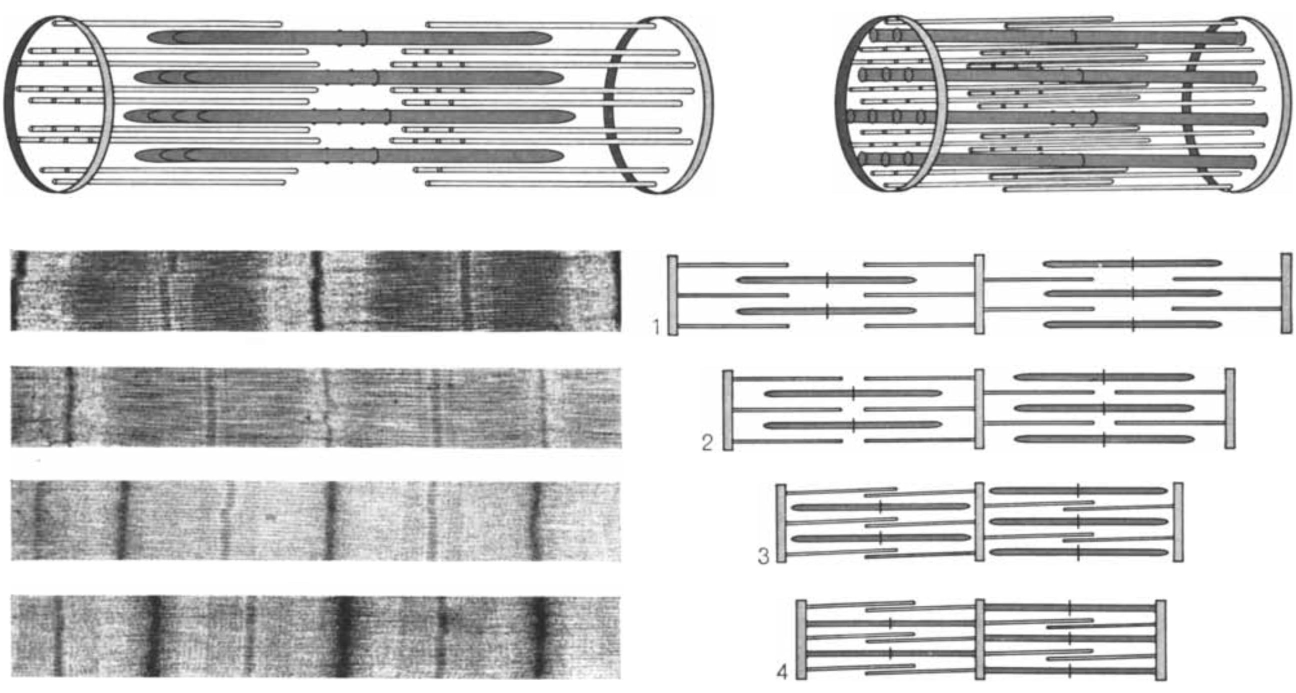
Let us briefly review what is known about the structure and function of muscle. Under the microscope voluntary muscles—for example those that can move the leg of a frog—appear regularly striated at right angles to their length. The muscles responsible for the slow and regular movements of organs that work involuntarily, such as the gut, appear smooth. For reasons of technical convenience most investigations of muscle have dealt with striated muscle, and so our discussion will refer specifically to muscle of that type. A good deal of what has been learned about striated muscle, however, may apply to smooth muscle as well.

Striated muscle can shorten at speeds equal to several times its length per second; it can generate a tension of some 40 pounds per square inch of its cross section; it can contract or relax in a very small fraction of a second. A muscle consists of individual fibers with a diameter of between 10 and 100 microns (a micron is a thousandth of a millimeter); the fibers run the length of the muscle, or a good part of it. Each fiber is surrounded by an electrically polarized membrane, the inside of which is generally a tenth of a volt negative with respect to the outside. Contraction is signaled by an impulse that travels down a nerve to a motor "end plate" in contact with the fiber. The arrival of the impulse depolarizes the membrane and causes the release throughout the fiber of an activating substance, probably calcium. It is this activation that enables one of the muscle proteins to act as an enzyme and split a phosphate group from ATP. The muscle stays contracted until nerve impulses cease (or until it becomes exhausted), at which point the activating substance withdraws, probably by being bound to the sarcoplasmic reticulum, a network of tiny channels within the fiber.

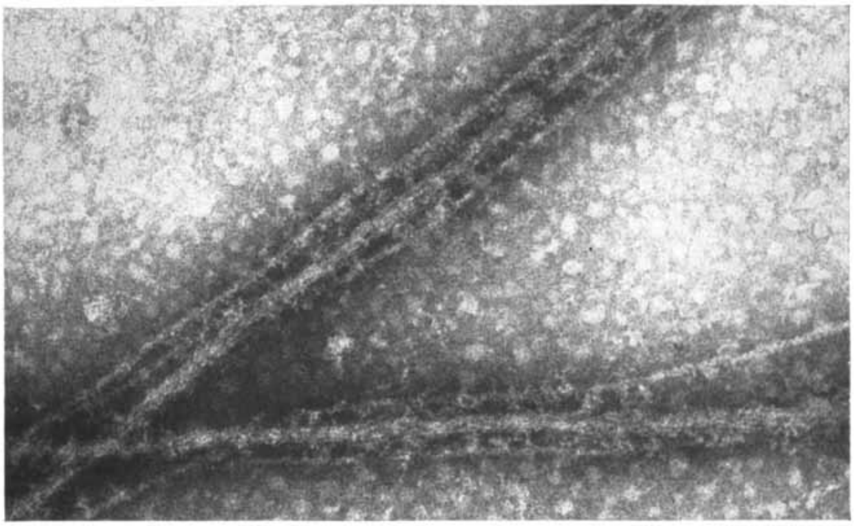
An individual fiber is made up of a number of parallel elements called myofibrils, each about a micron in diameter. Each myofibril itself consists of parallel actin and myosin filaments that, when they are viewed from the end, are seen to lie a few hundred angstrom units apart in a remarkably regular array. (An angstrom unit is a ten-thousandth of a micron.) The myosin filaments are some 160 angstroms in diameter but often appear somewhat thinner when fixed for electron microscopy. They are about a micron and a half in length. The actin filaments are only about a micron in length and 50 to 70 angstroms in diameter. The overlap between the arrays of thick and thin filaments gives rise to the pattern of striations visible in the microscope. The pattern is characterized by a succession of dense bands (called *A* bands) and light bands (*I* bands). In the *A* bands the myosin filaments lie in register in hexagonal array and are responsible for the bands' high density. The actin filaments are attached in register on each side of a narrow, dense structure that traverses the *I* band: the Z line. In a relaxed muscle the distance between Z lines—one sarcomere—is such that about half of the length of a thin filament and two-thirds of the length of an adjacent thick filament overlap. In the region of overlap in a relaxed fiber the array contains twice as many thin filaments as thick ones. The thin filaments terminate at the edge of the *H* zone, a region of low density in the center of the *A* band. In the center of the *H* zone lies the "pseudo *H* zone," a region of even lower density that maintains its width no matter how the length of the muscle changes. This light zone surrounds a thin, dark strip known as the *M* line, which is now thought to be caused by a slight bulge in the center of each thick filament.

When a longitudinal section of muscle is viewed in the electron microscope, it can be seen that the cross-bridges between a given pair of thick and thin filaments come at fairly regular intervals. The cross-bridges are the only mechanical linkage between the filaments, and they are responsible for the structural and mechanical continuity along the whole length of a muscle. It is the cross-bridges that must generate or sustain the tension developed by a muscle. As the sarcomere changes its length, either actively during contraction or passively (stretching or shortening while at rest), the filaments themselves do not perceptibly change in length but slide past one another; the thin filaments move farther into the *A* bands during shortening and farther out of them during stretching.

Since normal contractions involve changes in the length of the sarcomere of 20 percent or more, the thin filaments in each half of the *A* band must move distances of at least a quarter of a micron while maintaining tension. It seems physically impossible that the cross-bridges could remain attached to the same point on the actin filament throughout this process. We supposed, therefore, that they are attached to one site on the filament for part of the contraction, then detach and reattach themselves at a new site farther along. Moreover, we assumed that at each site



CONTRACTION OF MUSCLE entails change in relative position of the thick and thin filaments that comprise the myofibril (*top left and right*). The effect of contraction on the band pattern of muscle is indicated by four electron micrographs and accompanying schematic illustrations of muscle in longitudinal section, fixed at consecutive stages of contraction. First the *H* zone closes (*1*), then a new dense zone develops in the center of the *A* band (*2, 3 and 4*) as thin filaments from each end of the sarcomere overlap.



CROSS-BRIDGES between thick and thin filaments are enlarged 180,000 diameters in electron micrograph made by "negative staining." Technique involves surrounding very small objects with a dense salt (*white substance in background*) so that they stand out by contrast.

where cross-bridge and filament interact, one molecule of ATP is split to generate a sliding force between the two kinds of filament (and hence between arrays of filaments).

This general description of the structural changes associated with contraction is the sliding-filament hypothesis put forward a decade ago by Jean Hanson of the Medical Research Council unit at King's College in London and me, and independently by A. F. Huxley and R. Niedergerke of the University of Cambridge. Our hypothesis was partly based on observations of muscle prepared by what is called the thin-sectioning technique. That method involved steeping a chemically fixed (for preservation) and stained (for contrast) piece of muscle in liquid plastic and then cutting the solidified plastic into slices as thin as 100 angstroms. It turned out, however, that the thin-sectioning technique was not adequate to the task of illuminating many details of the hypothesis. In order to ascertain how a force might be developed between thick and thin filaments we needed information about the detailed structure of actin and myosin, and such information was not forthcoming until the arrival of the technique of electron microscopy known as negative staining.

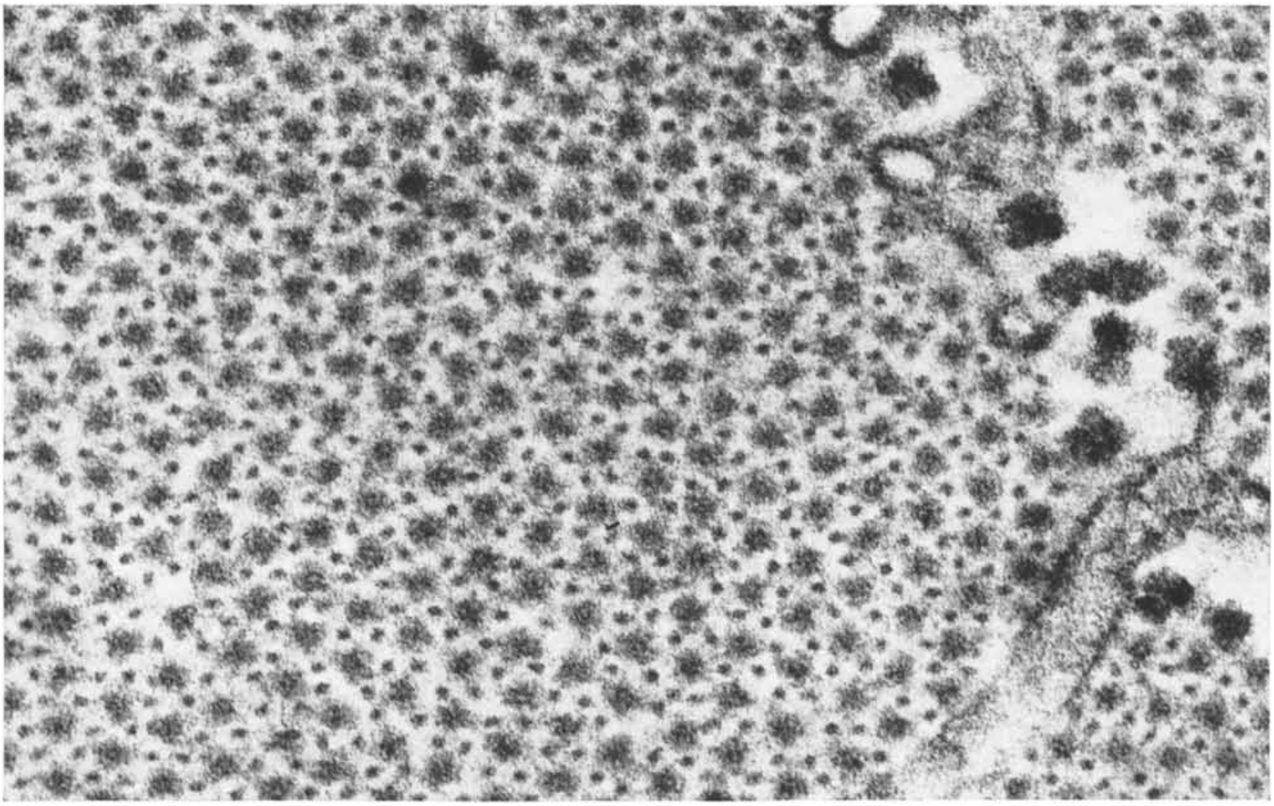
This new method, in which the specimen under examination is embedded in a thin film of some very dense material such as uranyl acetate, has in recent years revealed much about the structure of small spherical viruses and particles of similar size. As adapted in our laboratory at the Medical Research Council unit in Cambridge, the technique involves applying a drop in which particles of muscle are suspended to an electron microscope grid covered by a thin film of carbon. Many particles adhere to this film; the excess is washed away with a few drops of solvent. Before the preparation dries a shallow drop of the negative-staining material—a heavy metal salt in dilute solution—is applied. It is allowed to dry around the particles. The regions of the particles that are not penetrated by the stain show up clearly by negative contrast because they consist of protein and are much less dense than the salt that surrounds them.

The negative-staining method brings to light far more detail than the conventional positive-staining technique (which artificially increases the density of objects with respect to their background). Its disadvantage is that it can only be applied to very thin specimens; thick ones and the associated thick deposit of negative stain would impair the resolution of the electron microscope image. Thus the method is not directly applicable to whole pieces of tissue such as muscle. The muscle must first be broken down into fragments of suitable thickness (such as individual filaments), which is not easily accomplished.

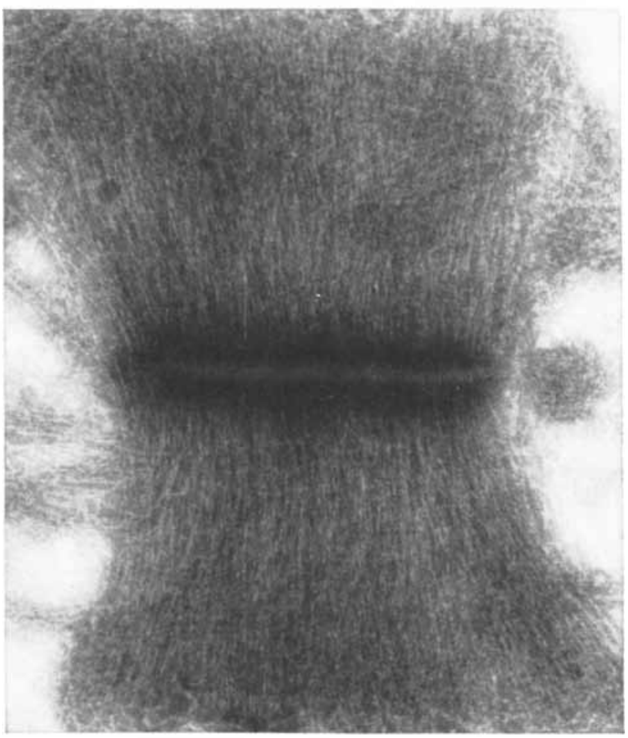
The usual method of breaking down muscle tissue for purposes of investigation is to homogenize it in the Waring blendor; under this treatment it disperses readily into its constituent myofibrils but no further. In fact, the myofibrils strongly resist further breakdown, probably because the cross-bridges between thick and thin filaments bind the whole structure together in a very robust fashion. Making the assumption that the cross-bridges are the sites where actin and myosin combine, we wondered if we might weaken the structure by suspending the fibrils in certain salt solutions that tend to dissociate the two proteins. We were delighted to find that if muscles, either freshly isolated or preserved in a deep freezer in a solution of water and glycerol, were placed in the appropriate salt solution and then homogenized in the blendor, they indeed broke down into their constituent filaments. Thus they could provide excellent material for examination by the negative-staining technique.

The first specimens we prepared by this method consisted of filaments from the psoas muscle in the back of a rabbit. In the electron micrographs the layer of negative stain was thickest in the region immediately surrounding the filaments; accordingly the filaments have a dense outline [*see illustrations at bottom of opposite page*]. We could at once recognize the thick filaments by their resemblance to the thick filaments in earlier preparations of striated muscle. The diameter of the filaments was the expected 160 angstroms; their length was apparently about 1.5 microns. (Longer structures were never observed but shorter ones, presumably fragments, were.) Small projections, extending sideways from the filaments along most of their length, seemed to correspond to the cross-bridges. Thinner filaments 50 to 70 angstroms in diameter could also be seen, and in places we noticed a large group of such filaments extending for about a micron on each side of a Z line, to which they were still attached [*see illustration at bottom left on opposite page*]. These observations of thick and thin filaments of characteristic size, lying side by side and sometimes still connected by cross-bridges, confirmed the conclusions about the structure of the myofibrils reached earlier by X-ray diffraction techniques and by conventional light microscopy and electron microscopy. We subsequently considered the appearance of the individual filaments more closely.

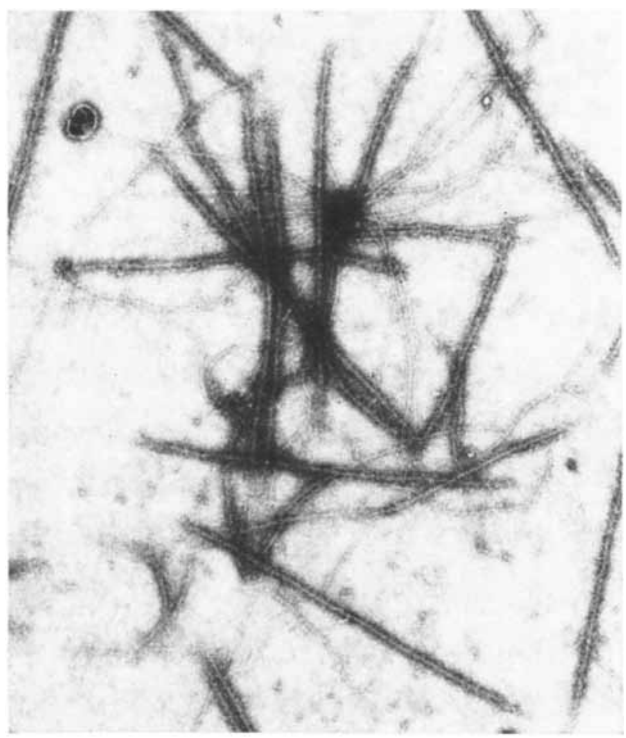
A regular feature of the thick filaments is a short region, midway along their length, from which the projections we believe to be cross-bridges are absent. This differentiated, projection-free area, some .15 to .2 micron long, can be seen not only in negatively stained



TRANSVERSE SECTION through a frog's leg muscle in its uncontracted state shows how thick and thin filaments are arrayed in a regular hexagonal pattern. Breaks in the pattern at the right side of the micrograph are channels of the sarcoplasmic reticulum. From the end thick and thin filaments look like large and small dots. This electron micrograph enlarges them some 200,000 diameters.



FILAMENTS IN REGISTER at *Z* line (*membrane in center*) are the thin filaments of actin, which alone comprise the *I* segment. This sample was obtained by homogenizing muscle from the back of a rabbit in the Waring blendor; it was prepared for the micrograph by negative staining. Magnification is some 47,000 diameters.



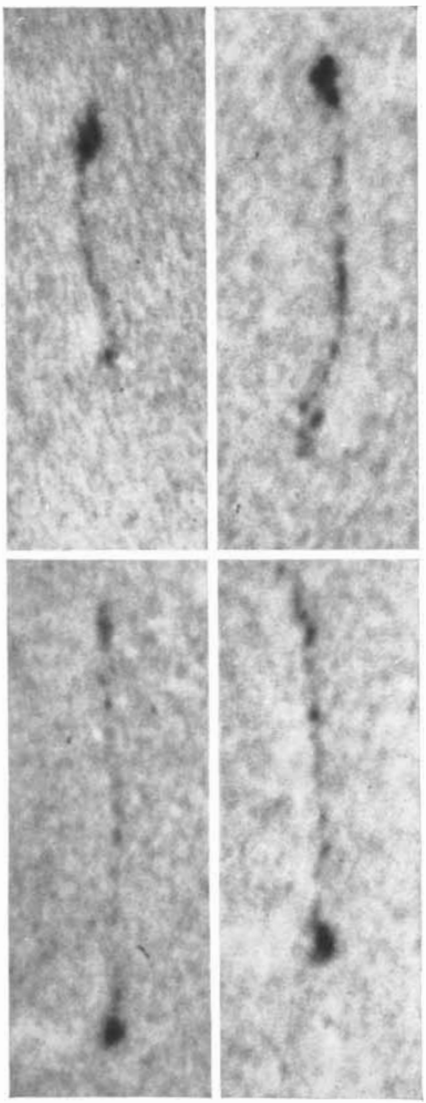
SEPARATED FILAMENTS are from rabbit muscle that has been homogenized in a Waring blendor. The dark, thick strands are filaments of myosin. The very faint thin strands are filaments of actin. Thin filaments are still attached to remnant of *Z* line (*dark patch at top center*). Filaments are enlarged some 35,000 diameters.

material but also in sectioned specimens. It is now apparent that the absence of cross-bridges from this region is responsible for the mysterious pseudo *H* zone. This zone maintains its uniform size at various muscle lengths because it is a structural feature of the filaments themselves and is not created by their pattern of overlap.

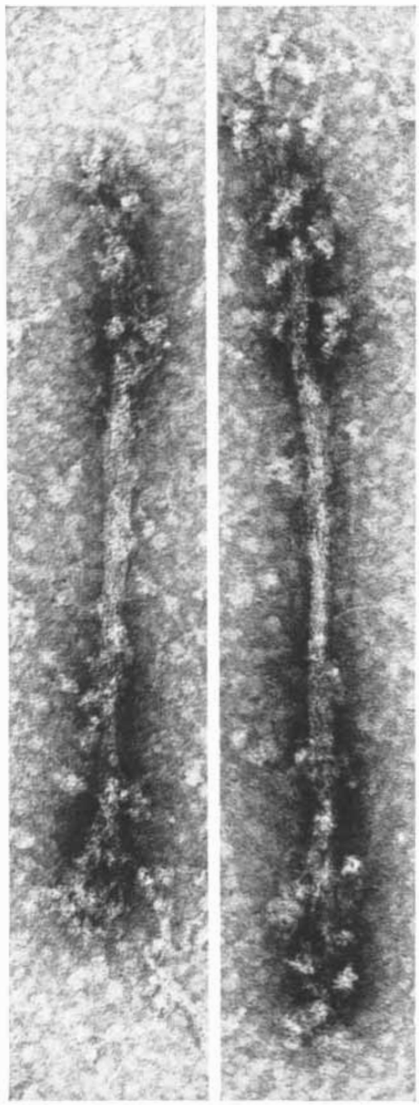
At first sight the projection-free middle region of the thick filaments did not seem particularly significant. It was conceivable that the region was composed of some other protein constituent of muscle. The situation was transformed, however, when we found that filaments of virtually the same appearance could be synthesized from purified solutions of myosin, the protein that is the main component of the thick filament.

The myosin molecule is known to be an elongated structure with a length of about 1,500 angstroms and a diameter of 20 to 40 angstroms. It can be split (by the enzyme trypsin) into two well-defined fragments; the fragments were named light meromyosin and heavy meromyosin by Andrew G. Szent-Györgyi of the Institute for Muscle Research in Woods Hole, Mass. The heavy-meromyosin fragment has the ability to split a phosphate group from ATP and the ability to combine with actin. The light-meromyosin fragment possesses neither of these attributes but retains the solubility properties that enable it to form the same kind of structure that intact myosin does. The molecule of heavy meromyosin appears to be more globular than the molecule of light meromyosin. The dimensions of the fragments suggest that before cleavage of the myosin molecule they are arranged in simple end-to-end fashion.

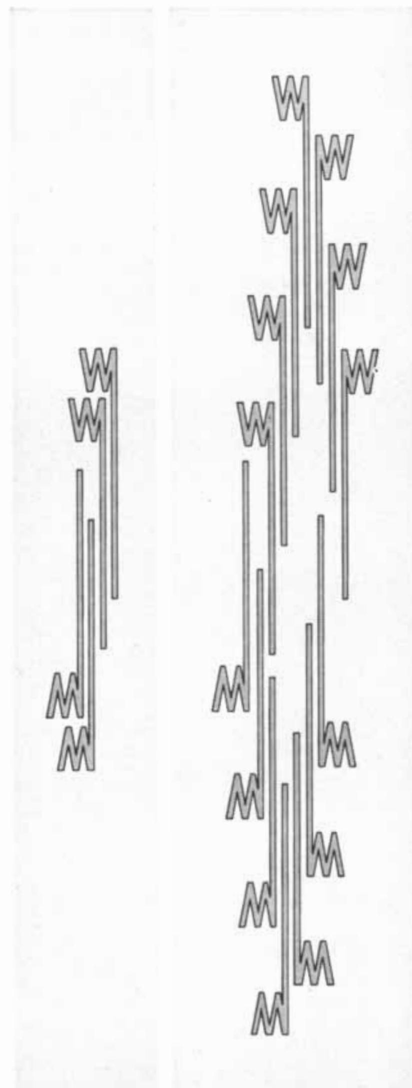
Isolated myosin molecules have been examined under the electron microscope, first by Robert V. Rice of the Mellon Institute in Pittsburgh and subsequently by other workers, by means of the technique known as shadow-casting. This entails treating particles on a film in a vacuum by spraying them at an angle with a vaporized heavy metal.



MYOSIN MOLECULES appear in electron micrographs prepared by shadow-casting method. The wide head has enzymatic properties and combines with actin. The straight tail can aggregate with other myosin molecules. Magnification is 300,000 diameters.



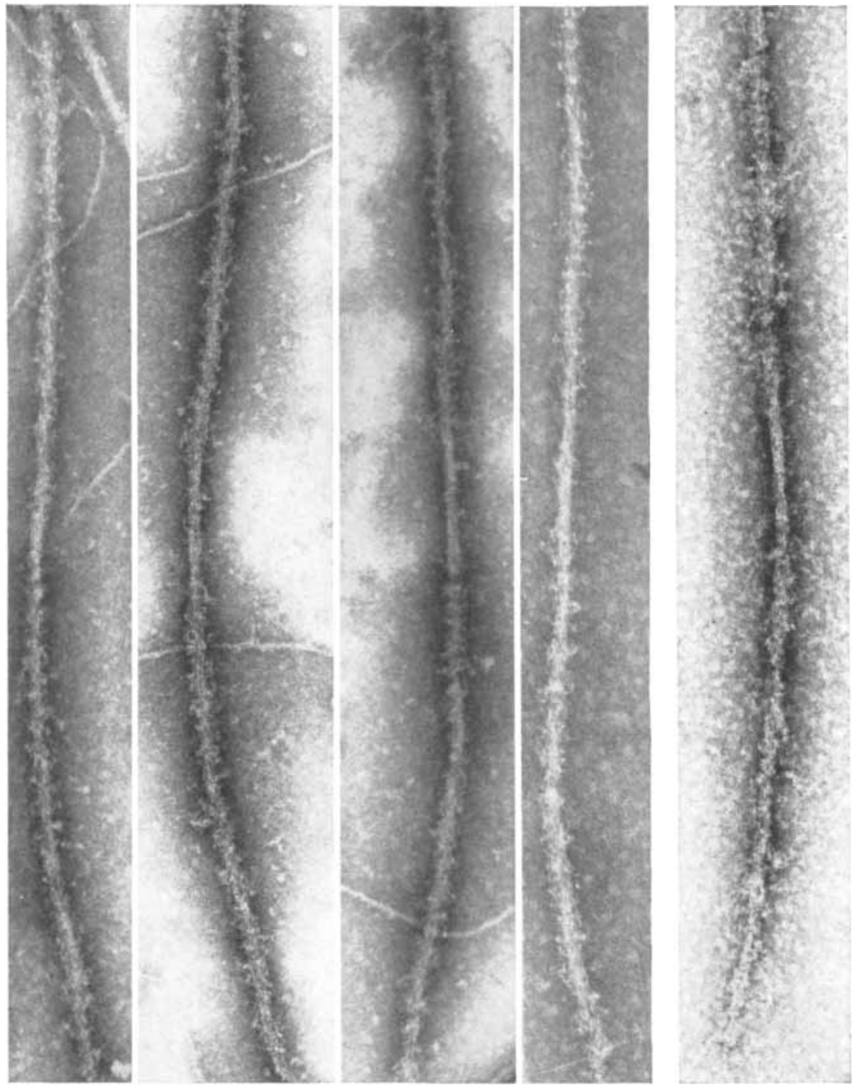
AGGREGATIONS of several molecules from a precipitate of pure myosin were negatively stained and magnified 175,000 diameters to reveal their characteristic appearance: a thick strand with projections near the ends and a bare region in the middle.



MOLECULAR STRUCTURE of myosin makes it aggregate in the manner shown here. Head of molecule is schematically represented by zigzag line, tail by straight line. Tails join in center; heads extend as projections at ends, oppositely pointed at each end.

In forming a layer over the sample the metal builds up the particles on the near side and leaves a shadow on the far side, where it is blocked from landing on the underlying film. When myosin molecules are prepared by this method for viewing in the electron microscope, they appear as linear structures with a globular region at one end [*see illustration at left on opposite page*]. Heavy-meromyosin fragments are seen to consist of a large globular head with a short tail. Light-meromyosin fragments appear as simple linear strands. It therefore seems that the intact myosin molecule is asymmetric—a molecule with a head and a tail. The sites (perhaps a single site) responsible for its enzymatic activity and its affinity for actin are located in its globular head, and the sites responsible for its affinity for other myosin molecules are in its tail. The head, which is 40 angstroms in diameter, accounts for about a sixth of the length of the molecule; the tail, 20 angstroms in diameter, accounts for the rest.

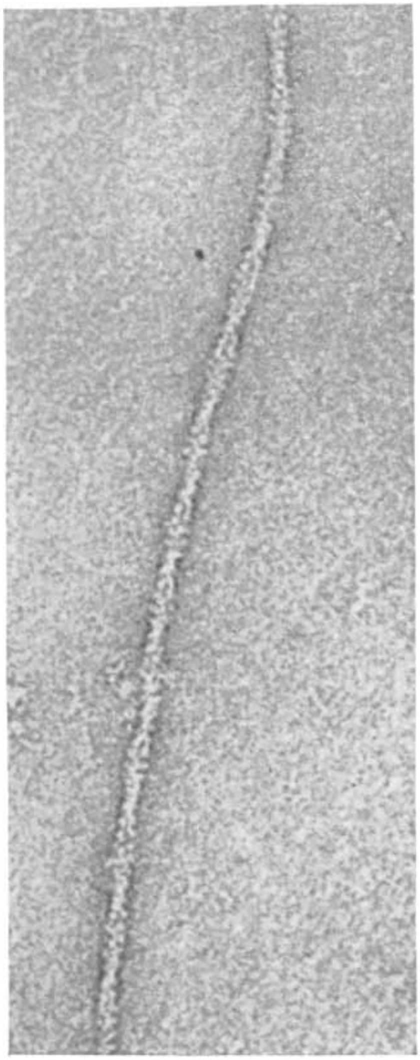
It is known that under certain conditions purified myosin in potassium chloride solution will precipitate. When we examined such a precipitate by the negative-staining technique, we were delighted to find that it consisted entirely of filaments. They varied somewhat in length and diameter but generally bore a most remarkable resemblance to the thick filaments prepared directly from muscle. Systematic examination of these synthetic filaments, first of short filaments only two or three times the length of a single myosin molecule and then of longer ones, turned up an even more remarkable feature. The shortest filaments were straight rods some 1,500 to 2,500 angstroms long, with clusters of globular projections at both ends. It occurred to us that we were looking at a small number of myosin molecules arranged in two opposite directions, with their globular heads forming the projections and their linear tails overlapping [*see middle illustration on opposite page*]. Longer filaments had longer clusters of projections, but the projection-free region in the middle of each filament was the same length as the corresponding region in the shorter filaments. The longest synthetic filaments we observed closely imitated the appearance of thick filaments extracted from muscle. It seems clear that myosin filaments grow by the addition of molecules parallel to the molecules that have already aggregated. The molecules are oriented in one of two opposite directions, depending on which end of the filament a given molecule is joining. It is this method of construction that gives rise to the projection-free region in the synthetic filaments and of course to the same feature in the natural filaments.



MYOSIN FILAMENTS were obtained directly from muscle homogenized in a blendor (*four electron micrographs at left*) for comparison with a synthetic filament from precipitate of pure myosin (*micrograph at right*). The thick filaments from muscle and the synthetic filament have the same form, characterized by the bridge-free zone in the center and the projections clustered at each end. The filaments are enlarged some 105,000 diameters.

This study of myosin molecules and the way they aggregate impressed on us two features that explain the role of these molecules in muscle. First, the head of the molecule has the enzymatic and actin-binding properties we have long assumed the cross-bridges must have. Second, because the molecules aggregate with their heads pointed in one direction along half of the filament and in the opposite direction along the other half, they have an inherent directionality. The first observation leads us to conclude that the heads of myosin molecules serve as the cross-bridges connecting the thick and thin filaments in muscle. The second is important because it explains a crucial feature of the sliding-filament hypothesis at the molecular level.

In a sliding-filament system in which a relative force is developed between actin and myosin molecules located in the two types of filament, it is essential that the appropriate directionality of sliding be built into the filaments in some way. In a striated muscle the thin filaments move toward each other in the center of the *A* bands, so that it is required that all the elements of force generated by the cross-bridges in one



ACTIN FILAMENT has a characteristic structure, visible in micrograph in which filament is enlarged some 420,000 diameters. The filament has the appearance of two coils of globular units wound in a double helix.

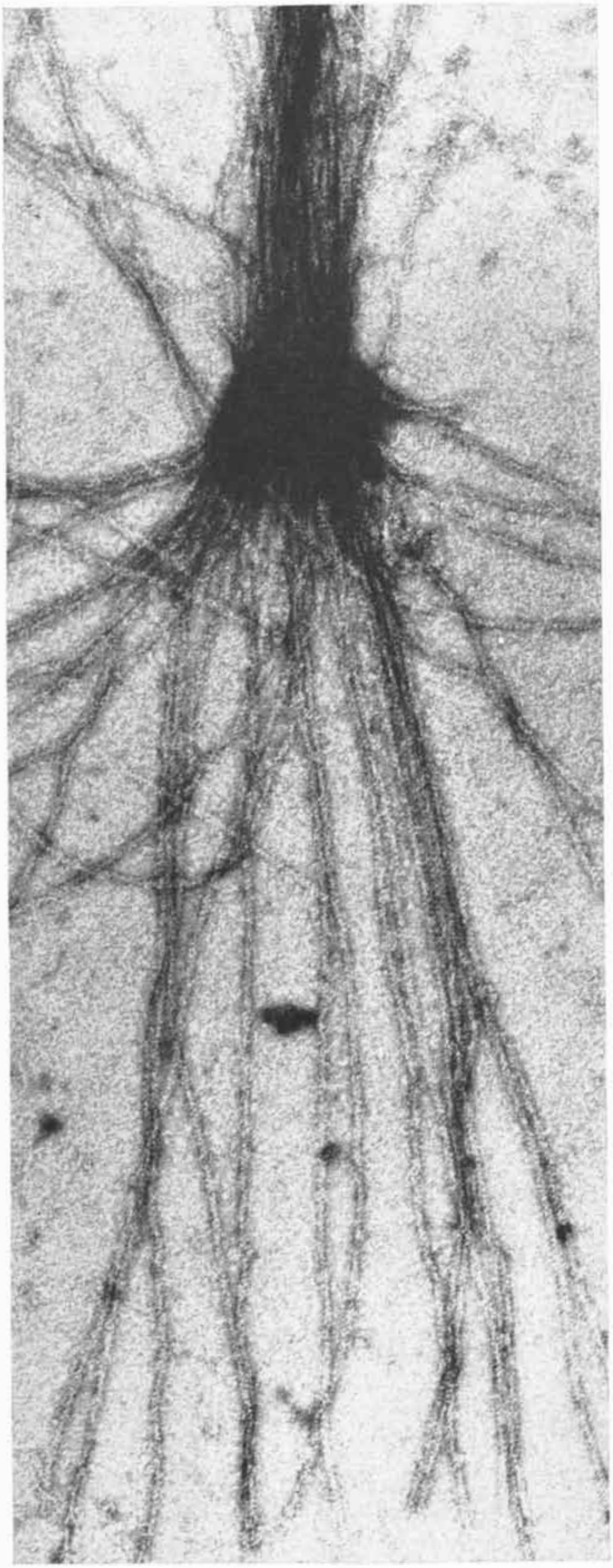
"ARROWHEADS" point in one direction along each filament of actin labeled with heavy meromyosin (extract of the globular halves of myosin molecules), implying that actin has an inherent polarity of its own.

half of the *A* band be oriented in the same direction, and that the direction of the force be reversed in the other half. The direction of the force developed as a result of the interaction of actin and myosin would depend either on the orientation of the myosin molecules, the orientation of the actin molecules or both. Our electron microscope observations suggest strongly that all or part of this directionality is achieved by the fact that the myosin molecules are arranged so that they point in the same direction in half of each thick filament (and hence in each *A* band) and in the opposite direction in the other half [*see illustration at right on page 22*]. Moreover, we have shown that filaments with this essential reversal of polarity at their midpoint will assemble themselves automatically in vitro from purified preparations of myosin; this finding has obvious relevance to problems of how muscle develops its structure.

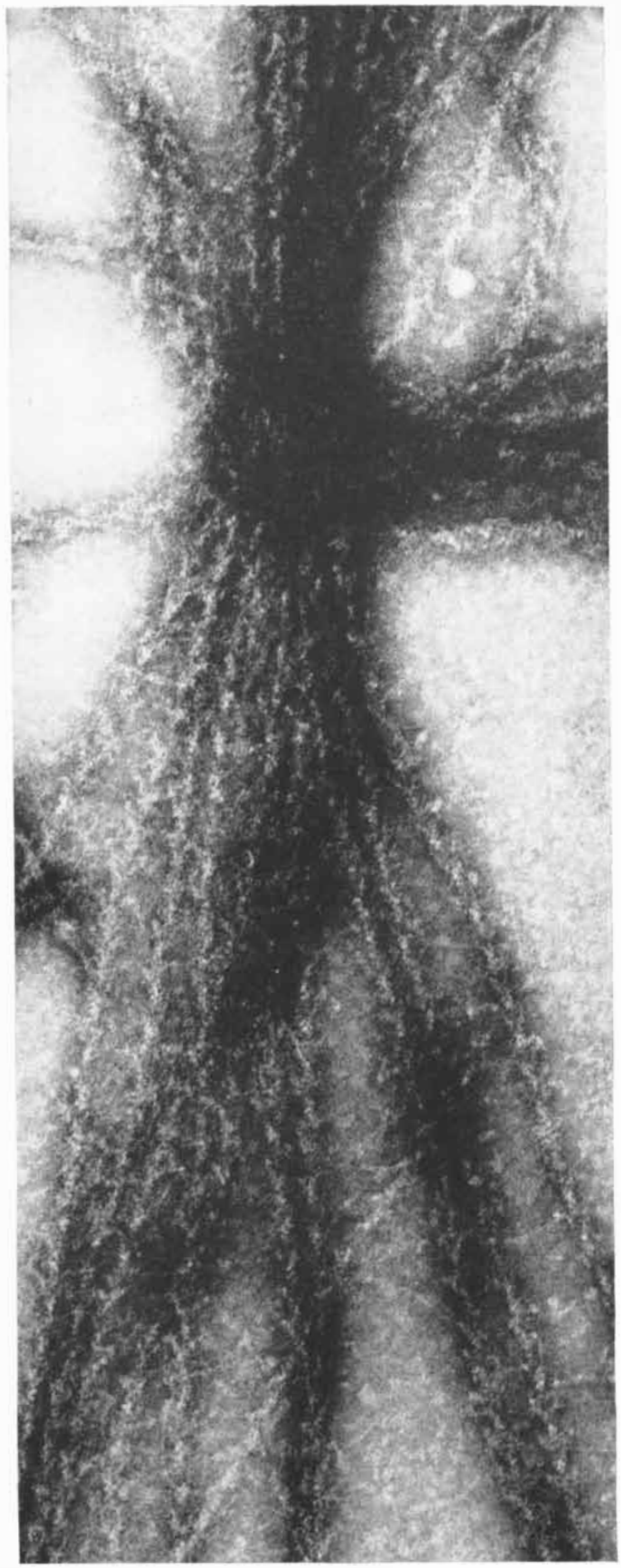
Let us now turn to the thin filaments. It was first noticed by Jean Hanson and J. Lowy of the Medical Research Council unit in London that the thin filaments from the smooth muscle of clams had a characteristic beaded appearance. They were able to show that the filament had the form of a double helix consisting of two chains of roughly globular subunits, the chains twisted around each other so that viewed from a given direction the crossover points were about 360 angstroms apart [*see illustration at left on this page*].

The thin filaments from striated muscle show an identical structure; it can often be seen even when they are still attached to a Z line. Filaments made from actin prepared by standard biochemical techniques again show the same pattern. Thus we can confirm that the thin filaments of striated muscle do contain actin, as we had supposed. We can also deduce that the globular subunits are molecules of actin that aggregate to build up the filament. The structure itself might resemble two strings of beads twisted around each other; its alternating high points and low points suggest a general arrangement for the successive active sites on the filament to which the cross-bridges may attach themselves (assuming that each globular unit has one site). We cannot directly view enough of the internal structure or shape of the subunits to make any deductions about their directionality. To reveal such polarity we have used a natural marker, namely heavy meromyosin, the fragment of myosin that combines with actin.

When actin filaments are treated with a solution of heavy meromyosin and examined in the electron microscope by negative staining, they assume a complex appearance that we do not yet understand in full detail. Nevertheless, one salient feature stands out immediately: the filaments of the resulting compound have a well-defined structural polarity that manifests itself in an obvious arrowhead pattern [*see illustration at right on this page*]. The arrows always point in the same direction over the length of a given filament, even when only dilute solutions of heavy meromyosin have been applied and the arrow pattern is interrupted by long stretches of normal uncombined actin. If the polarity were imposed by some local condition such as the direction along the actin filament at which a series of heavy meromyosin molecules were attached during the formation of the compound filament, one would expect the pattern of arrowheads to lack such consistency. Therefore it would seem that it is the underlying structure of the actin that imposes the pattern. Precisely which feature of the myosin-actin combination gives rise to the arrowhead effect is unclear; it may well be that the pattern reveals the actual orientation of some part of the heavy-meromyosin fragments. A general feature can be deduced, however: all the actin molecules in a filament will combine with heavy meromyosin in precisely the same way [*see top illustration on page 26*]. We can conclude that all



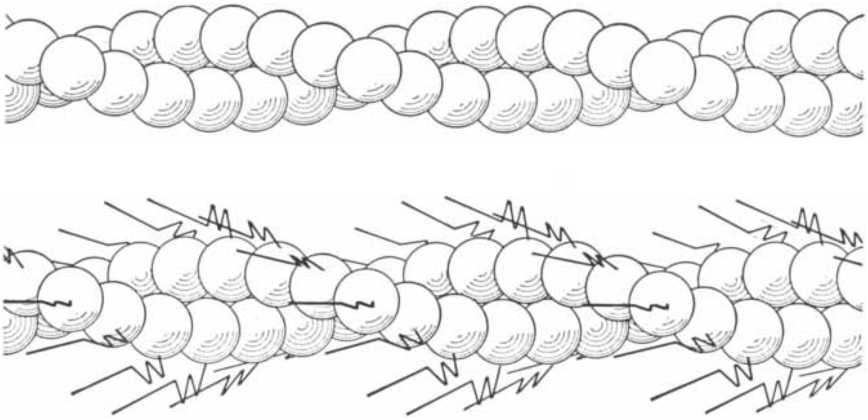
Z LINE, the membrane that forms the end of a sarcomere, appears as dark region from which strands radiate. The strands are thin actin filaments that comprise the *I* band. At times, as in this instance, they remain attached even after muscle has been homogenized. This micrograph and one at right were made by negative staining. They both have magnification of some 165,000 diameters.



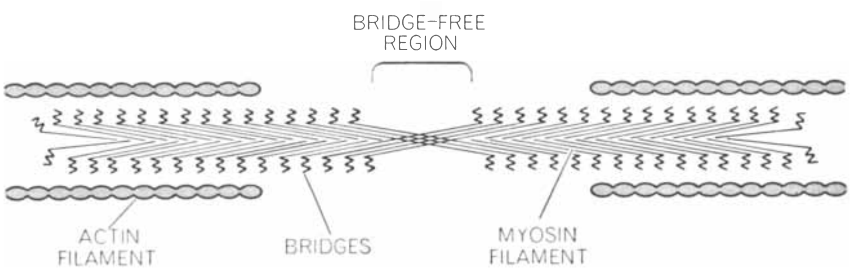
DIRECTIONALITY OF ACTIN is demonstrated when thin filaments attached at the *Z* line are labeled with heavy meromyosin. Arrowheads form, pointing away from the *Z* line on each side. In this micrograph they point up at top of *Z* line, down at bottom. Opposite orientation of the two *I* segments of a sarcomere enables filaments from left and right *I* segments to converge on center.

the actin molecules in a given thin filament are oriented in the same sense and that they can all interact in identical fashion with a given myosin cross-bridge.

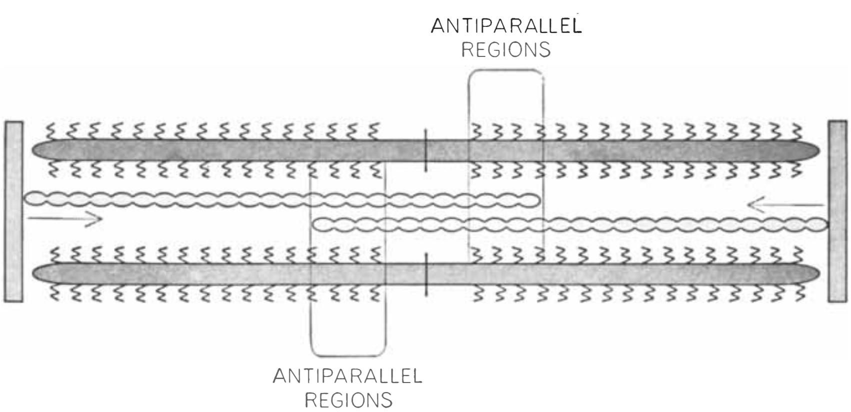
We have used the same technique to investigate the way in which the actin filaments are attached at the Z lines. As I have mentioned, preparations of thin filaments from homogenized muscle frequently contain groups of filaments still connected to both sides of a Z line. We find, in examining such assemblies after treatment with heavy meromyosin, that the arrows on all filaments always point away from the Z lines. The filaments forming the *I* substance on one side of a Z line are all similarly oriented; on the opposite side of the Z line the orientation is reversed. This is exactly the arrangement we require in order for the same relative orientation of the actin and myosin molecules to obtain in the two halves of the *A* bands but for the absolute orientation to be reversed. The direction of the forces developed will consequently be reversed and the actin filaments can move in opposite directions, that is, toward each other in the middle of the sarcomere.



STRUCTURE OF ACTIN is represented by two chains of beads twisted into a double helix (*top*). The way in which actin might combine with heavy-meromyosin fragments to give rise to arrowheads apparent in micrograph at right on page 24 is suggested at bottom.



CONTACT OF ACTIN AND MYOSIN in muscle might be made in the manner schematically illustrated here. The thin actin filaments at top and bottom are so shaped that certain sites are closest to thick myosin filament in the middle. The heads of individual myosin molecules (*zigzag lines*) extend as cross-bridges to the actin filament at these close sites.

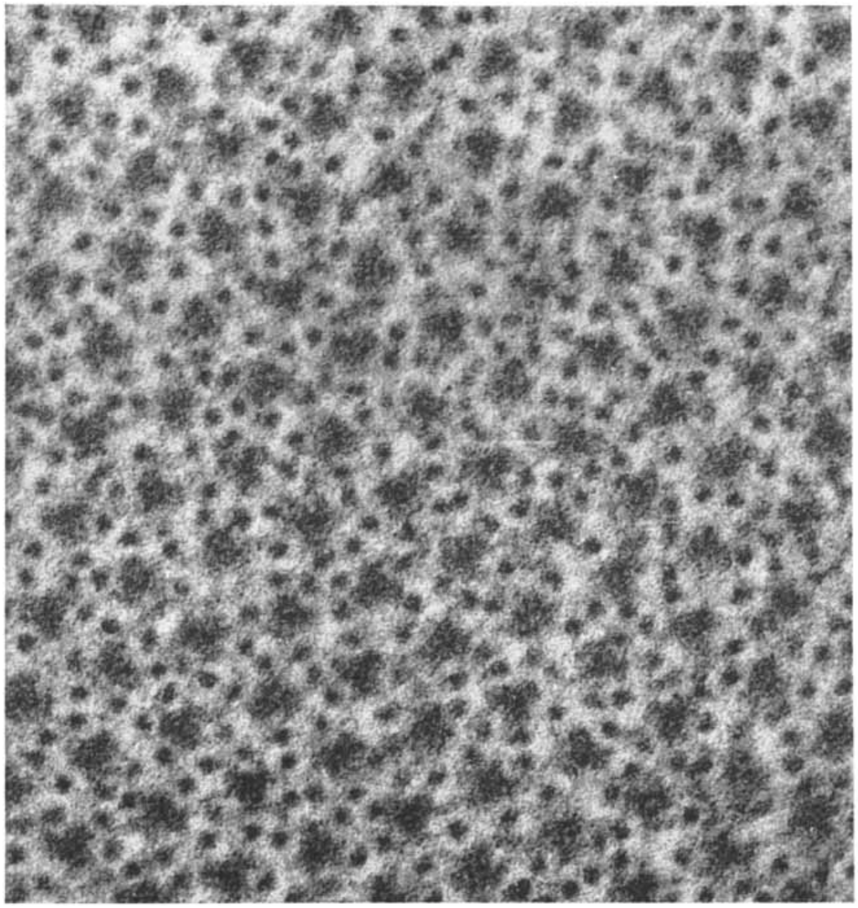


DOUBLE OVERLAP of thin filaments from each side of the sarcomere would result if the sliding-filament hypothesis is essentially correct. It is now assumed that muscle generates maximum tension when thin filaments reach center of *A* band, and that tension falls when thin filaments cross the center and interact with improperly oriented cross-bridges.

We conclude that both the thick and the thin filaments in a striated muscle are assembled and oriented in such a way that if a relative force were developed between a given actin and myosin molecule in either filament, all the elements of force in the whole system would be added together in the appropriate manner to give rise to the organized behavior we have observed. Several years ago we tentatively proposed the analogy of a ratchet to describe the interaction of sliding filaments. Now our understanding of the way in which cross-bridges of myosin seem to hook onto consecutive active sites on the actin filament makes the analogy seem even more appropriate.

Recently we have examined with our improved electron microscope techniques sections of muscle fixed at various stages of contraction. The filament lengths, measured by Sally G. Page of University College London, appear to remain constant and equal to the corresponding lengths in resting muscle (discounting small changes in length from tension during fixation and other preparative steps). The most interesting feature of the contraction sequences we have studied is that at the shorter sarcomere lengths a dense zone appears in the center of the *A* band; the zone progressively increases in width as the muscle shortens. This zone first appears after the *H* zone has closed up completely. We had shown previously that the closing of the *H* zone during shortening is caused by the ends of the thin filaments sliding toward each other in the center of the *A* band. Now when we measured the distance from the Z line to the opposite end of the new dense zone, we found that it was still equal to the length of the thin filaments. We therefore suspected that the new zone might correspond to a region where the thin filaments from each end of the sarcomere overlap [*see illustration on page 19*].

This view was confirmed when we examined cross sections of muscle cut through the region of supposed double overlap. Instead of the normal pattern of thick and thin filaments in regular hexagonal array with twice as many thin filaments as thick ones, the pattern was less regular and there were four times as many thin filaments as thick ones [*see illustration at right*]. Apparently we were seeing the thin filaments from both ends of the sarcomere at the same time, and these must have slid past one another during the shortening. This finding confirmed that the simple sliding process describes the behavior of the thin filaments under all conditions. (Objectors had proposed, for instance, that the thin filaments might coil up within the *A* bands.) The finding also suggested to our group and to A. F. Huxley, who is now at University College London, a possible explanation for the observable decrease in tension generated by striated muscles at sarcomere lengths shorter than resting length. Tension would fall off in the double-overlap region because there is a progressively increasing penetration of the thin filaments from one Z line into the "wrong" end of the *A* bands. We know that actin molecules in part of a thin filament penetrating the center of the *A* band would have an abnormal orientation with respect to the adjacent cross-bridges [*see bottom illustration on opposite page*]. Such a region would not be expected to contribute to the development of tension by the muscle, and by interfering mechanically and chemically with the interaction of the correctly oriented actin and myosin molecules it might reduce the tension.



CONTRACTED MUSCLE viewed end on in this electron micrograph has four times as many thin filaments (*small dots*) as thick (*large dots*). The regular array of thick filaments is well preserved; the array of thin filaments is not. Since the ratio of thin to thick filaments in relaxed muscle (*evident in micrograph at top of page 21*) is two to one, it appears that actin filaments from each end of the sarcomere overlap during contraction. This transverse section, made by cutting through the center of an *A* band of a muscle from the leg of a frog (the method used in making section at top of page 21), is enlarged 250,000 diameters.

Can we extend our investigations to consider changes in the arrangement or configuration of the actin and myosin molecules in muscles that are actually contracting? This goal has indeed been attained, thanks to the sophistication of a technique long used in the study of muscle: X-ray diffraction. Untreated muscle reflects X rays in a regular pattern. We can compare the way in which contracted and relaxed muscles reflect X rays and thus determine if activation and the development of tension are associated with appreciable changes in the length of the repeating units of pattern formed by the arrangement of actin and myosin molecules within the filaments (and hence with possible changes in filament length). Two groups of workers—W. Brown, K. C. Holmes and I in Cambridge, and G. F. Elliott, Lowy and B. M. Millman at the Medical Research Council Biophysics Research Unit at King's College in London—have independently conducted such studies, and both groups report that no such changes in length occur during contraction.

Another exciting finding, reported by our group, is that the relative intensity of some of the X-ray reflections associated with myosin filaments changes greatly during contraction. (Subsequently the London group reported observations consistent with our findings.) These effects have still to be analyzed in detail, but they indicate a substantial movement of the cross-bridges during contractile activity. Very recently members of our group and a group of investigators under J. W. S. Pringle at the University of Oxford have demonstrated a movement of the cross-bridges associated with the contraction of insect flight muscle. These latest findings open up new possibilities. Now that we know that measurable changes in the X-ray reflections do in fact occur during contraction, we have a method of distinguishing steps in the process by which energy for contraction is obtained.

A contracting muscle offers a uniquely favorable system for studying the outstanding problems of protein structure and function. In muscle we have now clearly identified the interacting protein molecules, the high concentration in which they are present and their regularity of arrangement. The major unsolved question about contractility is a general question of biochemistry: how do proteins act as catalysts for biochemical reactions, and what happens to them in the process? It is interesting in this regard to recall that ATP itself was first identified as the source of energy in the contraction of muscle and subsequently as the universal carrier of chemical energy in the living cell. We expect that the study of the precise basis of contractility will also lead to broadly applicable results.

Violations of Symmetry in Physics

Of seven "mirrors" invented by physicists to describe the symmetry of the laws of nature, three have been shattered. Of those remaining, only one may still be wholly intact. It is called the CPT *mirror*

by Eugene P. Wigner

It was just nine years ago this month that physicists learned to their astonishment that left-handedness and right-handedness are built into the universe at the most fundamental level. Until December, 1956, they had assumed that if an event is possible, its mirror image is also possible, and that if one looks at some real event in a mirror, what one sees could also actually happen. This was known as reflection symmetry, and it forms the basis of the parity principle. In the summer of 1956 certain puzzling phenomena in nuclear physics led T. D. Lee and C. N. Yang to question the principle's general validity. In a few months C. S. Wu, Ernest Ambler, Dale D. Hoppes and R. P. Hudson had demonstrated that the phenomena clearly violated the principle.

The parity principle was one of several symmetry principles that physicists had long accepted as axiomatic in developing their mathematical theories. With the fall of parity they became uneasy about the other principles and sought ways to test each of them in turn. As a result of this endeavor at least two more principles have fallen and a third has been called into serious question. This is time symmetry: the principle that nature is indifferent to the direction in which time flows. Physicists have believed deeply that nature is similar to an electric clock that will run forward or backward, depending on which way the starting knob is turned.

The various symmetries can be compared to mirrors that reflect natural events in carefully specified ways. The parity mirror, which we shall designate the *P* mirror, is simply the ordinary mirror of everyday life. It has one property, however, that may puzzle the layman; accordingly we shall also let "*P* mirror" stand for "physicists mirror" in order to distinguish it from the layman's mirror, which we shall call the *L* mirror.

Everyone is familiar with the fact that when an electric current flows in a coil of wire, it induces a magnetic field. We learned in school that the direction of the field—the direction of its north magnetic pole—can be determined by the "right-hand rule." This rule states that if the forefinger of the right hand has the shape and direction of the current flow, the thumb of the right hand points to the north pole of the induced magnetic field.

The early students of electricity defined the direction of current flow as being from the positive terminal of a battery to the negative. Now that we understand that an electric current depends on the flow of electrons, it seems more reasonable to speak of the direction of electron flow, which is from the negative terminal to the positive. Therefore if we are told the direction in which electrons flow in a coil of wire, we must use a *left-hand* rule to determine the direction of north in the magnetic field. (We realize, of course, that "north" and "south" are themselves conventions based on the fact that a compass needle is said to point toward the earth's North Pole.) In any case, in this article the direction of the magnetic field will be considered in relation to electron flow, which requires the left-hand rule. The reader is no doubt familiar with these elementary principles, but reviewing them may help to prevent confusion when we begin to look into mirrors.

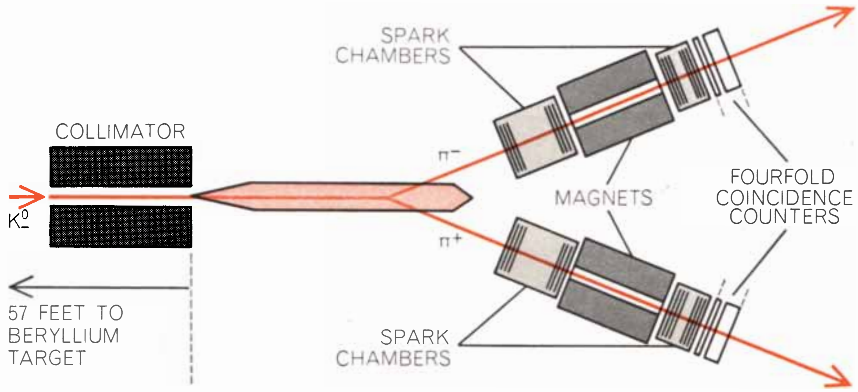
Let us examine the parity mirror first. Imagine that we have before us on a table a coil of wire in which electrons are flowing clockwise as seen from above. The left-hand rule tells us that the induced magnetic field is pointing upward [*see illustration on page 30*]. Now imagine that there is a mirror on the ceiling directly over the table; what will we see in it? If we have placed our left hand next to the coil and shaped it to form the left-hand rule, we shall see in the mirror what appears to be a right hand with the thumb pointing down. The hand in the mirror tells us (correctly) that the electron flow as seen in the mirror is counterclockwise, but it also tells us (incorrectly) that the magnetic field is pointing down. The hand in the mirror misinforms us about the direction of the magnetic field because it is (or appears to be) a right hand, and a real field is related to a real electron flow by a left hand. If we accept the right-hand (incorrect) view of the field direction, we can be said to be interpreting the mirror image as laymen; in this sense the mirror is an *L* mirror. If, however, we insist as physicists that the electron flow is the prime reality and that the magnetic field is secondary, we will insist on using the left-hand rule to determine the direction of the magnetic field in the mirror and conclude that it is actually pointing back into the mirror and not out of the mirror. Thus the magnetic field on the tabletop and the field in the mirror—the physicist's *P* mirror—are pointing in the same direction [*see illustration on page 31*].

We can now describe the parity experiment performed by Miss Wu and her collaborators. In the center of a ring of electric current they placed some radioactive cobalt, which emits electrons and neutrinos when it decays. The whole experimental arrangement has a plane of symmetry: the plane through the ring current. There is nothing to distinguish the upward from the downward direction. It nevertheless turned out that the electrons from the decaying cobalt atoms emerged asymmetrically: almost exclusively in the upward direction. If one were to place a mirror over the experiment, parallel to the plane of the ring current, the electrons would appear to be coming out of the mirror, or downward, which is not the direction they would travel if the current and radioactive material were real rather than mirror images [*see illustration on pages 32 and 33*].

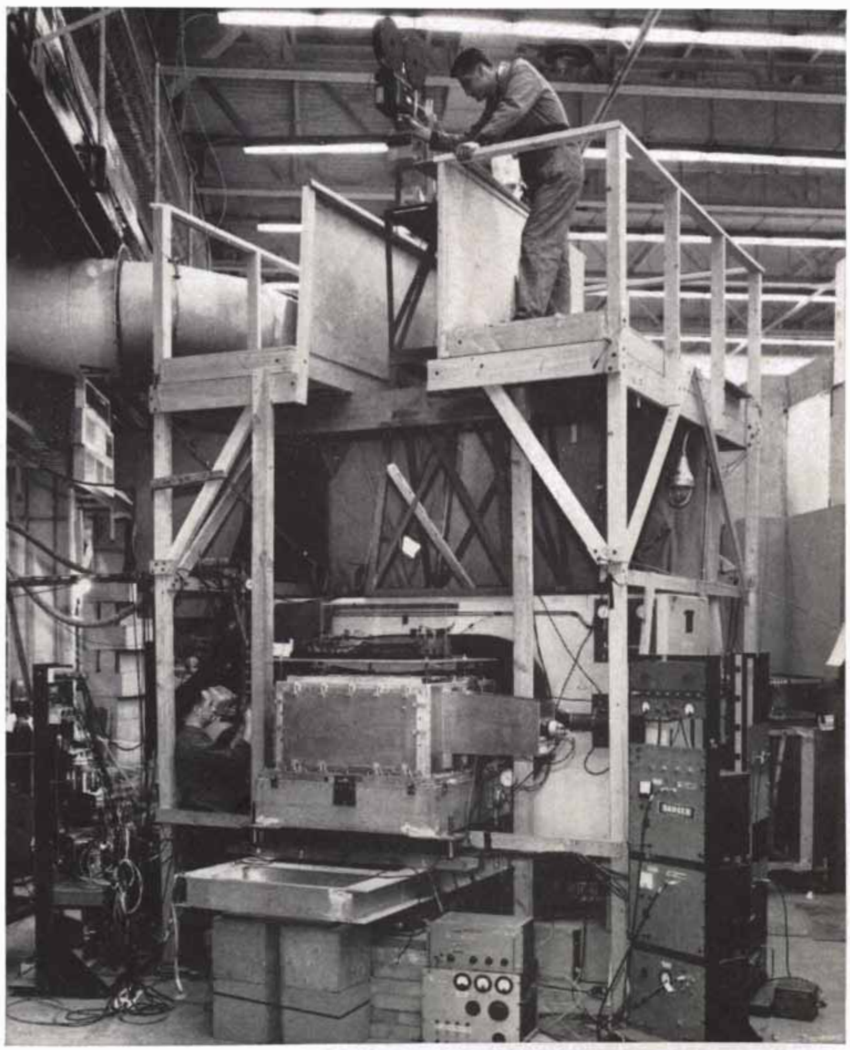
This unexpected result attracted a great deal of attention—and a Nobel prize. The fact that the electrons emerged with a preferential direction, a direction that can be represented by the thumb of the left hand if the forefinger has the shape and direction of the electron flow, meant that the radioactivity of cobalt is partial toward the left hand.

If I may recall days long past, nobody was very happy with this result. It is a fact, of course, that most of us are as partial toward our right hand as cobalt is toward its left. We feel, however, that radioactive cobalt is not entitled to be partial because it should have forgotten its past and because, at the time it emitted the decay particles, it was under no influence that would have favored one side of the plane of the ring of current over the other. This plane was a symmetry plane at the beginning of the experiment; it should have remained a symmetry plane as long as it was undisturbed by outside influences. This statement is equivalent to the postulate that a possible sequence of real events should remain a possible sequence of events if every event is replaced by its mirror image. Evidently this is not the case for the disintegration process of radioactive cobalt.

Before long a score of physicists had independently proposed a reinterpretation of the Wu experiment that salvaged the principle of reflection symmetry. In essence they proposed that nature does not see itself in the *P* mirror but in a "magic mirror" where the signs of all electric charges are reversed. In this mirror the mirror image of an electron is a positron (a positive electron) and the mirror image of a radioactive cobalt nucleus is a similar nucleus made of antimatter (antineutrons and antiprotons). If one could view the Wu experiment in this proper mirror, one would see positrons flowing in the direction that electrons had been assumed to flow. Since a flow of positrons is equivalent to a flow of positive cur-



FALL OF TIME REVERSAL seems implied by an experiment showing that the K_-^0 particle (also known as K_2^0) sometimes decays into two pi mesons (π^+ and π^-) instead of into three pi mesons, as required by *CP* symmetry. If the K_-^0 decays anywhere in the colored area there is a chance that the decay particles will pass through the two magnets and four spark chambers. The spark chambers are triggered to fire and thereby reveal particle tracks only if all four coincidence counters register the passage of a particle. The magnets produce a deflection (perpendicular to the plane of the page) that indicates the particle's momentum. The experiment was performed at the Brookhaven National Laboratory by James H. Christenson, James W. Cronin, Val L. Fitch and René Turlay of Princeton University.



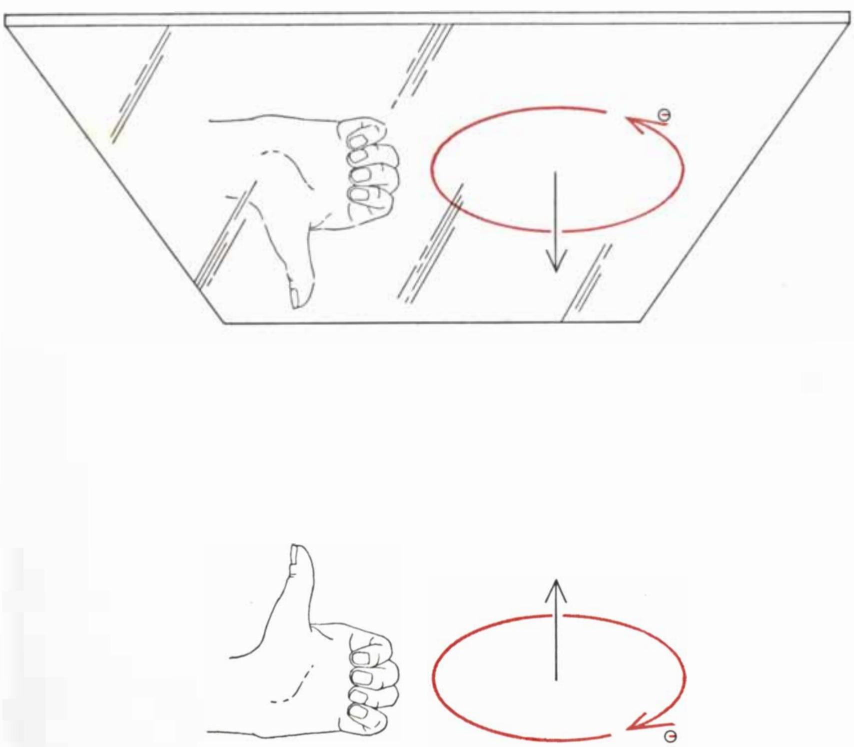
***K*-PARTICLE-DECAY EXPERIMENT** is being continued at Brookhaven National Laboratory by Cronin, Fitch and their associates, using the apparatus shown here. The motion picture camera atop the scaffold is used to record particle tracks in the spark chamber below it.

rent, one would have to use a *right-hand* rule to see how the magnetic field is pointing. One would then discover that the magnetic field is pointing out of the mirror, or downward, and thus directly opposite to the magnetic field in the real experiment. The decay particles emitted by the antimatter nuclei of radioactive cobalt would also tend to travel out of the mirror, or downward, thereby completing the mirror image of the Wu experiment [*see illustration at right on page 33*].

This reinterpretation of reflection symmetry was originally pure speculation, motivated solely by the desire to maintain the principle of reflection symmetry for the laws of nature. An experimental test was out of the question: even today we are far from being able to produce anticobalt, that is, a cobalt nucleus consisting of antiprotons and antineutrons. It was possible, however, to test the new hypothesis in other ways. The reinterpretation turned out to be relevant and was in agreement with all experimental findings until quite recently. These findings include the direction of flight of particles emitted in decay reactions other than that of radioactive cobalt. In particular there is a case in which a radioactive particle as well as its antiparticle can be produced and observed. These particles are the muon and the antimuon; the decay of the antimuon looks in all details as the image of the decay of the muon would look in the magic mirror just described.

We have not yet mentioned the role of the ring current in Miss Wu's experiment. Its purpose is to create a magnetic field perpendicular to the plane of the current. This field in turn orients the spins of the nuclei of the radioactive cobalt atoms. The direction of the decay particles is related directly to the spins of the radioactive nuclei emitting them, and only indirectly by means of the magnetic field to the direction of the flow of electrons in the ring.

The spins of the cobalt nuclei carry an angular momentum, a fundamental property associated with rotating motion. In all studies of rotating motion before Miss Wu's experiment angular momentum was found to have a symmetry plane in the plane of rotation. If this plane were kept horizontal, one would expect the disintegration products (if any) of a rotating object to proceed with equal probability upward and downward. The fact that they do not when the rotating object happens to be a radioactive cobalt nucleus means that the total symmetry of the laws of nature is smaller than physicists had previously believed. The laws are not invariant if reflected in a *P* mirror. The magic mirror that gives a true reflection is called a *CP* mirror; it is a combination of the parity (*P*) mirror, which reflects the positions of particles, and a "charge conjugation" (*C*) mirror, which changes the sign of electric charges.



"LAYMAN'S MIRROR" **provides incorrect picture of the relation of a magnetic field to the flow of electrons in a coil of wire. The "left-hand rule" applied to an actual electric coil (*bottom*) shows by the thumb direction that magnetic north (*black arrow*) points up when the forefinger of the left hand is curved in the direction of the flow of electrons (*colored arrow*). When the left hand is reflected in the mirror, however, it becomes a right hand, thereby indicating (incorrectly) that the magnetic field is pointing down. In the "physicist's mirror," shown on the opposite page, the field is shown (correctly) to be pointing up.**

How many mirrors has the theoretician conceived all together? I hope that we will not be suspected of patent-preemption if we claim to have "invented" seven mirrors. They are essentially various composites of the *P* and *C* mirrors and a third mirror: the *T* mirror, which reflects the direction of time. The seven mirrors are *P, C, T, CP, CT, PT* and *CPT*.

We have already seen how electric currents and magnetic fields are reflected in the *P* mirror. Let us now consider how the *P* mirror reflects the path of a particle as it is scattered, or deflected, by another particle [*see illustration on page 34*]. We can imagine that the scatterer is a heavy particle, such as an oxygen nucleus, and that the incident particle is a light particle, for example a positron. Thus each particle has a positive electric charge (represented by a plus sign in the illustration). The positron is so light that it will hardly affect the position of the oxygen nucleus; we need be concerned only with the path of the positron as it approaches the oxygen nucleus and is scattered.

We must also take into account the fact that the incident particle has an angular momentum, or spin, and that the axis of spin is parallel to the particle's direction of motion. After the particle has been scattered its direction of motion has changed, and the new direction of motion will be found to correlate with what has happened to the particle's spin angular momentum. If the spin remains pointing in the original direction (remains parallel), the particle's direction of motion will be somewhat above the plane of the original direction. If the spin flips around to point in the opposite direction (becomes antiparallel), the particle's direction of motion will be below the original plane. The particle can traverse either path and will take each path in a certain fraction of all cases observed.

The scattering event in front of the mirror will always be the same, but the image will be different in different mirrors. We shall assume that in each case the mirror is vertical and to the right, that is, between the object and the image. If the mirror is the physicist's *P* mirror, the reflected paths are just what one would expect. The path seen curving to the right in the actual case is seen curving to the left in the mirror. Moreover, the particle's direction of spin is reversed, so that if the particle seems to be spinning clockwise, as seen from the rear in the actual experiment, it will appear to be spinning counterclockwise as seen from the rear in the mirror image.

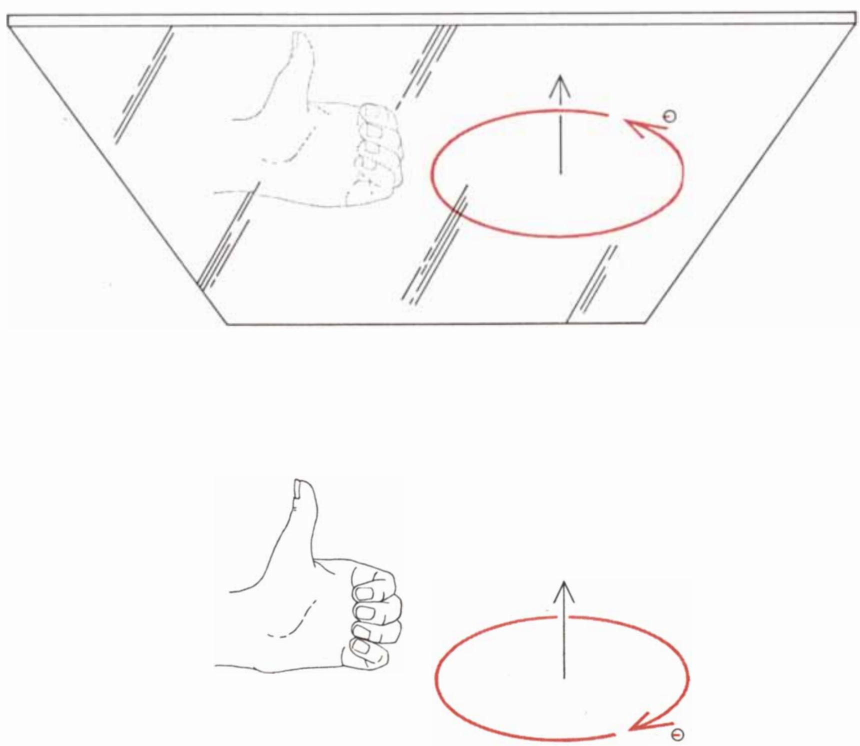
If one carried out this experiment, one would unquestionably find that the *P* mirror is right; with the accuracy of measurement now available one could not detect the difference between a real path and the path as it appears in the mirror. Yet we know from Miss Wu's experiment with radioactive cobalt that the mirror is not really right: in her experiment the *P* mirror gave an entirely incorrect picture. Hence we know that the *P* mirror is not quite right in general and that actuality will deviate from what it shows, even though in our scattering experiment its error would be immeasurably small.

Let us consider now how the scattering experiment looks in the *C* mirror [*see top illustration on page 35*]. The *C* mirror is not, of course, a material mirror: it does not change the location of points, the direction of motion or the sense of spin direction. All it does is substitute negative electric charges for positive electric charges and vice versa; or, more generally, it substitutes antimatter for matter and vice versa. Thus when we "look" into the *C* mirror we see that the oxygen nucleus of our scattering experiment is replaced by an antinucleus consisting of antineutrons and antiprotons, and so has an overall negative charge, and that the positron is replaced by an electron, which is also negatively charged.

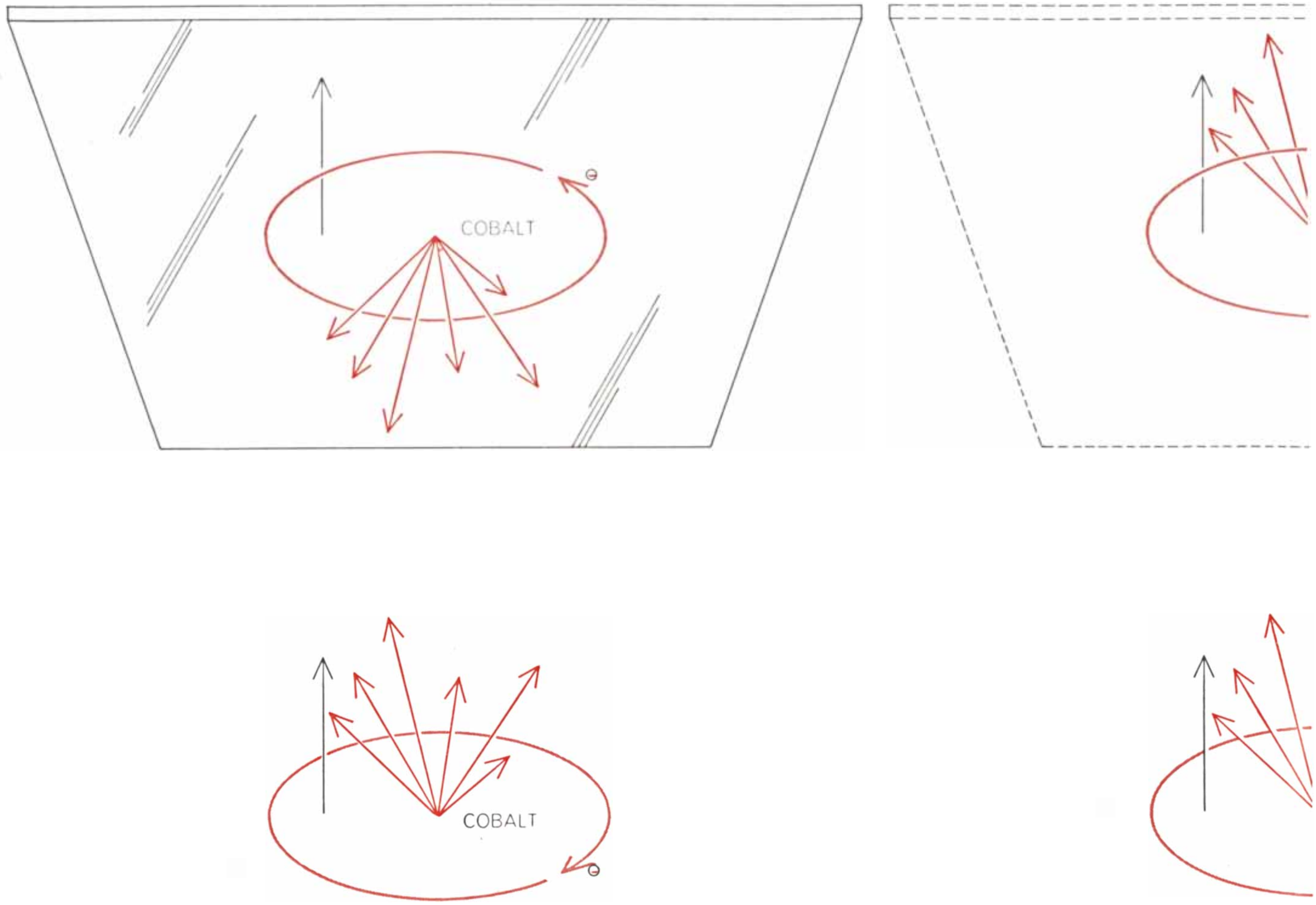
The situation with the *C* mirror is quite similar to that with the *P* mirror. Since no one knows how to make an antimatter nucleus as heavy as the nucleus of oxygen, however, our particular scattering experiment cannot be performed. But it is known from similar scattering experiments with antiparticles that there are no observable differences between actual scattering patterns and their reflections in the *C* mirror. Nevertheless, it has been established by other experiments that *C* reflection is no more an exact symmetry than *P* reflection is. Unfortunately the experimental demonstration of *C* violation is not as direct as Miss Wu's demonstration of *P* violation. The argument for the violation of *C* symmetry is a mathematical one based on the observed spin direction of electrons and positrons that are respectively emitted by negative and positive muons. The experiment was performed in 1957 by G. Culligan, S. G. F. Frank, J. R. Holt, J. C. Kluyver and T. Massam of the University of Liverpool.

If the *P* and *C* mirrors are known to be slightly defective when they are tested individually, is it possible that the magic *CP* mirror mentioned earlier still provides a faithful reflection of reality? The *CP* image can be obtained in either of two ways: by reflecting the *P* image in a *C* mirror or by reflecting the *C* image in a *P* mirror. The fact that the image obtained by two such reflections is an excellent picture of reality follows from the fact that the image produced by each mirror is extremely close to reality if reality is reflected in it. Indeed, until recently physicists believed the slight discrepancies in the individual mirrors canceled each other, so that the *CP* mirror was in exact accord with reality. This certainly seemed to be the case, at least for a number of phenomena that occur in radioactive decays and that violate *C* and *P* separately. Before discussing the experiment that has now cast doubt on the *CP* mirror, I should make a few comments on the *T* mirror.

Like the *C* mirror, the *T* mirror does not change the paths of particles. It merely reverses their direction, thus implying that the time axis is reversed [*see bottom illustration on page 35*]. In fact the designation *T* stands for time-reversal symmetry. The concept is hard to accept intuitively because our everyday experience with events that are patently irreversible is so compelling; the pieces of a shattered teacup have never been known to reassemble themselves spontaneously. Irreversibility of this kind is not at issue. The physicist is concerned rather with the detailed reversibility of events at the atomic and subatomic scale. A model for this kind of irreversibility would be the behavior of



"PHYSICIST'S MIRROR" is also the *P*, or parity, mirror. It is identical with the layman's mirror, but the physicist is alert to deception. He knows that if he were to substitute a real electric coil for the one he sees in the mirror and send electrons flowing counterclockwise as seen from below, the direction of the magnetic field would still follow the left-hand rule. He recognizes, in other words, that the mirror reflection of a left hand (that is, a right hand) is deceiving him about the direction of the magnetic field. He insists as a physicist that the electron flow is the prime reality and that the magnetic field arises as a consequence.



FALL OF PARITY, or reflection symmetry, followed the famous experiment performed in December, 1956, by C. S. Wu, Ernest Ambler and their collaborators. They placed a sample of radioactive cobalt in a magnetic field created by an electric coil and recorded the direction taken by one of the emerging decay products, namely electrons. According to the parity principle, the electrons should have emerged equally up and down; instead they emerged almost exclusively upward, in the direction of the magnetic field, as shown at the bottom in the diagram at left. If the experiment were reflected in the *P* mirror, the electrons would appear to emerge downward. If the radioactive cobalt and electric

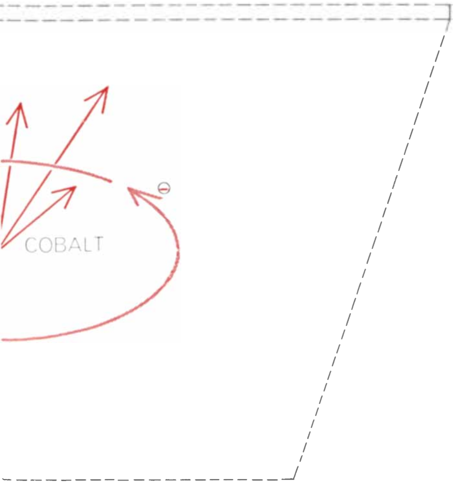
a perfectly elastic ball. If such a ball were dropped on a perfectly elastic surface, it would bounce forever. If one were to make a moving picture of this ball as it bounced, there would be no way to tell whether the film were being run forward or backward; the time axis would be completely reversible.

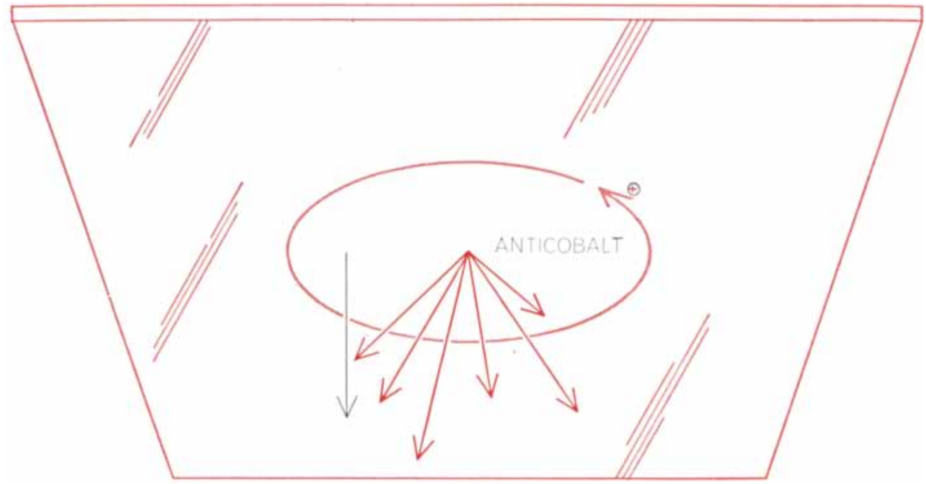
Until recently the *T* mirror, like the *CP* mirror, was believed to be exact. And for reasons I shall describe later, physicists are forced to believe that the combination of the *T* mirror with the *CP* mirror—the *CPT* mirror—may still remain exact, even though the *C*, *P* and *T* mirrors appear to fail separately!

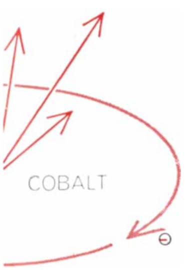
Let us turn to the experiment that has cast doubt on the validity of the *CP* mirror and, by implication, on the validity of the *T* mirror. The experiment was carried out a little over a year ago at the Brookhaven National Laboratory by James H. Christenson, James W. Cronin, Val L. Fitch and René Turlay of Princeton University. One of the original purposes of the experiment was the confirmation of *CP* invariance, not a demonstration of its failure. Experiments occasionally give surprising results, however; this one certainly did. Nonetheless, the evidence for the violation of *CP* invariance is not as direct as the evidence for the violation of *P* invariance furnished by Miss Wu's experiment or even the evidence for the violation of *C* invariance in the experiment of Culligan and his collaborators.

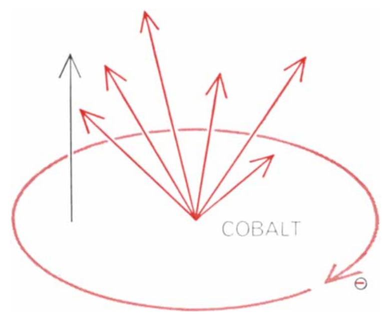
The evidence for the failure of the *CP* mirror stems from one mode of decay exhibited by the *K* meson, or *K* particle. *K* particles are readily produced in a high-energy particle accelerator when a proton beam is directed at a suitable target, such as beryllium. The interaction of a high-energy proton with a neutron (contained in the atomic nuclei of the target) invariably yields two heavy particles, one of which is usually a proton or a neutron. When the bombardment energy is around 30 billion electron volts, as it was in the Brookhaven experiment, the other heavy particle is likely to be one of the so-called strange particles, such as a lambda particle or a sigma particle. Simultaneously the interaction produces a *K* particle, which can be either positive (K^+), negative (K^-) or neutral (K^0).

The *K* meson is a very queer particle. It is the same particle whose puzzling decay behavior prompted Lee and Yang to question *P* invariance. Even before that it was ascertained that the K^0 is not a single particle but two particles that are antiparticles of each other. When a particle has an electric charge, it can easily be separated from its antiparticle because the latter must have an oppo-









current in the mirror were real, the electrons would actually go upward (*middle diagram*). Reflection symmetry had been disproved. The principle was salvaged by declaring that nature sees itself in a "magic mirror," or *CP*

mirror, in which matter is replaced by antimatter. This symmetric relation is shown in the diagram at right, where radioactive cobalt is replaced by radioactive anticobalt and the electrons flowing in the coil are replaced by antielectrons, or positrons. The decay particles, also positrons, then emerge downward. The magnetic field is likewise reversed because a flow of positive charges gives rise to a magnetic field opposite in direction to that created by a flow of negative charges.

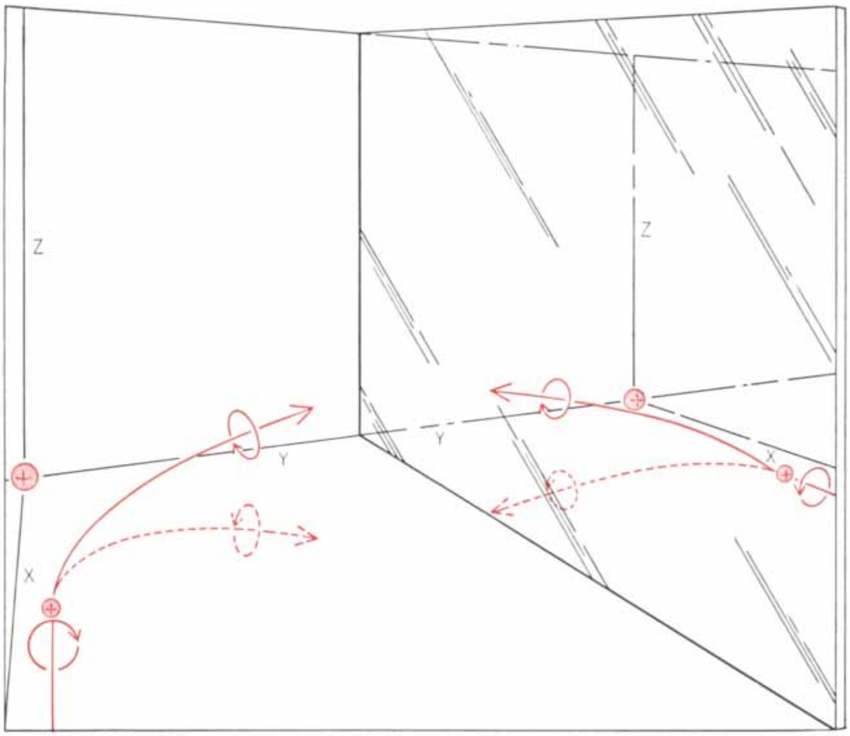
site charge. It is therefore impossible to create a charged particle that can be, with some probability, its own antiparticle.

The situation is different if a particle has no electric charge. In this case a state is quite conceivable in which a neutral particle such as a K^0 meson has a 50–50 chance of being either a particle or an antiparticle. An even more surprising result of present quantum-mechanical theory is that there is not one such state but a continuous manifold of "superpositions" of such states. For our purposes, however, we need be concerned only with the two states that are designated $(K^0 + \bar{K}^0)$ and $(K^0 - \bar{K}^0)$. The bar over the second K in each pair signifies antiparticle. It should be emphasized that each state stands for a single particle, but the properties of the two states are different and can be shown to be so by experiment.

The existence of such superposition states is a consequence of the wave nature of matter. Similar superpositions also play an important role in the low-energy region, in particular in the theory of optically active organic compounds, such as optically active amino acids and sugars. For example, one form of sugar can have the property of rotating the plane of polarization of polarized light to the right. Another sugar of identical chemical composition will have the property of rotating the plane of polarized light to the left. The difference in optical activity is accounted for solely by the fact that the two compounds have three-dimensional structures that are mirror images and thus bear to each other the relation of left and right hands [*see top illustration on page 36*].

The quantum-mechanical interpretation of the position of an atom that determines whether an organic compound is left-handed or right-handed is plotted in the bottom illustration on page 36. The horizontal axis gives the position of the atom, in terms of left or right, in the optically active compound. The vertical axis is the "probability amplitude" for each position of the atom; the probability of finding the atom at any particular position is defined as the square of the probability amplitude. When the curve of the probability amplitude lies entirely to the right of center, the atom is surely to the right, thereby creating an asymmetric situation. This corresponds to a right-handed, or dextro, compound. When the curve of probability amplitude lies entirely to the left, the atom is surely to the left, corresponding to the left-handed, or levo, compound.

The lower pair of curves in the illustration represents probability ampli-



***P*-MIRROR VIEW OF "SCATTERING" is exactly what one would expect to see in an ordinary mirror. In the actual experiment (*left*) a positron is being scattered, or deflected, to the right as it approaches the positively charged nucleus of a fairly heavy atom, such as oxygen. The positron also possesses spin, or angular momentum, shown by the colored arrow. If the spin remains unchanged after scattering, the positron will be found above the plane of its original path; if the spin direction reverses, the positron will be found below the plane. In the mirror, as expected, all spins are opposite to those in the real experiment.**

tudes for atoms in which left and right positions are equally probable, with the result that the rotational properties of the compound cancel each other and no optical activity is observed. In the curve at lower left the probability amplitude consists of two symmetrical humps, both positive. This state is optically inactive because it is a mirror image of itself. Such states are stable at low temperature and are described as racemic mixtures. In the curve at lower right the probability amplitude is asymmetric: the hump at the left is positive, whereas the hump at the right is negative. The probability, however, is the square of the vertical displacement of the asymmetric curve and therefore has a positive and equal value on both left and right. This state, although optically inactive also, has different properties from the first optically inactive state; in particular, its energy is very slightly higher.

These four states—two optically active and two inactive—have their counterpart in the neutral *K* mesons. When the neutral *K* meson is first created, it appears as the antiparticle $\bar{K}^0$ and corresponds to the optically active left-handed compound. This state can be considered as the sum of the symmetric and antisymmetric states representing the two optically inactive forms of the compound. In the case of the neutral *K* meson these two states can be designated K_+^0 and K_-^0 (also known as K_1^0 and K_2^0). The only essential difference between the two inactive states of the compound and the two neutral meson states K_+^0 and K_-^0 is that the reflections with respect to which the meson states are symmetric and asymmetric are not ordinary reflections but reflections in a *CP* mirror.

Now, the symmetric state K_+^0 can decay into two pi mesons and will do so in about 10^{-10} second. The asymmetric state K_-^0 can and should decay into three pi mesons, a decay process that takes about 600 times longer than the two-pi decay, or about 6×10^{-8} second. Therefore K_-^0 mesons will still be plentiful long after all K_+^0 mesons have disappeared. The K_+^0 can decay into two pi mesons because all the states of a system composed of two pi mesons are symmetric with respect to *CP* reflection, as is the K_+^0 state itself. The K_-^0 state, being antisymmetric with respect to *CP* reflection, should not be able to decay into a symmetric state, but it can decay into three pi mesons. A system of three pi mesons does have states that are antisymmetric with respect to *CP*. The three-pi decay is a slower process, hence the longer life of the K_-^0.

What Cronin, Fitch and their collaborators observed, however, is that a small fraction of the K_-^0 mesons do decay into two pi mesons, in defiance of *CP* symmetry. Since only about one in 500 of the K_-^0 mesons decays into two pi mesons, this mode of decay is more than 100,000 times slower for the K_-^0 than for the rapidly decaying K_+^0. Nevertheless, the "forbidden" decay does occur, and this is interpreted as a breakdown of *CP* symmetry.

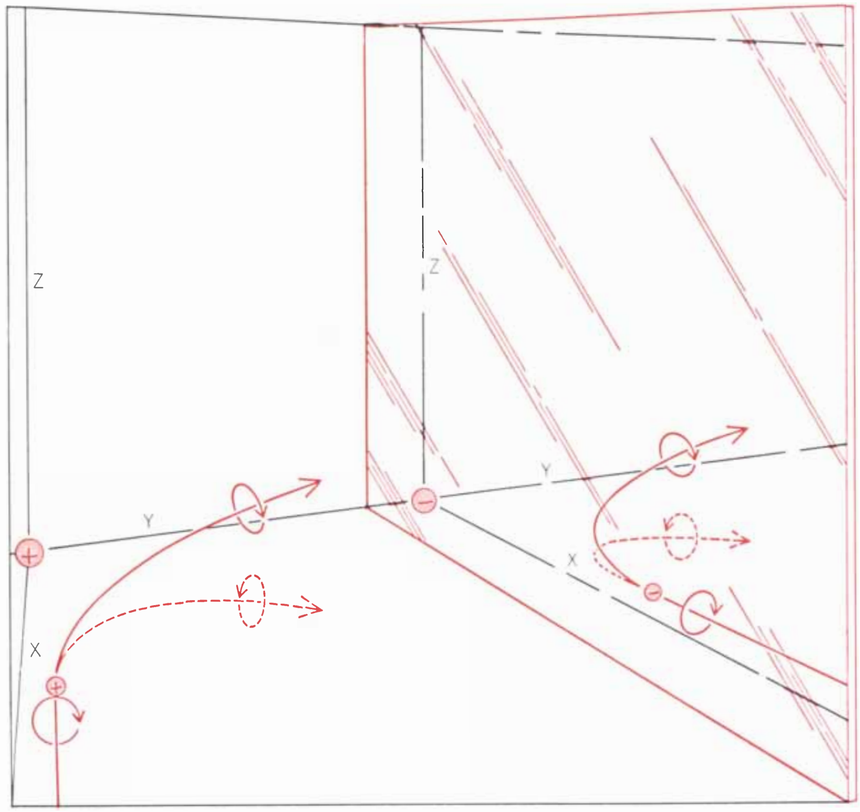
One can see that the preceding argument is quite involved and is by no means so simple as that represented in the breakdown of *P* symmetry in Miss Wu's experiment. As a result some physicists have been reluctant to accept the Cronin-Fitch experiment as conclusive evidence for the failure of *CP* symmetry. There may be a way out that preserves *CP* symmetry—in fact, several ways have been suggested—but the weight of the argument is increasing that *CP* has failed.

What follows from the violation of *CP* symmetry? Physicists are left with the belief that the very last mirror, the *CPT* mirror, is a true mirror. This belief is not based on nature's innate preference for symmetry; it is based on the stubborn fact that we cannot formulate equations of motion in quantum field theory that lack this symmetry and still satisfy the postulates of Einstein's special theory of relativity. If the principle of *CPT* symmetry is valid, it is evidence for the correctness of the general framework of quantum electrodynamics and of the special theory of relativity, not for nature's preference for any additional symmetry.

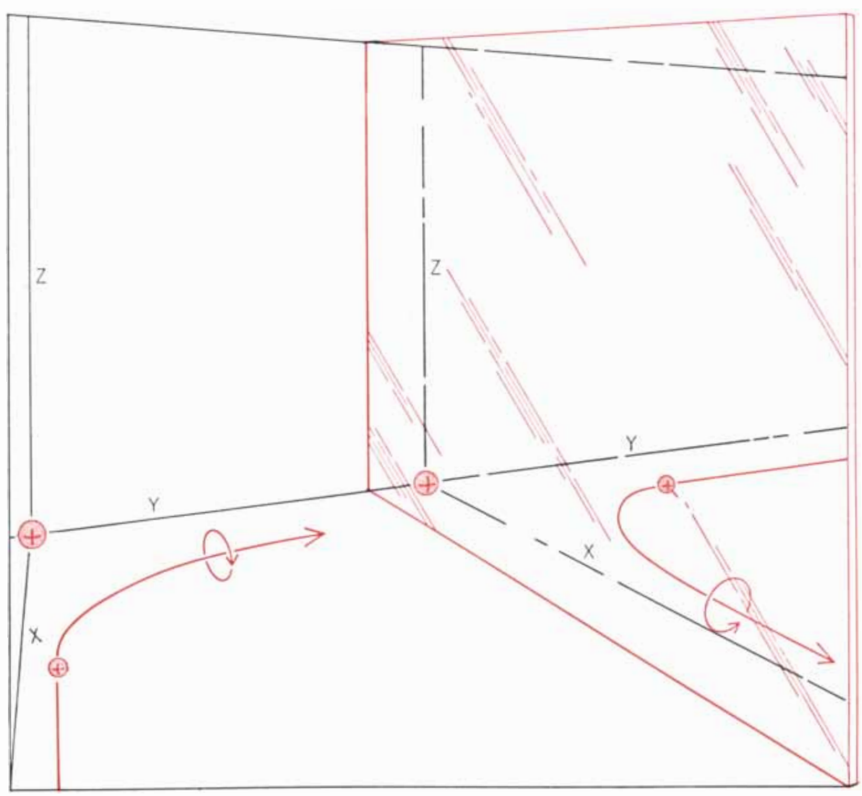
It must be noted with some apprehension, however, that in order for the *CPT* mirror to remain valid the *T* mirror itself must be invalid. The reasoning, based on the Cronin-Fitch experiment, is this. The K_-^0 begins in an antisymmetric state and decays into a symmetric state when it is reflected in a *CP* mirror, thereby proving the mirror defective. If the image in the *CP* mirror is now reflected in the *T* mirror, the original asymmetry should be restored—provided that the *CPT* mirror (*C* plus *P* plus *T*) is valid. To turn a symmetric state into an antisymmetric one, however, the *T* mirror by itself must produce an antisymmetric image. This is equivalent to saying that time is not invariant under reflection and that time-reversal symmetry has failed.

Physicists have scarcely begun to examine the implications of this final breakdown. Leaving aside the apparent collapse of *T* symmetry, one can conclude from the failure of *P*, *C* and *CP* symmetry that the laws of nature do show a preference for either the right or the left hand. We are surrounded by many phenomena that appear to show just such a preference, or, more precisely, such a distinction between right and left. Most of us are right-handed and our hearts are on the left side. On a large scale we observe that the earth rotates to the left (counterclockwise) as seen from above the North Pole and proceeds to the left around the sun. The sun, in turn, travels to the right around the galaxy as viewed from above the north galactic pole. Heretofore these asymmetries were attributed to asymmetries in the initial conditions. Now it is possible to attribute the same asymmetries to the laws of motion, that is, to assume that the universe was initially more symmetrical than it is now and that the present state evolved as a result of the asymmetry of the laws of motion. Few people are as yet ready to accept these speculations; I personally do not believe they are valid. Such speculations could nevertheless be tested if we had enough information about the sense of rotation of planets in other solar systems.

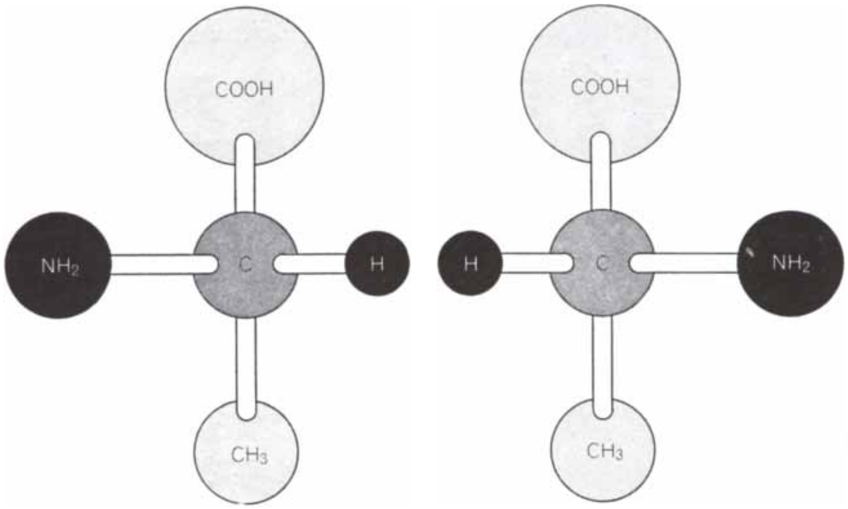
The fact that the laws of nature have no pure space-reflection symmetry has one consequence that is unpleasant to admit. It deprives us of the illusion that these laws are—in perhaps a subtle but nonetheless a real sense—the simplest laws that can be conceived and that are compatible with some obvious experience. If one law of nature is possible, an alternative law obtained by reflecting the first law on a plane would be equally possible and equally simple. We had previously thought the law obtained by reflection would be identical with the original law, just as the reflection of a sphere is also a sphere. Now we know that this is not so. The difficulty began when Miss Wu's experiment showed us that the preferential direction of the decay particles of radioactive cobalt was arbitrarily upward. We got out of this difficulty by postulating another substance: radioactive anticobalt that emits particles downward. This restores



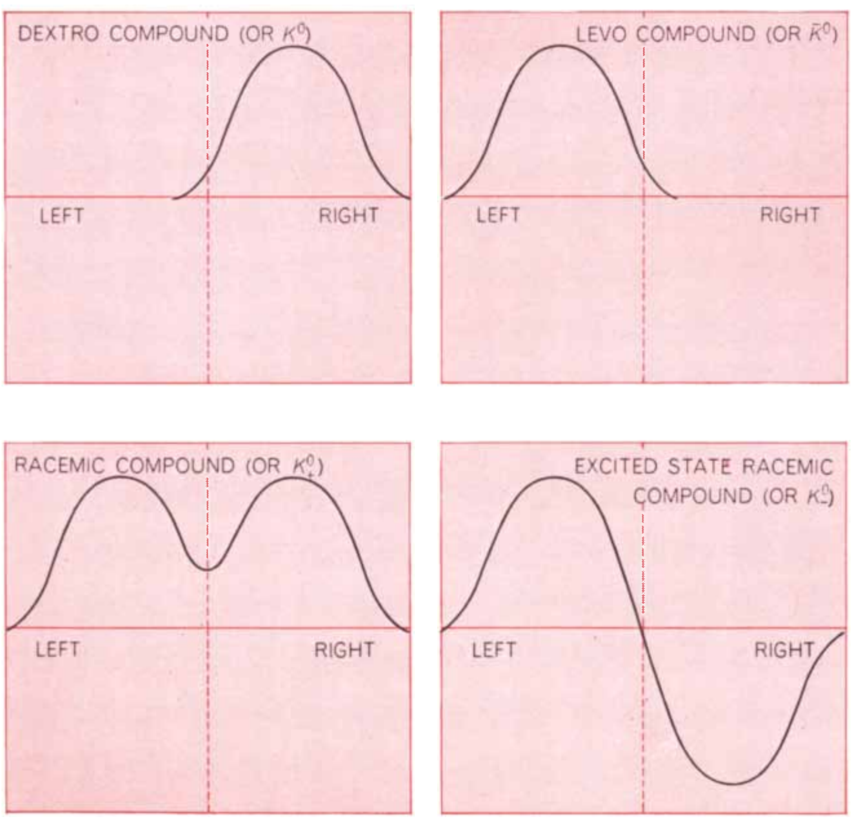
***C*-MIRROR VIEW OF SCATTERING** is unlike that seen in any material mirror. The direction of particle paths and spin remains unchanged, but all charges are reversed.



***T*-MIRROR VIEW OF SCATTERING** is also without resemblance to images seen in ordinary mirrors. In the *T* mirror the scattered particle travels the same path as in actuality, but proceeds in the opposite direction. The imaginary *T* mirror represents time-reversal.



MIRROR-IMAGE MOLECULES, called optical isomers, are well known in organic chemistry. This diagram shows two isomers of alanine, one of the 20 amino acids that living organisms use to build protein molecules. When placed in solution, the isomer at left, known as the levo form, rotates plane-polarized light to the left. Its mirror image, the dextro form, rotates polarized light to the right. Natural proteins are built exclusively from levo amino acids. Many other organic compounds occur in left-handed and right-handed configurations.



QUANTUM-MECHANICAL INTERPRETATION of dextro and levo organic compounds applies also to states of the neutral *K* meson. It invokes the concept of "probability amplitude," plotted as the vertical axis in these curves. The horizontal axis gives the position, in terms of left or right, of the atom that determines whether an organic compound is left- or right-handed. The probability of finding the atom at any particular position is the square of the probability amplitude. In the upper pair of curves the atom is surely either to the right or to the left. In the lower pair of curves the atom has an equal probability of being in the left or right position. How these curves apply to the *K* meson is explained in the text.

the symmetry because we can say that the laws of nature are symmetric but imply two kinds of substance, matter and antimatter. The apparent asymmetry in the laws of nature was thereby reduced to an asymmetry in the initial conditions that allowed matter to predominate over antimatter, at least in the only part of the universe we know at first hand.

The recent experiment of Cronin and Fitch indicates, however, that such an explanation is impossible. The indication, to be sure, is only indirect; we must explore all avenues that may yield another interpretation and preserve the spatial-reflection symmetry of the laws of nature. If these avenues do not lead out of the difficulty, we will have to admit that two absolutely equally simple laws of nature are conceivable, of which nature has chosen, in its grand arbitrariness, only one. The extent to which the laws of nature are the simplest conceivable laws has come to an end—no matter how subtly they may be formulated—as long as they are formulated in terms of concepts that are subject to the symmetry principles we are accustomed to associating with space-time.

The question naturally arises whether or not physics has experienced similar crises before. It has. In classical physics, matter was supposed to be infinitely subdivisible without change in its bulk properties such as specific gravity, viscosity or elasticity. The discovery of the atom put an end to this infinite subdivisibility. The atom therefore increased the complexity of the structure of matter, and this unavoidable new fact was for many people as obnoxious as the lack of reflection symmetry in the laws of nature is for us.

Most of the consequences of atomic structure that first appeared obnoxious were eliminated when physicists and chemists learned to use the atomic scale for their measurements and realized, for example, that atoms provide a natural unit of length. Without such a unit it would be difficult to understand why human beings have an average height somewhere between five and six feet; if all phenomena could be scaled up or down with impunity, men, mice and bacteria could be the same size. Atomic theory also provided explanations for the properties of matter, for its density, viscosity, elasticity and so on. Hence in its end result atomic theory enriched rather than complicated our picture of nature. There is hope, but as yet only a hope, that the present probing into the symmetry of space-time will have a similar result.

Kodak reports on:

Charlie Bridgman's availability . . . the availability of five papers . . . a fast catch onto microfilm

To x-ray rocks and mud

A movement appears under way to get x-ray machines into geological and oceanographic laboratories. We intend to encourage it.

Radiography will earn its way there by opening up the third dimension of specimens to the properly prepared mind's eye. An effective missionary of the movement has been W. K. Hamblin, now of Brigham Young University, Provo, Utah.

Dr. Hamblin first drew attention (*J. Sediment. Petrol. 32*, 201) to how radiographs can unmask sedimentary structure inside rock specimens that present a blankly homogeneous surface aspect. Very quickly thereafter the hint was being taken with informative results for cores of unconsolidated marine sediments (*Sedimentology 1*, 287). Next he pointed out (*American Mineralogist 49*, 17) how a stereoscopic pair of radiographs reinforce conventional microscope technique with an entirely new perspective on ore textures. (X-ray eyes in 3-D make it very easy to know whether fragments are skeletally connected and therefore younger than the matrix, or isolated and therefore older.) Then Dr. Hamblin made the acquaintance of Charles Bridgman.

C. F. Bridgman earns his pay here by enjoying himself. All he has to do is give sound technical advice to those who want to use radiography for other than the routines common in medicine, dentistry, and industry. His working days are filled with wonder, and when he voices complaint it is only to be sociable with those less fortunate. He has been quite helpful to Hamblin. His address is Radiography Markets Division, Eastman Kodak Company, Rochester, N.Y. 14650. Here are two samples of his own work:

The famous chambered nautilus *Nautilus pompilius* from Philippine waters.

Its 80-million-year-old Cretaceous cousin *Placenticeras whitfieldi* from South Dakota.

Vitamins at work

"Taking vitamins makes me feel
sort of all bubbly."

When we heard a lady report that item of data at a dinner party long ago, the public was simply mad about vitamins. Today the public doesn't seem to talk much about them any more, but commercial production of vitamins stands at several times the physical level of the craze years.

We ought to know, being one of the few basic producers of vitamins A and E, and not just for fun. We note that the pharmaceutical, food, and feedstuffs industries want all we make, that health standards continue to improve noticeably, and that chicken and turkey are no longer luxury foods. Agreement is being achieved on a minimum human daily requirement for vitamin E after years of debate. (For example, to meet U. S. Pharmacopoeia standards, each Decavitamin Tablet will henceforth have to contain 15 International Units of Vitamin E.) Research on vitamins continues actively. This year's Annual Meeting of the Federation of American Societies for Experimental Biology included a symposium on vitamins A and E. Highlights:

- The naturally occurring stereoisomer *d*-α-tocopherol appears to owe its emphatically higher vitamin E activity to preferential retention and transport by mechanisms involving selenium in some unknown way.
- Individual signs of tocopherol deficiency can to some extent be alleviated by one or the other of several structurally unrelated synthetic antioxidants if it can be delivered in large enough quantities to the target tissues.
- At the subcellular level, tocopherol concentrates in regions rich in phospholipids, while DPPD, one of the vitamin E-mimicking synthetic compounds, distributes with fat.
- Through some mechanism, nitrates and nitrites in the diet of ruminants inhibit the conversion to vitamin A of carotene, the only natural source of the vitamin for herbivora.

We shall be pleased to supply reprints of the five papers given. Address Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). There is no charge.

Computer milk

Design engineering is supposed to be a creative activity. Design engineers spend almost all their time searching for data that already exists. This is the activity that looks acceptably industrious and businesslike. The rare moment when the engineer's mind creates something truly new finds him brushing his teeth or staring at a traffic light to make it turn green. Now we are going to brag about saving the government inestimable millions of dollars by converting an estimated 16 million man-hours from searching to creating.

It is accomplished by feeding to computers every available scrap of information—physical and administrative—about every component of every device employed for every known purpose by every agency concerned with the defense of the nation. There are still people around whose minds are incapable of encompassing what we have just said. Let us hope you are not one of them. The computers organize this body of information in numerous ways. They also organize indexes and indexes of indexes, iterated in depth. The problem then arises of how to get the good out of it all.

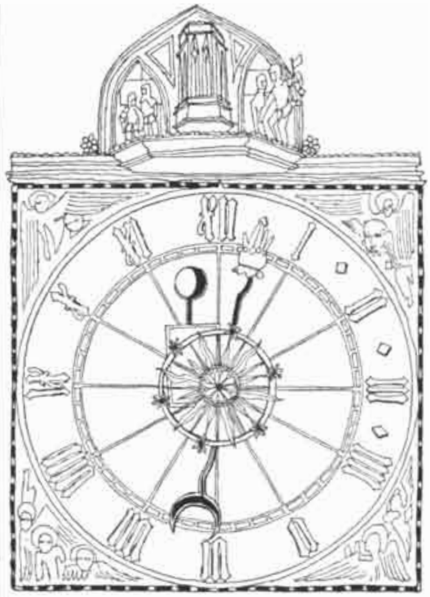
Perhaps one could try to taste, smell, or hear the results, but the preferred mode is to see them. Cathode-ray tubes are used quite a bit by computers to communicate with their lessees by drawing pictures. In this case the c-r tube is the only means of unloading the output of documents fast enough from the computer. The c-r tube can only dump it onto fast-running microfilm.

That's our cue. Now we make our contribution. We furnish equipment that takes over all the microfilm. Later, perhaps in some other place, a person will press some buttons on our equipment. In a few seconds a document will appear on the screen. He can also pull a paper copy of the document out of a slot, or he can make it appear down the corridor or around the world by facsimile transmission. It will be the exact document needed to avoid designing, making, or lacking an object that is already available, or to service the object. *Any object.*

Every link in this chain is already in existence, believe it or not. Questions about the use of microfilm the better to milk computers will be answered by Recordak Corporation, 770 Broadway, New York City 10003 (Subsidiary of Eastman Kodak Company).

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

SCIENCE AND



The Nobel Prizes

The 1965 Nobel prizes in science were awarded to three biologists who discovered new genetic mechanisms in living cells and viruses, to three physicists who reconstructed equations describing the behavior of the electron and to a chemist who has shown great virtuosity in synthesizing complex organic compounds.

The prize for physiology and medicine was awarded to André Lwoff, Jacques Monod and François Jacob of the Pasteur Institute in Paris. Lwoff was honored for demonstrating that the genetic material of a phage—a virus that infects a bacterium—can become incorporated into the genetic material of its bacterial host, whereupon the bacterial cell reproduces both itself and the phage through many generations. To the phage in this benign state of bacterial captivity Lwoff gave the name "prophage." He further discovered that the prophage can be "induced" (by exposure to ultraviolet radiation) to make infectious phage particles, which then destroy their host (see "The Life Cycle of a Virus," by André Lwoff; SCIENTIFIC AMERICAN, March, 1954).

Monod, the second member of the French group, was in some doubt at the beginning of his career whether he should become a professional musician or a scientist; finally he chose to seek a doctorate in bacterial physiology, which he received in 1941. Following the fall of France he joined the resistance movement and became the commander of an underground military unit. After the war he entered Lwoff's department at the Pasteur Institute and began studying the bacterial enzyme beta-galactosidase. One of several "inducible" enzymes, beta-galactosidase is manufactured only when the cell is provided with certain substrate materials. It was believed that the substrate somehow induced the formation of the enzyme by interacting with a protein precursor. Monod and his colleagues demonstrated that this was not so; they showed that the cell makes beta-galactosidase as a totally new protein molecule.

Jacob's work was related to both Lwoff's and Monod's. With Elie L. Wollman he showed that Lwoff's prophage is replicated as part of the chromosome of the bacterium. Subsequently Jacob and Wollman deduced that the bacterial chromosome is shaped like a ring and that it can integrate into itself various genetic fragments introduced into the cell from outside, to which Jacob and Wollman gave the name "episomes" (see "Viruses and Genes," by François Jacob and Elie L. Wollman; SCIENTIFIC AMERICAN, June, 1961).

Jacob worked directly with Monod in extending the study of beta-galactosidase. They showed that the role of the inducer substance is to neutralize an enzyme in the cell that represses the function of the gene for beta-galactosidase. In 1961 they proposed two concepts of fundamental importance: the concept of "messenger" ribonucleic acid (messenger RNA) and the concept of the "operon." They put forward the hypothesis that messenger RNA transcribes the genetic message from deoxyribonucleic acid (DNA) and carries it to the ribosomes, the particles that preside over the synthesis of protein molecules; the hypothesis was proved even before it had formally appeared in print. They gave the name operon to a group of genes that have related functions; they postulated that such genes occupy adjoining sites in the bacterial chromosome and are controlled by a single gene that acts as their "operator." Monod and Jacob explained the production or nonproduction of beta-galactosidase as evidence for an operator gene that is either "open" or "closed," depending on whether or not it is coupled to a specific repressor.

The prize in physics was shared by Julian S. Schwinger of Harvard University, Richard P. Feynman of the California Institute of Technology and Sin-Itiro Tomonaga of the Tokyo Education University. In the late 1940's they independently published a series of papers that cleared up long-standing difficulties in computing the interaction of charged particles—specifically the electron—with the electromagnetic field.

The problem developed when early workers in quantum mechanics tried to recast the equations of classical electrodynamics ("Maxwell's equations") in quantum form; these workers could see no alternative to the classical assumption that the electron must be regarded as a point charge. As early as 1930 J. Robert Oppenheimer had recognized that the coupling of such an electron to an electromagnetic field implied the paradox of an infinite displacement of the energy levels of atoms and thus an unpredictable shift of all spectral lines. These and other difficulties were still plaguing quantum theory when World War II suspended the search for a workable quantum electrodynamics.

The search took a new turn immediately after the war, when Willis E. Lamb, Jr., and Robert C. Retherford applied recently developed microwave techniques to obtain new measurements of the fine structure of the hydrogen spectrum. The Lamb-Retherford results showed clearly that the observed energy levels of the hydrogen atom were not those predicted by the existing theory, which had been worked out by P. A. M. Dirac. It was evident that the deviations resulted from the coupling of the electron and radiation in a manner that had resisted calculation.

Schwinger, Feynman and Tomonaga showed in various ways (later found to be mathematically identical) how to carry out a process of "renormalization" in which the previously used values of mass and charge for the electron could be replaced by values having immediate physical significance. As a consequence of these methods the electron acquired new electrodynamic properties that were entirely finite. These properties included a new value for the magnetic moment of the electron, which turned out to be in excellent agreement with that measured experimentally by H. M. Foley and Polykarp Kusch. (For this work Kusch shared the 1955 Nobel prize in physics with Lamb.) The new approach resulted in a complete reconstruction of the foundations of quantum electrodynamics, making it possible to compute accurately the behavior of the hydrogen atom to as many decimal places as can be measured by present experimental methods.

The Nobel prize in chemistry was awarded to Robert Burns Woodward of Harvard University. In 1942, at the age of 26, he collaborated with William V. E. Doering in the synthesis of quinine. Subsequently, with various collaborators, he achieved the synthesis of cortisone, lysergic acid, cholesterol, strychnine, lanosterol, reserpine (one of the original tranquilizing drugs, also known as rauwolfia) and, in 1961, chlorophyll. The synthesis of chlorophyll, the green substance of plants, took four years, during which Woodward—who works only with pencil and paper—was assisted by 17 young postdoctoral students, each of whom spent a year in his laboratory. The synthesis of chlorophyll proved once and for all that its structure was indeed the one that had been worked out over a period of 40 years by chemists in many countries.

Cigarettes and Atherosclerosis

A direct association has been established between cigarette smoking and coronary atherosclerosis, the condition in which fatty deposits build up in the arteries of the heart and reduce their interior diameter. Earlier studies had shown that the risk of coronary disease and of death from heart attacks is higher among cigarette smokers than among nonsmokers. These studies told nothing about a smoker's arteries, however; they could have meant merely that smoking imposes added burdens on the heart. Now Oscar Auerbach of the Veterans Administration Hospital in East Orange, N.J., and E. Cuyler Hammond and Lawrence Garfinkel of the American Cancer Society have reported in *The New England Journal of Medicine* that an advanced degree of coronary atherosclerosis is more common in cigarette smokers than in nonsmokers, and that it increases with the amount of smoking.

The findings are based on autopsies performed at the Veterans Administration Hospital from 1955 to 1960. In each case detailed observations of the condition of the coronary arteries were made and recorded. Interviewers (who had no knowledge of the autopsy findings) later obtained information on the smoking habits of the men from their families. Cases in which the principal cause of death was coronary heart disease were excluded to avoid a source of statistical bias. The current report analyzes the data for the remaining 1,372 men in terms of degree of atherosclerosis (none, slight, moderate or advanced), smoking history and other factors.

Since atherosclerosis increases with age, the results were tabulated by age group. In each group the proportion of men with moderate to advanced coronary atherosclerosis was "considerably greater" among cigarette smokers than among nonsmokers, and the proportion with advanced atherosclerosis increased consistently with the amount of cigarette smoking. Among men from 60 to 69, for example, 21.4 percent of those who had never smoked regularly had advanced atherosclerosis. The comparable figure for those who had smoked fewer than 20 cigarettes a day was 41.9 percent, for those who smoked 20 to 39 a day, 44.4 percent, and for those who smoked more than 40 a day, 52.6 percent. The same general picture emerged from several different statistical treatments. In one, an attempt to eliminate any bias stemming from the cause of death, the investigators made a "matched set" analysis, grouping 230 of their cases into 46 sets of five men each, all of whom had died of the same disease at about the same age but who had different smoking habits. Again moderate and advanced atherosclerosis were more common in cigarette smokers and most common in heavy smokers.

The Mountains of Venus

The exploration of Venus by radar has now shown that its surface is surmounted by extensive mountain ranges, which are hidden from view by the planet's perpetual cover of clouds. The initial discovery of mountain-like features, given the name Alpha and Beta, was made by Roland L. Carpenter and Richard Goldstein of the California Institute of Technology's Jet Propulsion Laboratory, who used the deep-space tracking facility at Goldstone, Calif. Details of Alpha and Beta have been provided by Gordon H. Pettengill and Rolf B. Dyce, with the aid of the 1,000-foot radio (and radar) telescope operated at Arecibo in Puerto Rico by Cornell University.

The mountain ranges on Venus were discovered by analyzing the echoes of intense radar signals directed at the planet at times when it approached within about 30 million miles of the earth. If the radar signal strikes a smooth surface, its echo closely matches the outgoing signal. If it strikes an uneven surface, however, the part of the signal that hits an elevation returns sooner than the part that hits a neighboring depression. With the help of a computer the complex reflection pattern can be interpreted to yield a pattern showing elevations. The fact that Venus rotates slowly on its axis (once in 247 days) provides additional information by changing the frequency of the signal slightly, depending on whether the signal strikes an elevated area when it is approaching or receding.

The mountainous features discovered by these methods are comparable in extent to the Rocky Mountains. The Alpha Mountains run about 2,400 miles in a north-south direction. The Beta Mountains, which are still more extensive, run east and west.

Immunity and the Thymus

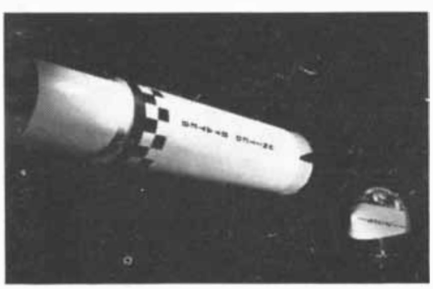
The thymus gland apparently plays a major role in immunological competence not only early in life but in adult life as well. It has been known that surgical removal of the thymus from newborn mice depletes their lymphocytes, white blood cells that are involved in the body's defense against foreign substances—whether microorganisms or tissue grafts. In all animals, however, the thymus atrophies with maturity; its importance in adults was therefore questionable. Now a Harvard Medical School group has reported (in *Science* and at a recent clinical session of the American College of Surgeons in Atlantic City) that in adult mice the recovery from an induced state of immunological depression involving lymphocyte depletion is dependent on the thymus gland.

Such a state is induced by treating animals with an antilymphocyte serum obtained from rabbits injected with mouse lymphocytes. The serum suppresses the treated animals' immune mechanism and enables them to retain a skin graft for a longer time than they would without the serum—up to 24 days instead of only about 10 days. Anthony P. Monaco, Mary L. Wood and Paul S. Russell tried removing the thymus glands from some mice before giving them antiserum. Almost all the grafts in thymectomized mice survived longer than those in animals that were not thymectomized. In some cases the grafts survived for more than 100 days in good condition, although they too were eventually rejected.

The results suggest that the thymus

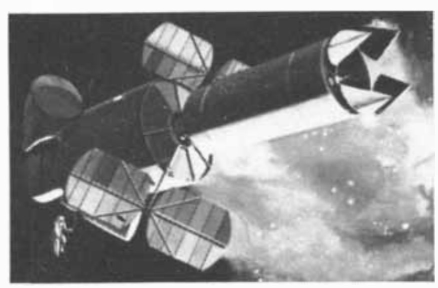
TWIN TURBINE Boeing/Vertol helicopters now serve with U.S. Army, Marine Corps and Navy. Sea Knight assault helicopter (at top above) can carry up to 25 fully-equipped combat troops in "vertical envelopment" and other prime missions. It's operational with Atlantic and Pacific Fleet Marine Forces. The U.S. Army's Boeing/Vertol Chinook (pictured with Sea Knight above) has been deployed to Viet Nam with the 1st Cavalry Division (Airmobile). Each Chinook can deliver a complete infantry platoon, or a complete artillery section, to assault landing sites. Chinook is U.S. Army's standard medium assault helicopter.

Capability has many faces at Boeing



SPACE maneuvers, such as rendezvous and docking, are simulated in Boeing Space Center. Pilots "fly" spacecraft, controlled through computers, in simulated trajectories, velocities and approach angles of space docking missions.

WORLD'S largest rocket, NASA's Saturn V, will launch first Americans to moon. Boeing holds NASA contract for S-1C booster, developing thrust equivalent to 160 million horsepower.



ORBITING EYE, a manned telescope to orbit earth 200 miles high, is subject of a Boeing study for NASA. Space telescope could penetrate 20 billion light years, compared to today's three. The Boeing study involves integrating orbital telescope with a manned space station.

BOEING

Space Technology • Missiles • Military Aircraft Systems • 707, 720, 727, 737 Jetliners • Systems Management • Helicopters • Marine Vehicles • Gas Turbine Engines • Also, Boeing Scientific Research Laboratories functions in regenerating the lymphocyte supply in adult animals if that supply has been depleted by antiserum to lymphocytes. Thymectomy is now being tested at several centers as a means of suppressing graft rejection in human patients undergoing kidney grafts or other organ-transplanting operations.

Superconducting Accelerator

The much discussed idea of exploiting superconductivity in order to design an extremely efficient particle accelerator has moved a step closer to realization with a recent demonstration at Stanford University. Alan H. Schwettman, Perry B. Wilson and William M. Fairbank have built a small superconducting "cavity"—a cylindrical chamber four inches long surrounded by liquid helium—in which they have successfully accelerated a beam of electrons. The role of the cavity is to trap as much as possible of the input energy, supplied in the form of microwave radiation, and make it available for the acceleration of particles.

The superconducting cavity is a copper cylinder plated on the inside with lead, which becomes superconducting at about 7 degrees Kelvin (degrees centigrade above absolute zero). The temperature must be held below that, however; otherwise the magnetic fields associated with the electric fields that accelerate the particles would destroy the superconductivity. The cavity of the Stanford apparatus is therefore bathed in helium at 1.8 degrees K.

The accelerating electric field in the cavity is produced by the microwave output of a klystron tube. When such a tube is used to accelerate electrons in a conventional linear accelerator, several megawatts of power are needed to overcome losses in the walls of the cavity. This means that power can be turned on only about .1 to .01 percent of the total time; otherwise the walls of the cavity would overheat. In the Stanford superconducting cavity the wall losses are only a few watts, with the result that power can be kept on continuously.

The success of a superconducting cavity depends on raising the "Q" to about a billion, Q being defined as the ratio of energy stored divided by the energy lost per cycle. The Stanford cavity has achieved a Q of about five billion—a factor of 100 higher than has been achieved elsewhere. It has also shown itself capable of producing about four million volts of acceleration per foot of length. The cavity was built with the assistance of two graduate students, John Pierce and John Turneaure.

With the backing of the Office of Naval Research the Stanford workers are developing plans for building full-sized superconducting accelerators. Such devices will require novel facilities for refrigerating large volumes of helium to 1.8 degrees K.; these also are being studied.

Dangerous Dirt

The severe damage produced in the city of Anchorage by the heavy Alaskan earthquake of March 27, 1964, was not all the direct result of ground vibrations, according to Paul F. Kerr of Columbia University; some of it was caused by landslides that occurred when a layer of the substance known as quick clay was suddenly turned into a liquid by the shock. A distinguishing characteristic of quick clay is that it is thixotropic: a sudden shock can transform it from a solid into a liquid (see "Quick Clay," by Paul F. Kerr; SCIENTIFIC AMERICAN, November, 1963). Its other main characteristics are a high content of water, a low content of salt and a high proportion of small, flaky particles, which are loosely distributed through the mass. Because of the low salt content, the clay is deficient in the electrolytes that tend to bind soil particles together.

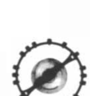
Kerr found a layer of quick clay 10 to 20 feet thick buried under the sand, gravel and sandy silt in the upper portion of the geological formation on which Anchorage lies. The clay was deposited long ago by glaciers; later earth movements caused both the clay and its cover to be raised to Anchorage's present average elevation of 100 feet above sea level. During the three minutes of the 1964 earthquake there was violent up-and-down motion that, according to Kerr, was more than adequate to turn the clay into a liquid.

Several methods of preventing future slides are under investigation by various groups, Kerr said. One involves electro-osmosis: steel electrodes are forced into the clay and high-amperage currents are passed between them. The purpose is to reorient the fine particles of clay in a more stable state. The method is reported to have been used successfully in Norway but it has not been tried in a seismically active area such as Anchorage. Another method, tried only in the laboratory, involves adding calcium salts to the clay; the salts increase the viscosity of the clay enough to make it no longer thixotropic.

Watch vs Accutron®: why they can't agree.

A watch is a machine. It uses a balance wheel mechanism that wears, gets dirty and tells fibs. The Accutron timepiece does not use these parts. Instead, the unchanging vibrations of a tuning fork split every second into 360 parts and we (Bulova) guarantee accuracy within one minute a month.*

What kind of guarantee did you get with your watch?



Old-fashioned balance wheel is still used in all wind, self-wind, and electric watches. It is not used in the Accutron movement.

Accutron tuning fork keeps virtually perfect time and comes with the first guarantee of accuracy ever given.

Accutron by Bulova Shown: Model "560", 14K gold case and mesh band, $395. Other styles from $125. *Accutron jeweler will adjust timekeeping to this tolerance if necessary. Guarantee is for one full year. © Bulova Watch Co., Inc.

FLEAS

They have evolved some remarkable adaptations to their hosts. Perhaps the most remarkable is found in the European rabbit flea, the breeding cycle of which is regulated by the reproductive hormones of the rabbit

by Miriam Rothschild

Mammals have been available as possible hosts for parasitic insects for some 180 million years. There is little doubt that fleas became parasites of mammals comparatively early in the history of their hosts; a fossil flea, scarcely different from living species and displaying all the specialized features associated with them, has been found in Baltic amber dating from 50 million years ago.

It is not known how one animal first becomes parasitic on another, but it is fairly certain that all the principal groups of parasitic insects arose as free-living organisms. The genesis of parasitism is opportunity. The future parasite and its host must be brought together by circumstances intimately and frequently, and then sooner or later the smaller of the two exploits the situation. As an Edwardian wag said, familiarity breeds contempt, but you cannot breed without familiarity! This is not quite correct; certain starfish and more highly evolved animals consign their eggs and sperm to the water and as adults can dispense with even fleeting intimacy. It nonetheless applies in parasitic relationships.

Fleas probably arose as winged scavenging flies, feeding as larvae on the excrement in the homes of burrowing mammals. Almost countless generations of such pre-fleas may have eked out a sheltered life in prehistoric burrows before the first pioneer crept into the fur of a passing ratlike occupant. Possibly there is an even shorter step between piercing the dried outer layer of excrement to reach the semifluid matter below it and piercing a mammal's skin and imbibing the first drink of blood. Blood as food may confer such advantages that the insect is immediately started along the risky road to overdependence and overspecialization. Once fleas became parasites their fate was linked to the fate of their hosts; moreover, the 100-million-year running battle between host and parasite was joined, never to end unless one or the other should perish.

Although parasitic animals may well be more numerous than other animals, fleas do not constitute a notably successful group of organisms. Some 300,000 kinds of beetles have been described and named, but only 1,500 species of fleas are known. There are many more types of bird lice than there are types of birds, but mammalian species greatly outnumber the species of fleas, and one may deduce that many kinds of fleas have been exterminated in the past. This fact is advantageous for the investigator who studies fleas: he (or she) has to cope with only a relatively small literature and consequently can spend more time at the microscope and in the field and less in the library. A mere 1,000 works on fleas have been published during the past five years; a quarter of them are written in Russian.

The Hazards of Parasitism

The problems that beset parasites differ from those confronting nonparasitic animals. The rat flea, once it is on the rat, has at its disposal a virtually limitless supply of food. Provided that the flea can avoid the extremely efficient extermination tactics of the host—an end to which the flea's whole external anatomy has become highly modified—its difficulties as an individual are over. The nonparasitic animal must strive endlessly for its daily food and has highly developed sense organs to assist it. The flea's breakfast is permanently at its feet, but on the other hand the future of the species is always in jeopardy. Sometimes the interest of the individual parasite may even run counter to the interests of subsequent generations. For example, if too many fleas live on one rat, they may weaken their host and eventually kill it. Parasites must be modest in their demands and unobtrusive in their ways; they must attract the minimum of attention and yet somehow ensure that their offspring are always in a position to find a similar opportunity and continue their long and now essential intimacy with the host.

Occasionally some unforeseen circumstance arises that turns the well-adapted flea, in whose interest it is never to seriously harm the host on which it depends, into an instrument of self-destruction. Thus the rat flea, carrying the plague bacillus from one sick rat to its neighbor and then moving on to the next available host, was responsible for initiating pandemics that in the Middle Ages exterminated a quarter of the human population of Europe. The rat flea must therefore rank as one of the greatest killers of all time. Yet for every rat or man that died 10 times as many fleas must have perished.

Such hazards engendered by the intimate relation between parasite and host are even more dramatic if specialization has gone one step further and the parasite can feed on only one species of host. This situation has been studied recently in Britain as a result of the introduction of myxomatosis, a lethal virus disease of rabbits. In South America both the indigenous rabbits and their fleas have become reasonably adapted to the myxoma virus and recover from infections. In Britain the rabbit population was not immune and an ideal vector existed in the host-specific rabbit flea *Spilopsyllus cuniculi* Dale, one of the most successful of all known fleas. An epizootic swept the British rabbit population; perhaps as many as 100 million rabbits died during the first outbreak. It is estimated that each rabbit in Britain carried some 75 fleas; few, if any, of these parasites infesting rabbits dying of myxomatosis can have survived, since this particular species of flea is confined to a single host. (There is some evidence, however, that it is becoming adapted to the hare.) At a conservative estimate the epizootic must have killed off a billion fleas in Britain alone.

Thus added to the dangers of the parasite's own existence are the dangers to which the host is subjected. The successful parasite must adapt itself closely to the life of the host, and yet such adaptation inevitably involves dependence and a loss of potential versatility. When a cataclysm such as the advent of myxomatosis occurs, there are no alternative possibilities for a species such as the rabbit flea. The rat flea, which is not quite so highly specialized, can leave the dying host for a man or a mouse; without the rabbit the rabbit flea dies. Perhaps nowhere in the animal kingdom are the danger and cost of success more clearly illustrated. Blessed are the meek—that is, the not too successful—for they shall inherit the earth. One of the unpalatable truths about natural selection is that it imposes a certain mediocrity.

Easily the most interesting features of fleas are their adaptations, which they have been perfecting for perhaps 100 million years. They have adapted firstly to the general parasitic mode of life on a hairy or feathered warm-blooded host; secondly, they have achieved the extremely subtle specializations that enable them to survive on a particular type of mammal or bird. The European rabbit flea is an outstanding example of specialization: it has even surrendered to the host the control of its own breeding cycle! Of this I shall have more to say later.

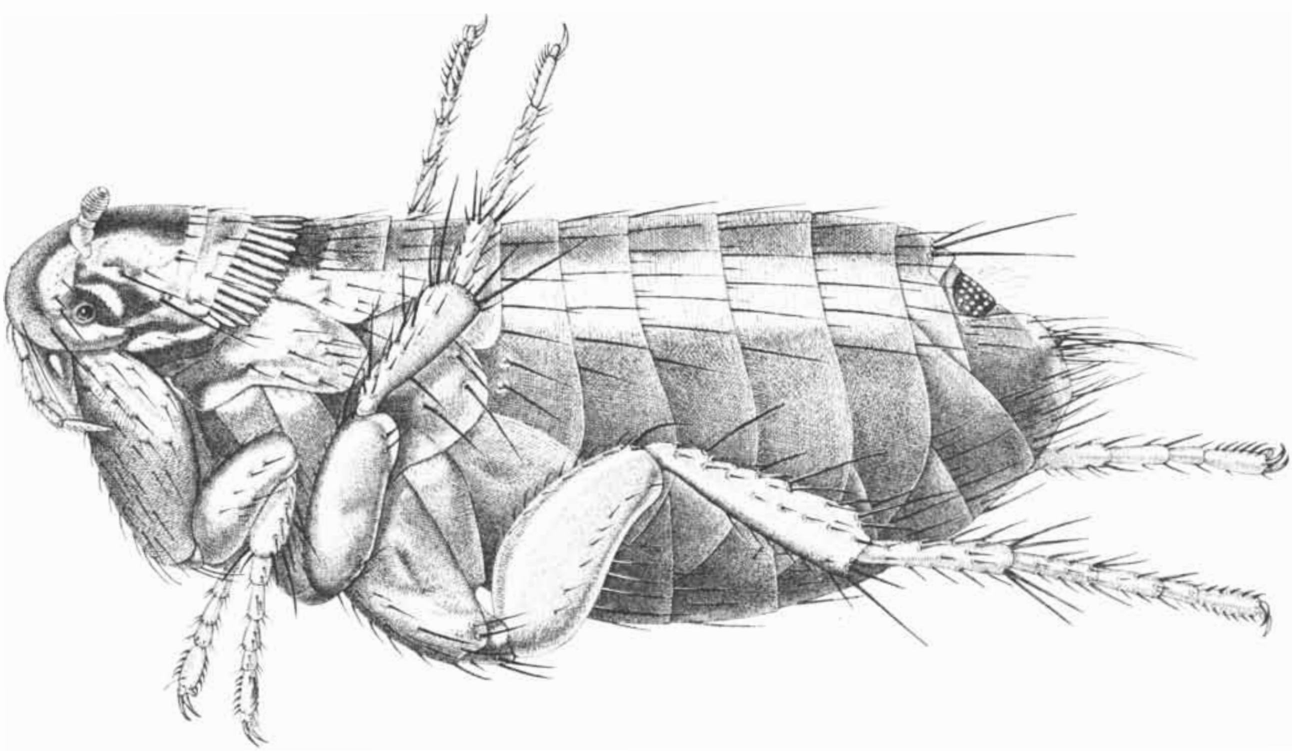
Adaptations of the Flea

The early stages of a flea's life cycle are passed in the nest of the host or in refuse on the floors of caves or lairs. The larvae feed on debris, but the majority also require iron in order to form their hard external cuticle. This they obtain from blood that is squirted out of the anus of the adult flea and that frequently falls into the host's nest or cracks and crevices or onto the ground where the host sleeps.

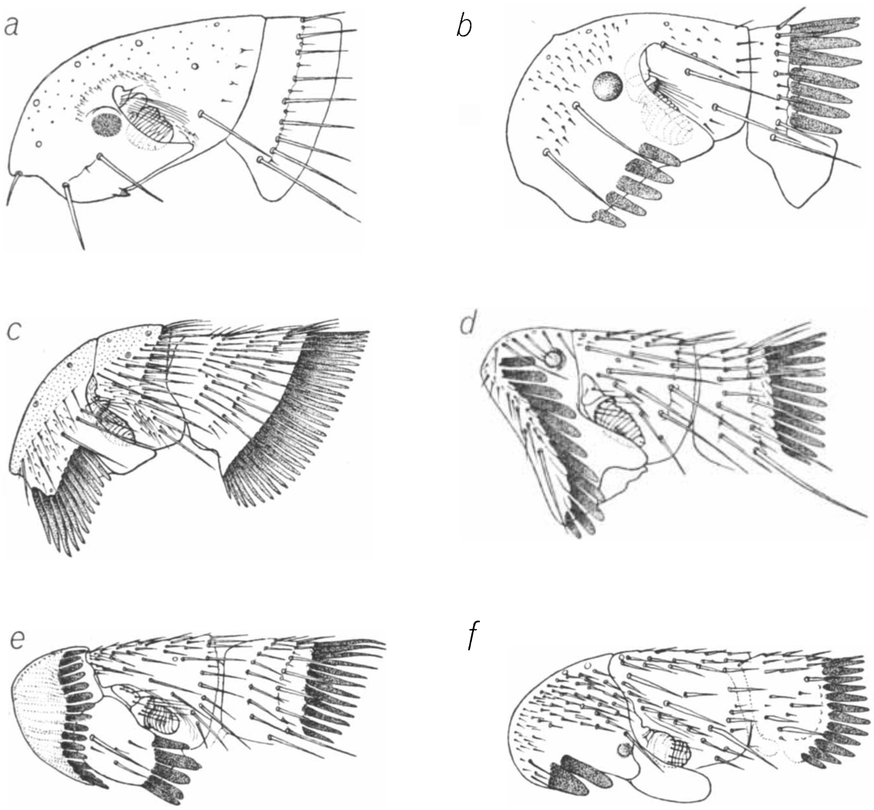
Flea larvae are very susceptible to dryness and thrive best in a humid atmosphere, which is of course characteristic of burrows. They can be remarkably indifferent to cold. For example, it has recently been discovered that a bird flea parasitizes an Antarctic petrel; these fleas are found in the nest of the petrel, which is presumably buried for nine months of the year under several meters of ice and snow.

Even the adult rabbit flea is well adapted to survive cold spells, probably because it lives in a cool climate on a host that does not hibernate. Specimens can be kept in a refrigerator for nine months at about −1 degree centigrade (but not below −10 degrees C.), rattling about like pebbles in their glass container, and yet they appear quite unharmed and able to feed and jump only a few minutes after defrosting. Adaptations, particularly those of a physiological nature, that enable a living insect to cope with extreme cold have recently excited considerable attention. The storage of live animals (as well as live sperm) in a state of suspended animation for comparatively long periods of time has become a reality, and therefore such natural adaptations as those exhibited by the Antarctic flea and the rabbit flea are of general as well as scientific interest.

Other examples of refined adaptations in the flea have to do with finding the host and staying on it. Wings are clearly disadvantageous when the flea is living in fur: they impede progress. The permanent parasite must be elusive on



JUMPING FLEA, the common rat flea (*Nosopsyllus fasciatus*), is depicted on the basis of a rare photograph made during a jump and the results of an experimental procedure in which fleas were made to jump into a fixative. The flea frequently turns end over end several times during a jump, holding one or two pairs of legs aloft for use as grappling hooks when it lands on the fur of its host.



FLEA HEADS, which are among the means of distinguishing one type of flea from another, are depicted for several kinds of flea: (*a*) the human flea, (*b*) the European rabbit flea, (*c*) a mole flea, (*d*) a South African flea, which is found on small rodents, (*e*) a helmet flea, appearing on marsupials in Ecuador, and (*f*) a bat flea. The heads are not drawn to scale.

the host's body, and the loss of a more general mobility is the lesser of two evils. Only a few genuinely parasitic flies have wings, and these are often shed or bitten off when the flies have found a host. It is generally assumed that the majority of insects parasitic on mammals or birds had winged ancestors but lost their organs of flight during the course of evolution.

Fleas are presumably no exception (traces of wing rudiments have been reported in their pupal stage), but they have secondarily evolved powerful jumping legs to assist them in reaching a host. Such legs are unquestionably the most important of all their adaptations. Some species of fleas are better jumpers than others; it has been noted that there are differences in leaping ability even in various strains of the human flea. The jump is too rapid to follow with the human eye, but it has been supposed that the powerful thrust of the flea's leg is the result of the simultaneous extension of its two middle segments—the femur and the tibia.

A flea such as the rat flea that carries plague weighs between .15 and .40 milligram. Its average jump is about 18 centimeters—the record distance is 31 centimeters. It is not necessary to postulate some mysterious mechanism to account for these performances; the flea's powerful muscles are adequate for the job. There are, however, certain curious features in the flea's jump. First, the flea frequently lands facing in the direction from which it came, which suggests that the insect turns over in midair. Second, by making fleas jump into a fixative that "froze" them in their jumping attitudes it was found that during their leap they often hold one of their three pairs of legs (sometimes the second pair and sometimes the third) aloft, rotated upward at the trochanter and femoral joints through an angle of about 160 degrees.

This originally gave me the idea that possibly the large air sacs in the legs of fleas, first described by Sir Vincent Wigglesworth of the University of Cambridge, fulfilled some special function in jumping and did not merely provide buoyancy. It also occurred to me that perhaps the flea obtained some special advantage by turning cartwheels rather than somersaults, but after I had watched fleas jump onto rabbits a much simpler explanation presented itself. Such a standing jump for a flea is rather like a leap onto the side of a hairy, windswept cliff. It becomes obvious at once that the legs held aloft, with their powerful claws directed forward, act as grappling irons. Under these circumstances all six legs provide a highly specialized and quite effective type of landing gear. In order to be sure that fleas do normally hold a pair of legs aloft while jumping, a camera was constructed by which the animal could take a photograph of itself in midair. The photograph showed that at that moment it was traveling through the air upside down with its second pair of legs held well and truly aloft [*see illustration on preceding page*].

It is in their host-finding abilities that fleas show their most impressive adaptability and versatility. One species of bird flea—the sand-martin flea—depends for its survival on a sensitive response to temperature and air currents and also possibly to shadows. These fleas, which spend the winter in the temporarily abandoned underground nests of sand martins, are so sensitive to the gradual onset of warmer spring weather in Britain that they may hatch from their cocoons on the very day the migrating sand martins return from Africa and arrive at their nesting sites. If an artificial sand martin with wings that are mechanically flapped is dangled on a string in front of the burrow nest, the expectant sand-martin fleas will jump onto it.

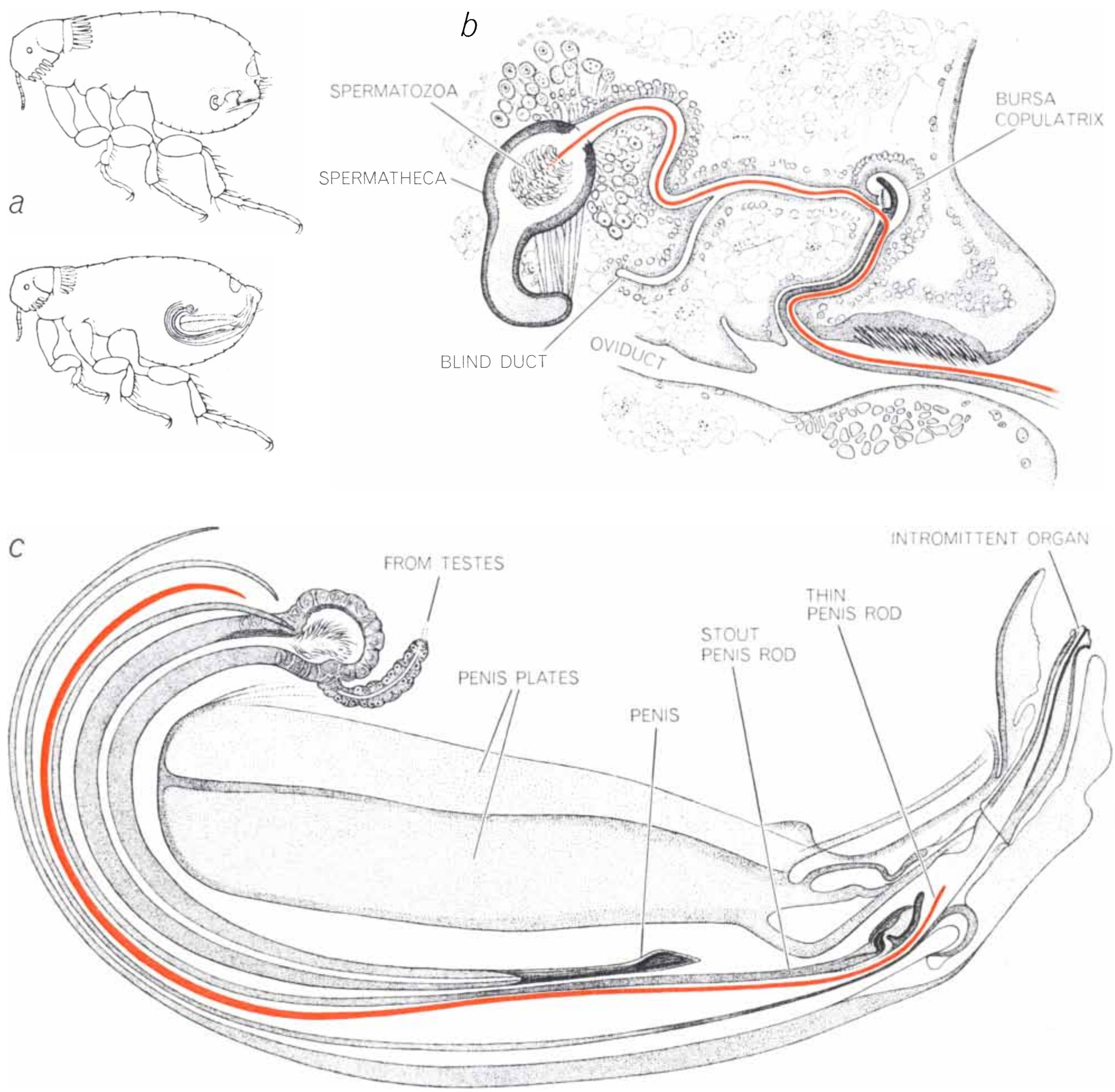
The cat flea, on the other hand, responds to the warm emanations of carbon dioxide exhaled by the cat, and the rat flea is attracted by the pungent odor of the rat. Fleas that are parasites of the large jird, a rodent that lives in the sandy soil along the Ili River of central Asia, congregate in the first bend of their host's burrow; it was observed that they became aware of the tread of a man within half a meter of the burrow and would emerge and pursue him for quite a distance. They can apparently distinguish the direction from which vibrations come and can also orient themselves to the direction of an air current. It seems that in their efforts to reach the right host, fleas are able to gain assistance from gravity, light, vibrations, noise, temperature gradients, atmospheric pressure, air currents, odors and other chemical stimuli.

Antony R. Mead-Briggs of the British Ministry of Agriculture has demonstrated the rabbit flea's talents in this regard. He liberated 270 marked specimens at intervals in an enclosed meadow with an area of 2,000 square yards. Into this enclosure he introduced three rabbits. Within a few days 45 percent of the marked fleas were recovered from them. The host-finding ability of the rabbit flea is therefore prodigious. It must be realized that a flea on the ground in a meadow is in the situation of a man in a forest where the trees are 600 feet high. (To be sure, the flea is much more mobile.)

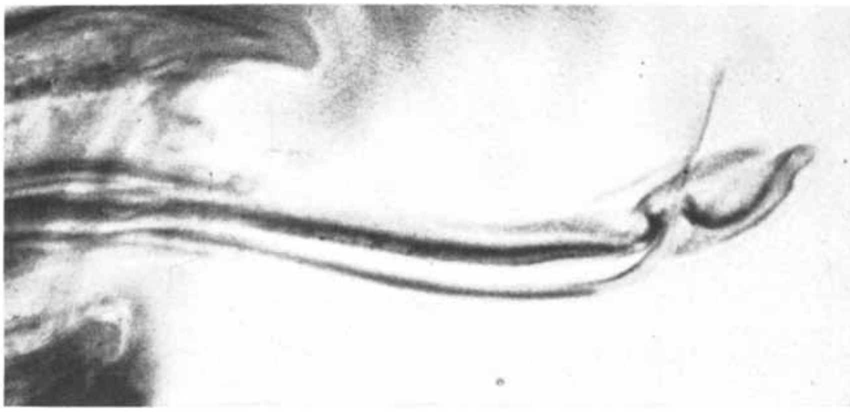
The Rabbit Flea

The rabbit flea merits detailed discussion because it provides an example of a unique type of adaptation: dependence on the sex-hormone cycle of the vertebrate host. Once on the rabbit the fleas make their way to the ears, where they attach themselves to the skin with their serrated mouth parts. Being a semisedentary species, they usually remain with their piercing mandibles more or less continuously embedded in the rabbit's flesh for long periods of their lives.

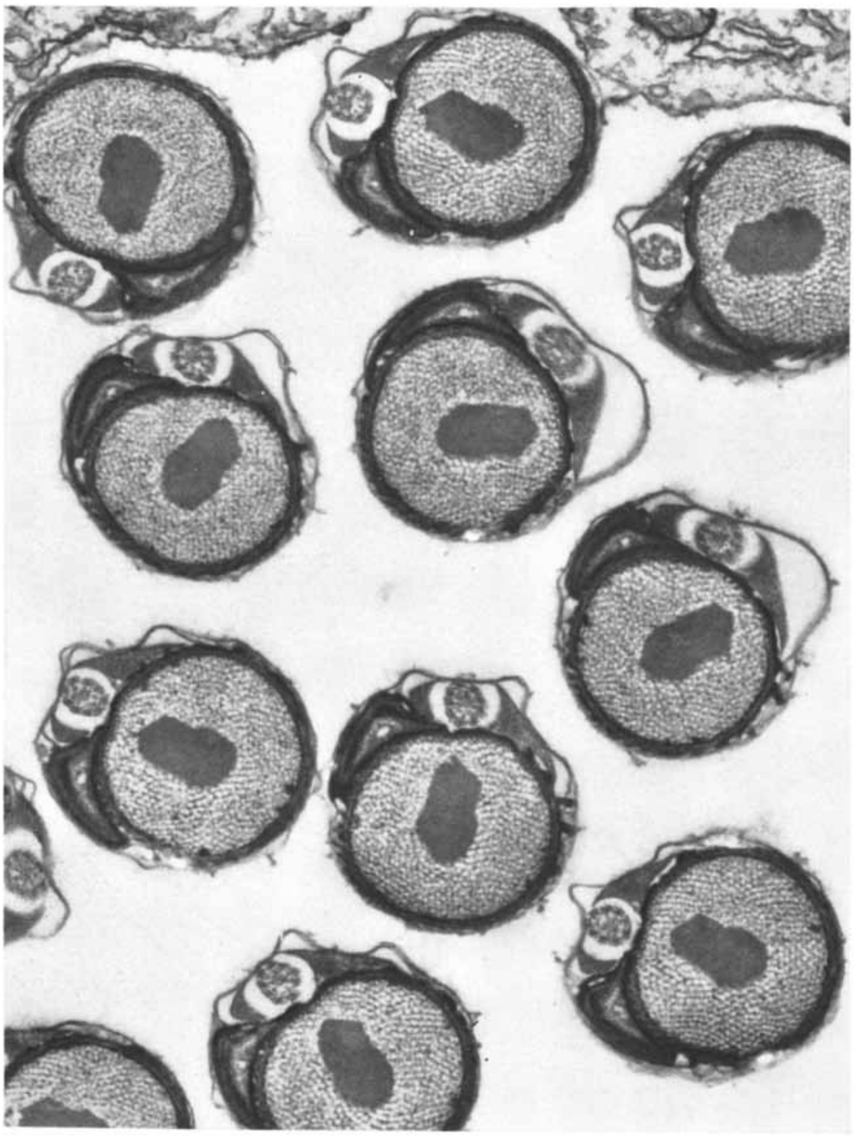
The fleas that settle on the rabbit's ears can never breed unless their host becomes pregnant or they can transfer to a rabbit already expecting young or to newborn nestlings. In this way the breeding cycle of the flea has become geared to the sex hormones secreted by the host and concentrated in its blood. Ten days before the young rabbits are born the eggs of the female fleas begin to develop, and by the last day of the host's pregnancy they are ripe. A few hours after the rabbits are born the fleas detach themselves from the mother's ears and move to her face. While the mother is tending her young and eating



EUROPEAN RABBIT FLEA reproduces with the aid of an unusually complicated genital apparatus. At *a* the female (*top*) and male are depicted with their copulatory organs outlined, at *b* the female's organs are shown in detail and at *c* details of the male organ are depicted in part. The thin penis rod (*color*) runs through a slot in the spoonlike end of the stout penis rod, picking up sperm. The thick rod enters the female's *bursa copulatrix* and guides the thinner rod into the threadlike duct leading to the spermatheca, or sperm-storage organ of the female, as shown in *b*. The precise method by which the thin penis rod deposits the sperm is not known.



PENIS RODS of a flea appear in a photograph made by freezing two fleas during copulation and then gently separating them. These structures are shown in the illustration on the preceding page as they appear before protraction. The thinner rod is visible passing through the slot in the thicker rod like a rope over a pulley and then projecting upward. The faint fuzz at the end of the thinner rod is sperm, which is wound around the tip of the rod.



SPERM TAILS of the rat flea are shown in cross section at an enlargement of 58,000 diameters in this electron micrograph made by A. V. Grimstone of the University of Cambridge. The cross section is through the tails of a bundle of rat-flea sperm. A different view of such a bundle of sperm is shown in the illustration at top left on the opposite page.

the placenta, the fleas pass on to the nestlings, on which they feed voraciously. There they mate and lay eggs. After about 12 days of egg-laying in the nest the fleas suddenly abandon the young rabbits and return to the mother. If she becomes pregnant again, they can begin a new breeding cycle.

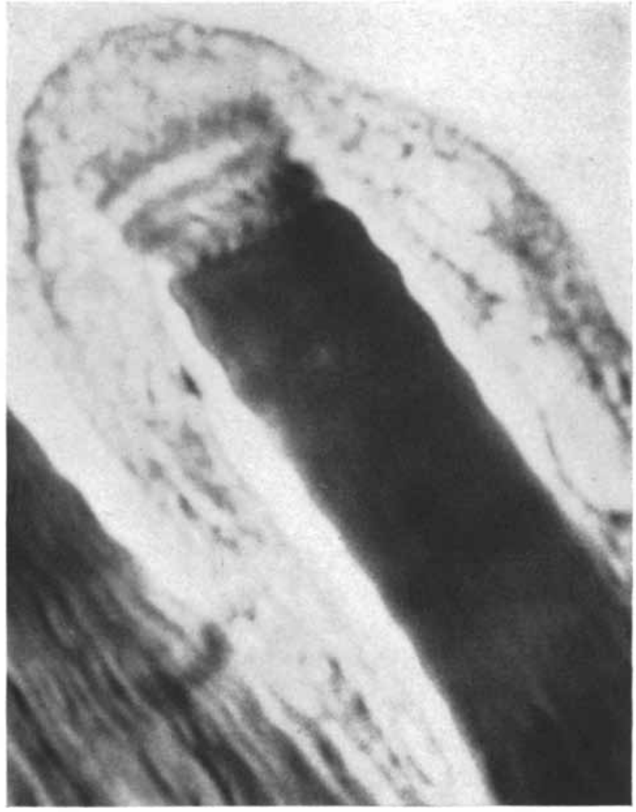
The fleas come under the influence of physiological changes in the rabbit the moment the buck rabbit sets eyes on the doe. The temperature of pairing rabbits' ears rises precipitately—sometimes by as much as seven degrees centigrade—and the fleas as well as their hosts become excited and can be seen hopping about and moving from the buck to the doe and back again. In female rabbits ovulation follows coitus; within a few hours, perhaps sooner, the anterior lobe of the pituitary gland—the master gland controlling the sexual cycle of the rabbit—releases sex hormones into the blood. The sex hormones in turn stimulate target organs such as the ovaries and the adrenal glands to secrete other hormones.

One of the first noticeable effects on the fleas is to induce them to attach themselves more firmly to the skin of the doe. In spite of their semisedentary inclinations there is a considerable exchange of fleas between rabbits that come into contact with each other, but once a flea has moved onto a pregnant doe under the influence of the sex hormones it remains there. The future mother thus tends to amass a heavier load of fleas than her virgin companions or the bucks—to the great advantage of the fleas.

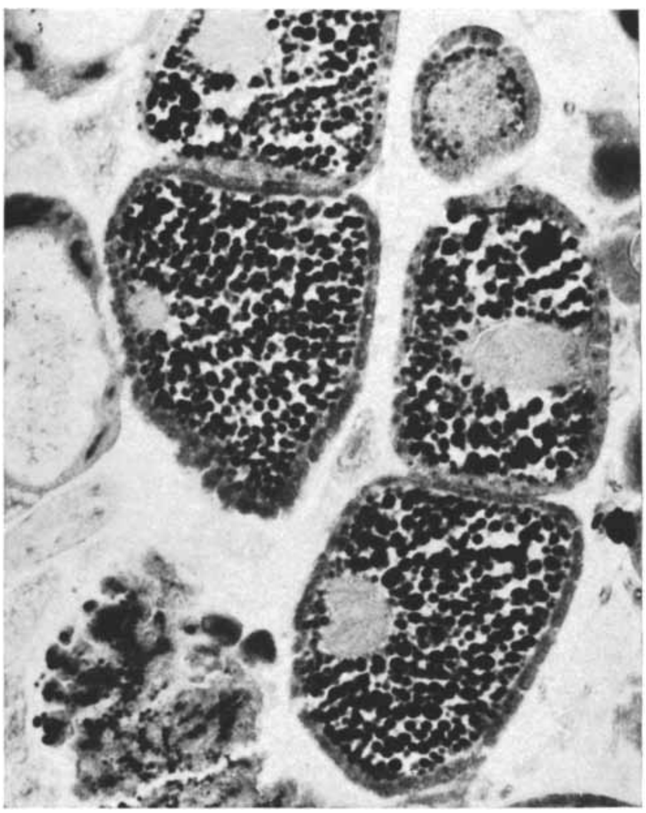
Ten days before the rabbit gives birth there is a rise of the level in its blood of another hormone from the anterior lobe of the pituitary: the adrenocorticotrophic hormone, which stimulates the adrenal glands to release corticosteroids. These are the principal hormones controlling maturation and egg-laying in the rabbit flea, although thyroxine and estradiol also play a significant role in these processes. The hormones known as progestins are responsible for checking the growth of the flea's ovaries and for initiating the regression and resorption of the yolk and developing eggs. It is worth mentioning that man-made progestins are used as human contraceptives—this is "the pill" that has recently attracted so much notice.

Apart from the development of the female reproductive organs both male and female fleas undergo profound changes under the influence of the maturation hormones. The salivary glands develop and more than double in size;

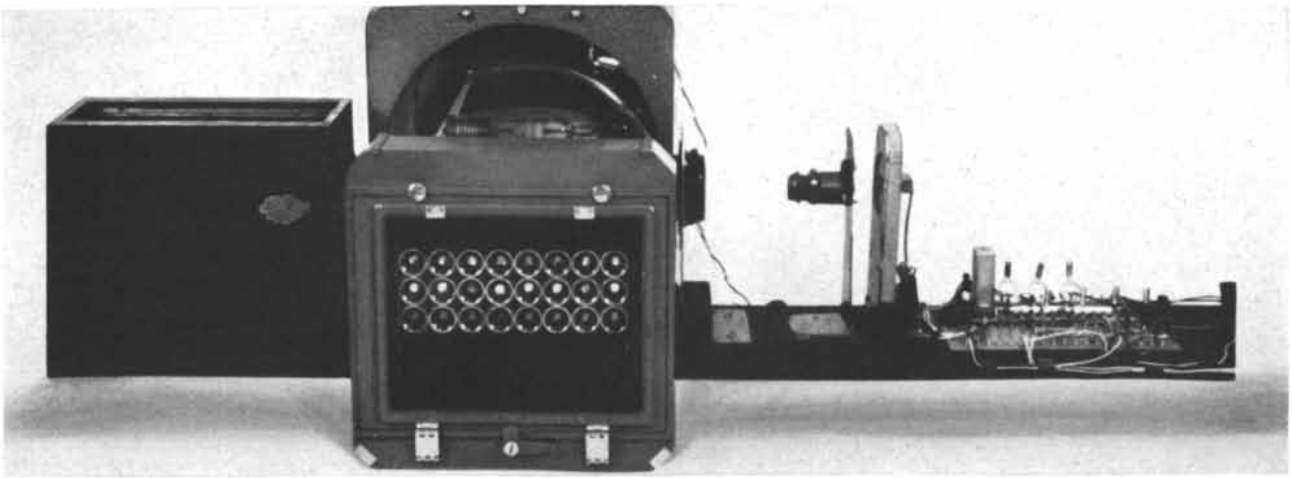
RAT-FLEA SPERM is shown enlarged 250 diameters. The partially developed heads (*center*) are held together in a gelatinous pointed cap. The tails of these sperm have short wave frequencies.



RABBIT-FLEA SPERM, enlarged 325 diameters, has a membranous envelope along the sides reminiscent of a bridal veil. The wave frequencies in the tails are longer than those in the rat-flea sperm.



INFLUENCE OF HORMONES of the host on the eggs of a rabbit flea is depicted. At left the eggs are developing after the rabbit has been injected with hydrocortisone. At right the eggs, which are the dark circular structures to the right of the pale, dark-rimmed structures, are regressing after injections of a progestin hormone into the rabbit. The enlargement is approximately 40 diameters.



SPECIAL CAMERA constructed at a Royal Air Force experimental station to photograph the jump of a flea consisted of a bank of one-inch lenses with overlapping fields that covered all of a glass cell in which the flea jumped. The flea itself triggered the camera by interrupting a narrow beam of light as it jumped. The glass cell was nine inches long, seven inches in height and one inch thick.

there is an overall increase in the size of the gut, together with great enlargement and proliferation of the epithelial cells lining its middle portion, and the rate at which the fleas defecate increases steadily as the levels of corticosteroids rise. Normally a flea defecates about once every 20 minutes; immediately before the rabbit gives birth the female flea is squirting blood out of its anus once every one to four minutes and the male flea about once every four to six minutes. This blood, as I have previously noted, subsequently provides the flea larvae with an essential factor in their diet.

Whereas a slight increase in the level of hormones in the blood of the rabbit induces the fleas to attach themselves more firmly to the host—a fact easily demonstrated experimentally—a big rise reverses this effect: the fleas detach themselves and run onto the doe's face. A change in hormone levels is almost certainly the cause of their detachment immediately before they pass on to the young. By this extraordinary adaptation the fleas are assured of a suitable place in which to breed. The female rabbit generally builds her nest some distance from the main warren, in a "stop," or short tunnel. By gearing their own reproduction to that of the host the fleas are guided to the nest at precisely the right moment, and the eggs are ready for fertilization the very day the young rabbits are born. Moreover, the larvae are assured of enough dried blood on which to feed.

It has been possible to sort out which of the various pituitary hormones are involved in these processes by injecting the rabbits with each in turn, and in different combinations and at different levels; it has been particularly useful to employ castrated buck rabbits as the experimental hosts, since they have a minimum of their own sex hormones. It has also been found that the fleas react to steroid hormones sprayed on them, and that they respond differently to the different corticosteroid hormones. Thus the rabbit flea, used as a kind of biological indicator, suggested that the corticosteroids cortisol and corticosterone were both present in the pregnant female rabbit during the last 10 days of pregnancy and in the rabbit from one to seven days old, but that when the young were three to four weeks old the levels in their blood had fallen precipitately. These indications were subsequently confirmed by D. Exley of the University of Oxford, who examined the rabbit's blood by means of thin-layer chromatography and with the aid of radioactive tracers and fluorescent techniques.

Many bird fleas, if they are slightly warmed, copulate on emerging from their pupae, without a blood meal and before their ovaries mature. In the large majority of species, however, the female has to take a blood meal before she will mate. It has been noted that at least one species of male flea lacks the sexual drive if it is reared on an unusual host but recovers its keenness after a meal of blood from its normal host. The rabbit flea is quite an exceptional case; in nature it will mate only after the female has fed on rabbits one to seven days old. The two flea sexes can remain side by side for weeks or months on an adult rabbit, the females either immature or full of ripe eggs, and no attempt at mating is made. After a period of feeding on the young rabbits a transformation occurs in the female; she suddenly attracts the male and is herself willing to mate.

In this species neither maturation of the eggs nor maturation of the sperm is concerned with copulation. After feeding on a young rabbit a female flea with unripe eggs will mate with a male that lacks fully ripe sperm in its testes. What is the signal the female gives when she has imbibed the necessary copulation factor? Does she release a pheromone—a hormone secreted externally—that stimulates the male? The characteristic zigzag approach made by the male on these occasions suggests that it is following some airborne trail of scent.

In spite of the fact that the fleas do not mate on the pregnant doe there was considerable evidence to suggest that the factor was present in her blood but in weak concentrations. This clue was followed up; it was found during preliminary experiments that still another hormone secreted by the anterior lobe of the pituitary—somatotropin, the growth hormone—is one of the factors that can control the copulation of fleas. This hormone, unlike the corticosteroids, tends to be specific in its action. That is, the growth hormone of cattle or the human growth hormone can be expected to work effectively only if it is injected into the animal that normally secretes it. No rabbit growth hormone, which would be expected to activate the rabbit flea more effectively than any other growth hormone, is yet available for experiments. Nevertheless, injections of human growth hormone into the rabbit can sometimes stimulate the rabbit flea to copulate on the adult host and more frequently on young rabbits more than eight days old. (It is of interest

FLEA DURING JUMP was photographed with the apparatus shown on the opposite page. Base of cell is dark area at bottom.

that somatotropin is one of the hormones that have been used to increase fertility in women and that have attracted considerable attention following several multiple births to women so treated.) Other factors not fully understood also play a part in controlling the copulation of the European rabbit flea.

The Reproductive Process

Even though the male flea freshly emerged from its pupa already has a full complement of sperm in its testes, the sperm are by no means fully developed. They are gathered together in bundles; their heads, which are barely distinguishable at this stage, are held firmly in a pointed gelatinous capsule with a giant nucleus at its apex. Seen through the microscope, the bundles of sperm are enveloped in membranes that resemble gracefully flowing bridal veils [*see illustration at top right on page 49*]. Sometimes the individual sperm heads are already developed (their development may depend on the food supply of the larvae), but even so there is always plenty of space between the bundles of sperm in the testes. When the heads of the sperm are well developed, the tails are sufficiently free within their capsules to produce wonderfully synchronized wavelike undulations in the available space. After the male flea begins to feed on a host these spaces are gradually obliterated by the fact that the sperm increase in size, but it is only after the male flea has been feeding on the pregnant rabbit and her newborn young for a certain period that both the flea and its sperm reach their maximum size.

At this stage sections of the fleas' testes reveal a solid tangled mass; possibly the sperm are not capable of fertilizing the eggs until this stage of development is reached. It would require rather a long period of study with the aid of the electron microscope to clarify and work out the effect of the rabbit's sex hormones on the development of the sperm. The picture at the bottom of page 48 was made with such a microscope by A. V. Grimstone of the University of Cambridge. It is a transverse section, enlarged 58,000 diameters, through partly developed sperm from the testes of a flea feeding on a nonpregnant host. Each tail seen in the section has two fibers surrounded by a circular array of nine other fibers; this arrangement is characteristic of all cilia and flagella and is the basis for the swimming abilities of the sperm.

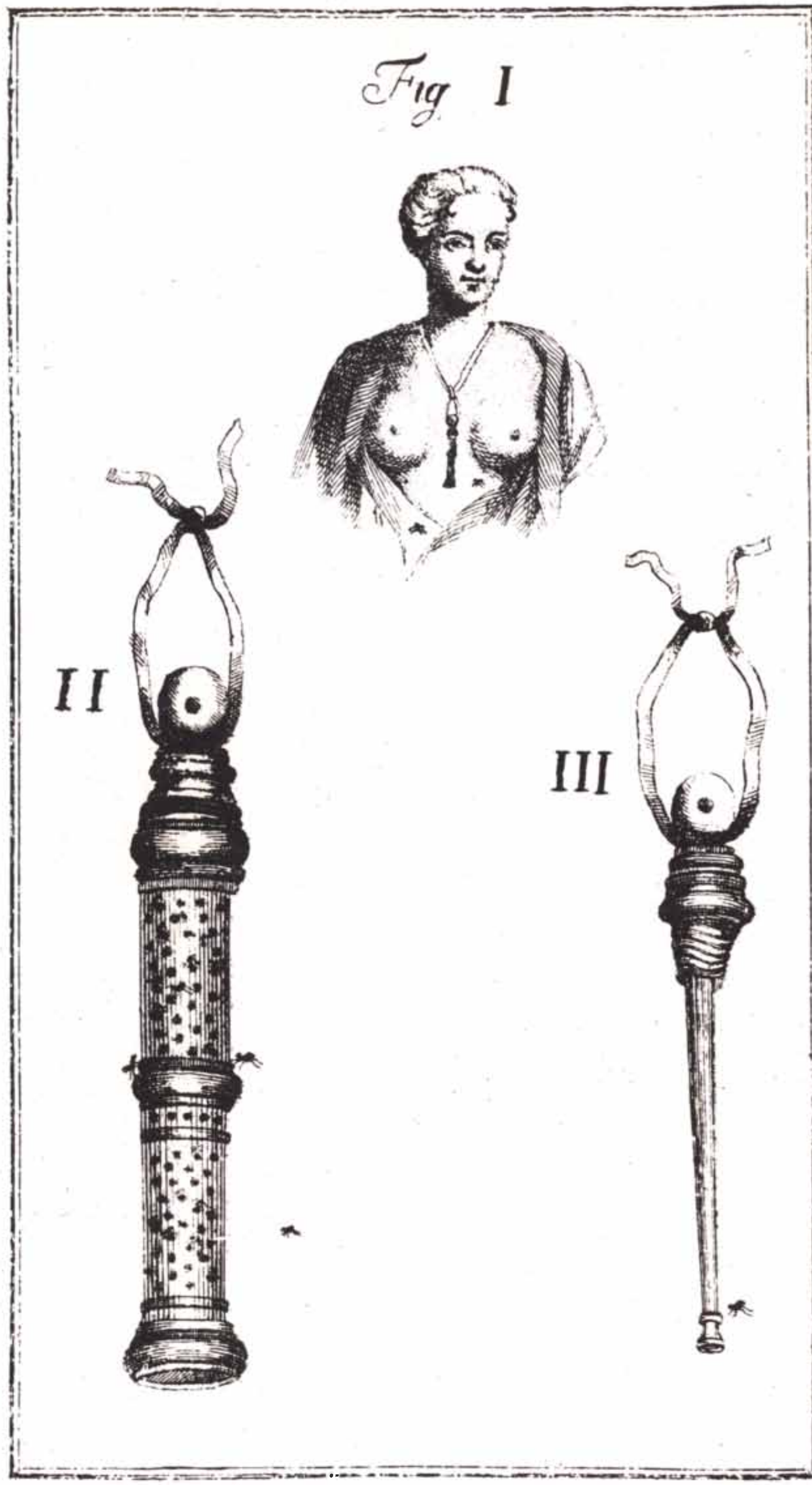
Even with the relatively low magnification of the light microscope it is possible to note differences between the sperm of different species of fleas. If the reader compares the micrographs of rat-flea and rabbit-flea sperm at the top of page 49, he will see that the wave frequency of the tails of the former is very much shorter than that of the latter; each tail of the rat-flea sperm at this stage of development has a kinky appearance. Rat-flea sperm are also much larger than rabbit-flea sperm. There appears to be a correlation between the size of the spermatheca, or sperm-storage organ of the female, and the size of the sperm. The mole flea (*Hystrichopsylla talpae*) belongs to a group of the largest fleas (between five and seven millimeters in length), but its sperm cell is relatively small and is stored in two correspondingly small spermatheca.

It would be interesting if an electron microscope study of the sperm confirmed the evolutionary relation of the order of fleas that was worked out by the late Karl Jordan of the Tring Museum in England. This classification is partly based on the organs that assist in conveying the sperm into the female. The copulatory apparatus of the male flea is the most elaborate genital organ in the animal kingdom. Recently the German entomologist Kurt Günther has described it for the mole flea and has clarified many obscure features. A glance at the illustration on page 47 will convey some idea of its complexity. Any engineer looking objectively at such a fantastically impractical apparatus would bet heavily against its operational success. The astonishing fact is that it works. Twenty-four hours after the rabbit fleas leave the doe for her young all the female fleas have been fertilized.

The various complicated steps in fertilization have not been observed in detail. The only part of the male flea's genitalia capable of extrusion are the two penis rods; these slide forward and uncurl like watch springs. Only in the rabbit flea has the conveyance of sperm actually been observed. The sperm is wound around the terminal portion of the thinner of the two penis rods rather like spaghetti on the end of a fork. This rod runs through a slot in the spoonlike end of the thicker penis rod like a rope running over a pulley. The thick rod enters the female's *bursa copulatrix*, into which it fits very snugly, and guides the thinner rod into the threadlike duct leading to the sperm-storage organ of the female. The photograph at the top of page 48 shows the end of the stouter rod with the thin rod running through the slot. The faint fuzz surrounding the tip is the mass of sperm. In order to take this photograph it was necessary to freeze two fleas during copulation, so that the penis rods remained erect when male and female were separated. Unfortunately the duct leading to the spermatheca is covered with heavy cuticle and therefore is not transparent. This makes direct observation by transmitted light impossible, and as a consequence the method by which the rod packs sperm into the spermatheca through this duct is not known.

George P. Holland, a Canadian entomologist who has greatly enlarged our understanding of copulation in various fleas, has described an odd membranous organ somewhat resembling a willow catkin with which the male strokes the female sensillum during the act of coitus. An analogous structure probably exists in many fleas but escapes attention because it is so transparent and diaphanous that it disappears entirely when specimens are prepared for permanent preservation. This is the case with the organ in the rabbit flea, which resembles a feather duster and is erected only during mating. Apparently it is also used for stroking the female, but on the lower surface. This is quite an astonishing fact; the clasping organs of the male flea are so elaborate and so encumbered with spines, struts and hooks that it would appear that only brute force is used to subdue the female. Furthermore, serious injuries are frequently inflicted on the female during impregnation, and it seems curious that she could notice the effect of this feather-like stimulator during the violent treatment she appears to be receiving simultaneously. Perhaps our interpretation of this organ is quite incorrect. Is it conceivable that it is the male who receives stimulation and with his feather duster sweeps up a pheromone released by the female?

Two particularly interesting questions are posed by the unraveling of the life cycle of the rabbit flea. First, how do these hormones act? Do they work by way of substances secreted by specialized cells in the flea's brain, which in turn act on the appropriate organ that releases the flea's own hormones, or do the corticosteroids, estrogens and progestins act directly on the various tissues of the flea? Second, what role do



FLEA TRAP was depicted in a German book of 1739. Old books often show such traps being worn by women; it was often said that women were attacked by fleas more often than men were. The cause may conceivably have been a response by fleas to ovarian hormones.

the host's hormones play in the lives of parasites in general? Is the hormonal dependence of the European rabbit flea unique?

Obviously the most promising species to investigate in this respect are the American rabbit fleas, which are fairly closely related to the European species. Unfortunately the cottontail rabbit is a difficult host to keep in captivity. It is quite certain, however, that the breeding of the plague-carrying Oriental rat flea (*Xenopsylla cheopis*) is not dependent on the hormones of the rat. This flea copulates and lays eggs even on a rat that has been castrated and in addition has had both its adrenal glands and its pituitary gland removed surgically, so that it is virtually deprived of all sex hormones. The fleas are probably less fertile than those laying eggs on a normal rat, and it is not yet known if their eggs produce offspring. It has been noted, however that the number of fleas on female bats increases noticeably in the spring just before the bats migrate to their summer breeding roosts. This suggests that in the case of bat fleas, as in that of the European rabbit flea, the hormones of the host may play an active role in the fleas' reproductive cycle.

Open Questions

It is characteristic of nature that some apparently unique feature displayed by a particular animal is only unique in degree. A careful examination of related species shows that the same tendencies are present but to a very modest extent and have consequently escaped notice. It seems reasonable to suppose that in the future many instances will be discovered in which the hormones of vertebrate animals play some unobtrusive but definite role in the development of their parasites, particularly those such as the parasitic worms that live in such naked intimacy with their hosts.

In the old literature it was repeatedly stated that women are attacked more frequently by fleas than men are. This has been generally attributed to the more delicate skin and more sensitive nature of the fair sex. In old books it is always women who are pictured wearing the latest flea trap [*see illustration on opposite page*]. Perhaps this is faulty reasoning and the truth of the matter is that the human flea (*Pulex irritans*) also responds to the attraction of the ovarian hormones. This is food for reflection. Here we have a simple and fascinating line of research on which any one of us can embark tomorrow.

BRILLIANT COLORS displayed by several different types of aurora are captured in these photographs made by the author in the neighborhood of the University of Alaska at Fairbanks. The photograph at top left is of a quiet and diffuse auroral arc; at top right is a similar arc with a strong enhancement of the pink light emitted by excited nitrogen molecules in the earth's upper atmosphere. The remaining four photographs are of a ribbon-like auroral type known as an active rayed band. The photographs were all made with a 35-millimeter camera, using a high-speed color film and an $f/1.2$ lens. The exposure time was between one and five seconds.

THE AURORA

The information gathered by rockets and artificial satellites has contributed to a new physical description of the aurora in which the earth's magnetosphere acts like a gigantic cathode-ray tube

by Syun-Ichi Akasofu

It is almost impossible to capture in photographs or describe in words the unearthly beauty of the aurora as it shimmers and flames in the polar night sky. Familiar to almost everyone from pictures and descriptions but only occasionally visible where most people live, the phenomenon has long lacked a satisfactory explanation. Now, within the past few years, ground-based observations have been combined with information acquired by rockets and artificial satellites to produce a physical description of the aurora that relates it to the large-scale interaction of, on the one hand, the magnetic fields that surround the earth in space and, on the other, the high-velocity "wind" of electrically charged particles streaming from the sun. According to this view the magnetosphere of the earth acts like a gigantic cathode-ray tube that marshals charged particles into beams and focuses them on the earth's polar regions. The aurora is a shifting pattern of images displayed on the fluorescent screen provided by the atmosphere.

In more technical terms the aurora is a fluorescent luminosity produced by the interaction of atoms or molecules in the upper atmosphere and energetic charged particles entering the atmosphere from space. The incoming particles, guided by the lines of force in the earth's magnetic field, are electrons and protons. The atoms and molecules are chiefly those of oxygen and nitrogen. When they are struck by incoming particles, they are stripped of one or more electrons (ionized) or raised to a higher energy state (excited); when they return to their original condition, by acquiring electrons or by losing energy, they emit radiation of a characteristic wavelength. Thus the spectrum of the aurora can provide detailed information about the atoms and molecules present in the upper atmosphere.

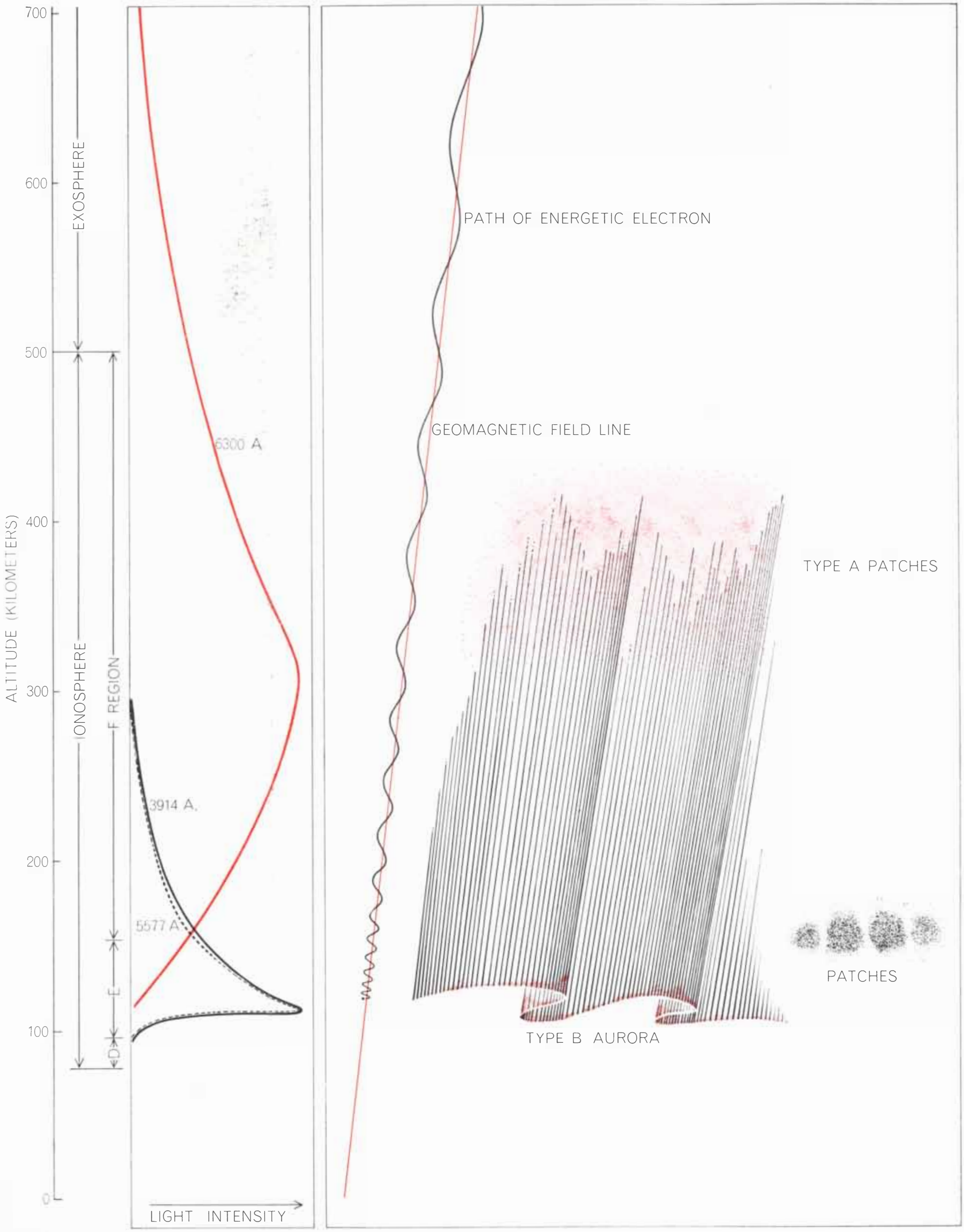
To the eye most auroras are green or blue-green, with occasional patches and fringes of pink and red. Excited oxygen atoms account for both green and red light, at the respective wavelengths of 5,577 angstrom units and 6,300 angstrom units. Ionized nitrogen molecules emit intense light, particularly violet and blue light in a group of spectral bands between 3,914 and 4,700 angstroms. Excited nitrogen molecules account for a series of emission bands that are particularly intense in the deep red part of the spectrum between 6,500 and 6,800 angstroms [*see top illustration on page 57*]. The oxygen radiation at 5,577 angstroms and the nitrogen radiation at about 3,900 angstroms originate predominantly at an altitude of about 110 kilometers (70 miles). The 6,300-angstrom radiation of oxygen originates chiefly between 200 and 400 kilometers.

At an altitude of 100 kilometers there is often no dearth of oxygen atoms excited to the level at which they could emit red light at 6,300 angstroms, but such spontaneous emission does not occur until about 200 seconds after excitation has taken place. In this period the probability is large that an excited oxygen atom will lose part of its energy in a collision with another atom or molecule. On the other hand, spontaneous emission at 5,577 angstroms (green light) takes place in about .7 second; hence green radiation predominates over red at low altitudes. Higher up in the atmosphere collisions are infrequent enough so that the 6,300-angstrom emission of excited oxygen atoms has time to take place. At such altitudes, however, the density of oxygen is so low that the red radiation is faint unless the flux of incoming particles is high enough to excite a large fraction of all the oxygen atoms present.

Another weak source of red light is the emission of radiation by excited hydrogen atoms, which enter the atmosphere originally as protons (hydrogen nuclei). Along the way the protons pick up electrons to form hydrogen atoms. When these atoms are first created, they are in an excited state and identify themselves as they decay to lower levels by emitting the familiar Balmer series of spectral lines.

The excited and ionized states that supply most of the visible light of the aurora are produced by beams of incoming electrons that have energies of less than 10,000 volts, or less than half the energy of the electrons in the beam of a television picture tube. The energies of auroral electron beams have been measured by precisely coordinating ground-based measurements, which record luminosity profiles, and rocket or satellite measurements, which supply information on the interactions taking place in the upper atmosphere. Among those who have made important contributions to such studies are C. E. McIlwain of the University of California at San Diego, B. J. O'Brien of Rice University and a cooperating group made up of investigators at the Lockheed Aircraft Company and our laboratory at the University of Alaska.

Auroral luminosity takes two basic forms: ribbons and cloudlike patches. A vigorous auroral display generally evolves from the former to the latter, but many auroras disappear without ever breaking up into patches. A ribbon display has a vertical dimension of a few hundred kilometers and an east-west dimension of at least a few thousand kilometers. The ribbon itself is



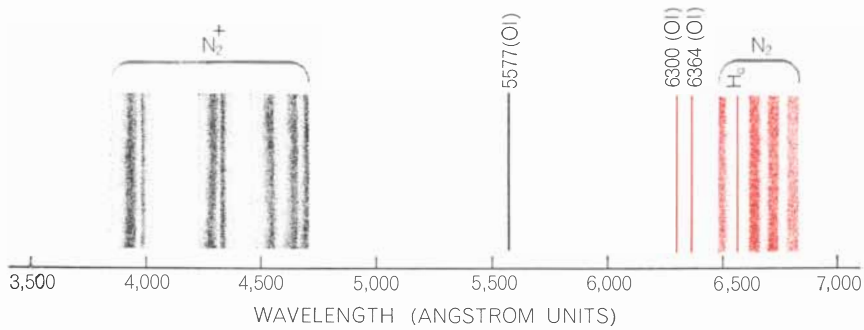
COMMON TYPES OF AURORA are shown with their average heights and characteristic radiations. The normal ribbon-like type, represented here by a "rayed band," has a vertical dimension of a few hundred kilometers and an east-west dimension of at least a few thousand kilometers. The ribbon itself is only a few hundred meters thick. An intensely active rayed band often develops a pink glow at the bottom; this is described as the Type *B* aurora. During the most intense activation the ribbon-like form collapses and is succeeded by cloudlike patches; these usually occur after midnight. When oxygen atoms become sufficiently excited to emit light at 6,300 angstrom units, rosy patches of Type *A* aurora appear at an altitude of 300 to 400 kilometers. A single energetic electron is shown gyrating down a geomagnetic-field line. Light is emitted as a result of its collisions with resident particles in upper atmosphere.

only a few hundred meters thick, which suggests that it is produced by a sheetlike electron beam that comes from the magnetosphere into the polar upper atmosphere. The ribbon form usually appears in multiple tiers—like stage curtains hanging one behind the other—stretching across the entire sky.

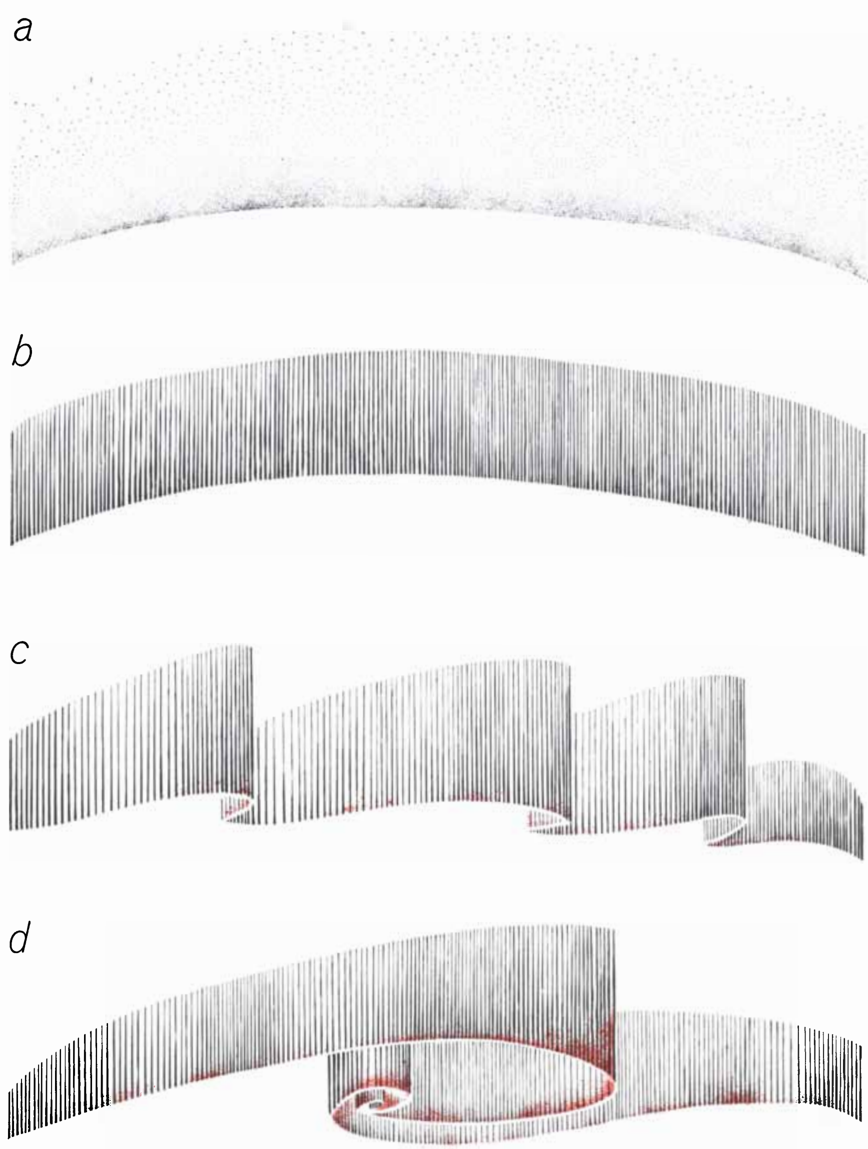
Students of the aurora have developed a series of descriptive terms to identify various subcategories of the ribbon form [*see bottom illustration at right*]. When the ribbon is in its simplest and quietest configuration, it is known as a homogeneous arc; at such times it has a fairly smooth luminosity, brightest at the bottom and fading into the night sky at the top. As the ribbon becomes slightly more active it develops fine folds a few kilometers in width, with the result that the aurora seems to be composed of aligned columns, or rays, of light; this is called a rayed arc. With more intense activation the folds spread to a few tens of kilometers in width. When the larger folds are superposed on the more delicate ones, the ribbon is called a rayed band. If the activation continues to increase, the rayed band develops a beautiful pink glow at the bottom of the folded ribbon; this is often described as a Type *B* aurora. Finally, if the activation rises still further, the folds or loops grow to a truly grand scale, with widths of a few hundred kilometers. As soon as the activation ceases, however, the folds tend to disappear and the ribbon resumes its homogeneous form. This suggests that the homogeneous form represents the fundamental structure of the aurora and that the folds and convolutions are indeed evidence of increased activation.

During the most intense activation the ribbon form collapses and is succeeded by the cloudlike patches; these appear most commonly after midnight. A comparison of reports from observers widely separated around the Arctic Circle leaves no doubt that the various active forms at different places and different local times are closely related to one another. For example, when one observer sees unactivated homogeneous arcs in the evening sky, other observers will report that auroras have been fairly quiet all around the Pole. On the other hand, when the quiet arcs become activated during the evening to form rayed arcs and rayed bands, observers watching the morning sky elsewhere will see previously quiet arcs break up into cloudlike patches.

I have spoken so far only of the most common types of aurora, but several



SPECTRUM OF THE AURORA can provide detailed information about the kind of particles present in the upper atmosphere and their normal energy states. Excited oxygen atoms account for both green and red light at the specific wavelengths of 5,577, 6,300 and 6,364 angstroms. Ionized nitrogen molecules supply violet and blue light in a group of spectral bands between 3,914 and 4,700 angstroms. Excited nitrogen molecules supply a series of emission bands in the deep red part of the spectrum between 6,500 and 6,800 angstroms.



RIBBON-LIKE FORM of the aurora has various subcategories, depending on the intensity of the activation. When the ribbon is in its simplest and quietest configuration, it is known as a homogeneous arc (*a*). As the ribbon becomes slightly more active it develops fine folds and is called a rayed arc (*b*). With more intense activation larger folds are superposed on the more delicate ones and the ribbon comes to be known as a rayed band (*c*). An extremely active Type *B* aurora develops a pink glow at the bottom of the folded ribbon (*d*).

AURORAL ZONE, which is defined as a narrow band centered on the line of maximum average annual frequency of auroral visibility (*broken white line*), has only a statistical significance. At any given hour or minute slightly activated auroras tend to appear, on the average, along an oval zone that coincides with the nearly circular auroral zone only at the observer's local midnight. (In this view of the world it is approximately midnight at the Geophysical Institute of the University of Alaska at Fairbanks.) When the sun is very calm, the auroral oval is smaller and essentially circular, with its center at about the geomagnetic pole (*white dot*). As soon as the sun becomes a little active the oval expands to its average location and becomes eccentric with respect to the geomagnetic pole. During intense solar and geomagnetic storms the auroral oval shifts even farther south toward the Equator.

other varieties are seen, some only at rare intervals. One of these is the Type *A* aurora, a spectacular rosy variety that appears at an altitude of 300 to 400 kilometers when oxygen atoms become sufficiently excited to emit light at 6,300 angstroms. Type *A* auroras occur only a few times in a dozen years. Incoming protons frequently give rise to an extensive but faint band of whitish-green luminosity. During intense magnetic storms a "midlatitude red arc" appears at latitudes considerably south of New York City; it consists of a wide but not very bright band of 6,300-angstrom radiation and thus is not easily seen with the unaided eye. A few hours after an intense solar flare the entire polar region is bombarded by energetic protons expelled from the sun, producing the whitish-green "polar-cap glow." In addition to all these natural varieties of aurora, high-altitude nuclear-bomb tests have produced brilliant crimson auroras. None of these special types of aurora need concern us further.

What are the actual mechanisms involved in the production of the aurora? Instruments carried by satellites have shown that the earth and its magnetic field are confined in a huge cavity carved in the solar wind. The cavity is the magnetosphere; it contains all the belts of particles trapped in the earth's magnetic field [see "The Solar Wind," by E. N. Parker, SCIENTIFIC AMERICAN, April, 1964, and "The Magnetosphere" by Laurence J. Cahill, Jr., SCIENTIFIC AMERICAN, March].

Furthermore, the magnetosphere has a long cylindrical tail that is carried downstream by the solar wind; this was first suggested by J. H. Piddington of the Commonwealth Scientific and Industrial Research Organization in Australia. Norman Ness of the Goddard Space Flight Center has recently confirmed the existence of this comet-like tail with satellite measurements. Within the cylindrical tail the lines of force in the earth's magnetic field are bunched together like a bundle of spears. The lines of force above the plane of the magnetosphere's equator are directed toward the sun; those below the plane are directed away from the sun. The equatorial plane therefore constitutes a neutral sheet. The secret of the aurora seems to be hidden in the tail of the magnetosphere.

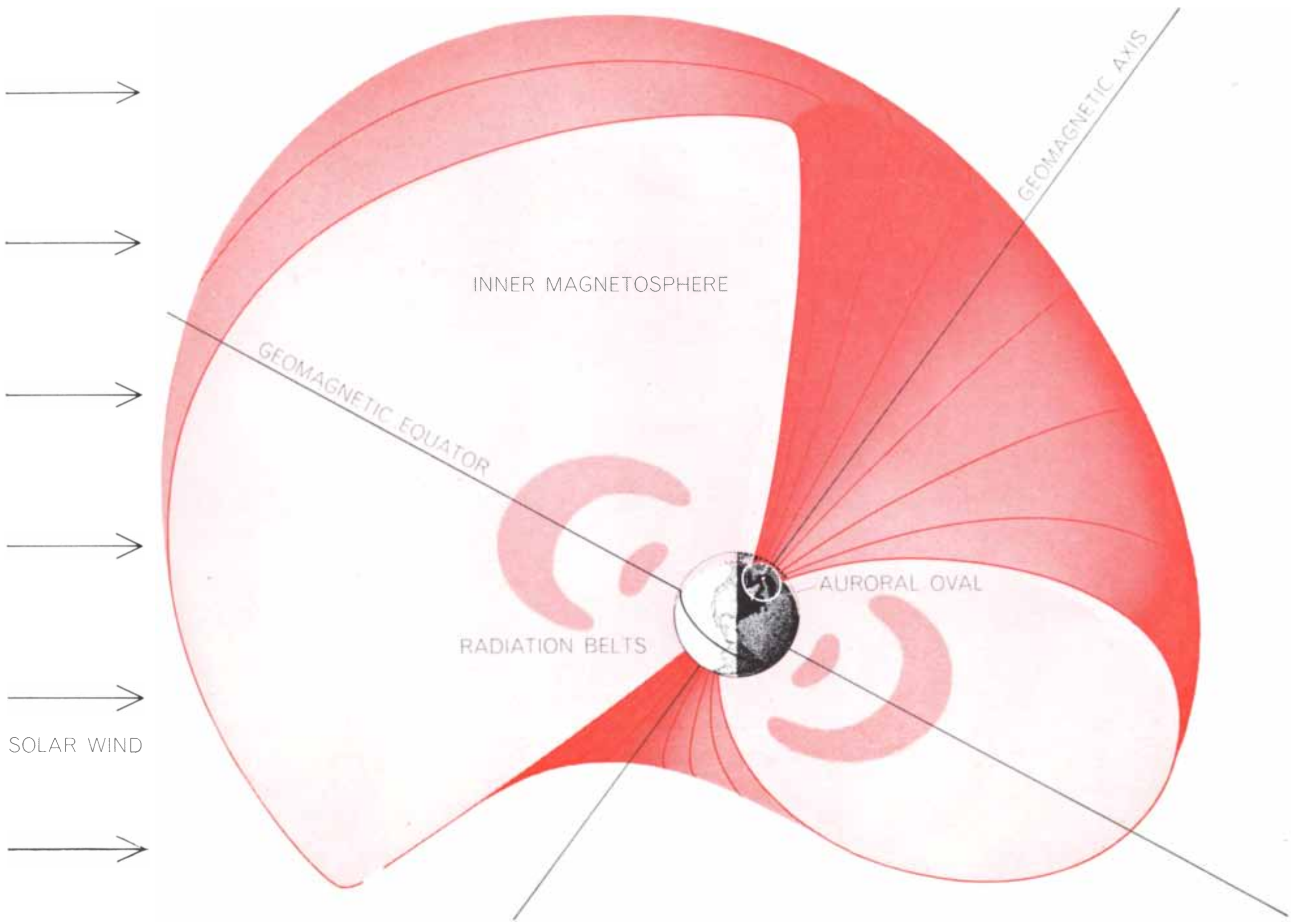
The role of the magnetosphere's tail can be visualized by comparing the magnetosphere to a cathode-ray tube; this analogy was suggested to me by C. T. Elvey, formerly director of the Geophysical Institute of the University of Alaska. In a cathode-ray tube electrons are emitted by a heated filament and accelerated toward an anode that is perforated with a small hole. Some of the electrons pass through the hole and form a pencil-like beam that is deflected, on its passage to the face of the tube, by electric fields between two pairs of plates or, in some tubes, by magnetic fields set up by coils. The electron beam strikes a fluorescent material on the tube face, producing a luminous image. The luminous display on the screen thus supplies evidence of changes in both electric and magnetic fields along the path of the electron beam.

In much the same way the shifting patterns of the aurora over the entire polar night sky supply evidence of changes in the magnetic and electric fields along the path of electrons streaming toward the earth. In some obscure fashion the tail of the magnetosphere accelerates and collimates electrons in the magnetosphere into ribbon-like beams that impinge sharply on the upper atmosphere. The task ahead is to identify the precise mechanisms that play the role of the electron gun, the anode, the electric plates and the magnetic coils.

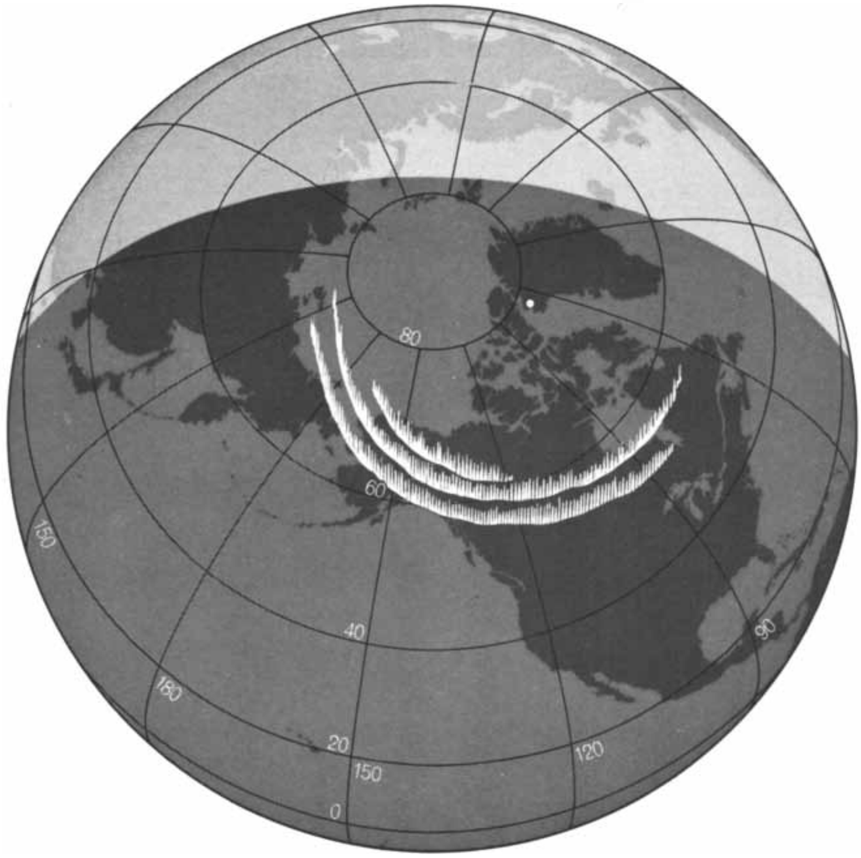
Clues to these mechanisms can be found in changes in the magnetic field on the earth's surface and in space, as well as in the auroral display itself. Let us, therefore, "watch" the auroral display as it appears on the "screen" of the entire polar night sky. If one travels northward from the border between the U.S. and Canada, one will see the aurora with increasing frequency. The increase does not continue all the way to the North Pole; the frequency reaches a maximum over the southern part of Hudson Bay. Excellent maps have been prepared that show auroral "isochasms": the lines of equal average annual frequency of visible auroras. The auroral zone is defined as a narrow band centered on the line of the maximum isochasm. There is, of course, an auroral zone in the Southern Hemisphere as well as in the Northern. The center of the northern auroral zone is not, as one might think, the magnetic dip pole near Resolute Bay in Canada (73.5 degrees north latitude and 100 degrees west longitude), but what is known as the dipole, or geomagnetic pole, at the northwestern tip of Greenland (78.5 degrees north and 69 degrees west).

The auroral zone, however, has only a statistical significance. At any given hour or minute auroras tend to appear, on the average, in an oval zone that coincides with the nearly circular auroral zone only at the observer's local midnight [*see illustration on opposite page*]. Elsewhere the oval zone falls inside the auroral zone. The oval zone, if it were viewed from a point above the geomagnetic pole, would appear as an oval glow roughly fixed in space above the geomagnetic pole. The earth turns below the oval pattern once a day, and the locus of the midnight portion of the oval traces out a circle that coincides with the auroral zone. The auroral oval is a new concept that has evolved gradually as the result of cooperation among workers in Australia, Canada, Denmark, Finland, Norway, Sweden, the U.S.S.R., the United Kingdom and the U.S.

From investigations of the outer belt of particles trapped in the earth's magnetic field (particularly studies by James A. Van Allen and L. Frank of the State University of Iowa), it seems likely that the oval belt of the aurora lies immediately poleward of the curve of intersection between the ionosphere (which begins about 80 kilometers above the earth's surface) and the shell of trapped particles that forms the outer boundary of the inner magnetosphere [*see illustration below*]. This region is populated with electrons whose energies range upward from about 40,000 volts. Such electrons are produced in the tail of the magnetosphere and flow along the boundary of the inner magnetosphere, creating a more or less steady glow where they intersect with the upper atmosphere. The oval has the shape it



THE MAGNETOSPHERE is a vast cavity in the solar wind that contains the earth's magnetic field; its role in the production of the aurora is to act like a gigantic cathode-ray tube that focuses electron beams, as well as proton beams, toward the earth in the vicinity of the magnetic poles. The oval belt of the aurora coincides roughly with the intersection curve between the ionosphere, which begins about 80 kilometers above the earth's surface, and the outer boundary of the inner magnetosphere (*color*). This region of the magnetosphere is populated with electrons whose energy ranges from about 40,000 volts upward; the extended tail of the magnetosphere, whose magnetic-field lines terminate inside the auroral ovals, is not shown here. The auroral oval has the shape it does because the inner magnetosphere is highly asymmetric with respect to the solar wind, and hence to the earth's noon-midnight axis.



AURORAL SUBSTORM, the most spectacular auroral display, occurs during major magnetic storms and coincides with a rapid buildup of circumpolar ring currents. Such substorms originate in the midnight sector of the auroral oval and usually last for two or three hours. These two views show the quiet homogeneous arcs of the aurora before the substorm (*top*) and the complex display of many auroral types at the substorm's height (*bottom*).

does because the magnetosphere is highly asymmetric with respect to the solar wind and hence to the noon-midnight axis on the earth's surface.

The size of the oval changes greatly with solar activity. When the sun is extremely quiet, the midnight portion of the oval recedes toward the geomagnetic pole and the oval becomes almost circular and faint. The oval occupies its typical position when the sun is in a state of average activity. After a major solar storm the oval expands rapidly toward the Equator, the amount of expansion being roughly proportional to the volume of electric current flowing in the tail of the magnetosphere and also to the intensity of a gigantic ring current that grows within the magnetosphere and flows westward around the earth. The expansion of the oval toward the Equator indicates that the inner magnetosphere is shrinking. Thus by watching changes in the oval one can visualize large-scale changes in the internal structure of the magnetosphere.

The most dynamic auroral displays occur during major magnetic storms, which are evoked in turn by intense solar activity. The most violent displays, known as auroral substorms, coincide with a rapid buildup of the circumpolar ring currents in the ionosphere. Such substorms originate in the midnight sector of the auroral oval and usually last for two or three hours [*see illustration at left*]. The first indication of the substorm is a sudden increase in the brightness of one of the quiet arcs. Soon the brightened auroras, having assumed the character of rayed arcs and bands, begin to spread explosively toward the poles at speeds of about five kilometers per second or even higher. When the poleward expansion is very rapid, the rayed bands begin breaking up in the midnight sector.

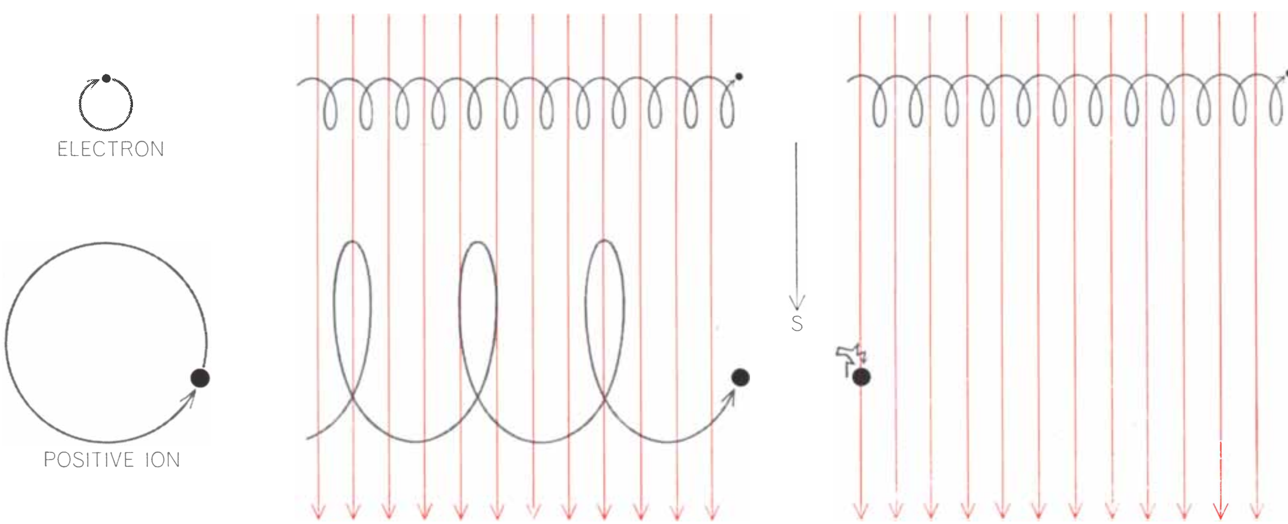
Meanwhile, in the evening sector of the polar region, the auroral expansion generates large-scale folds and loops that travel westward along preexisting arcs with a speed of about a kilometer per second. Such westward surges commonly sweep across the Alaskan sky and then the Siberian sky only 20 or 30 minutes after they have first appeared in the Canadian sky.

In the morning sector of the polar region the auroral arcs or bands that lie in the northern part of the oval also expand explosively, but those that lie in the southern part of the oval often disintegrate into cloudlike patches. Both the bright bands and the patches drift rapidly eastward. As the substorm subsides, the scattered auroral frag-

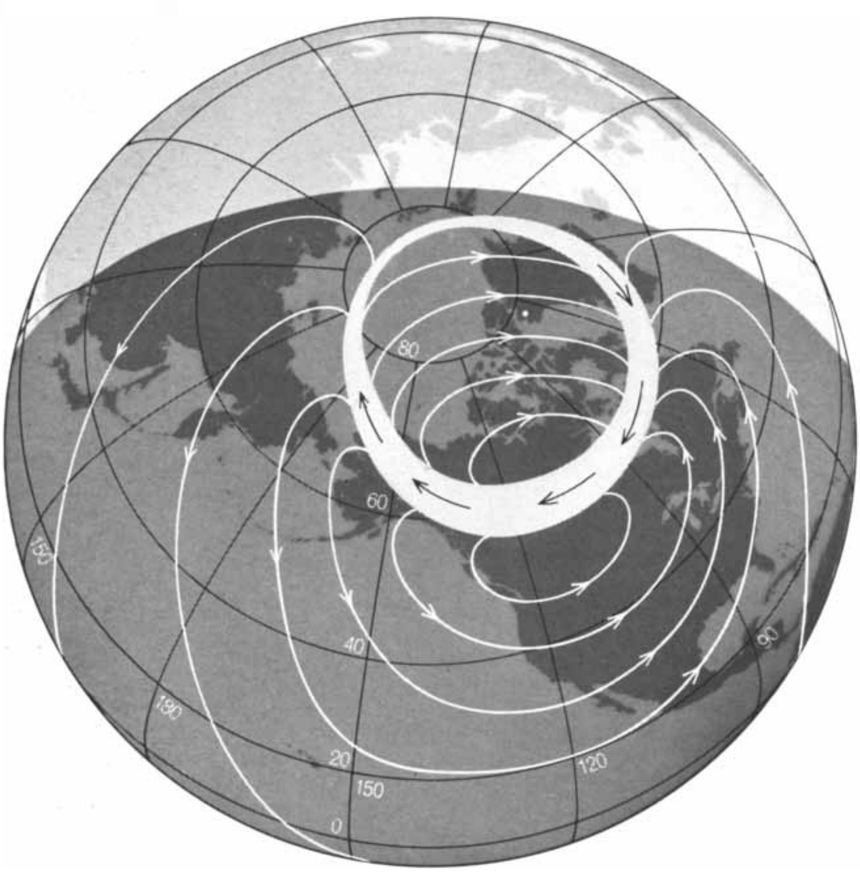
MOST INTENSE AURORAL SUBSTORM of recent years occurred during the great magnetic storm of February 11, 1958, which resulted from an intense solar flare on February 9. By 1020 hours (universal time) on February 11 at least three large substorms were observed. At the height of the magnetic storm (*left*) the auroral oval was driven so far south that it formed a line connecting Redmond, Ore., Vermillion, S.D., Williams Bay, Wis., Ithaca, N.Y., and Hanover, N.H. Curiously no bright auroras could be seen north of this line. Then a fourth substorm began and within 30 minutes the active auroras had spread northward until they covered a band some 2,000 kilometers wide (*right*). An intense shower of X rays was recorded at the height of the fourth substorm.

ments converge slowly and reassemble into quiet homogeneous arcs, tracing out the auroral oval as it was before the substorm began.

Perhaps the most intense auroral substorm of recent years occurred during the great magnetic storm of February 11, 1958, which resulted from an intense solar flare on February 9. About 29 hours after the flare the magnetosphere was enclosed in a violent wind of charged particles. Within a few hours ring currents began building up within the magnetosphere and reached maximum intensity between 1000 and 1100 hours (universal time) on February 11. During this buildup period at least three large auroral substorms occurred. At the height of the magnetic storm the auroral oval was driven so far south that it formed a line connecting Redmond,



ELECTRONS AND POSITIVE IONS in the earth's ionosphere respond differently to the onset of an auroral substorm, depending on their altitude. Before such a substorm (*left*) electrons are forced to rotate clockwise, whereas positive ions are forced to rotate counterclockwise, around the geomagnetic-field lines, which in this view must be imagined as entering the page at right angles from above. The events that underlie the substorm also give rise to an electric field (*colored arrows*) that points southward, causing both electrons and positive ions to be deflected eastward. At levels above the *E* region of the ionosphere (*middle*) the density of gas particles is so slight that electrons and positive ions have about equal mobility; even though both may travel violently eastward together there is no net displacement of electric charge and hence no flow of current. In the *E* region (*right*), however, the positive ions, being larger, collide more frequently with other particles than the electrons do and thus tend to be stopped, whereas the electrons continue to drift eastward. This separation of electric charges gives rise to the westward-flowing polar electrojet (*see illustration on next page*).



POLAR ELECTROJET ***(black arrows)*****, an intense electric current that flows westward around the auroral oval, occurs only during an auroral substorm. Part of the electrojet leaks away from the auroral oval and spreads southward over the whole ionosphere** ***(white arrows)*****.**

Ore., Vermillion, S.D., Williams Bay, Wis., Ithaca, N.Y., and Hanover, N.H. Curiously no bright auroras could be seen north of this line. Then the fourth substorm began, and within 30 minutes the active auroras had spread northward until they covered a band some 2,000 kilometers wide [*see top illustration on preceding page*]. In anticipation of the magnetic storm J. R. Winckler and his co-workers at the University of Minnesota sent a balloon aloft over Minneapolis with radiation-recording instruments. At the height of the fourth substorm the instruments recorded an intense shower of X rays generated when energetic auroral electrons collided with atoms and molecules in the upper atmosphere.

X-ray production is just one of several interesting phenomena associated with the auroral substorm. For example, during such a storm intense electron beams penetrate deeper into the atmosphere than usual and greatly increase the ionization of the lower parts of the ionosphere known as the *E* and *D* regions. The *E* region reflects short radio waves and makes long-distance radio communication possible. When abnormal ionization occurs in the *D* region, communication is often disrupted. On the other hand, heavy ionization in that region tends to scatter shorter radio waves: the microwaves that ordinarily pass through the ionosphere. When such waves are scattered, television viewers sometimes receive a channel that originates in a distant city. It has also been observed that the atmosphere is heated and expands upward during the auroral substorm, causing satellites to decelerate at a slightly faster rate.

The large-scale activity of the magnetosphere during the substorm has at least one other major effect. When the magnetosphere interacts with the *E* region of the ionosphere, it generates the "polar electrojet," an intense electric current that flows westward around the auroral oval [*see illustration above*]. To understand the origin of this current, let us imagine that we are looking down on the polar ionosphere, where we find that the lines of force in the earth's magnetic field are penetrating the ionosphere from above. Under the influence of this field electrons moving through the upper ionosphere are forced to travel in a clockwise direction, whereas positive ions are forced to travel in a counterclockwise one [*see bottom illustration on preceding page*].

When energetic charged particles flow out from the tail of the magnetosphere toward the earth, they develop (in the Northern Hemisphere) an electric field that points southward. Such a field, being directed at right angles to the magnetic field, causes both electrons and positive ions to be deflected eastward. At levels above the *E* region the density of gas particles is so low that electrons and positive ions have about equal mobility; even though both may flow strongly eastward together, there is no significant net displacement of electric charge and hence no flow of current. In the *E* region, however, the positive ions, being larger, collide more frequently with other particles than the electrons do and thus tend to be stopped, whereas the electrons continue to drift eastward. This separation of electric charges gives rise to the westward polar electrojet. (According to convention, current flow is opposite to electron flow.) It has been found that part of the electrojet leaks away from the auroral oval and spreads southward over the whole ionosphere.

The study of the auroral substorm owes much to photographic records made by an all-sky camera, the first models of which were designed by Carl W. Gartlein of Cornell University. This instrument consists of a camera mounted above a convex mirror that reflects the whole sky from horizon to horizon. The all-sky camera was first used extensively during the International Geophysical Year (1956–1957), when 67 nations participated in a worldwide geophysical program. Since then all-sky photographs from as many as 115 stations in the Arctic and Antarctic have been collected and studied by our laboratory at the University of Alaska.

Our task has been to analyze successive photographs of the auroral substorm taken simultaneously at various polar stations and to infer minute-to-minute changes in the magnetosphere. These analyses and inferences are then correlated whenever possible with measurements made simultaneously by instrumented satellites. Out of this coordinated study has emerged the account of the aurora I have presented in this article.

HOW RCA MICROELECTRONICS

brings the hospital to the patient...

The patient is too ill to go to the hospital—so the "hospital" comes to him.

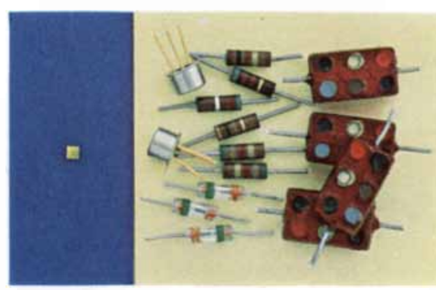
Soon, thanks to RCA research in microelectronics, a doctor's "little black bag" may carry an electronic medical laboratory to a patient's bedside. There—in involved cases—the doctor could take instant diagnostic readings, feed the results by telephone directly to a hospital computer, and get back confirmation of his findings within minutes.

What will make this possible? RCA integrated microelectronic circuits: unique devices made possible by a revolutionary technique of designing circuits in "picture form," reducing them to microscopic dimensions, and then fabricating them in this minute size—to perform the same functions as many conventional full-size components.

Through integrated circuits, a whole new world of medical instruments is at hand. These will enable a doctor to inject a radio transmitter as small as a grain of sand into a patient's bloodstream to pinpoint obstructions ... to insert an electrocardiograph recorder/transmitter into a patient's body to monitor his heart condition ... to administer a "radio pill" which, when swallowed, transmits signals indicating the functioning of the internal organs through which it passes ... to make instantaneous measurements of blood counts and blood viscosity ... to detect and locate diseased tissues.

But microscopic size is only one of the advantages of integrated circuits. They hold promise of creating electronic devices low in cost and more reliable than their present-day counterparts. Already a reality, RCA is today using integrated circuits in satellites, spacecraft and in new RCA "third generation" computers.

Helping pioneer the development of these "tiny electronic giants" is another way RCA is bringing the benefits of electronic innovation to more people at lower cost.



THIS... **REPLACES ALL THIS**

The "tiny chip" on the left—shown full size—is a complete integrated digital computer circuit; it does the work of all the 15 standard circuit components (also full size) on the right.

RCA ELECTRONIC COMPONENTS AND DEVICES

RCA **The Most Trusted Name in Electronics**

Polaroid's new close-up camera lets you come in closer and closer and

The close-up can be the trickiest of photographs. Figuring out field size, determining correct lighting and exposure, and getting an accurate focus become increasingly difficult problems as camera moves closer to subject. With the new Polaroid CU-5 Close-Up Camera, however, none of these problems exist.

To make your picture, simply aim the camera at the area or object you want to photograph and squeeze the trigger. One minute later, you peel off a perfect color close-up. Or 10 seconds later, a perfect black and white. How close do you want the close-up? You have a choice of four different images. There are interchangeable lenses and attachments for making ¼ to 1, 1 to 1, 2X and 3X pictures. (In our three close-ups of a 15th-century oil by the Master of Moulins*, you can see the sharpness of detail you get in the close-up images. The close-ups go from one-quarter life-size to twice life-size, and have been enlarged slightly for reproduction.)

You don't have to focus the camera. Distance from lens to subject is determined for you by simple extensions from the camera for the 1 to 1, 2X and 3X close-ups, and by a special, pre-set viewfinder for the ¼ to 1 picture.

Correct exposures are automatic. The CU-5 camera has a built-in electronic flash

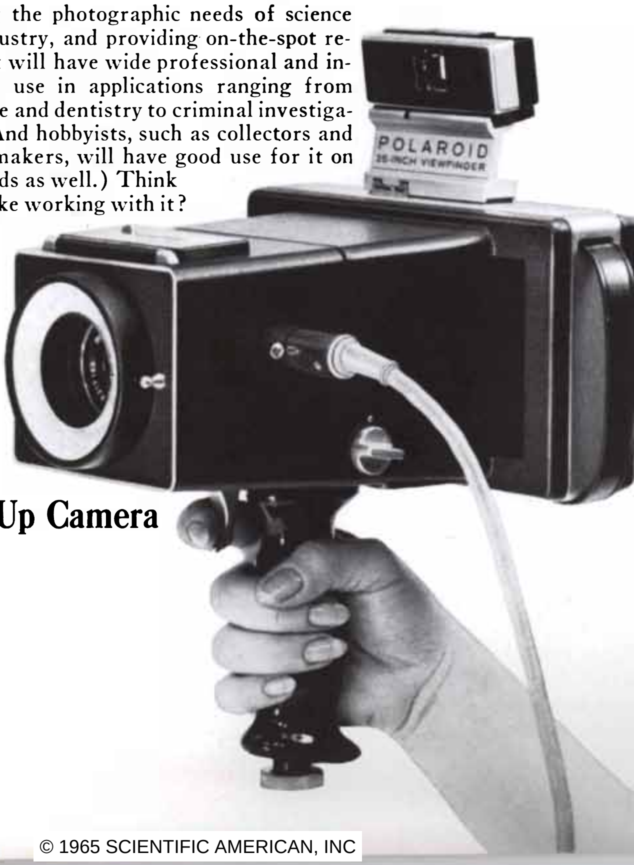
*Courtesy of the Lehman collection.

closer without figuring or focusing. And you get your picture in seconds.

designed specifically for Polaroid Land films (it's a ring light on the shutter housing), and automatic settings for black and white or color. Just flip a single switch on the camera, and perfect lens and shutter settings are guaranteed. (Or, if you prefer, you can make manual settings.)

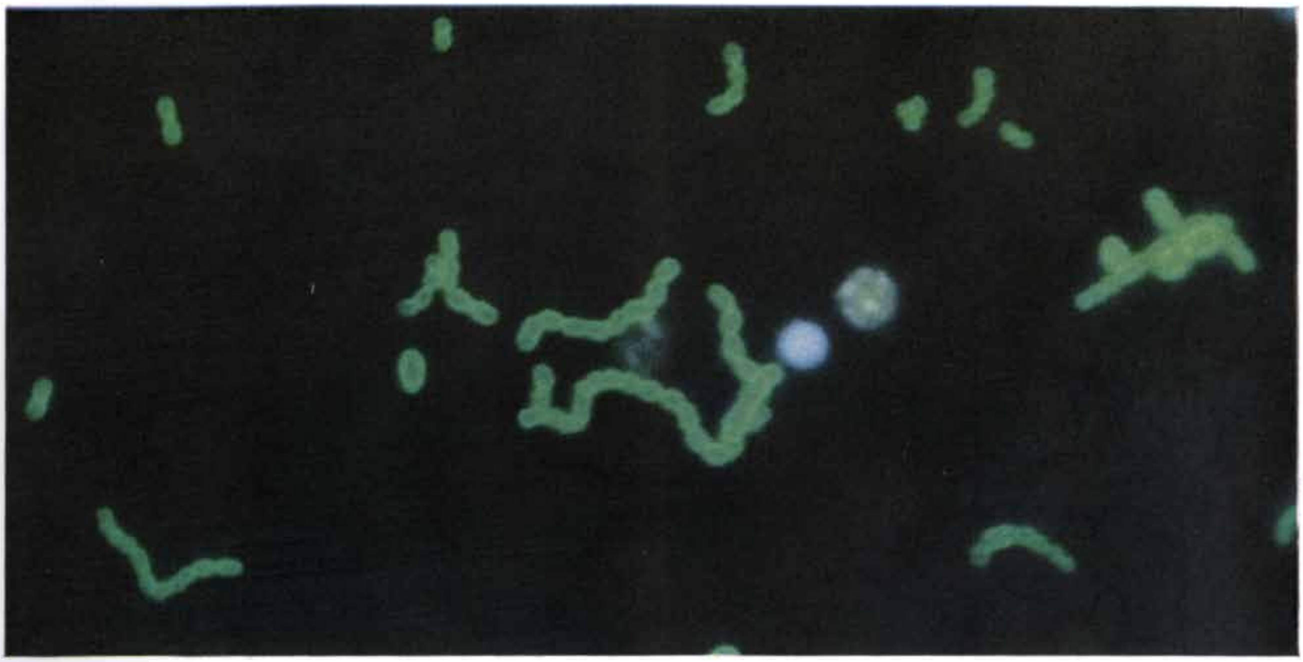
The camera is easy to handle. It's compact, designed for hand-held, pistol-grip operation. And it's easy to load. It uses Polaroid Land pack films which drop right into the camera back in seconds.

This new precision instrument from Polaroid, which eliminates the problems of close-up photography, is the latest addition to a unique family of cameras and films meeting the photographic needs of science and industry, and providing on-the-spot results. It will have wide professional and industrial use in applications ranging from medicine and dentistry to criminal investigation. (And hobbyists, such as collectors and model makers, will have good use for it on weekends as well.) Think you'd like working with it?

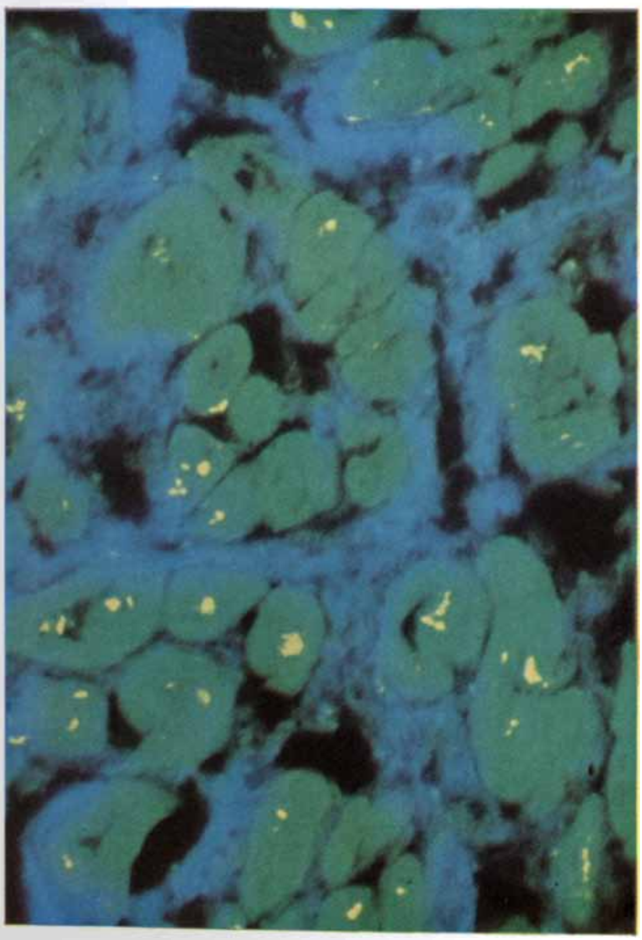


The Polaroid CU-5 Close-Up Camera

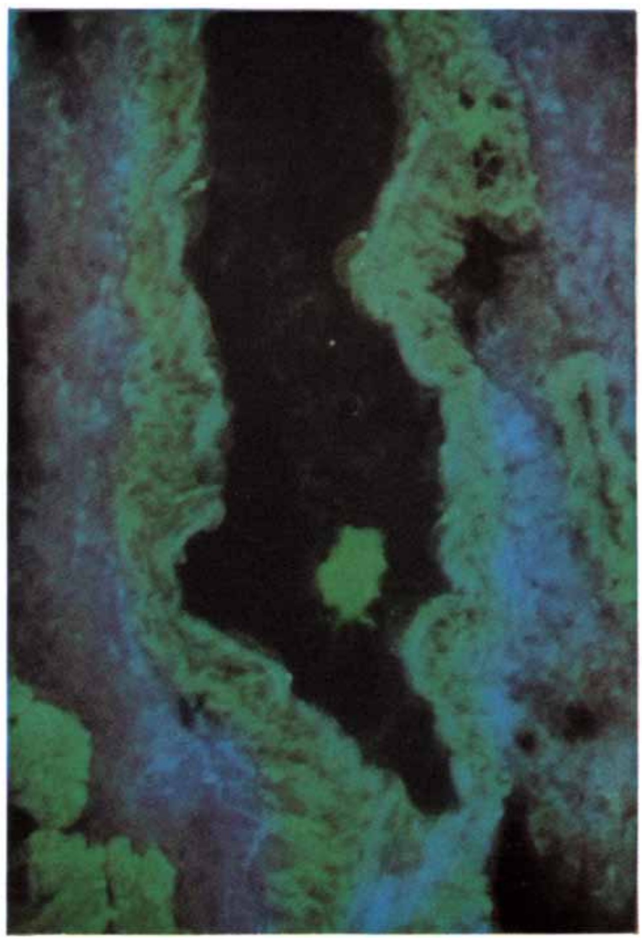
"POLAROID"®



STREPTOCOCCI, the bacteria that cause rheumatic fever, are enlarged 2,500 diameters in a photomicrograph made by one of the authors (Freimer) and John Zabriskie at Rockefeller University. The bacteria, having combined with antibody tagged with a fluorescent compound, glow under ultraviolet radiation. The antibody is directed against antigens in the streptococcal membrane.



HEART MUSCLE also binds antibody to streptococcal membrane. The fluorescent antibody, applied to a cross section of human cardiac muscle, has combined with antigens in the muscle cells and glows green under ultraviolet. The blue areas are connective tissue.



ARTERIAL MUSCLE shows the same immunological relation to streptococcal membrane. Smooth muscle in the wall of a small artery in the heart has bound the fluorescent antibody and glows. Rheumatic fever involves small arteries and may damage the heart.

RHEUMATIC FEVER

It is clear that this baffling disease, which often damages the heart, stems from streptococcal infection. No link has yet been found, however, between the infection and the rheumatic process

by Earl H. Freimer and Maclyn McCarty

Over the centuries few diseases of childhood have induced a greater feeling of helplessness among physicians or aroused more concern in the families of patients than rheumatic fever. Although the acute symptoms—such as the swollen, tender joints for which the disease was named—were disturbing, it was known that they usually subsided without producing any permanent disability. Rheumatic involvement of the heart, on the other hand, sometimes brought sudden death in a fulminating attack and more often led to chronic heart disease. To this day the menace of rheumatic fever is measured primarily in terms of scarred heart valves that may eventually impair cardiac function.

It is the severity of this end result, which affects several million people in the U.S., that has made rheumatic fever one of the most extensively investigated of mankind's diseases. In the past half-century it has been the focus of a host of clinical investigations and has stimulated fundamental studies in immunology and microbiology. By now it is clear that streptococcal infection may lead to rheumatic fever. Yet no specific link has been found between the infection and its rheumatic sequel. Although streptococcal infections can be cured and the rheumatic symptoms can be allayed, the disease remains mysterious and essentially unconquered.

What is this dread disorder that "licks the joints but bites the heart"? Rheumatic fever is basically an arteritis, an inflammation that involves small blood vessels. The inflammation results in lesions that are widely distributed through the connective tissues of the body. Many organs are affected, but the diverse manifestations appear to be unrelated to one another. Involvement of the joints illustrates the classic description of the inflammatory state: *calor* (heat), *rubor* (redness), *tumor* (swelling) and *dolor* (pain). Sometimes a single joint is affected, but typically the arthritis appears to migrate from joint to joint. One day the right elbow may be involved, the next day the left knee. In young children an early symptom, and often the only one observed, is abdominal pain that is sometimes mistaken for appendicitis. Roughly circular areas of redness may appear on the skin, fade and then reappear from time to time. In severe cases firm, insensitive nodules occur under the skin.

The most striking of all the manifestations of rheumatic fever is Sydenham's chorea, or St. Vitus's dance. This appears late in the course of rheumatic fever, often months after the initiating streptococcal infection; sometimes it is the only sign of rheumatic activity. The irregular and uncontrollable movements of chorea were vividly described by the 17th-century English physician Thomas Sydenham as "a kind of convulsion in which the hand cannot be steady for a moment. It passes from one position to another by a convulsive movement, however much the patient may strive to the contrary. Before he can raise a cup to his lips, he makes as many gesticulations as a mountebank."

In the course of a rheumatic attack various parts of the heart are often affected. The cardiac symptoms are usually vague, but involvement of the pericardium (the outer lining of the heart) or the myocardium (the heart muscle itself) can often be detected by examination with a stethoscope and by X-ray and electrocardiographic studies. In contrast, it is particularly difficult to demonstrate the presence of endocarditis, an inflammation of the endocardium (the inner lining of the heart). And it is endocarditis that is responsible for the scarring and distortion of the valve leaflets that lead to permanent heart disease. Like the submerged portion of an iceberg, the most deadly aspect of the rheumatic process—the extent of involvement of the endocardium—remains undetected until it is disclosed by subsequent valvular dysfunction.

For many centuries rheumatic fever was a totally baffling disorder. Then in the 19th century physicians began to note that acute rheumatism was often preceded by a septic sore throat or by scarlet fever. When, early in this century, streptococci were shown to be the agents responsible for many cases of tonsillitis and for scarlet fever, the way was opened at last for systematic investigations into the cause of rheumatic fever. In recent decades the search has focused to a large extent on the fundamental nature of the bacterium.

Streptococci comprise a biologically diverse collection of microorganisms that have in common a tendency to grow in chains. Some of them lyse, or dissolve, mammalian red blood cells. One group of these hemolytic streptococci, known as Group *A*, is responsible for most of the streptococcal infections of man. The Group *A* streptococcus has been studied in great detail, and several independent lines of evidence clearly implicate it in the development of rheumatic fever.

First, the Group *A* streptococcus is the only bacterium that causes human infections with an epidemiological pattern that parallels the seasonal incidence and geographical distribution of rheumatic fever. Second, this streptococcus can cause repeated infections at intervals throughout childhood, and it is such repetition that probably sets the stage for the first attack of rheumatic fever. Third, rheumatic fever can be prevented by vigorous treatment of streptococcal infections with such antimicrobial agents as penicillin, suggesting that the elimination of the organisms early in the course of the infection interrupts a chain of events that leads to rheumatic fever. Fourth, a specific immune response to streptococcal antigens occurs almost uniformly in patients with acute rheumatic fever; with sufficient antibiotic therapy this response to streptococcal antigens is suppressed.

Although it is clear that streptococcal infections can lead to rheumatic fever, the mechanism by which the streptococci initiate the rheumatic process remains obscure. In an infection a microorganism actively produces the disease state, as the streptococcus produces a sore throat. The symptoms of rheumatic fever, however, do not appear until weeks after the acute infection. By this time hemolytic streptococci are not usually detectable in the affected tissues, and doses of antibiotics large enough to eliminate any that are there do not influence the manifestations or the course of the illness.

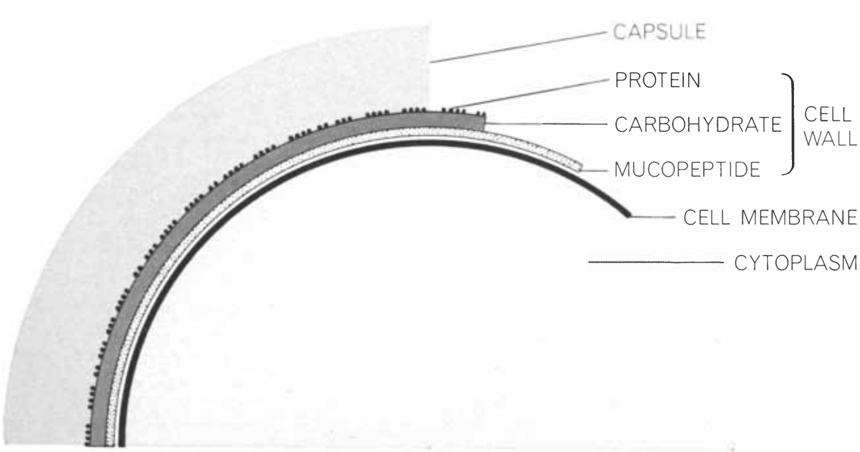
The organism must therefore exert its effect through some indirect process rather than by the continued presence of infectious streptococci in the tissues of the host. Many investigators now believe that rheumatic fever represents a state of hypersensitivity resulting from the combination of some streptococcal antigen with host antibody. Hypersensitivity is a special form of the immune reaction, a process by which the body resists the intrusion of foreign substances, or antigens. In the immune reaction specialized cells synthesize antibodies in response to these antigens. The state of hypersensitivity develops in some individuals after one or more exposures to a certain antigen; the reintroduction of the same antigen stimulates increased production of the specific antibody, which reacts with the antigen. When the resulting antigen-antibody complex reaches certain cells, it triggers an acute inflammatory process. Allergies to foreign substances such as pollens or bee venoms are examples of hypersensitivity, and diseases such as hives or asthma are the result of hypersensitive states.

The natural history of rheumatic fever supports the concept that this disease may be the result of a state of hypersensitivity. The interval between the streptococcal infection and the onset of the rheumatic disease is about equal to the time required for an antigenic stimulus to provoke a maximal antibody response. The typical pattern of the rheumatic attack—a latent period during which the patient shows no signs of illness, followed by the sudden development of fever and joint pain—is quite similar to the pattern in acute serum sickness, a disorder in which sensitivity to an antigen is well established. The observed hyperactivity of rheumatic patients in producing antibodies in response to streptococcal antigens also gives support to the hypersensitivity hypothesis. Patients who have rheumatic fever show a greater outpouring of streptococcal antibodies, on the average, than those who have a streptococcal infection without rheumatic fever. Finally, histological examination reveals that rheumatic lesions are very similar to those obtained in studies of experimental hypersensitivity in animals. In rabbits injected with streptococci George E. Murphy of the Cornell University Medical College has found lesions similar to the Aschoff body, which is seen in the heart muscle of people who have had rheumatic fever [*see illustration on page 74*].

The investigation of rheumatic fever has progressed through several stages. Clinicians described the course of the disease, pathologists studied the lesions, epidemiologists implicated the hemolytic streptococcus and bacteriologists proceeded to study the microorganism. In the past two decades new techniques have been introduced that have made it possible to take the streptococcus apart antigen by antigen. It has been particularly interesting to identify the outer structures of the bacterium and the various substances it releases into its environment during growth.

The streptococcus has a complex surface containing a number of potential antigens [*see illustration on this page*]. Its outer covering is a capsule composed of a gel, hyaluronic acid. Within this capsule is a tough protective structure, the cell wall. The streptococcal wall can be conceived of as having three layers. The outer layer is made up of a number of different proteins. The middle layer, the major component of the wall by weight, is a carbohydrate; each streptococcal group, such as Group *A*, has a different carbohydrate. The inner layer of the wall, the one that provides its structural rigidity, is composed of a mucopeptide, repeating units of several amino acids and two amino sugars. Similar mucopeptides form the skeletons of all bacterial cell walls. Inside the cell wall there is a delicate membrane that encloses the cytoplasm of the bacterium.

One of the cell-wall proteins, the *M* protein, is highly significant. It identifies the various types of Group *A* streptococci. It also plays a dominant role in determining the virulence of the bacterium by inhibiting phagocytosis, the process in which white blood cells engulf and dispose of foreign particles. The *M* protein thus aids the streptococcus in its invasion of the host's tissues, where it can multiply. This antiphagocytic effect of *M* protein can be neutralized by specific antibody that renders the microbe vulnerable to destruction by the white cells. Each type of Group *A* streptococcus, however, has its own distinct *M* protein; there are some 50 types, and the body must produce a different antibody to combat each of them. This multiplicity of *M* proteins, many different types of which may be widely disseminated throughout a human population, explains the repetitive nature of streptococcal infections, since the production of antibodies against one



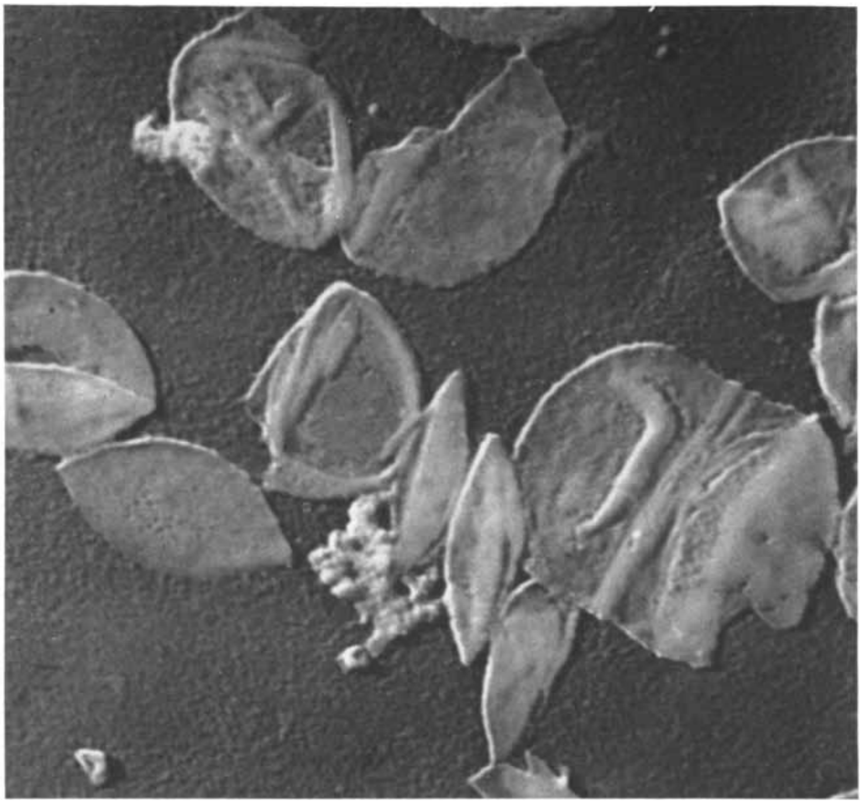
STREPTOCOCCUS, the structure of which is shown schematically, is about a thousandth of a millimeter in diameter exclusive of the outer capsule. The protective cell wall is characteristic of bacteria. The cell membrane is comparable to that of a mammalian cell.

type of streptococcus confers no immunity against a second type.

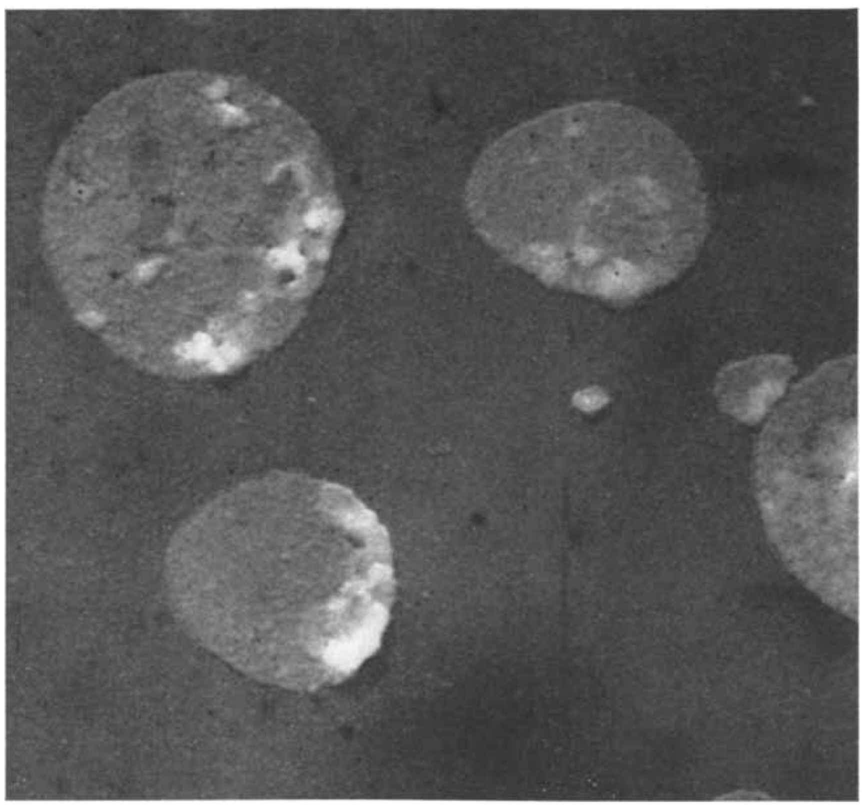
Another distinctive characteristic of the Group *A* streptococcus is its ability to synthesize a wide variety of enzymes and toxins. In the never ending struggle between infecting organisms and their hosts, parasites with characteristics that increase their pathogenic capability are favored. Although the precise contribution of the extracellular products to the genesis of streptococcal disease is not clear, they presumably contribute to the survival and propagation of the streptococcus. Indeed, an important part of the host response to a streptococcal infection is the formation of specific antibodies to most of these substances.

There are, first of all, two specific enzymes that lyse the red blood cells. Other enzymes split the coenzyme diphosphopyridine nucleotide (DPN), activate the process that dissolves the blood-clotting agent fibrin, break down hyaluronic acid in the connective tissue of the host, decompose deoxyribonucleic acid (DNA), break down various proteins and hydrolyze glycogen (animal starch). Another identified product of the streptococcus is "erythrogenic toxin," which is responsible for the rash of scarlet fever. John Zabriskie of our laboratory at Rockefeller University has discovered that the ability to produce this toxin depends on a nonlethal infection of the streptococcus by a bacteriophage, or bacterial virus. Apparently a streptococcal infection is capable of generating scarlet fever when the bacteria happen to be carriers of these bacteriophages. (It is because of the persistence of antibodies to erythrogenic toxin that scarlet fever, unlike streptococcal infections in general, usually occurs only once.)

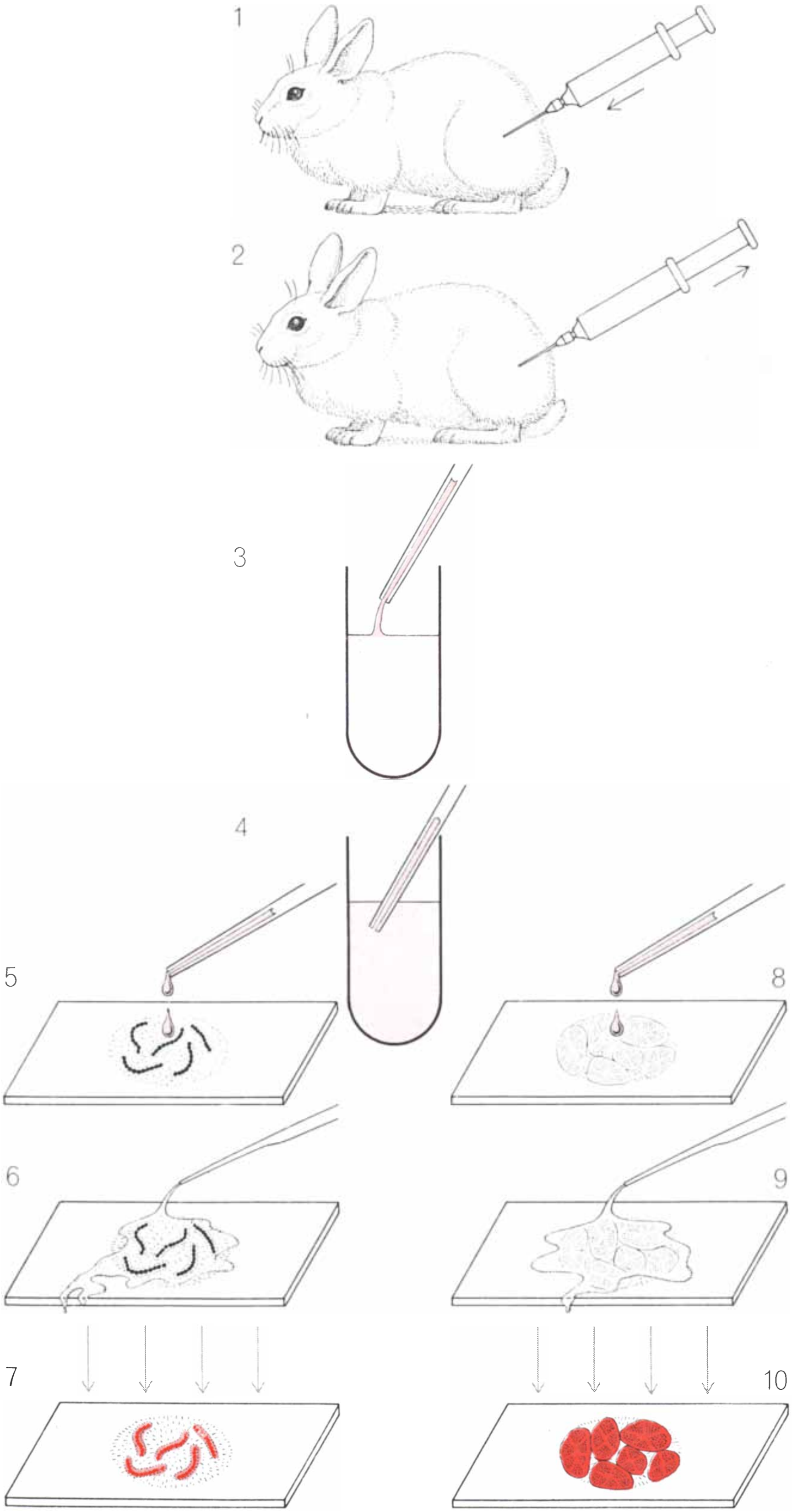
In our laboratory we have been investigating the properties of the streptococcal membrane, the structure that lies inside the cell wall. Unlike most bacterial membranes, it contains lipoproteins in which the lipids, or fatty substances, are essentially identical with those in mammalian tissues. There are variant forms of streptococci, called *L* forms, that lack a cell wall and in which the membrane is therefore the outer covering. We have prepared similar incomplete forms, called protoplasts, by dissolving the cell wall of the bacteria with enzymes. We find that both *L* forms and protoplasts are capable of many of the biological functions of the intact bacterial cell. They are also resistant to penicillin, which acts by in-



CELL WALLS are enlarged about 12,500 diameters in this electron micrograph made, like the one below, by the authors and Richard M. Krause. Streptococci were disrupted mechanically; their walls were suspended in water, mounted on grids and shadowed with chromium.



CELL MEMBRANE is much thinner than the cell wall. These membranes were prepared from protoplasts, fragile bacterial forms from which the cell wall had been removed by an enzyme. The protoplasts were disrupted by being placed in water. The membranes were collected by centrifugation, mounted, shadowed and enlarged about 12,500 diameters.



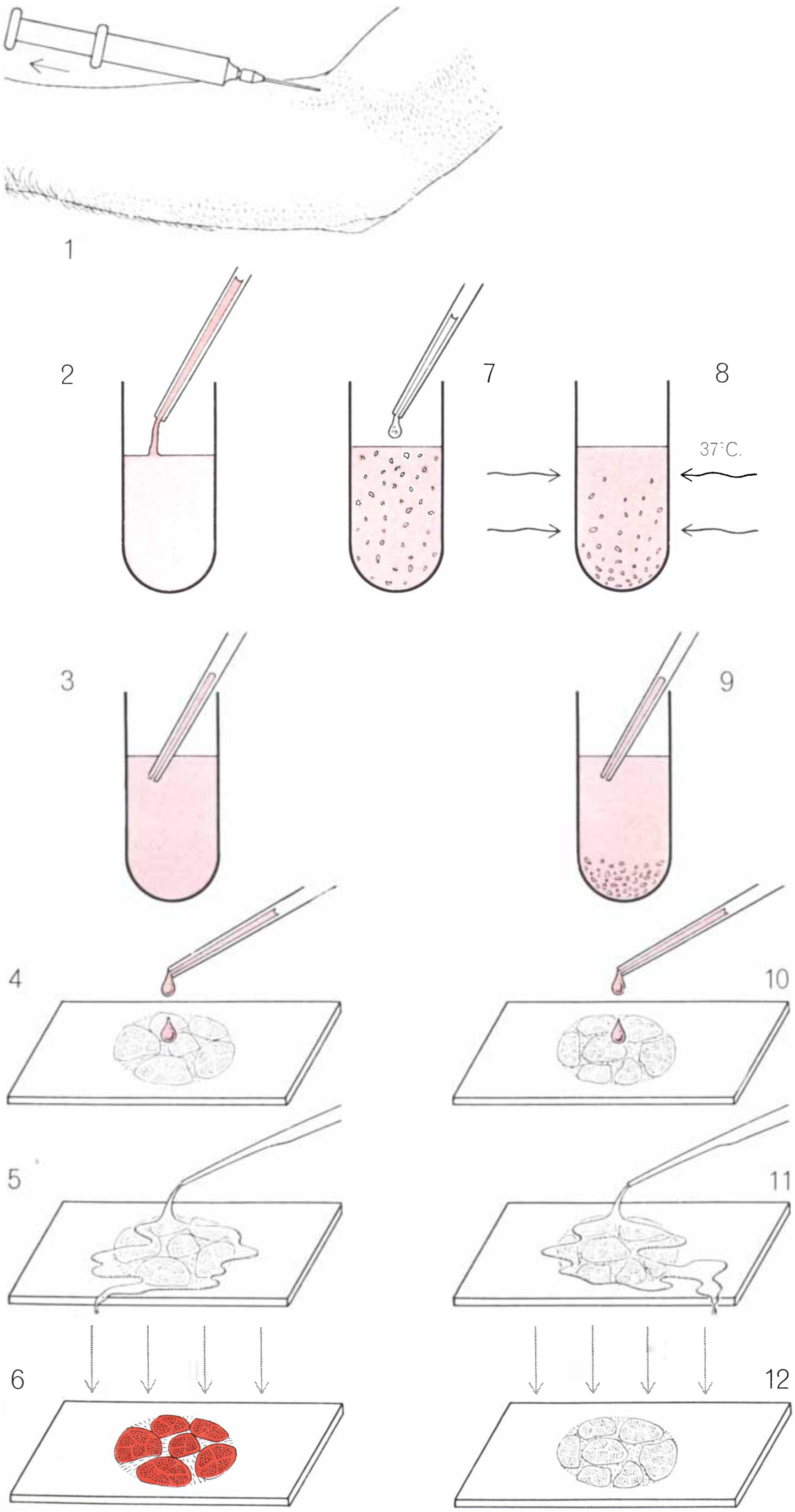
IMMUNOLOGICAL RELATION between the streptococcus and heart muscle is demonstrated by an experiment in which streptococcal membranes are injected into a rabbit (*1*). The globulin fraction, containing antibody formed against the membranes, is isolated from the rabbit's blood (*2*) and coupled to a fluorescent compound (*3*). When the fluorescent antibody is tested on streptococci (*4, 5*), it reacts with antigen in the bacteria, so that in spite of washing (*6*) it remains bound to the bacteria, which glow under ultraviolet radiation (*7*). Tested on heart muscle (*8*), the antibody reacts in the same way (*9, 10*).

hibiting the formation of the cell wall. One might postulate that a bacterial variant with a surface of related lipid, rather than of alien cell-wall carbohydrate and protein, might survive unchallenged within the host. The streptococcus would persist as an *L* form, undetectable by the usual bacteriological techniques but with the potential for reversion to an active bacterial form. There is still no firm evidence to support this concept, however.

In 1962 Melvin Kaplan of the Western Reserve School of Medicine reported the existence of an immunological cross-reaction between Group *A* streptococci and cardiac muscle. Following a similar line of investigation, we have found that the membrane of the bacterium appears to contain an antigen that cross-reacts with the membrane of cardiac muscle cells and the muscle layer in small arteries. This may provide a promising clue to the genesis of rheumatic fever; moreover, the discovery of an immunological relation between the membranes of a bacterial cell and a mammalian cell is exciting and may prove to be of broad biological significance.

The experimental procedure begins with the injection of a preparation of streptococcal membranes into rabbits. Over a period of weeks the animals form antibodies to the membranes. Having isolated the globulin (the blood fraction containing the antibodies) from the rabbits' blood, we couple it to a fluorescent substance and layer the fluorescent globulin over the specimen to be tested. If the antibody reacts with an antigen in the specimen, it becomes fixed, and the antigen-antibody complex will fluoresce under ultraviolet radiation. As one might expect, antibody to streptococcal membrane does combine in this manner with streptococci. What is interesting is that this antibody also reacts with muscle from human heart—both from the myocardium and from the wall of small arteries [*see illustration at left*]. It does not react with tissues other than muscle, nor do antibodies to other bacterial species react with the muscle. If instead of rabbit globulin we test globulin from patients with rheumatic fever, we get a similar set of results [*see illustration on page 72*]. It is therefore tempting to form the hypothesis that it is antibody produced to combat the streptococcus that later takes part in a hypersensitivity reaction involving the heart and small blood vessels of the rheumatic fever patient.

There is no dearth of attractive speculations about the possible genesis of rheumatic fever, but none of them is yet



HUMAN ANTIBODY from the blood of a rheumatic fever patient (*1*) is similarly tested. The antibody-containing globulin is isolated, coupled to the fluorescent compound (*2*) and tested on heart muscle (*3, 4*). It is bound, and in spite of washing (*5*) the heart section glows (*6*). Is the reaction caused specifically by antibody to streptococcal membrane? An indication that it may be comes from the following procedure: Membrane is added to the globulin solution (*7*) and the suspension is incubated (*8*). Antibody is bound by the membrane; when the supernatant is tested on a heart section (*9, 10, 11*), the muscle fails to fluoresce (*12*).

supported by solid evidence—and "many a beautiful idea has been slain by ugly fact." The rheumatic process is so complex and so diverse that it is difficult to conceive a single scheme that would account for all the observed phenomena. What kind of process can produce localized lesions not only in the joints and the heart but also in the skin all over the body, and by what means does the same process involve the nervous system and express itself in chorea? How can the various rheumatic symptoms continue to appear so long after the inciting infection has disappeared? Why are some people apparently "susceptible" to rheumatic fever and other people not? Rheumatic fever poses many such difficult questions.

Although the genesis of rheumatic fever remains unexplained, enough has been learned about the disease to make it far less of a menace than it was in the past. The identification of the streptococcus as the inciting organism and the development of effective antistreptococcal agents had far-reaching effects. As recently as World War II epidemics of streptococcal sore throat swept through recruit-training camps in the U.S., and roughly 3 percent of those who were infected developed rheumatic fever. The introduction of penicillin and other drugs effective against Group *A* streptococci essentially eliminated rheumatic fever in military populations and has greatly reduced the risk in the general population. It is clear that the prompt and intensive treatment of a streptococcal infection with penicillin can prevent rheumatic fever.

For those who do develop rheumatic fever the control of streptococcal infection becomes a matter of special significance. The repetitive nature of these infections used to pose a constant threat of recurring rheumatic attacks. Now rheumatic fever patients are first treated intensively with penicillin to eliminate any remaining streptococci and then protected from reinfection by the daily administration of penicillin. The success of this continuous prophylaxis has been dramatic. During the past 15 years very few patients maintained on penicillin have developed another episode of rheumatic fever. The elimination of repetitive attacks, each contributing further damage to the heart valves, should significantly reduce the incidence of serious heart disease in rheumatic individuals.

In view of the deluge of antibiotics with which the U.S. population has been dosed in the past two decades,

There.

We did it.

We did it and we're glad.

We should have done it years ago.

"We" is the U.S. Rubber Company, and UniRoyal is our brand new trade-mark, now going up all over the world.

We did it because UniRoyal tells you more about the U.S. Rubber Company and what it makes today than "U.S. Rubber" does.

"U.S. Rubber" on a bra or a girdle or a pair of stretch pants says rubber to a woman, and our new Vyrene® spandex elastic fiber has nothing to do with rubber.

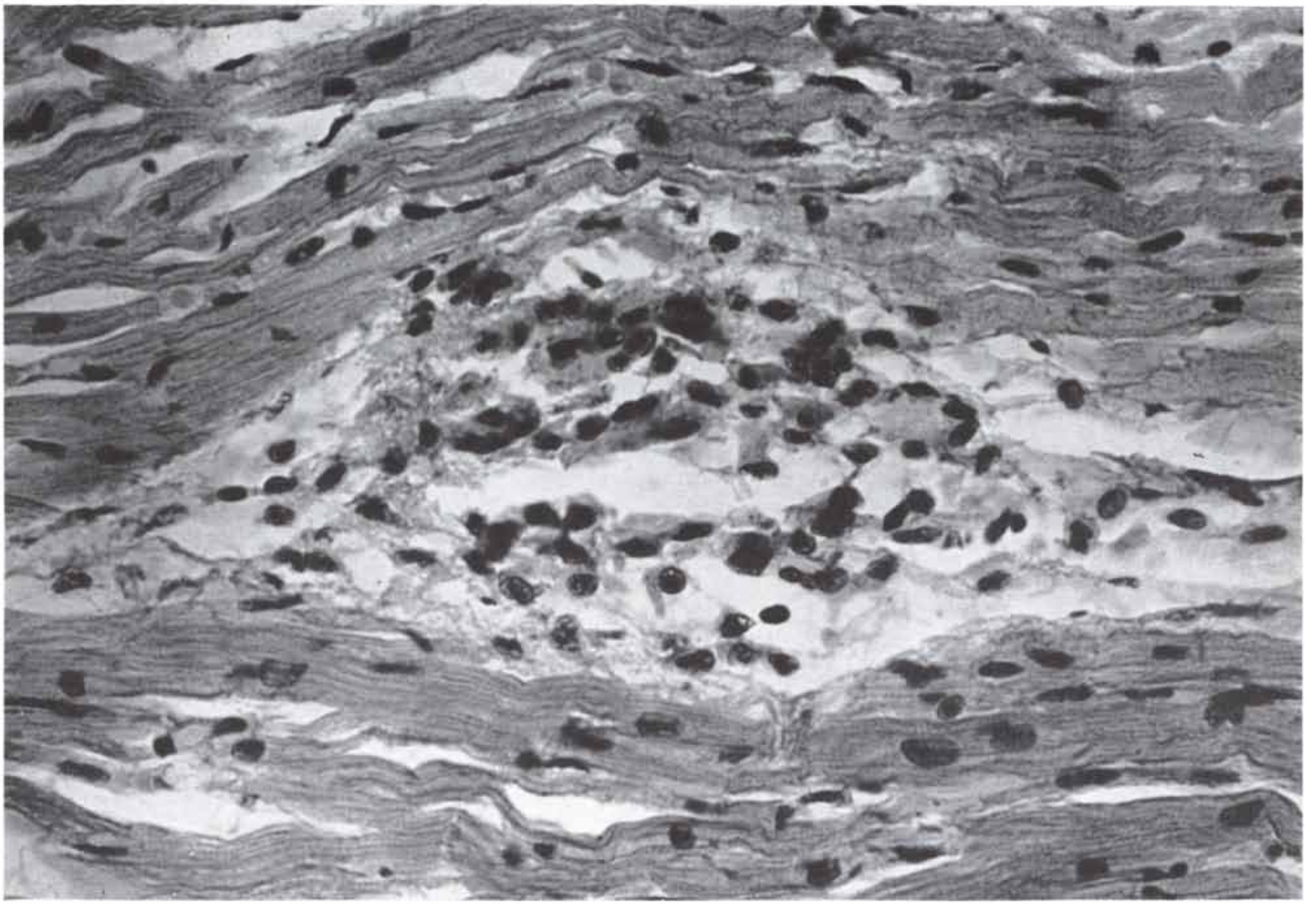
"U.S. Rubber" on a piece of furniture says rubber to a homemaker, and our supple Naugahyde® upholstery has nothing to do with rubber.

Even our rubber isn't rubber, for the most part, but synthetic rubber. (The most exciting synthetic is Royalene,® the crackless rubber that's going to have a revolutionary impact on tires, hose, gaskets and cable.)

"U.S. Rubber" on any of our products says Made in U.S.A. to a consumer in Europe, Canada or Latin America, which causes a lot of confusion now that U.S. Rubber has 28 big manufacturing plants in 23 foreign countries (besides its 45 plants in this country).

Obviously, the U.S. Rubber Company needed a new international trade-mark; one that didn't smell of rubber. And now we have it: UniRoyal.

UNIROYAL
U.S. RUBBER



ASCHOFF BODY, the classic lesion of rheumatic fever, is enlarged about 570 diameters in this photomicrograph made by George E. Murphy of the Cornell University Medical College. It is in the striated muscle of the myocardium, the heart muscle itself. Lesions also occur in the endocardium, or inner lining of the heart, in a layer of smooth muscle much like the muscle of a small artery.

one might suppose that streptococcal infection and therefore rheumatic fever should have been all but eradicated by this time. For various reasons, however, both the infection and the disease remain a danger. Three factors are particularly important.

First, many streptococcal infections are so mild that they escape notice, and a "subliminal" infection can incite rheumatic fever in a susceptible individual. Even when the infection is recognized, it is not always treated promptly or vigorously enough.

Second, rheumatic fever is hard to diagnose. Any one of its characteristic manifestations can also be a sign of some other disease. Moreover, the course of the disease is variable. The classic case—in which fever, joint pain, skin lesions and evidence of cardiac inflammation develop some three weeks after a sore throat—is easy enough to recognize, but not every case follows that pattern. Some people become symptom-free in a few days, whereas in others the rheumatic activity may persist for months or even years, or the episodes may come and go in cyclic fashion. In still other individuals who have rheumatic fever no clear-cut symptoms ever appear; the disease goes unrecognized until, years later, they are found to have valvular heart disease. Even laboratory tests will not specifically identify rheumatic fever. The blood of a person with the disease shows a high white-cell count and a heightened concentration of fibrinogen, gamma globulin and a substance called *C*-reactive protein that is not normally present, but all these changes merely indicate the presence of an inflammatory process. A rise in the blood level of antibodies to the Group *A* streptococcus and its products, on the other hand, only shows that the patient has recently had a streptococcal infection. Even in combination these tests do not prove the presence of rheumatic fever. The physician must therefore season the laboratory data with his evaluation of the broad clinical pattern—history, symptoms and physical signs—and, as we have seen, these are not always clearly defined.

Finally, rheumatic fever remains a danger because there is no specific therapy for it (as there is against the inciting infection). The only available treatment is the use of aspirin or a steroid hormone such as cortisone to suppress the inflammatory response. This relieves the patient's symptoms but does not eliminate the underlying disease process.

Current therapy, in other words, is largely defensive. The elimination of the disease depends on gaining a clearer understanding of the chain of events whereby an infection with hemolytic streptococci sometimes develops into rheumatic fever. This will require continued investigation not only of the streptococcus but also of the susceptible host. If the role of the bacterium is being stressed in our laboratory and others, that is because the inciting action of streptococcal infections in rheumatic fever is the one key that is currently available to the fundamental nature of the disease. It is this relation to a specific bacterial agent that sets rheumatic fever apart from the other diseases of connective tissue.

Heat Transfer in Plants

Plants, like animals, must regulate their temperature in order to function at optimum physiological efficiency. This is accomplished through three mechanisms: radiation, transpiration and convection

by David M. Gates

There is an old Iowa saying that on a hot summer night one can hear the corn grow. This is no tall tale. Many physiological processes in plants depend primarily on temperature rather than on light, and among them is the enlargement and elongation of cells; if the weather is warm enough, corn will grow at night. A plant's temperature can also affect its photosynthetic activity, even though photosynthesis is primarily dependent on light. The photosynthetic process will slacken or halt if the plant's temperature gets too high or too low; it will reach an optimum at some intermediate temperature level. Evidently the temperature of a plant is a major factor in determining how efficiently the plant functions. But what determines the temperature of a plant?

The answer is that a plant's temperature is determined by its total environment. If the plant gives up more energy than it receives, it will become cooler; if it receives more energy than it gives up, it will become warmer. If the inward and outward flows of energy are equal, the plant is in thermal balance with its environment. Three separate phenomena govern the transfer of energy: radiation, transpiration and convection. In this article I shall first describe each of these processes and then consider some of the means by which they work together to regulate plant temperatures.

Radiation is quantitatively the most important of the three processes. In this connection it has two distinct forms. The first is solar radiation, the primary external source of energy for all physical and biological processes on the earth; this radiation is broadcast over a wide range of wavelengths [*see top illustration on page 80*]. The second is thermal radiation; this is the energy emitted by any object that is warmer than absolute zero. Thermal radiation is broadcast within a much narrower band than solar radiation; objects with temperatures between zero and 50 degrees centigrade, for example, radiate only at infrared wavelengths, and their peak output is at a wavelength of about 10 microns.

Solar energy falls on the earth's upper atmosphere at an average rate of two calories per square centimeter per minute; this energy flow is known as the solar constant. Minor constituents of the atmosphere absorb portions of the sun's radiation at each end of the visible spectrum. The ozone in the upper atmosphere screens out ultraviolet radiation at wavelengths shorter than 2,900 angstrom units (.29 micron); water vapor and carbon dioxide do the same for infrared radiation at wavelengths longer than 22 microns. Although the resulting "window" in the earth's atmosphere is only a narrow band of the sun's entire radiant spectrum, the sun emits most of its energy at these visible wavelengths; consequently a large fraction of the solar constant reaches the earth's surface.

In summer the surface of the earth in the Temperate Zones receives solar energy at a rate of between 1.2 and 1.4 calories per square centimeter per minute; mountains and deserts, which are often free of cloud cover, may receive as much as 1.6 calories. The solar energy that impinges on a tree or a stalk of corn includes not only direct sunlight but also sunlight that has been scattered by the atmosphere and sunlight that is reflected up from the earth's surface or down from clouds. On high mountains, on which intense direct sunlight and sunlight reflected from clouds occasionally fall at the same time, radiation values go as high as 2.2 calories—higher than the solar constant.

Solar radiation affects the earth's surface only between sunrise and sunset; thermal radiation, on the other hand, is always present. Every part of the environment steadily broadcasts energy at infrared wavelengths. If human eyes were sensitive to infrared radiation, the daytime sky would not be blue. Instead broad shafts of different hues (the "colors" of different infrared wavelengths) would be seen extending from the sky to the ground and from the ground to the sky. Even during the day the total amount of thermal energy radiating from the ground and from the atmosphere can equal or exceed the sun's radiation.

If a plant continuously absorbed energy without dissipating any, its temperature would increase steadily until it had suffered heat death. In actuality plants dispose of considerably more than half of the radiant energy they absorb by reradiating it. Plants also transpire; this second process of energy transfer further helps to rid a plant of surplus heat.

Transpiration converts the water in the leaves of a plant from a liquid to a gas; the water vapor then passes from the leaf into the surrounding atmosphere. The process of evaporation consumes energy and the transpiring leaf grows cooler. The water vapor is emitted through the pores in the leaf called stomates; there can be as many as 20,000 of these openings in one square centimeter of leaf surface. Specialized sausage-shaped cells of the leaf epidermis, which are known as guard cells, control the opening and closing of the stomates. Normally the stomates are closed during the night and open during the day.

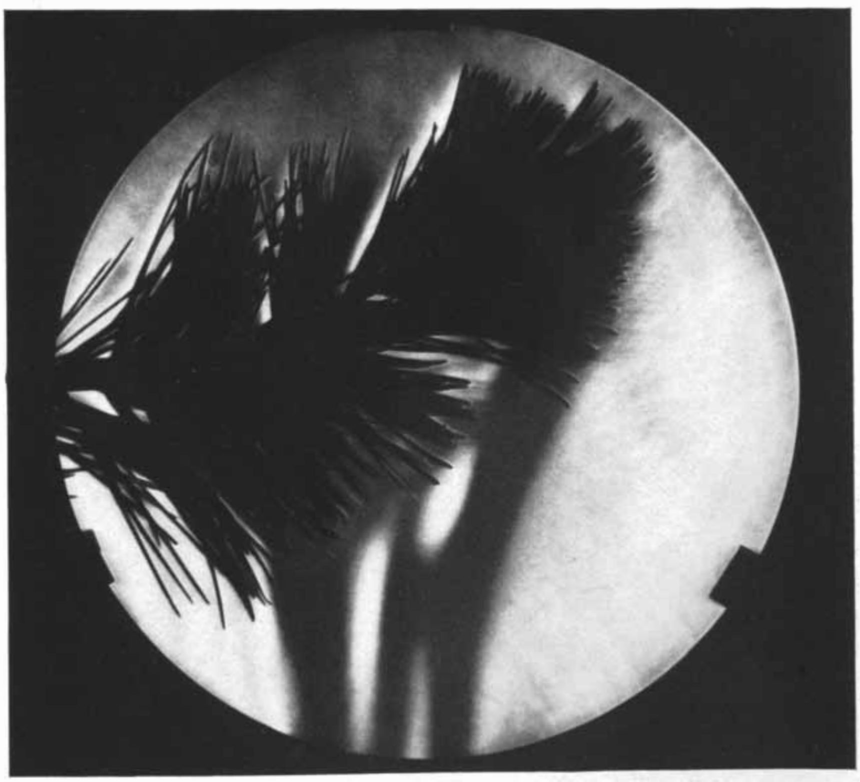
The effectiveness of transpiration in transferring energy can be judged by the fact that a transpiration rate of only five ten-thousandths of a gram of water per square centimeter per minute gives rise to an energy loss of approximately three-tenths of a calorie. This is enough to lower the temperature of a transpiring leaf by as much as 15 degrees C. The process of transpiration can nonetheless be halted under circumstances that seem to threaten the plant with imminent heat death.

As the morning passes on a warm summer day a plant's sunlit leaves steadily rise in temperature and their photosynthetic activity approaches the optimum rate. At midday, when the heat load is at its peak, each leaf's transpiration rate is also at its highest and produces the maximum cooling effect. In spite of this energy transfer, the temperature of the leaf now rises above the optimum level and the photosynthetic process slows down. The concentration of carbon dioxide in the leaf's guard cells increases; the cells react and close the leaf's stomates. This puts an end to further transpiration; the leaf's temperature rises even higher and photosynthesis stops. At this point the leaf wilts and the plant appears to be on the verge of thermal catastrophe.

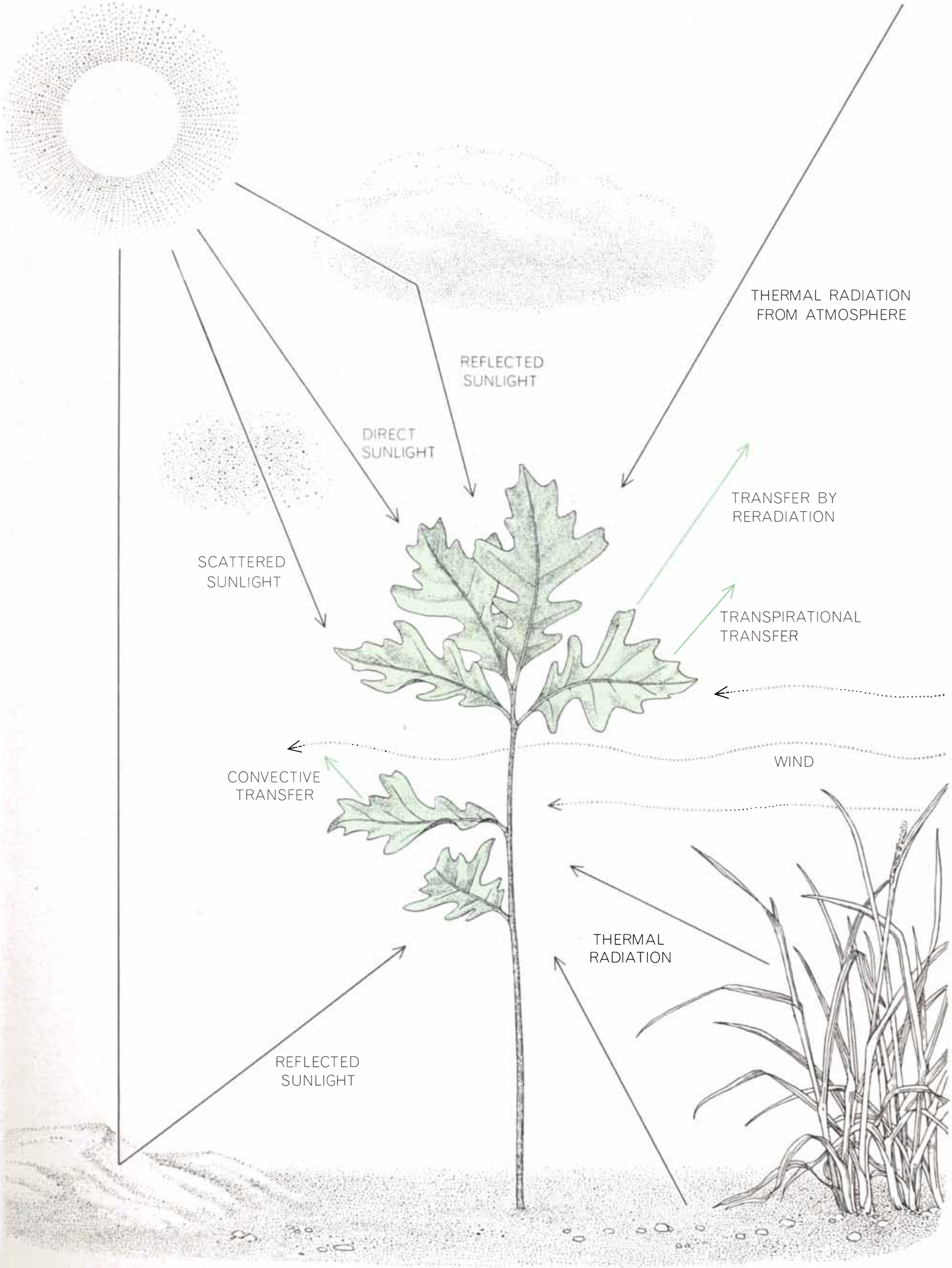
Fortunately wilting changes the leaf's orientation with respect to direct sunlight, so that the heat load is reduced. A cooler leaf temperature may allow photosynthesis to resume, thus reducing the concentration of carbon dioxide in the guard cells and causing the stomates to reopen. Normally, however, once the leaf temperature has gone too high the leaf will remain wilted until the sun has fallen low in the sky and the air has cooled.

I witnessed a remarkable example of temperature control by transpiration in August, 1963, when I accompanied W. M. Hiesey, Harold W. Milner and Malcolm A. Nobs of the Carnegie Institution of Washington on a visit to the institution's botanical study area near Yosemite National Park in California's Sierra Nevada range. Our purpose was to record the leaf temperatures of native species of the monkey flower, *Mimulus,* at various altitudes. The day was dry and cloudless. As we climbed the slopes above the tree line, where the alpine species *Mimulus lewisii* grew at an altitude of 10,600 feet, the sunshine was brilliant and the sky had a clarity that is seldom seen at lower altitudes. There was no wind; the air temperature was 19 degrees C. We found that the temperature of the alpine species' sunlit leaves was warmer than the air; it

WARM PINE BRANCH is cooled by rising convection currents. Each needle yields some of its heat conductively to the cooler air in contact with the needle surface. As the air is heated it rises (*shadows above the branch in this schlieren photograph*). Cool air replaces it and repeats the process. The rising current is somewhat turbulent because of a slight wind.



COOL PINE BRANCH that has lost heat by radiation to the night sky is warmed by falling convection currents. Each needle now absorbs heat from the warmer air in contact with its surface. As the air is cooled it sinks (*shadows below the branch in this schlieren photograph*). In both examples the heat transfer helps to stabilize the plant's temperature.



EXCHANGE OF ENERGY between a plant and its environment is shown schematically. Of the two inputs, solar radiation reaches the plant as direct, scattered and reflected sunlight. The second input, the thermal radiation, is emitted at infrared frequencies by the atmosphere, the ground and other plants and animals. A plant would die of heat if most of this energy were not dissipated (*color*). The bulk of the heat load is reradiated; evaporative cooling by transpiration and heat transfer by convection removes the rest.

ranged between 25 and 28 degrees C. We returned to our jeep and quickly set off to check the temperatures of other monkey flowers growing at lower altitudes. On the edge of the San Joaquin valley, at an altitude of 1,300 feet, the sky was just as clear as it had been above the tree line and the air temperature was 37 degrees C. We examined some flowers of another species, *Mimulus cardinalis*, growing at this comparatively low altitude. I was quite prepared to predict that these sunlit leaves, which had a higher heat load than the alpine species, would yield temperature readings between 42 and 47 degrees C.

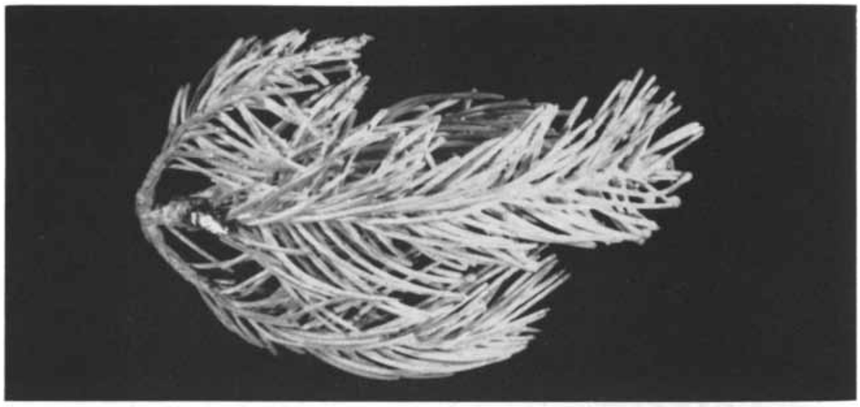
Instead the lowland leaves were cooler than the air surrounding them; their temperature ranged from 30 to 35 degrees C., not much warmer than the leaves above the tree line. This finding, contrary to all my previous experience, made me suspect that transpiration was involved. Monkey flowers are water-loving plants. Even the alpine species favor damp soil, and the plants we were examining in the valley grew along the border of a drainage ditch. When we measured the leaf temperatures of other species of plants growing in the same well-watered zone, they proved to be equally low. Then we tested the leaves of a live oak that was growing a few yards away in drier soil; their temperature was above the air temperature, ranging from 40 to 43 degrees C. It seemed likely that an abundant water supply, allowing liberal transpiration, accounted for the other plants' cooler temperatures.

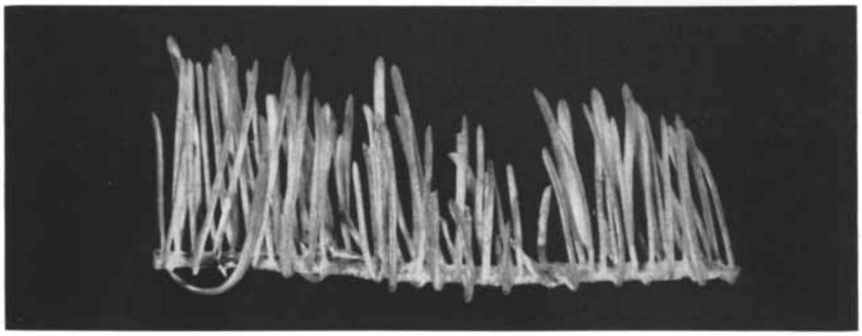
This raised the question of whether the observations could be duplicated with monkey flowers raised in a growth chamber in which the temperature could be varied to match the range of natural conditions from valley to tree line. We placed monkey flower plants in a growth chamber under even and constant illumination and raised the air temperature successively from a low of 10 degrees C. to a high of nearly 60 degrees. The plants' leaf temperatures almost exactly duplicated those measured at various altitudes in the Sierras. It soon appeared that some kind of threshold effect was operating. When the air temperature was about 30 degrees C. or lower, the monkey flower leaves were warmer than the surrounding air; when the air temperature was raised above 30 degrees, the leaves remained cooler than the air.

As the leaf temperature rose, the plants' transpiration rate slowly increased until another kind of threshold was reached at 41.5 degrees C. Just below that temperature the transpiration rate was about .0005 gram of water per square centimeter per minute. At the threshold temperature the rate jumped to .0022 gram, an increase of more than 400 percent. It was evident that a dramatic increase in leaf permeability took place at this temperature; the additional cooling effect was enough to prevent the monkey flower leaves from becoming warmer than 42 degrees C. even when the air temperature in the growth chamber was raised nearly 20 degrees higher than that.

A number of other plants—including species of cactus, agave, rhododendron and oleander—were included in these experiments. Their leaves also remained cooler than the air when the temperature was 30 degrees C. or higher, as long as the plants were watered abundantly. None of them, however, performed as dramatically as the monkey flowers.

These experiments clearly demonstrate that transpiration is an efficient mechanism for heat transfer in plants. Independent confirmation of this conclusion came recently from an experiment conducted at Purdue University. There G. D. Cook, J. R. Dixon and A. Carl Leopold painted the leaves of tomato plants with a substance that prevented the stomates from opening. This treatment of course suppressed transpiration. When the experimenters then measured the temperature of treated and untreated leaves, they found that the transpiring leaves were cooler than the nontranspiring ones by 5 degrees C.

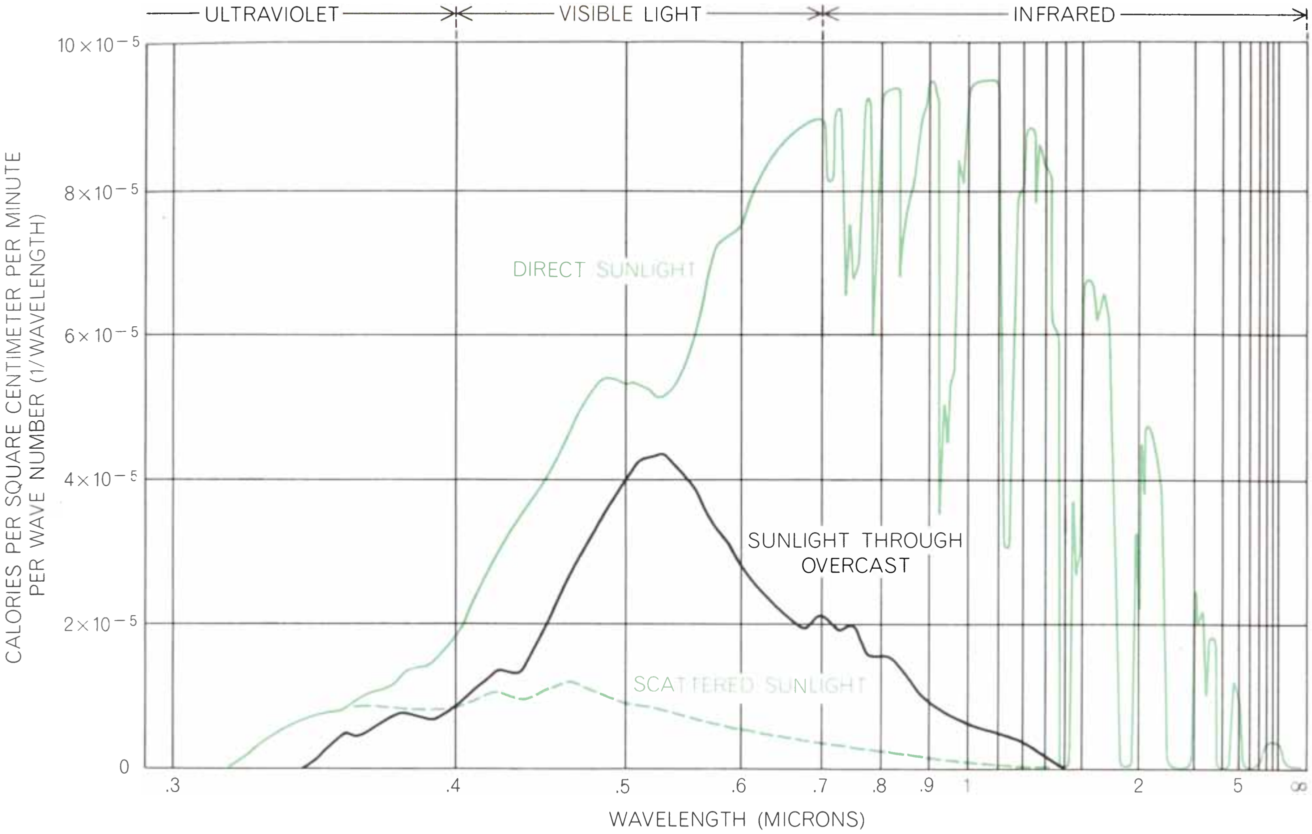




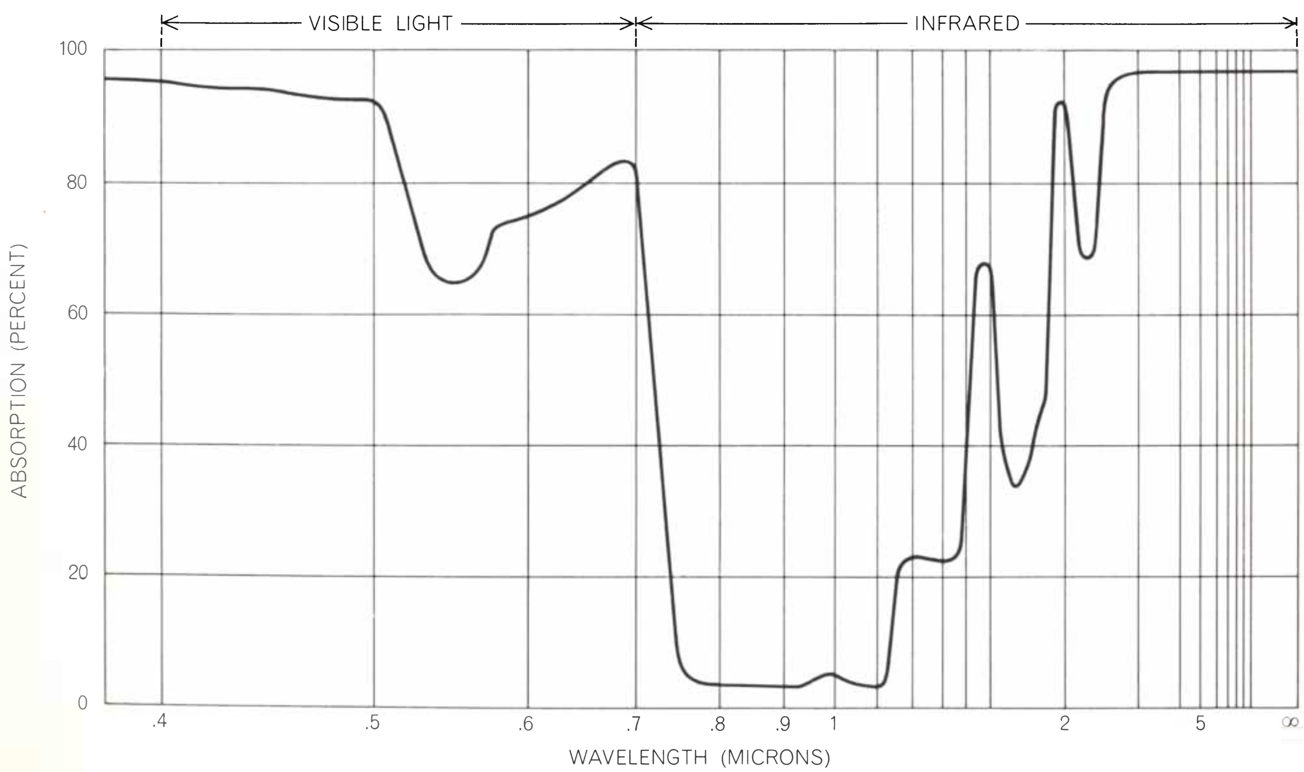
SILVER REPLICAS of conifer twigs were among the casts of various plants that the author made to determine which leaf shapes were the most efficient for heat transfer by convection. The conifers' cylindrical needles proved to be far superior to the flat leaf surfaces.

Convection, the third mechanism that allows energy transfer between a plant and its environment, has an important feature not shared by the other two. Radiation raises a plant's temperature and transpiration lowers it; convection will warm a cool plant or cool a warm one with equal facility, depending on whether the air is warmer or cooler than the plant. Convection acts across a thin atmospheric zone, known as the boundary layer, that surrounds all surfaces in still air. The rate at which energy is transferred across the boundary layer depends on the thickness of the layer and on the difference in temperature between the object and the atmosphere.

In still air the boundary layer is often about one centimeter thick. By means of schlieren photography, sometimes called shadow photography, the boundary layer and other regions of small variations in air density can be made



SOLAR RADIATION is not of equal intensity in all parts of the spectrum. Three curves show the variations from ultraviolet to infrared in the case of direct sunlight, of sunlight diffused through an overcast, and of sunlight scattered in the atmosphere. Divisions of the horizontal scale are proportional to frequency of radiation because the energy per quantum is similarly proportional. On this basis direct sunlight reaches peak intensity in the near infrared; how plants escape this heat load is shown in the illustration below.



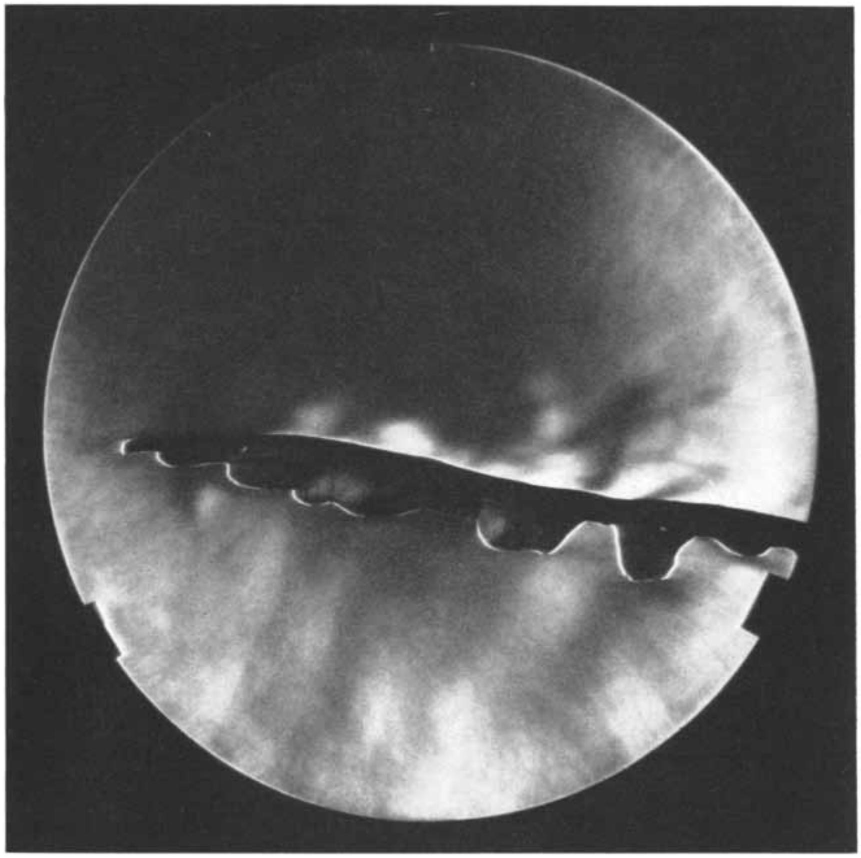
ABSORPTION OF ENERGY by the leaves of a plant averages nearly 90 percent of solar radiation in the spectral range from ultraviolet through visible frequencies. At near-infrared frequencies, however, absorption falls off sharply and stays at a low level throughout the range at which solar radiation is the most intense (*see illustration at top of page*). The curve shows absorption by a leaf of the poplar *Populus deltoides;* as at top, the divisions of the horizontal scale are proportional to the frequency of the radiation.

visible. Schlieren photography soon taught me that the air near the surface of a leaf is never really still. Consider a sunlit leaf becoming warm from solar radiation. If the air is cooler than the leaf, the molecules of gas in physical contact with the leaf's surface will be warmed by conduction and gain energy. The increase in the molecules' energy causes the mass of air to expand and rise like smoke going up a chimney [*see top illustration on page 77*]. As the warm air rises, cooler air replaces it along the leaf's surface; this air in turn is warmed, rises and is replaced, and thus the process of draining heat from the warm leaf continues.

At night, or whenever a leaf is cooler than the air, the situation is reversed. In darkness a leaf may emit more energy than it receives and become cooler than the surrounding air. Convection now forces the warmer air to give up energy to the cooler leaf. As the gas molecules lose energy the air sinks and streams downward to form a cool mass around the base of the plant [*see bottom illustration on page 77*]. This reverse transfer warms the leaf and tends to stabilize its temperature at a point near the temperature of the surrounding air.

A decrease in the efficiency of this energy transfer, which may occur on clear and still nights when the air temperature falls to near the freezing point, can bring disaster to a citrus grove. The leaves and fruit, radiating to the cold sky, can fall several degrees below air temperature and freeze. One way to combat this result is to use wind machines that create strong air currents among the trees. The airflow increases the rate of energy transfer from the warmer atmosphere to the cold trees and keeps them above the freezing temperature.

As the example of the citrus grove suggests, even a small amount of air movement rapidly destroys the boundary layer and thereby increases the rate of conductive heat transfer. As long as the flow of air over the surface of a leaf remains laminar, or unturbulent, the rate of heat transfer remains proportional to the square root of the wind velocity. The flow of air through vegetation, however, quickly becomes turbulent, and when this occurs the transfer rate becomes almost proportional to the actual wind velocity.



FLOW OF AIR over the leaf of a bur oak (*Quercus macrocarpa*) is revealed in schlieren photograph. Laminar near the leaf tip (*left*), the flow becomes quite turbulent farther along the leaf surface. This accelerates convection and also carries away transpired water vapor.

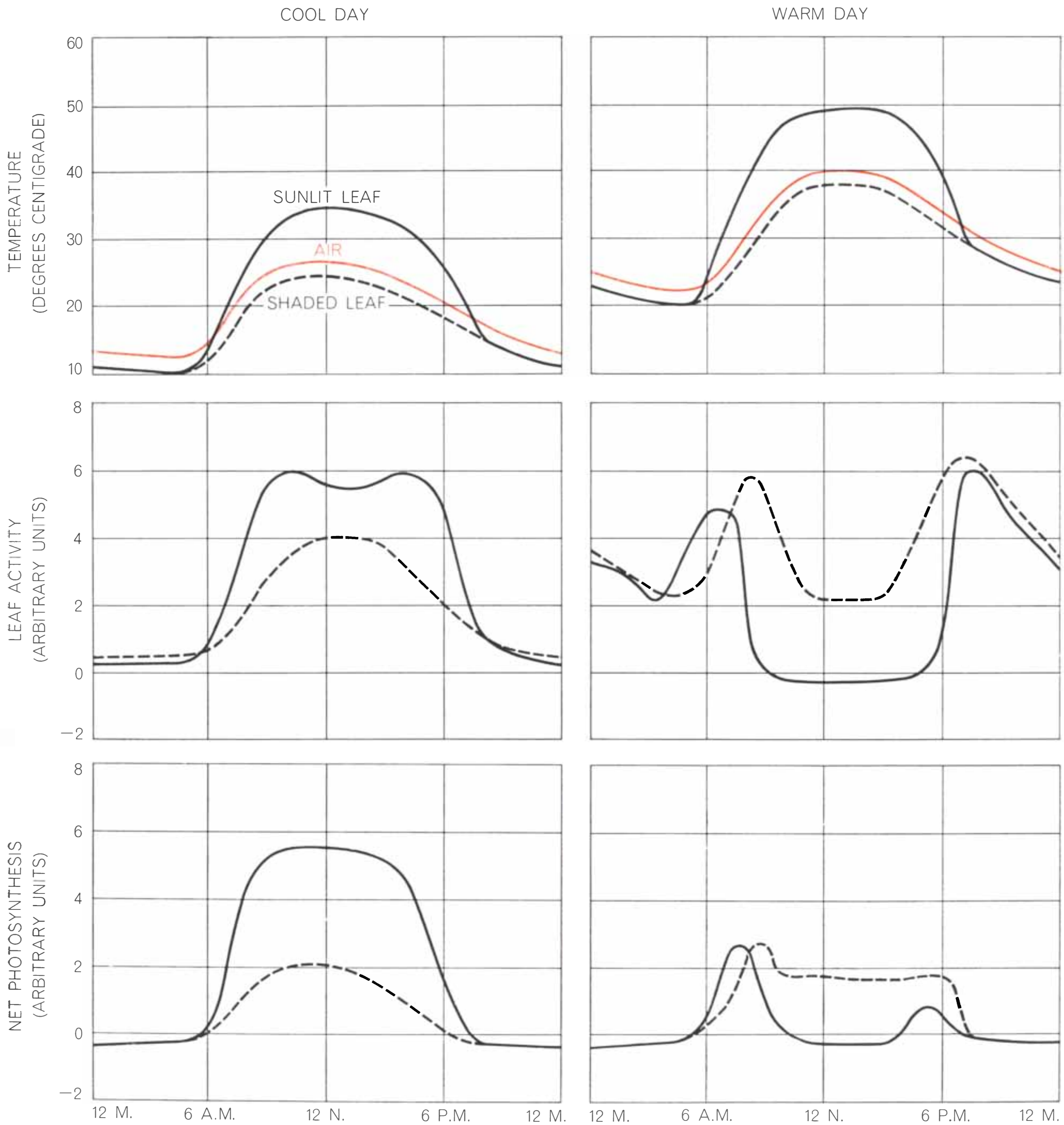
In a study of comparative convection efficiencies Frank Kreith, Cam Tibbals and I made precise silver casts of leaves and branches at the University of Colorado and measured the properties of the casts in a wind tunnel. It soon became clear that, as leaf size increased, the amount of heat transferred to the air by convection per unit of surface area became smaller. The air flowing across the surface of a leaf cast quickly approached the temperature of the surface; as the gradient between the temperature of the air and the temperature of the surface decreased so did the air's capacity for energy transfer over the downstream remainder of the surface.

The wind tunnel studies of silver casts showed that, per unit of surface area, the rate of energy transfer by convection would be many times greater for a pine needle than for a poplar leaf. Moreover, when the pine needle cast and poplar leaf cast were exposed to equal amounts of radiation, the temperature of the pine needle cast remained much closer to the air temperature than did that of the poplar leaf cast. These studies obviously could not account for cooling effects that would have been operated if our silver casts had been capable of transpiration.

The roles that radiation, transpiration and convection play in the life of a plant during the daylight hours are quite different from the roles they play at night. In daylight, for example, the energy budget for a horizontally oriented leaf exposed to the noonday sun in still air has the following breakdown. Direct sunlight and sunlight scattered in the sky irradiate the leaf's upper surface at the rate of 1.4 calories per square centimeter per minute. In addition, perhaps 20 percent of the sunlight that strikes the ground nearby is reflected upward and irradiates the lower surface of the leaf; this adds another .28 calorie per square centimeter per minute to the leaf's potential absorption of solar energy. Actually the leaf absorbs only 60 percent of the solar radiation impinging on it, so that the total load of absorbed heat attributable to solar radiation is 1.01 calories per square centimeter per minute. In addition to this the leaf is exposed to thermal radiation. The flow of energy at infrared wavelengths down from the atmosphere and the flow up from the ground respectively add to the leaf's heat load at the rate of .5 and .6 calorie per square centimeter per minute. The leaf absorbs 100 percent of this radiation, bringing the total input of radiant energy up to a rate of 2.11 calories per square centimeter per minute.

Assuming a leaf temperature of 36 degrees C. and a transpiration rate of .00054 gram per square centimeter per minute, the leaf will start to balance its energy budget by reradiating 68 percent (1.44 calories) of the radiant energy it is absorbing. Transpiration will dissipate an additional 29 percent (.62 calorie) of the load. Only 3 percent of the total (.05 calorie) remains to be disposed of by convection cooling. This is quite a small figure, but we have been assuming that the leaf is in still air; given a wind, convection would account for a much larger part of the energy transfer and might even play a larger role than transpiration.

At night a different series of transfers is required to keep the energy budget in balance. First, with the leaf stomates closed, transpiration is negligible. Second, as the leaf temperature drops below the temperature of the surround-



COOL SUMMER DAY produces sharply contrasting performances by a sunlit and a shaded leaf. Between sunrise and sunset the sunlit leaf is much warmer than the air (*top*). Its warmth favors physiological activity (*center*); net photosynthesis during the hours of daylight (*bottom*) attains a high level. The shaded leaf never gets enough light to engage in strong photosynthetic activity.

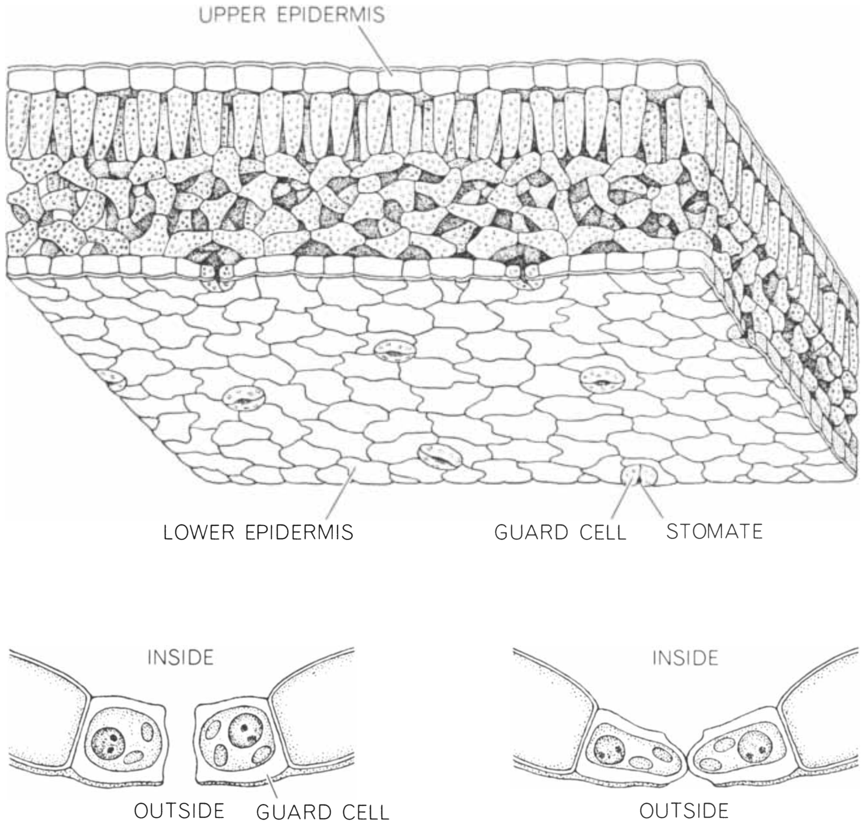
WARM SUMMER DAY produces the opposite effect by bringing the sunlit leaf to the brink of thermal catastrophe. As the leaf temperature rises during the forenoon it soon reaches the level at which biochemical activity is inhibited; photosynthesis stops (*bottom*) and cannot resume until late afternoon. In contrast, the shaded leaf is near optimum temperatures during most of the day.

ing air the convection process ceases to extract energy from the leaf and adds energy instead. Third, between sunset and sunrise the leaf has no solar radiation load to cope with. Although thermal radiation continues throughout the night, even the output of this energy source is somewhat reduced. The night budget has the following breakdown.

Thermal radiation from the atmosphere reaches the leaf at a rate of .4 calorie per square centimeter per minute, compared with the daylight rate of .5 calorie. Thermal radiation from the ground adds .55 calorie per minute, compared with the daylight rate of .6 calorie. The total night heat load from radiation is thus only .95 calorie per square centimeter per minute. Assuming still air, an air temperature of 15 degrees C. and a leaf temperature of 10 degrees, an additional .04 calorie per minute (4 percent of the total heat load) will be supplied to the leaf by convection. The energy input from radiation and convection combined comes to less than one calorie per square centimeter per minute. Reradiation suffices to dispose of this small input and balance the energy budget.

In nature, of course, matters are by no means as simple. There are cool days and warm nights; there are winds, clouds and overcast skies. The variations in energy transfer and fluctuations in leaf temperature under such changing circumstances are evident from a few examples of leaf-temperature readings I made during the summer in the yard of my former home in Boulder, Colo. I found that on overcast days all leaf temperatures remained below the temperature of the air. On cloudy days the leaf temperatures shifted rapidly from 6 to 8 degrees C. above the air temperature to 2 to 4 degrees below it as the clouds alternately exposed and obscured the sun. In the middle of a sunny summer day leaves that were exposed to the sun were warmer than the air by 5 degrees or more; the highest leaf temperature I recorded at Boulder–51 degrees C.–was 22 degrees warmer than the air. Leaves that were in the shade on the same kind of day, however, ranged from close to air temperature to as much as 5 degrees below it.

Each such variation naturally affects the plant's physiological activities. A sunlit leaf's approach to thermal catastrophe was described earlier; the midday heat load broke the leaf's photosynthetic activity into morning and afternoon intervals. A leaf that had been in shade throughout such a day would easily outdo the sunlit leaf in total photosynthetic

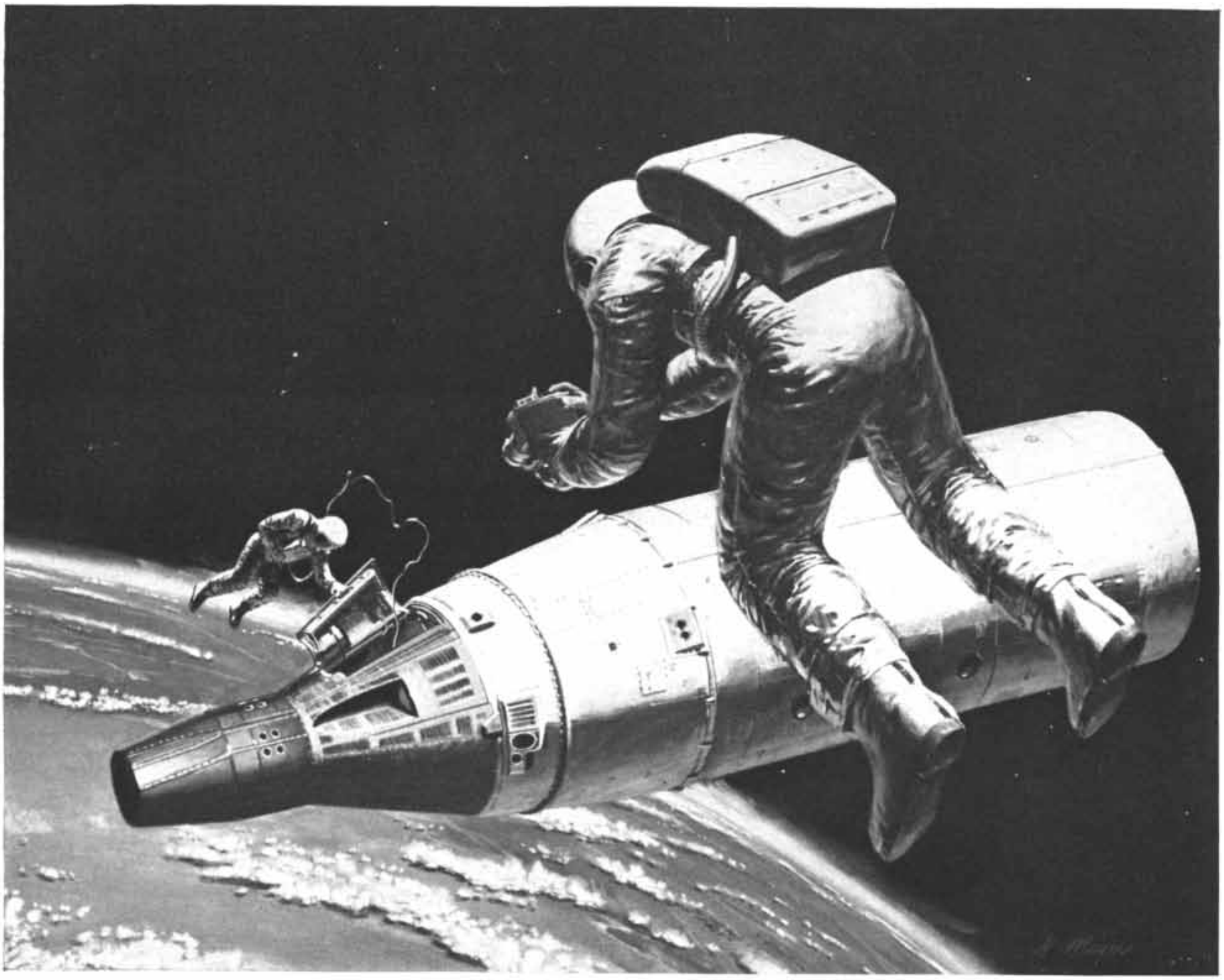


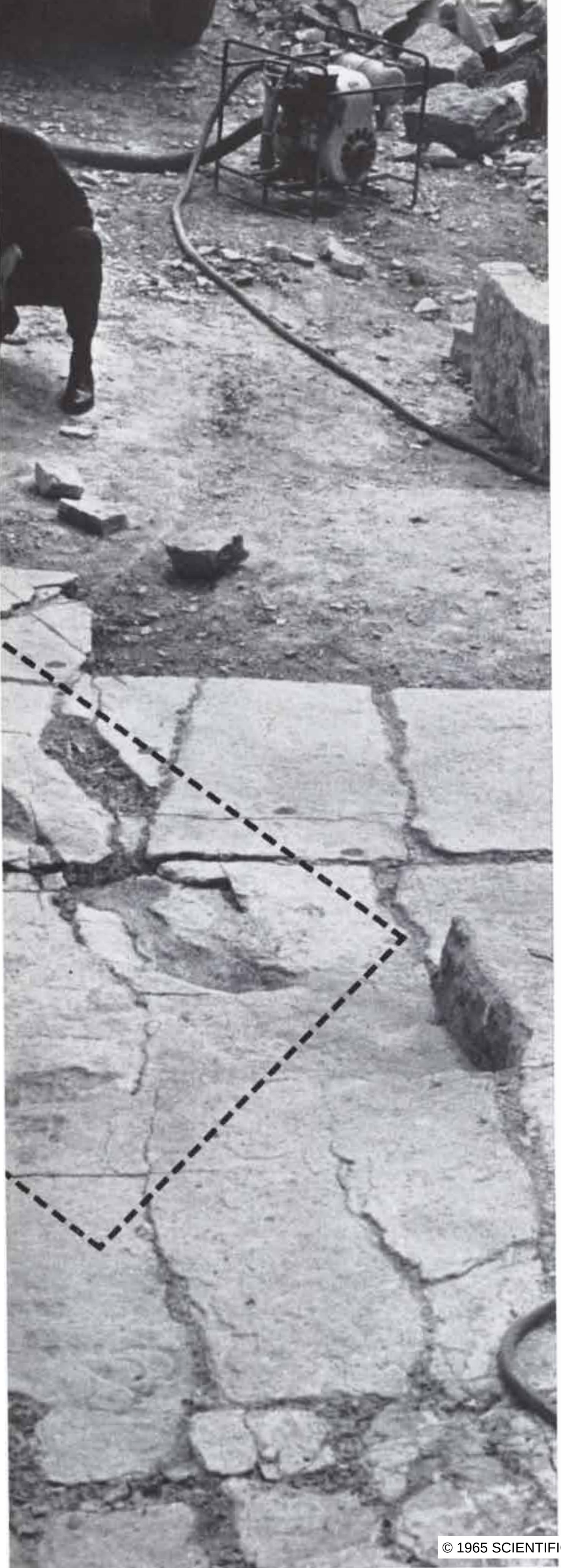
LEAF CROSS SECTION shows the paired sausage-shaped guard cells that control the opening and closing of the stomates, through which water vapor is emitted during transpiration. Stomates are normally closed at night and open during the day. Details show how guard cells bend to form an opening when turgid with moisture (*lower left*) but straighten to close when less turgid (*lower right*). An excess of carbon dioxide also closes the cells.

production. By the same token the pattern of energy transfers during a cool summer day would favor the sunlit leaf and prevent the shaded leaf from reaching the optimum temperature range for photosynthesis.

In spite of such variations there appears to be a balance of factors working in favor of overall plant efficiency. First, the energy transfers we have noted—which tend to keep leaves warmer than cool air but cooler than warm air—serve to maintain the leaves reasonably near the temperature range for optimum physiological activities. Second, taking photosynthesis as an example, the optimum temperature range for the process varies a great deal. For many plants in temperate regions the optimum ranges from 25 degrees C. to 30 degrees; the optimum for arctic and alpine plants can be as low as 15 degrees. One indication of how such optimums may have evolved has been discovered by H. A. Mooney of the University of California at Los Angeles. Mooney and his associates have found that the optimum temperature for photosynthesis depends at least in part on a plant's own life history. When they were raised under conditions of moderately low temperature, Mooney's experimental plants achieved optimum photosynthesis at one temperature level. When they were acclimatized to warmer temperatures, optimum photosynthesis occurred at temperatures as much as 5 degrees higher than before. This kind of adaptability would be vitally important to plant populations that were extending their range into extreme environments.

In summary, it has been shown that one of the key interactions between a plant and its environment is transfer of energy between the two; the transfers determine the plant's temperature and the plant's temperature affects its physiological efficiency. A question that remains unanswered is why it is that different plants show optimum efficiency at different temperatures. The eventual answer to this question will probably ininvolve the catalytic activity of plant enzymes; when it is found, it should open the door to the understanding of a fundamental mechanism in the ecological system of our planet.





To remove dinosaur tracks, cut along dotted lines

but only with a diamond saw.

Scientists removed 24 yards of clearly defined dinosaur tracks from a quarry in Dorset, England. They chose a natural-diamond saw blade to do the actual cutting because of its ability to cut quickly and evenly, without splintering or cracking the precious slabs.

But don't think that diamond tools are good only for unusual jobs like this. On the contrary, natural and synthetic diamond tools are now used routinely to shape carbide, to cut barium glass, to drill neat holes into concrete walls, to slice joints in sidewalks and highways. Why? Because only diamonds can do these jobs so well . . . and so economically.

Are you frightened by the cost of diamond tools? Don't be. Because if you cut, sharpen or smooth *anything* in your business, your tool manufacturer can show you how to cut your operating costs with diamond tools. Or write to this magazine for more information.

De Beers

World's leading source of natural *and* synthetic diamonds for industry . . . backed by the Diamond Research Laboratory

Shannon, Ireland

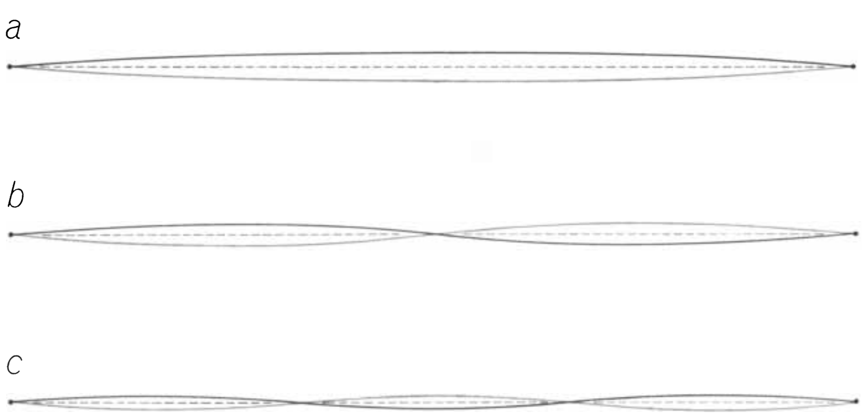
The Physics of the Piano

Most musical instruments produce tones whose partial tones, or overtones, are harmonic: their frequencies are whole-number multiples of a fundamental frequency. The piano is an exception

by E. Donnell Blackham

Almost every musical tone, whether it is produced by a vibrating string, a vibrating column of air or any other vibrating system, consists of a fundamental tone and a number of the higher-pitched but generally fainter tones known as partial tones or overtones. The complex sound produced by this combination of separate tones has a timbre, or characteristic quality, that is determined largely by the number of partial tones and their relative loudness. It is timbre that enables one to distinguish between two musical tones that have the same pitch and the same loudness but are produced by two different musical instruments. A pure tone—one that consists solely of the fundamental tone—is rarely heard in music.

It is widely believed that the partial tones produced by all musical instruments are harmonic—that their frequencies are exact whole-number multiples of the frequency of a fundamental tone. This certainly holds true for all the woodwinds and under certain conditions for many of the stringed instruments, including the violin. It is only approximately true, however, in the most familiar stringed instrument: the piano. The higher the frequency of the partial tones of any note on the piano, the more they depart from a simple harmonic series. In our laboratory at Brigham Young University my colleagues and I, under the direction of Harvey Fletcher, have succeeded in measuring with considerable precision the degree to which the modern piano is inharmonic and have demonstrated the importance of this factor in determining the distinctive quality of the piano's tone.



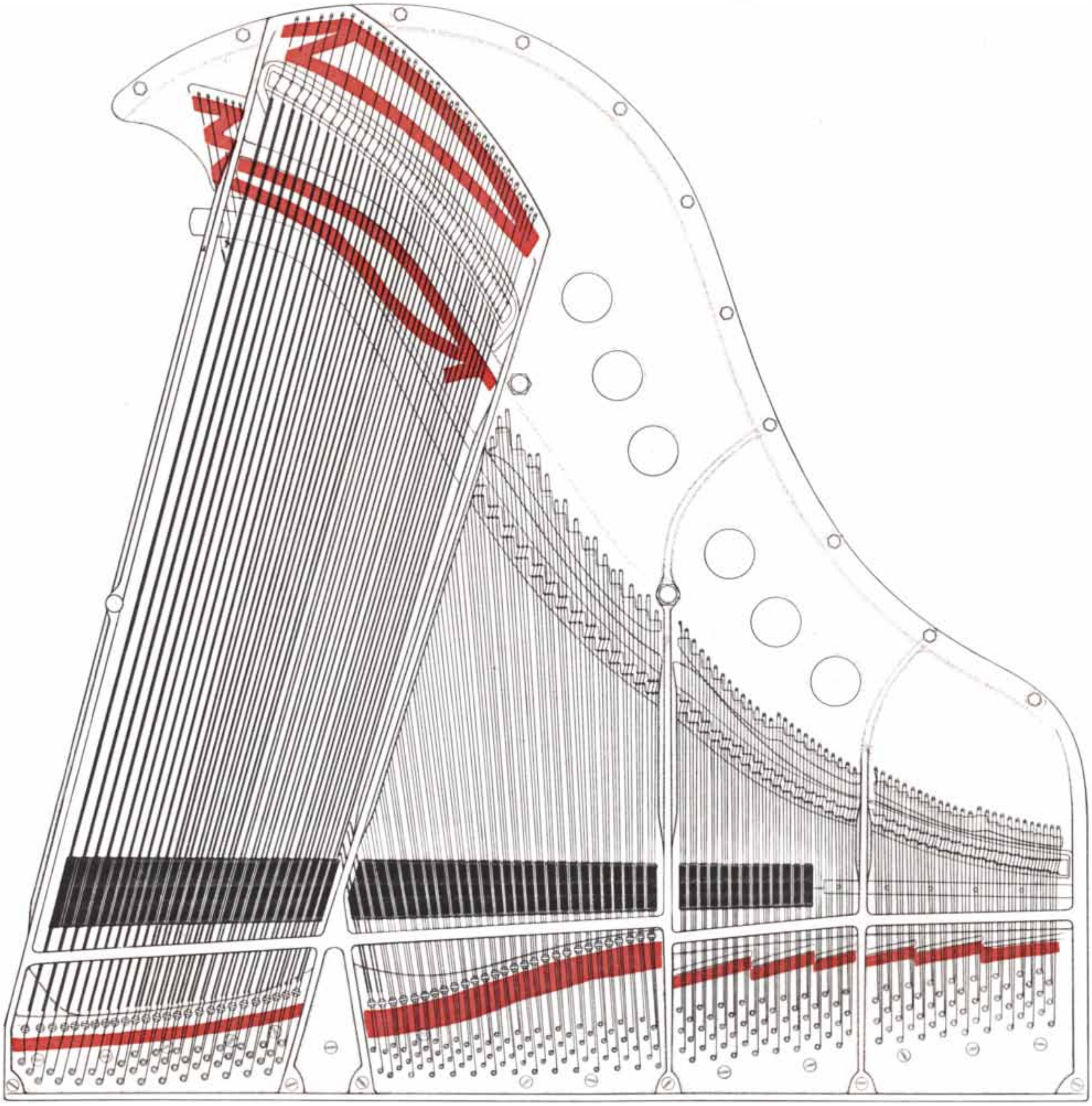
IDEAL STRING, that is, one without any stiffness, can be made to vibrate at many different frequencies: the fundamental frequency (*a*) produces a pure tone, rarely heard in music, whereas higher-pitched partial tones, or overtones, are produced by harmonic vibrations (*"b" and "c"*), whose frequencies are whole-number multiples of the fundamental frequency.

SIMULTANEOUS VIBRATION of a string at two or more different frequencies is normal for stringed instruments. Here the string vibrates at the fundamental frequency and the second partial frequency (*"a" and "c" in upper illustration*). In the piano the stiffness of the strings causes higher partials of a complex tone to depart from the simple harmonic series.

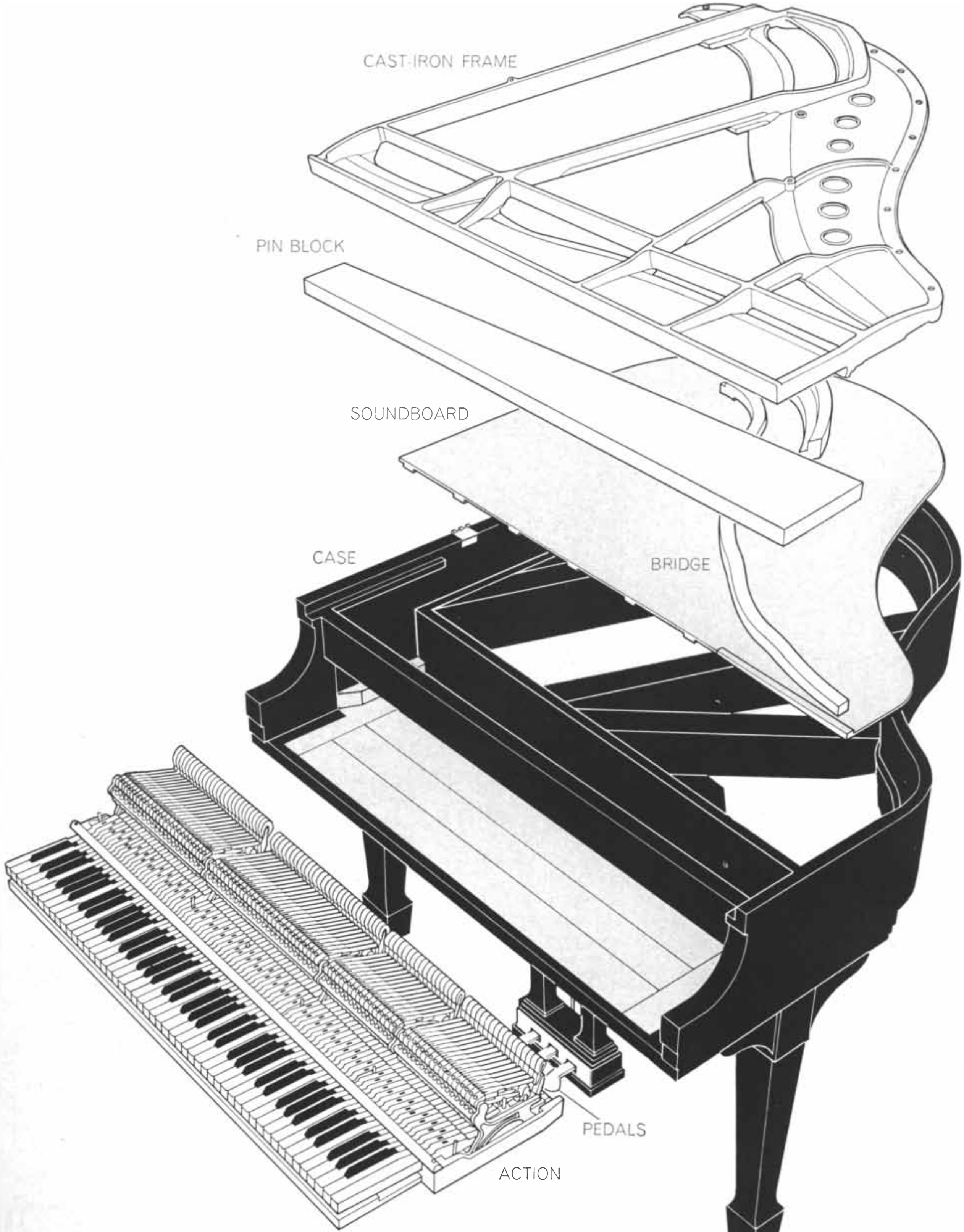
The physics of the piano can best be understood by first reviewing the evolution of the modern piano and its principal components. Archaeological evidence shows that primitive stringed instruments existed before the beginning of recorded history. The Bible refers several times to an instrument called the psaltery that was played by plucking strings stretched across a box or gourd, which served as a resonator. A similar instrument existed in China some thousands of years before the Christian era. In the sixth century B.C. Pythagoras used a simple stringed instrument called the monochord in his investigation of the mathematical relations of musical tones. His monochord consisted of a single string stretched tightly across a wooden box. It was fitted with a movable bridge that could divide the string into various lengths, each of which could vibrate freely at a different fundamental frequency.

Another important component of the modern piano—the keyboard—did not arise in conjunction with a stringed instrument but with the pipe organ. The organ of Ctesibus, perfected at Alexandria in the second century B.C., undoubtedly had some kind of keyboard. The Roman architect Vitruvius, writing during the reign of Augustus Caesar, describes pivoted keys used in the organs of his day. In the second century A.D. Hero of Alexandria built an organ in which the valves admitting air to the pipes were controlled by pivoted keys that were returned to their original position by springs.

We do not know who first conceived the idea of adding keys to a stringed instrument. From this obscure beginning there eventually evolved in the 15th century the clavichord. In the early clavichords a piece of metal mounted vertically at the end of the key acted both as a bridge for determining the pitch of the string and as a percussive device for producing the tone [*see upper illustration on page 92*]. Since one string could be used to produce more than one tone, there were usually more keys than strings. A strip of cloth was interlaced among the strings at one end in order to damp the unwanted tone from the shorter part of the string.



TOP VIEW of the interior of a modern "baby grand" piano shows the powerful construction of the full cast-iron frame, which sustains the tremendous tension exerted by the strings. In this particular piano the frame, which is cast in one piece, weighs about 250 pounds and sustains an average tension of some 50,000 pounds; in a larger concert-grand piano the frame weighs as much as 400 pounds and sustains an average tension of 60,000 pounds. The strings are made of steel wire with an ultimate tensile strength of from 300,000 to 400,000 pounds per square inch. In order to make the bass strings (*left*) vibrate slower and thus produce a lower pitch, they are wrapped in copper or iron wire; two such wrappings are often used in the extreme bass. In all modern pianos the bass strings are "overstrung" in order to conserve space and to bring them more nearly over the center of the soundboard. Starting from the treble, or right-hand, end of the keyboard there are 60 notes with three strings each, then 18 notes with two strings each and finally, in the extreme bass, 10 notes with only one string each. Larger pianos have more strings but the same total number of notes: 88. Rectangular black objects in a row near the bottom are the heads of the dampers. Parts made of felt are in color. Strips of cloth interlaced among the strings at top damp unwanted tones from the short parts of the strings beyond the bridge (*see illustration on next page*).

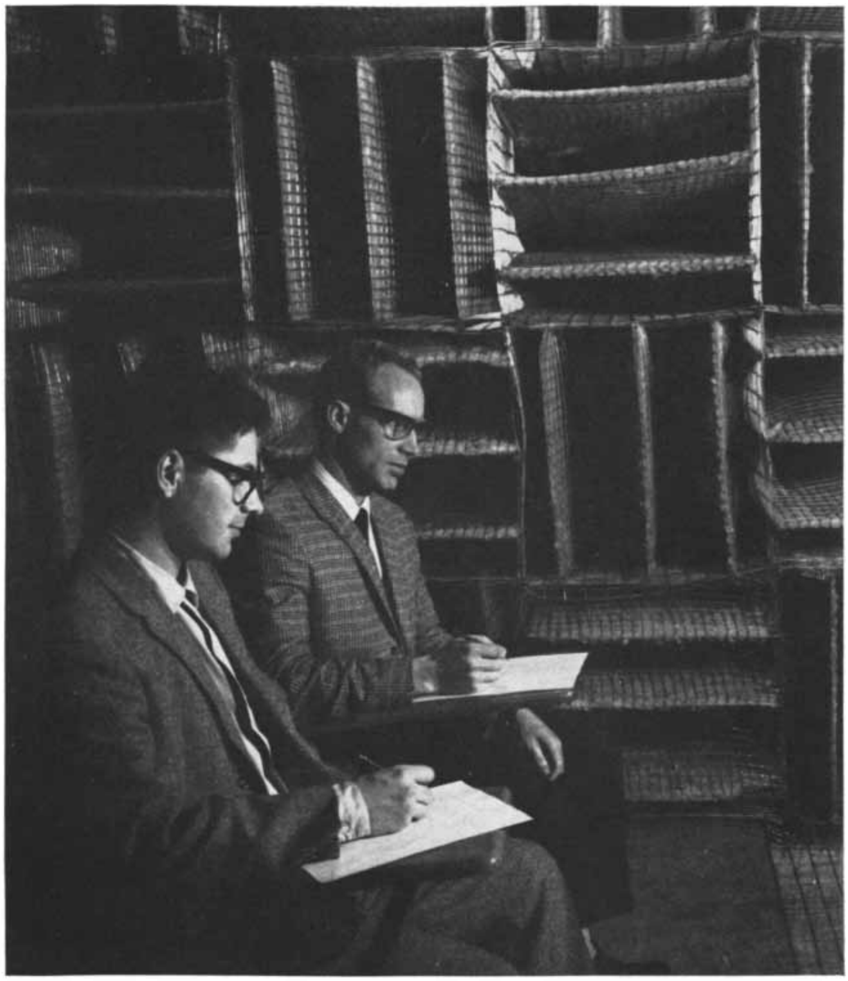


EXPLODED VIEW of the baby-grand piano depicted from above on the preceding page shows the relations of several main components. The keyboard (*bottom left*) has 88 keys divided into seven and a third octaves. Each octave has eight white keys for playing the diatonic scale (whole notes) and five raised black keys for playing the chromatic scale (whole notes plus sharps and flats). Connected to the keyboard is the action, which includes all the moving parts involved in the actual striking of the string. Three pedals (*bottom center*) serve to control the dampers in the action. When a key is struck, the hammer sets the strings in vibration and, after a very short interval known as the attack time, sound is translated by means of a wooden bridge to the soundboard, from which it is radiated into the air. During the attack time sound is also radiated to a lesser degree from both the strings and the bridge.

Several essential characteristics of the modern piano are inherited from the clavichord. The clavichord had metal strings, a percussive device for setting the strings in vibration, a damping mechanism and also an independent soundboard: the board at the bottom of the case did not also serve as the frame for mounting the strings. Moreover, although the tone of the clavichord was weak, the instrument allowed for the execution of dynamics, that is, for playing either loudly or softly.

At about the same time another forerunner of the modern piano was in process of development. In the spinet, or virginal, longer strings were introduced to produce a louder tone. Now the metal percussive device of the clavichord was no longer adequate to produce vibration in the strings. Instead the strings were set in motion by the plucking action of a quill mounted at right angles on a "jack" at the end of the key [*see lower illustration on next page*]. When the key was depressed, the jack moved upward and the quill plucked the string. When the jack dropped back, a piece of cloth attached to it damped the vibration of the string.

Around the beginning of the 16th century experiments with still longer strings and larger soundboards led to the development of the harpsichord. Although this instrument was essentially nothing more than an enlarged spinet, it incorporated several important innovations that have carried over to the modern piano. The wing-shaped case of the harpsichord is imitated by that of the grand piano. The stratagem of using more than one string per note in order to increase volume was adopted for the harpsichord by the middle of the 17th century. The harpsichord also had a "forte stop," which lifted the dampers from the strings to permit sustained tones, and a device for shifting the keyboard, both of which are preserved in the modern piano.



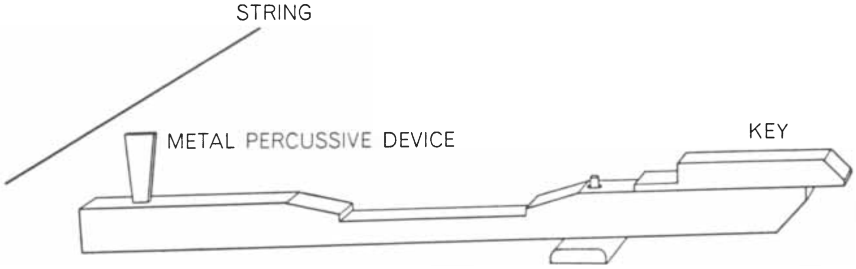
JURY composed of both musicians and nonmusicians was asked to distinguish between recordings of real piano tones and synthetic ones. When the synthetic tones were built up of harmonic partials, the musicians on the jury were able to distinguish 90 percent of these tones from real piano tones; the nonmusicians, 86 percent. When inharmonic partials were used, results showed that in most cases both the musicians and the nonmusicians were guessing; both groups identified only about 50 percent of the tones correctly. In this photograph two members of the jury are listening to tones in an anechoic, or echoless, chamber.

The invention of the piano was forecast by inherent defects in both the clavichord and the harpsichord. Neither the spinet nor the harpsichord was capable of offering the composer or performer an opportunity to execute dynamics. The clavichord, on the other hand, allowed a modest range of dynamics but could not generate a tone nearly as loud as that of the harpsichord. Attempts to install heavier strings in order to increase the volume of either instrument were futile; neither the metal percussive device of the clavichord nor the quill of the harpsichord could excite a heavy string. Moreover, the cases of these early instruments were not strong enough to sustain the increased tension of heavier strings.

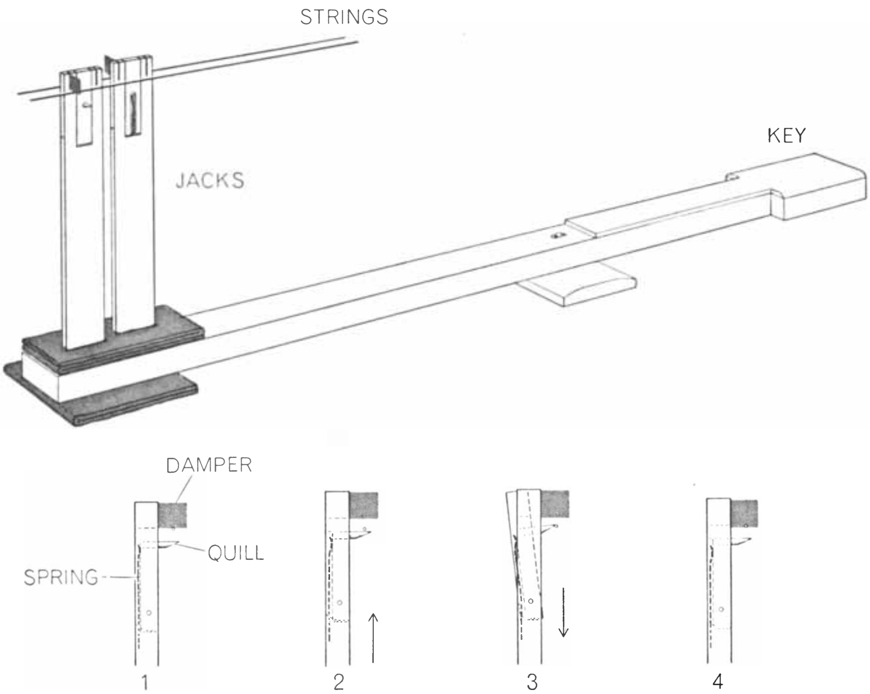
A remedy for these defects was provided by the Italian harpsichord-maker Bartolommeo Christofori, who in 1709 built the first hammer-action keyboard instrument. Christofori called his original instrument the "piano-forte," meaning that it could be played both softly and loudly. The idea of having the strings struck by hammers was probably suggested to him by the dulcimer, a stringed instrument played by hammers held in the hands of the performer. Christofori recognized that his new instrument would need a stronger case to withstand the increased tension of the heavier strings. By 1720 an improved model of the pianoforte included an escapement device that "threw" the free-swinging hammer upward at the string and also a back-check that regulated the hammer's downward return [*see upper illustration on page 93*]. An individual damper connected to the action of the hammer was provided for each note.

For a century and a half after Christofori's first piano appeared inventors worked to improve the new instrument, particularly its novel hammer action. Several other types of action were developed, some new and others modeled closely on Christofori's original. Pianos were built in a variety of forms: traditional wing-shaped pianos, square pianos, upright pianos and even a piano-organ combination.

Among the major innovations toward the end of this period was the full cast-



CLAVICHORD ACTION included one essential feature found in all modern pianos: a percussive device for setting the strings in vibration. A piece of metal mounted vertically at the end of the key acted both as a bridge for determining the pitch of the string and as a percussive device for producing the tone. Since one string could be used to produce more than one tone, there were usually more keys than strings. A strip of cloth was interlaced among the strings at one end to damp the tone from the shorter part of the string.



HARPSICHORD ACTION was capable of producing a louder tone than that of the clavichord, but, unlike the clavichord, it did not allow for the execution of dynamics, that is, for playing either loudly or softly. The strings were set in motion by the plucking action of a quill mounted at right angles on a "jack" at the end of the key. When the key was depressed, the jack moved upward and the quill plucked the string. When the jack dropped back, a piece of cloth attached to it damped the vibration of the string. The stratagem of using more than one string per note was adopted in the harpsichord in the 17th century.

iron frame. Constant striving for greater sonority had led to the use of very heavy strings, and the point was reached where the wooden frames of the earlier pianos could no longer withstand the tension. In 1855 the German-born American piano manufacturer Henry Steinway brought out a grand piano with a cast-iron frame that has served as a model for all subsequent piano frames. Although minor refinements are constantly being introduced, there have been no fundamental changes in the design or construction of pianos since 1855.

A part of the piano that has received a great deal of attention from acoustical physicists is the soundboard. Some early investigators believed the sound of the piano originated entirely in the soundboard and not in the strings. We now know that the sound originates in the strings; after a very short interval, called the attack time, it is translated by means of a wooden bridge to the soundboard, from which it is radiated into the air. During the attack time sound is also radiated to a lesser degree from both the strings and the bridge. In the late 19th century Frederick Mathushek and his associates proved that the quality of a piano's sound was not influenced by the transverse, or horizontal, vibrations of the soundboard. They glued together two soundboards so that the grain of one was at right angles to the grain of the other, thereby eliminating any transverse vibrations, and found that the quality of the sound was not affected by this arrangement. The behavior of the soundboard has also been analyzed theoretically by a number of eminent physicists, including Hermann von Helmholtz, but such analyses have added nothing to the principles of soundboard construction arrived at empirically by the builders of the early clavichords and harpsichords.

The development of the full cast-iron frame gave the sound of the piano much greater brilliance and power. The modern frame is cast in one piece and carries the entire tension of the strings; in a large concert-grand piano the frame weighs 400 pounds and is subjected to an average tension of 60,000 pounds. In order to maintain the tension of the strings each string is attached at the keyboard end to a separate tuning pin, which passes down through a hole in the frame and is anchored in a strong wooden pin block. Since the piano would go out of tune immediately if the tuning pins were to yield to the tremendous tension of the strings, the pin block is built up of as many as 41 cross-grained layers of hardwood.

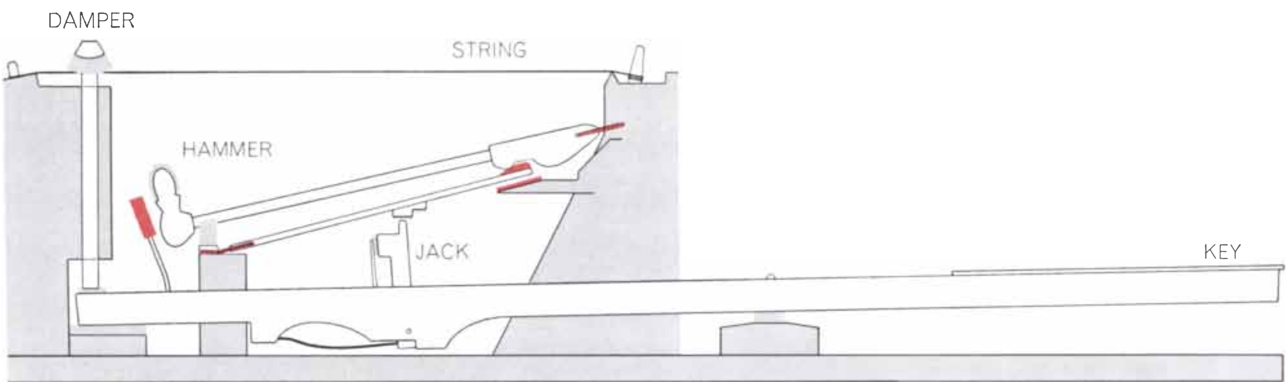
The keyboard of the modern piano is constructed on essentially the same principles that had been fully developed before the 15th century. The standard keyboard has 88 keys divided into seven and a third octaves, the first note in each octave having twice the frequency of the first note in the octave below it. Each octave has eight white keys for playing the diatonic scale (whole notes) and five raised black keys for playing the chromatic scale (whole notes plus sharps and flats). In all modern pianos the white keys are not tuned exactly to the diatonic scale but rather to the equally tempered scale, in which the octave is simply divided into 12 equal intervals.

The moving parts of the piano that are involved in the actual striking of the string are collectively called the action [*see lower illustration on opposite page*]. One contemporary piano manufacturer asserts that the action in one of his pianos has some 7,000 separate parts. Nearly all modern actions are versions of Christofori's original upward-striking ones, which took advantage of the downward force of gravity for the key's return. Some workers have experimented with downward-striking actions, so far without success.

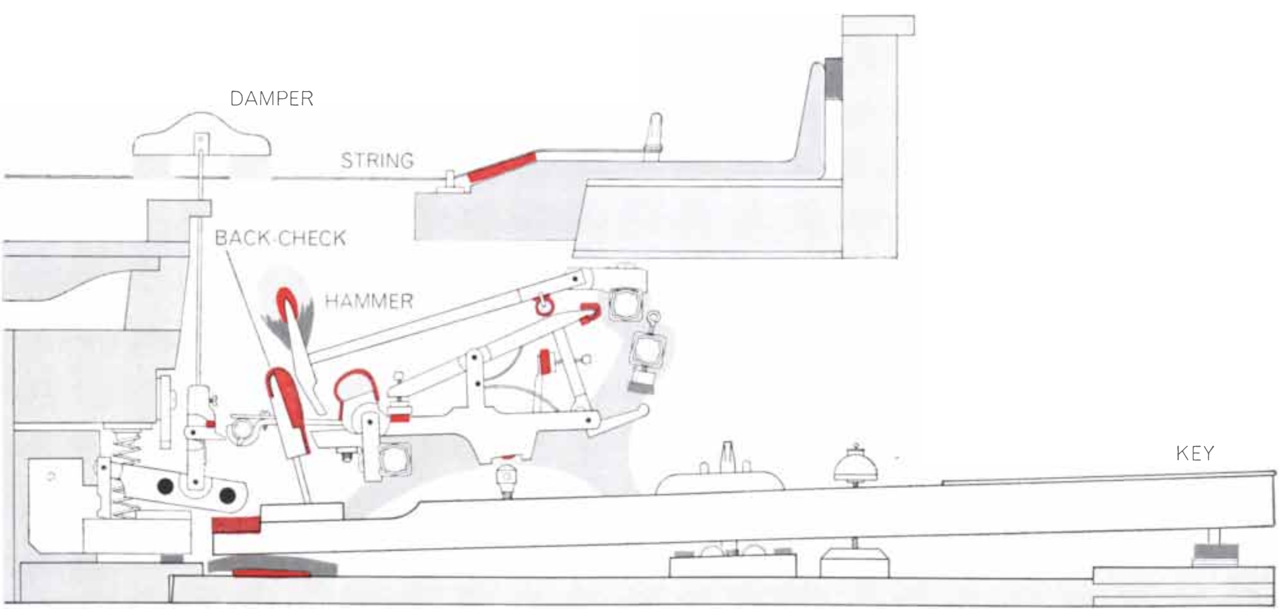
Early in the history of piano-building the hammers were small blocks of wood covered with soft leather. The inability of leather to maintain its resiliency after many successive strikings led eventually to the use of felt-covered hammers. If the felt is too hard and produces a harsh tone, it can be pricked with a needle to loosen its fibers and will produce a mellower tone. If the tone is too mellow and lacks brilliance, the felt can be filed and made harder.

A standard piano has three pedals that serve to control the dampers. The forte, or sustaining, pedal on the right disengages all the dampers so that the strings are free to vibrate until the pedal is released or the tones die away. The sostenuto pedal in the middle sustains only the tones that are played at the time the pedal is depressed; all the other tones are damped normally when their respective keys are released. The "soft" pedal on the left shifts the entire action so that the hammers strike fewer than the usual number of strings, decreasing the loudness of the instrument.

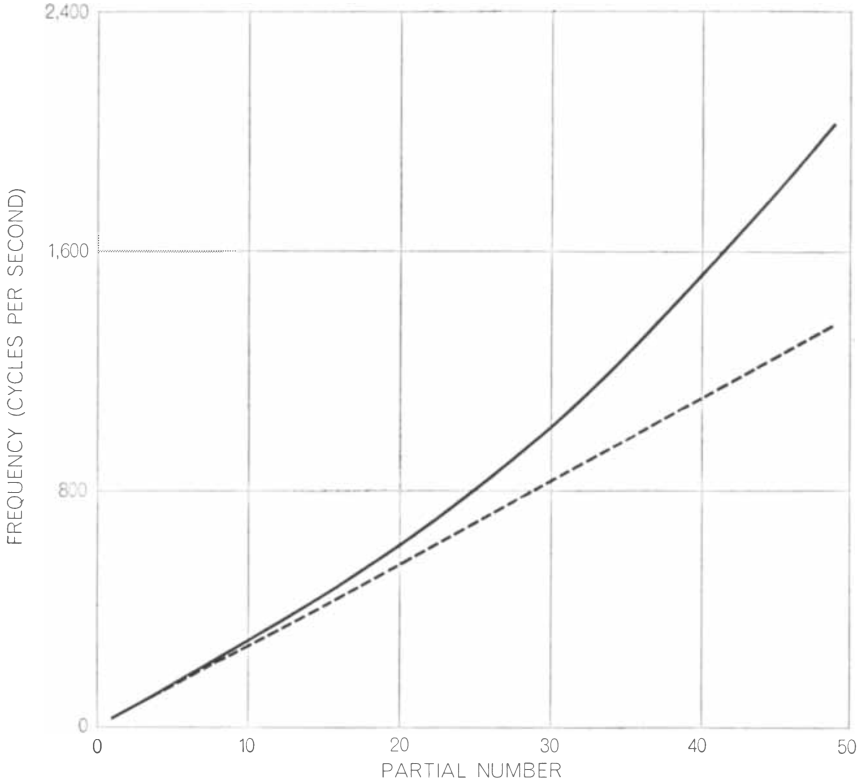
The most interesting part of the piano from the standpoint of the acoustical physicist is of course the strings. The strings used in pianos today are made of steel wire with an ultimate tensile strength of from 300,000 to 400,000 pounds per square inch. Additional weight is needed to make the bass strings vibrate slower and so generate sounds of lower pitch; this is provided by wrapping the steel wire with wire of



CHRISTOFORI ACTION, invented by Bartolommeo Christofori in the early 18th century, was the first hammer action and the prototype of all modern piano actions. It included an escapement device that "threw" the free-swinging hammer upward at the string and also a back-check that regulated the hammer's downward return. An individual damper connected to the action of the hammer was provided for each note. Christofori called his instrument the "piano-forte," meaning it could be played either softly or loudly.



MODERN PIANO ACTION is modeled closely on Christofori's original upward-striking actions, which took advantage of the downward force of gravity for the key's return. Unlike the early hammers, which were small blocks of wood covered with soft leather, the modern hammer is covered with felt. If the felt is too hard and produces a harsh tone, it can be pricked with a needle to loosen its fibers and will produce a mellower tone. If the tone is too mellow and lacks brilliance, the felt can be filed and made harder.



INHARMONICITY of a real piano tone is evident in this graph, based on data obtained from an electronic analysis of the partial tones of the lowest note on the piano keyboard (an *A*). The partials of the real piano tone (*solid line*) become increasingly sharper—that is, higher in frequency—compared with the partials of a pure harmonic tone (*broken line*).

copper or iron. Two such wrappings are often used in the extreme bass.

The vibration of a string that is attached securely at both ends is caused by a restoring force—a force that seeks to return the string to its original position after it has been displaced from that position. In a string that lacks stiffness the partial tones set up under the influence of the restoring force will be harmonic. In the piano the stiffness of the strings affects the restoring force to such a degree that some of the partials generated are not harmonic. This effect was known to Lord Rayleigh, who took it into account in formulating his classic equations for vibrating strings in the late 19th century. Many other investigators have since worked on the problem; our current effort is a continuation of the same line of inquiry.

Part of our program includes a series of tests in which a jury composed of both musicians and nonmusicians is asked to distinguish between recordings of real piano tones and synthetic ones. The synthetic tones are made by a bank of 100 audio-frequency oscillators that can be tuned to cover a range of from 50 to 15,000 cycles per second. Fine tuning is achieved by means of an attenuator connected to each oscillator circuit; the attenuator covers a range of 50 decibels, 10 decibels being a tenfold increase or decrease in the intensity of sound. With this apparatus it is possible to build up synthetic tones that represent a wide variety of partial-tone combinations. Real piano tones can be closely imitated by tuning a separate oscillator to the precise frequency and intensity associated with each partial tone of the real tone. The complex synthetic tone thus generated can then be fed into an "attack and decay" amplifier in order to give it the attack-and-decay characteristics found in the real piano tone.

In our early tests the synthetic tones were arbitrarily built up of harmonic partials. The musicians on the jury were able to distinguish 90 percent of these tones from real piano tones; the nonmusicians, 86 percent. In later tests synthetic tones built up of inharmonic partials were used. Results from these tests showed that in most cases both the musicians and the nonmusicians were guessing; both groups identified only about 50 percent of the tones correctly. Whenever a synthetic tone and a real tone were judged to be identical, we could give a description of the quality of the real tone based on our knowledge of the quality of the synthetic tone.

Recorded piano tones can also be analyzed directly by means of a conventional audio-frequency analyzer that is adjusted to pass only a narrow band of frequencies (about four cycles per second). The analyzer is set at different frequencies until it registers a maximum response for the particular partial being analyzed. A pure tone from one of the oscillators is then sent through the analyzer, and its frequency is adjusted until it gives a maximum response at the same setting as that of the real partial. An electronic counter is used to measure the frequency of the oscillator tone to an accuracy of within about a tenth of 1 percent. This frequency is assumed to be the frequency of the real partial being analyzed.

A sample of this kind of analysis for the lowest note on the piano keyboard (an *A*) is given in the illustration at the left. It is evident that the partials of the real piano tone become sharper—that is, higher in frequency—compared with the partials of a pure harmonic tone. The 16th partial, for example, is a semitone sharper—half a step higher—than it would be if it were harmonic. The 23rd partial is more than a whole tone sharp, the 33rd partial is more than two tones sharp and the highest partial in the analysis, the 49th, is 3.65 tones sharp.

In addition to the fact that the piano's tones are generally inharmonic, the partials of any particular note tend to vary considerably in loudness. This variation is called the harmonic structure of the tone, or in the case of the piano, the partial structure. One way to analyze the partial structure of a piano tone is to measure the maximum response of each partial as it passes through the audio-frequency analyzer. This method was used to obtain the partial structure of the four *G*'s shown in the illustration on the opposite page.

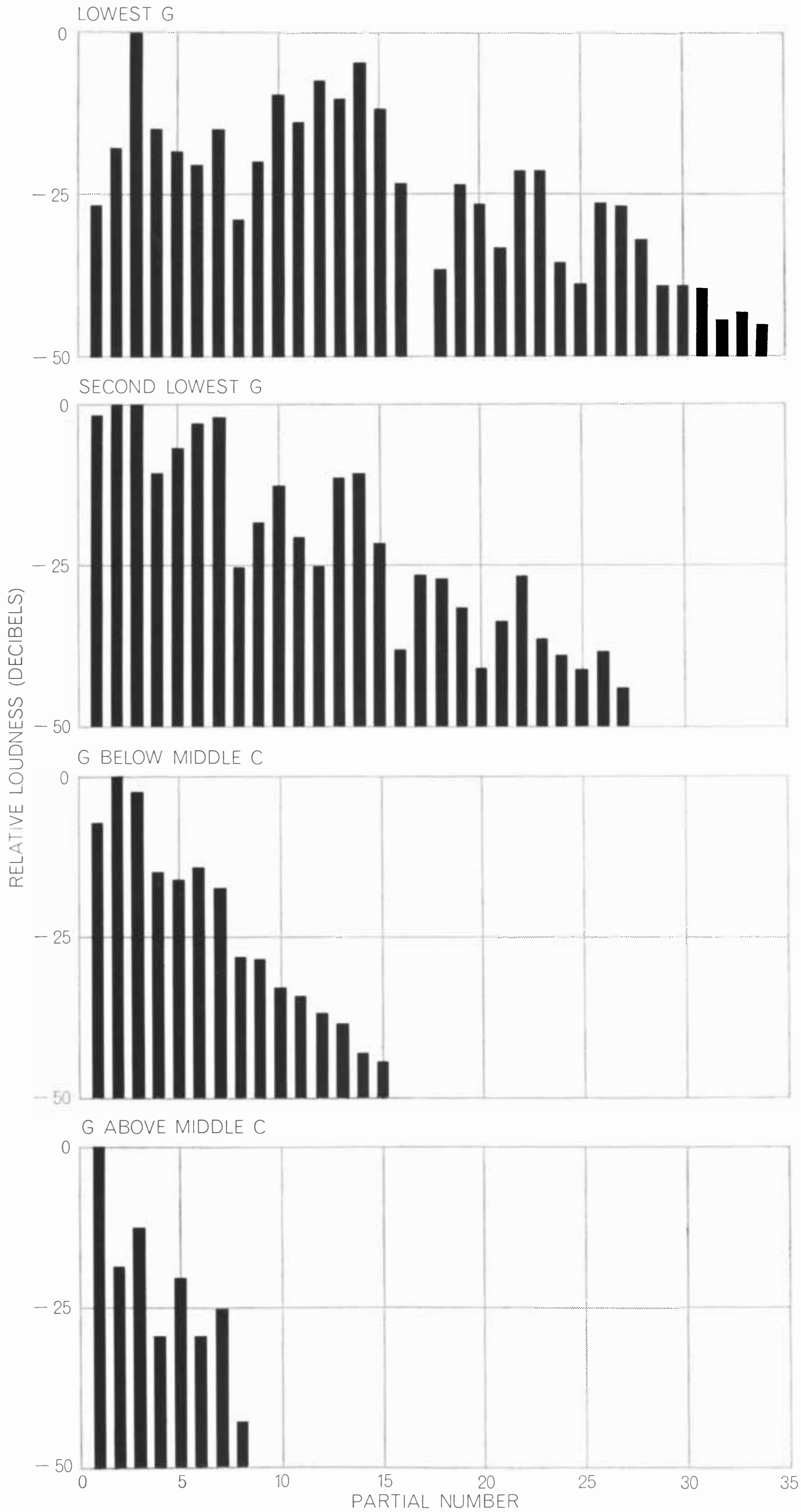
The foregoing method does not yield the most accurate description of the partial structure of a piano tone, because the structure is continuously changing. When a piano string is struck by its hammer, its response reaches a maximum an instant later. From this moment on the tone dies away as the string gradually ceases to vibrate. Because the ear perceives the entire tone dying away uniformly, it might seem that all the partials of the tone die away at an equal rate. An examination of the decay curves of individual partials proves that this is not the case [*see illustration on next page*]. It is obvious from these curves that if the partial structure of a tone were measured at any given time, it would be different from the structure at any other time. Nonetheless, some authors still refer to a decay rate of a tone as so many decibels per second. In actuality the partials do not all decay at the same rate; in some cases they may even increase in intensity before starting to decay.

The tones used for our decay-time analyses were recorded in an ordinary music studio. It was thought at first that the irregular variations during decay might be related to the acoustic characteristics of the room or the piano. Accordingly the experiment was repeated in three different rooms: a normally reverberant studio, a very reverberant room and an anechoic, or echoless, chamber. The irregularities in the decay curves were present in all three rooms [*see illustration on page 99*].

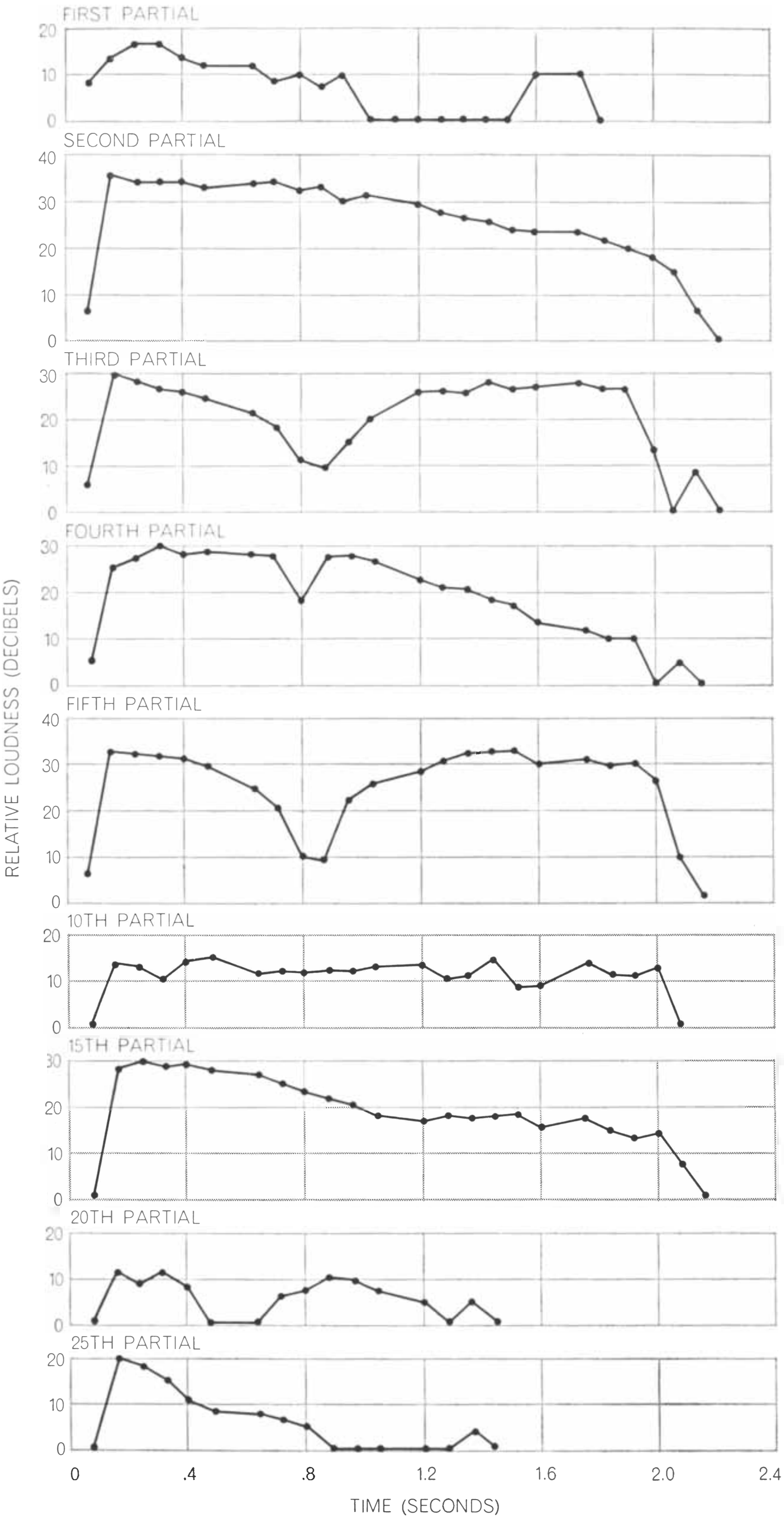
One of the main advantages of our synthetic-tone system is that it can be used to produce synthetic tones identical with one another and with a real tone except for certain selected characteristics. For example, a group of synthetic tones can be produced that differ only in attack time, the time required for the loudness of the tone to reach its first maximum after the hammer strikes the string. By presenting such a group of tones to our jury we were able to determine that for the *G* just above middle *C* the attack time has to be between zero and .05 second to sound like the *G* on a piano. An attack time in the range of from .05 to .12 second made the note seem questionable, and one longer than .12 second made it sound decidedly unlike a *G* struck on a piano. For lower notes the required attack time tended to be longer; for higher notes it tended to be shorter.

Synthetic tones can also be produced that are identical with one another and with a real tone in every respect except decay time, the time required for the string to stop vibrating after it has reached its maximum loudness. For an undamped *G* above middle *C* the decay time required for the synthetic tone to sound piano-like was between two and 5.5 seconds. Again acceptable decay times were longer for lower notes and shorter for higher notes.

Another procedure is to give synthetic tones a piano-like attack and decay but



PARTIAL STRUCTURES of the four lowest *G*'s on the piano keyboard are presented in these four bar charts. The partial structure of a musical tone is the variation in loudness of the partial tones that constitute that particular tone. The partial structures of these four notes were obtained by measuring the maximum response of each partial as it passed through an audio-frequency analyzer that was adjusted to pass only a narrow band of frequencies. The readings are given in relative decibel levels with the loudest partial of each note set at zero; the other partials can then be read as so many decibels below zero.



DECAY CURVES for nine partial tones of the lowest *C* on the keyboard demonstrate that the partial tones of a piano note do not all die away from an initial maximum at the same rate. In some cases they may even increase in loudness before beginning to decay. For each curve 30 measurements were made at equal intervals of .08 second each. Obviously the partial structure of a tone at any given time is different from the structure at any other time.

to vary the partial structure. In one test synthetic tones were built up in such a way that the loudness of each successive partial was a constant number of decibels less than that of the partial just below it in frequency. For example, if the difference was two decibels, then the second partial would be two decibels fainter than the first partial, the third partial would be four decibels fainter than the first, and so on. The limits of this "decibel difference" for obtaining a piano-like tone from the *G* above middle *C* were from five to 13 decibels per partial. In this case the acceptable range was narrower for lower notes and wider for higher notes. Tones produced when the decibel difference was below the lower limit were judged by the jury to sound "dead" or "hollow." Tones above the upper limit were described as sounding "like a harpsichord" or having "too much edge."

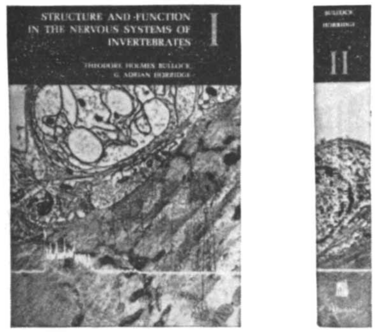
Synthetic tones that were built up of perfectly harmonic partials were described by the musicians and nonmusicians alike as lacking "warmth." Musicians generally use this term to suggest a certain quality of musical tone. For instance, a number of violins playing the same note at the same time produce a tone that is said to be warmer than that produced by a single violin playing alone. This quality appears to result from the fact that it is impossible for a number of musicians to play exactly in tune. When two different frequencies are sounded together, "beats" can be detected, the number of beats being equal to the difference in cycles per second between the two tones. A difference as small as two cycles per second between the fundamental frequencies of two tones can, however, produce much larger differences in the upper partials. Thus the beats that occur when two tones, each with a large number of partials, are sounded simultaneously can be quite complex. It is such beats between tones that account for the warmth produced by several violins or by a chord on the piano.

In the piano some additional warmth can be attributed to the fact that most of the hammers strike more than one string at a time. If the strings are not identically tuned, beats will occur between the high partials produced by each string. If such beats become too prominent, of course, the strings are declared to be out of tune.

The quality of a piano's tone also depends on several outside influences that

"A superb work . . . unique in the literature of modern biology. It must rank as one of the finest publications extant in science."

GRAHAM HOYLE, Professor of Biology
University of Oregon



Structure and Function in the Nervous Systems of Invertebrates

"... This monumental, two-volume treatise is no ordinary review. It is a comprehensive, coherent account of what is known, believed, and understood about nervous systems and how they work. It is a reasoned, evaluated survey of the literature in this field, spanning nearly a century of time. It is information distilled and judged. Evidence abounds on every page that the material selected for inclusion has been tempered by a keen and attentive human mind.

"The scope and extent of coverage is prodigious. It encompasses the entire animal kingdom exclusive of the vertebrates, embracing as well the minute details of ultrastructure as the topography of entire "systems," and considering every facet of function from excitability to integration. In 21 chapters the pertinent, relevant data on invertebrate nervous systems are judiciously considered. But that is not all.

"Volume 1 begins with six chapters that give a concise but comprehensive overview of what is known in fact about the way nervous systems are put together, and of what is understood in principle about the way they work. These introductory chapters are background to the remaining 21; they are also, by themselves, a coherent, masterful summary and evaluation of the present state of knowledge in each of the topics treated: patterns of nervous system organization; microanatomy of neural elements; excitability and conduction; transmission; integration; and neurosecretion. ... For those who are beginning their career and for research workers whose experience has been limited to the vertebrate animals, these six chapters are a boon—and a necessity.

. . .

"The liberal use of top-quality illustrations is a delight to the eye. Although they abound, their number is not superfluous for each serves to clarify, amplify, or extend the text. Every technique and mode of illustration is included, some because they have been taken or adapted from another source, and others because the authors consciously chose the best means of illustration, whether that be micrograph or drawing, diagram, chart, record, or halftone.

. . .

"From the elegant frontispiece ... to the glossary of terms in wide use and having a special meaning, this work fully justifies the authors' expectation of producing a 'synthetic, personal evaluation of the state of our knowledge.'

. . .

"No student of nervous systems could, by the expenditure of many times $75, duplicate what is here presented in coherent fashion. For as long as men investigate nervous systems and try to understand their perplexing ways, so long will Bullock and Horridge be remembered with gratitude."

—From a review in SCIENCE, July 23, 1965, by Dixy Lee Ray, Department of Zoology, University of Washington and Pacific Science Center, Seattle

THEODORE HOLMES BULLOCK, University of California, Los Angeles, and **G. ADRIAN HORRIDGE,** University of St. Andrews, Scotland. With chapters by **Howard A. Bern,** University of California, Berkeley, **Irvine R. Hagadorn,** University of North Carolina, and **J. E. Smith,** Queen Mary College, University of London.

1965, two volumes, xxviii + 1719 pages, 881 illustrations (more than 35 in color)
$75

W. H. FREEMAN AND COMPANY
660 Market Street
San Francisco, California 94104

Send me_______set(s) of STRUCTURE AND FUNCTION IN THE NERVOUS SYSTEMS OF INVERTEBRATES.

___ I enclose full payment. (California residents please add 4% sales tax.)

___ Bill me. I agree to send full payment within four months. (Publisher pays postage.)

Name ____________________

Address ____________________

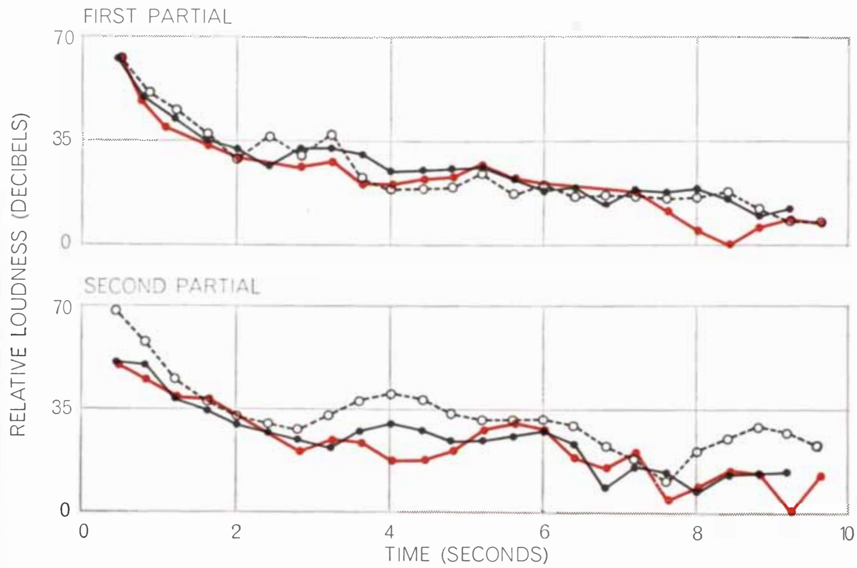
(NOTE: Because this book is a treatise, no complimentary or on-approval copies are available.)

Send me a free descriptive brochure.

W. H. Freeman and Company

660 Market Street, San Francisco, California 94104

Warner House, 48 Upper Thames Street, London, E.C. 4



ACOUSTICS OF ROOM in which the tones used in the decay-time analyses were recorded were shown by the author and his colleagues to have a negligible effect on the irregularities present in the decay curves of different partial tones of the same note. To obtain these curves the decay times for the first and second partials of the *G* above middle *C* were recorded in three different rooms: a normally reverberant studio (*broken black curves*), a very reverberant room (*solid black curves*) and an anechoic chamber (*solid colored curves*).

are not usually considered intrinsic properties of a vibrating string. There is the impact noise of the hammer as it strikes the string, the mechanical noise of the damping pedals, the effect of the damper on the end of a tone, and the noise level of all the other strings, which are free to vibrate sympathetically when they are not damped. In early tests it became quite evident that our juries were using these factors as clues to distinguish the real tones from the synthetic ones.

The impact noise of the hammer is not as noticeable in the lower register as it is in the upper. For the high strings the impact noise is almost as loud as the tone itself. A similar noise had to be superposed on the synthetic tones before they could be effectively used in our tests. Preference tests were set up to see if piano tones without this noise were more acceptable musically than tones in which the noise was present. In general the individuals tested were satisfied with the quality of piano tones as it is, and any large departures from this quality were disparaged. Obviously this is the result of years of conditioning, of hearing piano tones produced by pianos. Some composers even write with this specific quality in mind. An example can be found in *Piano Concerto No. 2* of the American composer Edward MacDowell, in which certain passages are marked *martellato,* presumably to indicate that as much hammer noise as possible should be introduced into the passage.

The mechanical action of the pedals or dampers also makes a noise that has become part of the piano's tone. Moreover, there is a distinctive effect evident when the felt on the dampers is brought into contact with the string: the tone is not cut off cleanly but rather sounds as though it is being swallowed. The problems involved in trying to duplicate these "side effect" sounds can be eliminated by using piano tones that are produced by striking a key and allowing the sound to decay naturally by holding the key down. In this way all the other strings remain damped. The pedals are not used and only the damper of the struck string is disengaged by the action of the key.

Our studies have clearly shown that a complete description of the quality of the piano's tone must contain more than partial structure, attack time and decay time. Above all, the inharmonicity of the piano's tones must not be neglected. Some believe that the tone quality of the piano could be improved merely by making the tones more harmonic. Our tests have proved that synthetic tones built of harmonic partials lack the quality of warmth that is associated with the piano as it exists today.

MATHEMATICAL GAMES

Magic stars, graphs and polyhedrons, and answers to last month's problems

by Martin Gardner

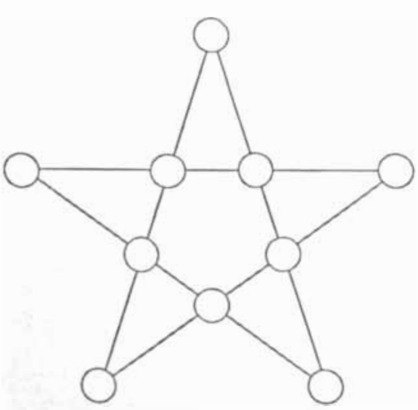
"I've always been poor at geometry," he began...

"You're telling me," said the demon gleefully.

Smiling flames, it came for him across the chalk lines of the useless hexagram Henry had drawn by mistake instead of the protecting pentagram.

—Fredric Brown,
from "Naturally," in *Honeymoon in Hell*

The field of combinatorial arithmetic has been getting increasing attention from mathematicians during the past decade, and along with this revival has come a new interest in combinatorial problems that were once considered mere puzzles. Herbert J. Ryser begins his excellent little book *Combinatorial Mathematics* (published in 1963 by the Mathematical Association of America) by displaying the three-by-three magic square, which was known in China centuries before the Christian era. "Many of the problems studied in the past for their amusement or aesthetic appeal are of great value today in pure and applied science," he writes. "Not long ago finite projective planes were regarded as a combinatorial curiosity. Today they are basic in the foundations of geometry and in the analysis and design of experiments. Our new technology with its vital concern with the discrete has given the recreational mathematics of the past a new seriousness of purpose."



The pentagram

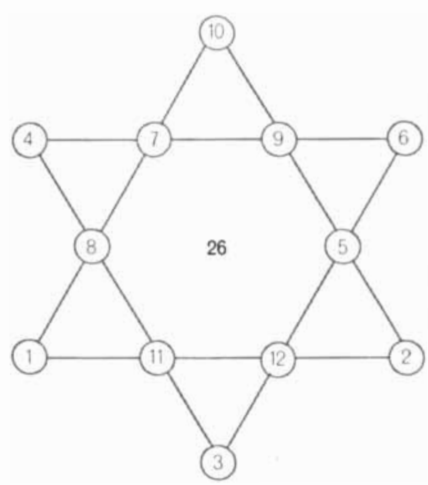
Magic squares were briefly introduced in this department in March, 1959. This month I turn to the less widely known but closely related topic of magic stars. It is a branch of recreational combinatorics that has a fascinating overlap with graph theory and the skeletal structure of polyhedrons. It is also rich in problems.

The simplest star polygon is the familiar five-pointed Christmas star, which as children we learned to draw in one continuous path of five straight lines. It served as a recognition symbol for the ancient Greek Pythagoreans, and it was also their symbol of health. In medieval and Renaissance witchcraft it was the mystic "pentagram" or "pentalpha." (The second name derives from the fact that it can be formed by superposing five capital *A*'s.) The three large isosceles triangles that can also be superposed to make the star were taken as symbols of the Trinity and the star's points were often labeled J-E-S-U-S. When Goethe's Faust draws a pentagram on the threshold of his study, he fails to close the path. This slight break at one of the outer points allows Mephistopheles to enter the room, only to find himself trapped by the closed curve of the star's inner pentagon. Later, while Faust sleeps, the demon escapes by ordering a rat to nibble an opening in this pentagon.

Make a circle at each vertex of a pentagram [*see illustration at left*]. Is it possible to put the integers 1 through 10 in these 10 circles so that each line of four numbers will have the same sum? It is easy to determine what this sum, the "magic constant," must be. The numbers 1 through 10 sum to 55. Each number appears in *two* lines, therefore the sum of all five line sums must be twice 55, or 110. Since the five line sums are equal, each line must have a sum of 110/5, or 22. If a magic pentagram exists, therefore, its magic constant must be 22.

The fact that no such magic pentagram appears in the literature of witchcraft is strong evidence for its impossibility, and with a little ingenuity one can indeed prove that it cannot be accomplished. (Known proofs are lengthy, and so I must refer the interested reader to Harry Langman's *Play Mathematics*, published in 1962, in which a proof is given.) The best we can do—without duplicating a number or using zero or negative numbers—is to label the vertices with 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, as shown at the left in the upper illustration on the opposite page. This makes a defective magic pentagram with the lowest possible constant, 24, and the lowest high number, 12.

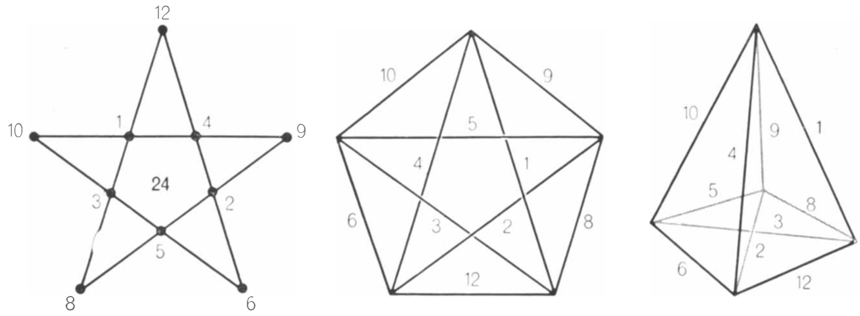
Consider now the following question, seemingly unrelated to the pentagram. Is it possible to label the 10 *edges* of the pentatope, or four-dimensional tetrahedron, so that at each corner the sum of the edges meeting at that corner is the same? Surprisingly, the question has just been answered; in its combinatorial aspect it is identical with the question about the pentagram! First draw the graph shown in the middle of the upper illustration on the opposite page. This is called the "complete graph" for five points, because it joins each point to all the others. If you compare the numbers at the vertices of the pentagram with those on the edges of the graph, you will see that there is an identity of combinatorial structure. Every line of four numbers in the star matches a cluster of four numbers on edges meeting at a common point. Because the magic star is impossible, it is impossible to make the complete graph



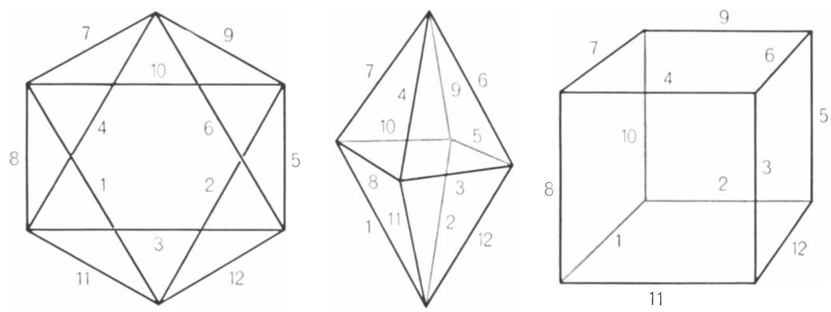
Magic hexagram

for five points "magic" at its vertices. Now, the complete graph for five points is topologically the same as the skeleton of the four-dimensional tetrahedron, as you can verify by comparing the numbers on the graph with those on a projection in three-space of the pentatope's skeleton [*at right in illustration*]. A pentatope that is magic at the vertices is therefore not possible. Since the numbers shown on the pentatope's skeleton map back to those on the pentagram, we know that we have provided the pentatope with a nonconsecutive solution that has the lowest constant and lowest high number.

The situation grows in interest when we turn to the hexagram—also known as the hexalpha, Solomon's seal and the Star of David [*see illustration at bottom right on opposite page*], a figure almost as prominent in the history of occultism and superstition as the pentagram. Because there are six lines, with each vertex common to two lines, and because the numbers 1 through 12 sum to 78, we obtain the magic constant $(2 \times 78)/6$, or 26. As the illustration shows, a magic hexagram is possible.



Pentagram (left) *and equivalent graph* (middle) *and pentatope* (right)



Graph of hexagram (left) *and equivalent octahedron* (middle) *and cube* (right)

The problem of cataloguing all the different hexagram solutions, not counting rotations and reflections as being different, is not easy. One way to obtain new patterns is to transform the hexagram to its dual graph [*at left in lower illustration on this page*], on which the same numbers mark lines that are magic at the vertices. It is easy to see that this graph is topologically the same as the skeleton of the octahedron [*middle*], one of the five Platonic solids. We can now rotate the octahedron and mirror-reflect it in any way we please, then map the numbers back to the hexagram (mapping edges to vertices according to the *original* numbering) and obtain new patterns for the hexagram. Other transformations of the hexagram can be made, unrelated to rotations and reflections of the octahedron, that give still more solutions. Moreover, every magic star has what is called its "complement," obtained by replacing each number with the difference between that number and $n + 1$, when n is the highest of the star's consecutive integers. There are 74 different solutions, 12 with outer star points that also sum, as in the solution shown, to the constant.

There is still more to be said: the octahedron has what is called its "polyhedral dual," in which every face is replaced by a vertex and every vertex by a face, the edges remaining the same. The octahedron's dual is the cube. This allows us to label the 12 edges of a cube [*at right in illustration*] with numbers 1 through 12 so that the cube is magic at its *faces;* that is, the sum of the four edges bounding every side is 26.

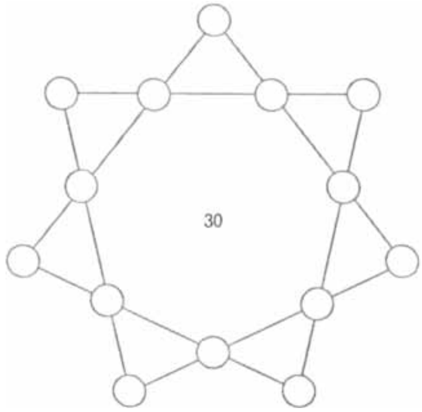
Can the septagram, or seven-pointed star [*top left on next page*], be made magic by labeling its vertices with numbers 1 through 14? Yes, and I leave it to the reader to see how quickly he can find one of its 56 different solutions. The constant is $(2 \times 105)/7$, or 30. The best way to work on it is to draw a large figure, then put the numbers on small counters that can be slid over the paper. Warning: Once you start, you will find it hard to stop until you get a solution. An answer will be given next month.

One solution for the octagram, or eight-pointed star, is shown at the top of the bottom illustration on the next page. Note that the magic constant, 34, is also the sum of the four corners of each of the two large squares. The middle drawing shows a corresponding graph that is magic at its vertices, and the drawing at the bottom shows a solid with an equivalent skeleton. It has not yet been determined, as far as I know, how many solutions there are for the octagram.

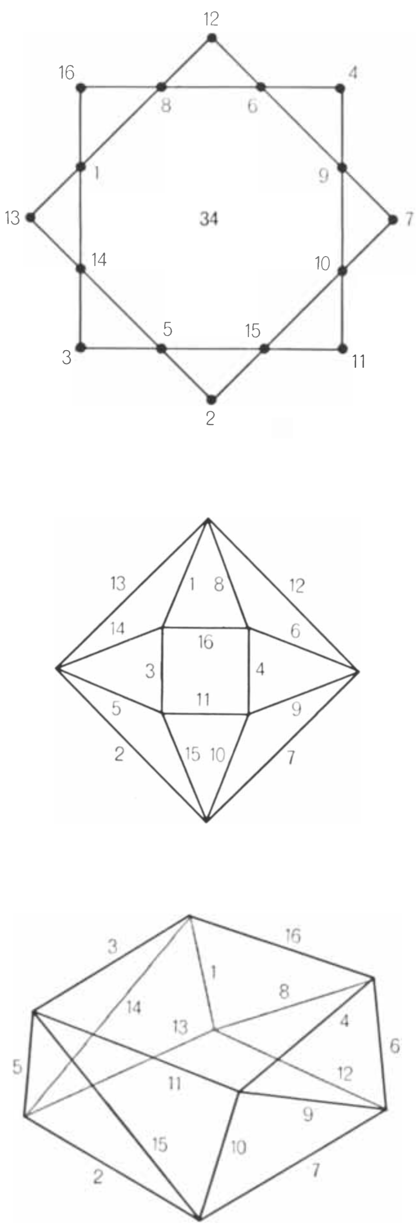
Clearly there is no end to combinatorial problems that have to do with the labeling of edges, vertices or faces of various polyhedrons so that magic constants are obtained in various ways. Many of these problems translate to equivalent magic star problems. For example, which of the five regular solids can be made magic at their corners by being labeled along their edges with consecutive integers? It is easy to show that this is not possible on the tetrahedron. (See this department for last March.) Is it possible on the cube? The cube's 12 edges [*top of illustration at top right on next page*], map to the 12 black spots on the vertices of the octagram [*bottom*]. Since each spot is in two lines, the constant must be $(2 \times 78)/8$, or 19½. This is not an integer, so that we know at once the problem has no solution. The best we can do is to label the spots (or the cube's edges) as shown, to get a defective solution with the lowest constant, 20, and the lowest high number. Since the octahedron is the polyhedral dual of the cube, this automatically solves the problem of labeling the octahedron's edges with different nonconsecutive, nonzero, positive integers to obtain the lowest constant at the faces.

We have seen that the octahedron's edges can be labeled with consecutive integers to make it magic at its corners. On the icosahedron and dodecahedron the constant is not integral, so that they have no solutions. Since each is the other's polyhedral dual, there are no solutions for the corresponding problems of making them magic at their faces.

If we mark only nine of the hexagram's vertices as shown by the spots at



The septagram



Octagram and two equivalents

the left in the top illustration on the opposite page, we obtain a magic star problem equivalent to that of labeling the nine edges of a triangular prism [*at right*] with numbers 1 through 9 to make it magic at its six corners. The constant must be $(2 \times 45)/6$, or 15. Can it be done? It is not a difficult question, and next month I shall give either a proof of impossibility or a solution.

The answers to the collection of short word and number problems presented last month follow.

1.

Dmitri Borgmann, author of *Language on Vacation,* is my authority for the following answers to the questions about the anagram dictionary.

1. Among common noncolloquial words, STY, *sty,* is probably the last entry. But this is followed by TTU, *tut,* TTUU, *tutu* (a short ballet skirt), TUX, *tux* (short for tuxedo) and ZZZZ, *zzzz* (to snore), which Borgmann says is in the second edition of *The American Thesaurus of Slang,* by Lester V. Berrey and Melvin Van Den Bark.

2. The first and second entries are A, *a,* and AA, *aa* (a kind of lava).

3. The last entry is AY, *ay,* unless we accept AYY, *yay* (an obsolete variant of "they").

4. Among common words, the first entry beginning with *B* is BBBDEI, *bibbed.* It is preceded by the less common BBBBBEEHLLUU, hubble-bubble (a bubbling sound, also a hookah).

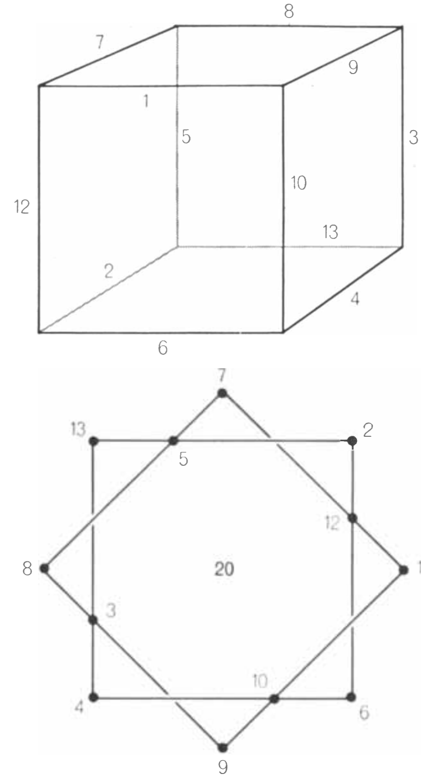
5. ABCDEFOL, *boldface.*

6. The longest entry that is itself a common word (that is, a word with letters in alphabetical order) is *billowy.* In *Language on Vacation* Borgmann supplies a longer word, *aegilops* (a genus of grasses).

7. The longest common English word that does not repeat a letter is *uncopyrightables.* But Borgmann supplies some longer coined words, such as *vodkathumbscrewingly,* with 20 letters, which means to apply thumbscrews while under the influence of vodka. The longest such word ever created, he says, is the 23-letter monster *pubvexingfjordschmaltzy,* which means "as if in the manner of the extreme sentimentalism generated in some individuals by the sight of a majestic fjord, which sentimentalism is annoying to the clientele of an English inn."

2.

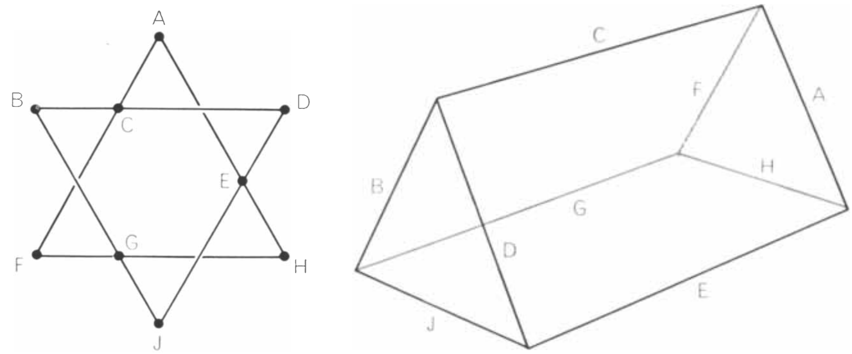
The girl's escape strategy is first to row so that the lake's center, marked by the raft, is always between her and the man on shore, the three points maintaining a straight line. The man runs four times faster than she can row, so that she can do this, and at the same time move shoreward, until she reaches a distance from the center that is a quarter of the radius of the lake. That is the point at which the angular velocity she must maintain to keep him opposite her just equals his, leaving her no reserve energy to use in moving outward. As soon as she reaches this point she heads straight for the nearest spot on shore. She has a distance of $3r/4$ to go (r is the lake's radius), whereas he has to travel a distance of πr to catch her when she lands. Because he travels four times faster than she rows, by the time she has reached the shore he has gone a distance of only $3r$. This is less than πr, and the result is that he misses her.



Magic cube skeleton (top) *and octagram*

3.

To transfer the key from one side of the door to the other, first pass the key through the loop so that it hangs as shown at the left in the bottom illustration on the opposite page. Seize the double cord at points *A* and *B* and pull the loop back through and out of the keyhole. This will pull two new loops out of the hole, as shown in the middle. Move the key up along the cord, through both projecting loops. Grasp the two cords on the opposite side of the door and pull the two loops back through the hole, restoring the cord to its original state [*right*]. Slide the key to the right, through the loop, and the job is done.



Is a magic triangular prism (right) *possible? Equivalent star form is at left*

4.

The smallest number of unit line segments that can be removed from a four-by-four checkerboard to render it "square-free" is nine. One way to do this is shown on the interior four-by-four square at the top of the top illustration on the next page.

To prove this minimum, note that the eight shaded cells have no side in common; to break the perimeters of all eight at least eight unit lines must be removed. The same argument applies to the eight white cells. We can, however, "kill" all 16 cells with the same eight lines if we pick lines shared by adjacent cells so that each erased line kills a white and a shaded cell simultaneously. But if we do this, not one of the removed lines will be on the board's outside border, which forms the largest square. Therefore at least nine cells must be removed to kill the 16 small cells plus the outer border. As the solution shows, the same nine will eliminate all 30 squares on the board.

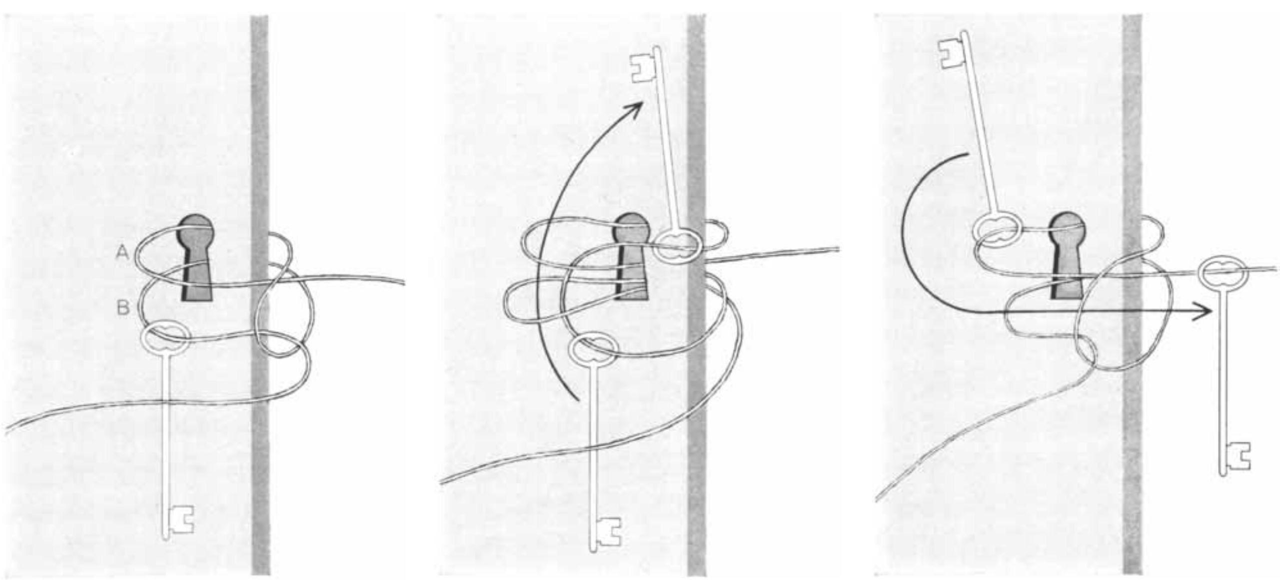
The same argument proves that every even-order square must have a solution at least equal to $\frac{1}{2}n^2 + 1$, n being the square's order. Can this be achieved on all even-order squares? A proof by induction is implicit in the procedure shown in the illustration. We merely plug a domino in the open cell on the border of the four-by-four, then run a chain of dominoes around the border as shown. This provides a minimum solution of 19 for the order-six board. The same procedure is applied once more to give the minimum solution of 33 for the eight-by-eight board. It is obvious that this procedure can be repeated endlessly, with each new border of dominoes raising the open cell one step, as shown by the arrow.

On the order-five board the situation is complicated by the fact that there is one more shaded cell than there are white cells. At least 12 lines would have to be removed to kill 12 shaded and 12 white cells simultaneously. This would, of course, form 12 dominoes. If the remaining shaded cell were on the outside border, both this cell and the border could be killed by taking one more line, which suggests that odd-order squares might have a minimum solution of $\frac{1}{2}(n^2 + 1)$. To achieve this, however, the dominoes would have to be arranged so as not to form an unbroken square higher than order-one. It can be shown that this is never possible, so that the minimum is raised to $\frac{1}{2}(n^2 + 1) + 1$. The lower drawing in the top illustration on the next page shows a procedure that achieves this minimum for all odd-order squares.

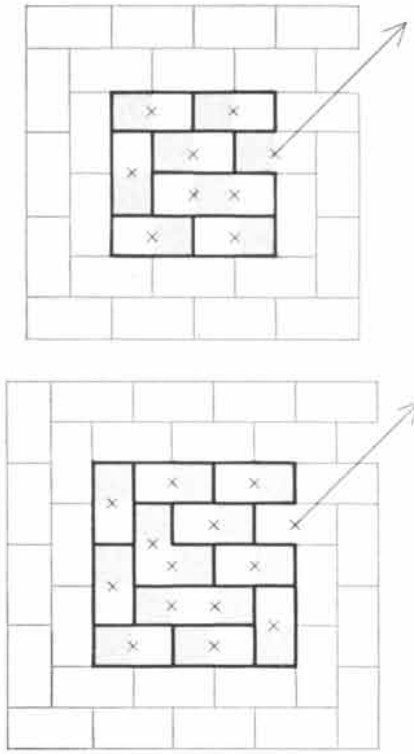
5.

It is easy to show that for any finite set of points on the plane there must be an infinity of straight lines that divide the set exactly in half. The following proof for the six points in the bottom illustration on the next page applies to any finite number of points.

Consider every line determined by every pair of points. Pick a new point, *A*, that lies outside a closed curve surrounding all the other points and that does *not* lie on any of the lines. Draw a line through point *A*. As this line is



Solution to key-and-cord puzzle



Solutions for toothpick problems

rotated about point *A*, in the direction shown, it must pass over one point at a time. (It cannot pass two points simultaneously; this would mean that point *A* lay on a line determined by those two points.) After it has passed half of the points inside the curve it will divide the set of points in half. Since *A* can be given an infinity of positions, there is an infinity of such lines.

6.

The first two statements can be satisfied only by two arrangements of Kings and Queens: KQQ and QKQ. The last two statements are met by only two arrangements of Hearts and Spades: SSH and SHS. The two sets combine in four possible ways:

KS, QS, QH
KS, QH, QS
QS, KS, QH
QS, KH, QS

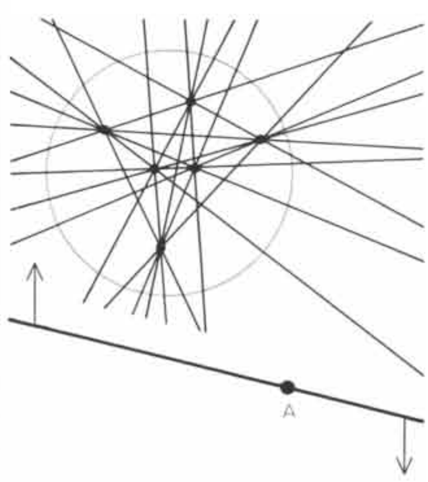
The last set is ruled out because it contains two Queens of Spades. Since each of the other three sets consists of the King of Spades, Queen of Spades and Queen of Hearts, we can be sure that those are the three cards on the table. We cannot know the position of any one card, but we can say that the first must be a Spade and the third a Queen.

7.

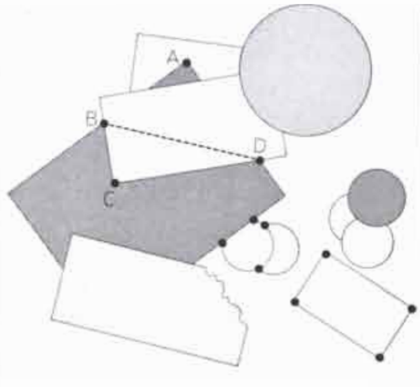
The three sets of four cocircular points on the picture of randomly dropped rectangles and disks are shown as black spots in the top illustration on the opposite page. The four corners of the rectangle were mentioned last month. The four points on the small circle are obviously cocircular. The third set consists of points *A, B, C, D*. To see this, draw dotted line *BD* and think of it as the diameter of a circle. Since the angles at *A* and *C* are right angles, we know (from a familiar theorem of plane geometry) that *A* and *C* must lie on the circle of which *BD* is the diameter.

8.

The most efficient procedure for testing any number of glasses of liquid in order to identify a single glass containing poison is a binary procedure. The glasses are divided as nearly in half as possible. One set is tested (by mixing samples from all the glasses and testing the mixture). The set known to include the poison glass is then again divided as nearly in half as possible, and the procedure is repeated until the poison glass is identified. If the number of glasses is from 100 to 128 inclusive, as many as seven tests might be required. From 129 to 200 glasses might take eight tests. The number 128 is the turning point, because it is the only number between 100 and 200 that is in the doubling series: 1, 2, 4, 8, 16, 32, 64, 128, 256.... There must have been 129 glasses in the hotel kitchen, because only in that case (we were told that the number was between 100 and 200) will the initial testing of one glass make no difference in applying the most ef-



Proof for million-point problem

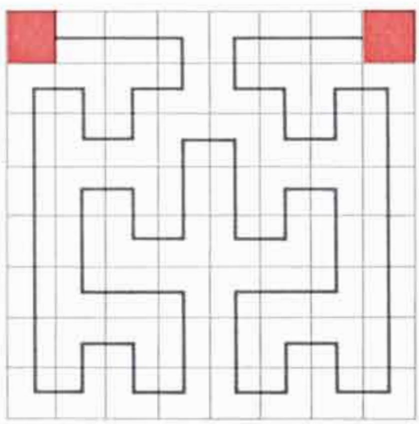


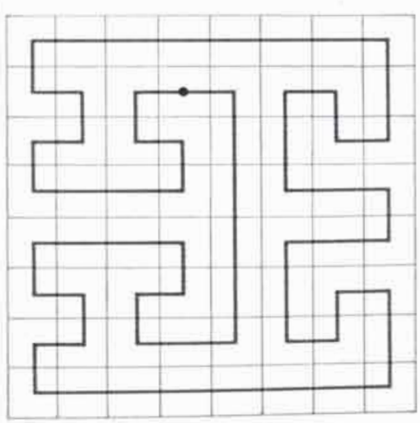
The three sets of cocircular points

ficient testing procedure. Testing 129 glasses, by halving, could demand eight tests. But if a single glass is tested first, the remaining 128 glasses require no more than seven tests, so that the total number of tests remains the same.

9.

Solutions to the cube-rolling tour problems are shown below. In the first solution the red side of the cube is up only on the top corner squares. In the second, the dot marks the start of the tour, with the red side down.





Cube-rolling solutions

THE AMATEUR SCIENTIST

Deep-sky photographs with a 35-millimeter camera, and more about the homemade laser

Conducted by C. L. Stong

The photographs on the opposite page and the following two pages show four splendid wide-field views of the night sky. They also demonstrate how effectively an amateur can use an ordinary 35-millimeter camera for making pictures of stars and nebulae. All the exposures were made on September 24 from Mount Pinos in California's Los Padres National Forest by Robert T. Little, an advertising salesman who lives in Canoga Park, Calif. Little used two cameras, one equipped with a conventional 50-millimeter lens and the other with a 500-mm. telephoto lens—the latter a catadioptric, or both reflecting and refracting, system chosen for its light, compact design. The cameras were mounted on a Questar telescope that served merely to keep the lenses trained on the stars during exposure intervals that ranged from 10 to 45 minutes.

"My interest in observational astronomy," Little writes, "began about five years ago when I acquired a 10-inch reflecting telescope. After a few months, when the thrill of 'just looking' began to pall, I fitted the telescope with a plateholder so that I could try deep-sky photography. This proved disappointing. My successes averaged about 1 percent of my tries, even when I set up the apparatus far beyond the range of city lights. Wind was my big enemy. A gentle breeze can vibrate the tube of a long telescope enough to destroy the sharpness of the photographic image. In addition I learned that big telescopes are difficult to move and to set up at distant locations.

"Such problems disappeared when I acquired my Questar, which is a miniature telescope weighing only seven pounds. It has an electric motor for tracking, or rotating the lens system in step with the apparent motion of the stars. To power the motor in the field I constructed a variable-frequency oscillator that operates from the storage battery of my car. This device enables me to guide the telescope—that is, keep it locked onto a desired star by changing the frequency of the oscillator [see "The Amateur Scientist," October, 1959]. A set of brackets was improvised for attaching the 35-mm. cameras to the tube of the telescope. I also made a set of illuminated cross hairs for the eyepiece. To make a photograph of the sky I center a selected star on the cross hairs and then adjust the frequency of the oscillator to keep the star in position as long as the shutters of the cameras are open.

"The beauty of the equipment is in its compactness, solidity and ease of transportation and use. I have photographed deep-sky objects in winds up to 20 knots without adverse effects. I am always able to work from a comfortable sitting position. As many as 20 photographs of deep-sky objects have been made during the course of a single night.

"Experience has taught me a few basic rules for those who may be inclined to try this hobby. First, exposure time must be determined experimentally. Exposures that are reported by others can be grossly misleading. Many amateurs, for example, report exposures of one hour 45 minutes at a lens opening of $f/5$ for the Horsehead Nebula in Orion. My photograph of this formation was made in 30 minutes at $f/5$ [*see top illustration on opposite page*]. Long exposures tend to emphasize guiding errors—that is, to allow the movement of star images with respect to the film. Excessive exposure time also permits scattered light from the sky to fog the film and degrade the contrast of the image. My best photographs have been made with Eastman Kodak Spectrographic film Type 103 aE. My second preference is Tri-X.

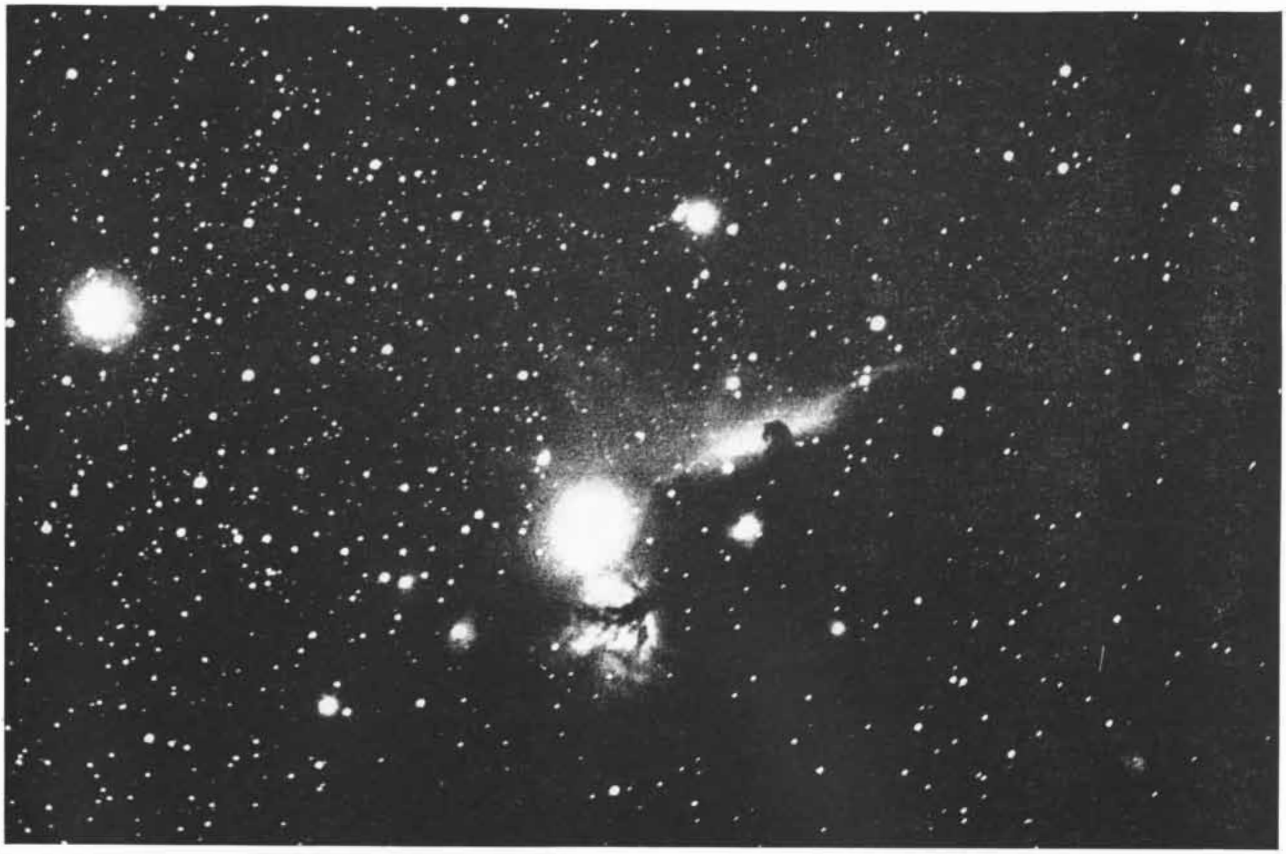
"Effective tracking requires that the polar axis of the telescope be parallel with the earth's axis of rotation. This adjustment can be difficult to accomplish in the field. I have hit on a method of making the adjustment that works quite well. First I set the declination axis of the telescope mounting to the latitude of the location. Then, with the lens tube set at 90 degrees declination, I center the cross hairs as accurately as possible on the pole star by adjusting the position of the whole telescope.

"The tube is now rotated in declination and right ascension, without disturbing the position of the mounting, until a bright star near the celestial equator is centered on the cross hairs. This is the part of the sky that includes the path of the sun. If the polar axis of the instrument is not accurately parallel with the earth's axis, the selected guide star will drift in declination away from the cross hairs.

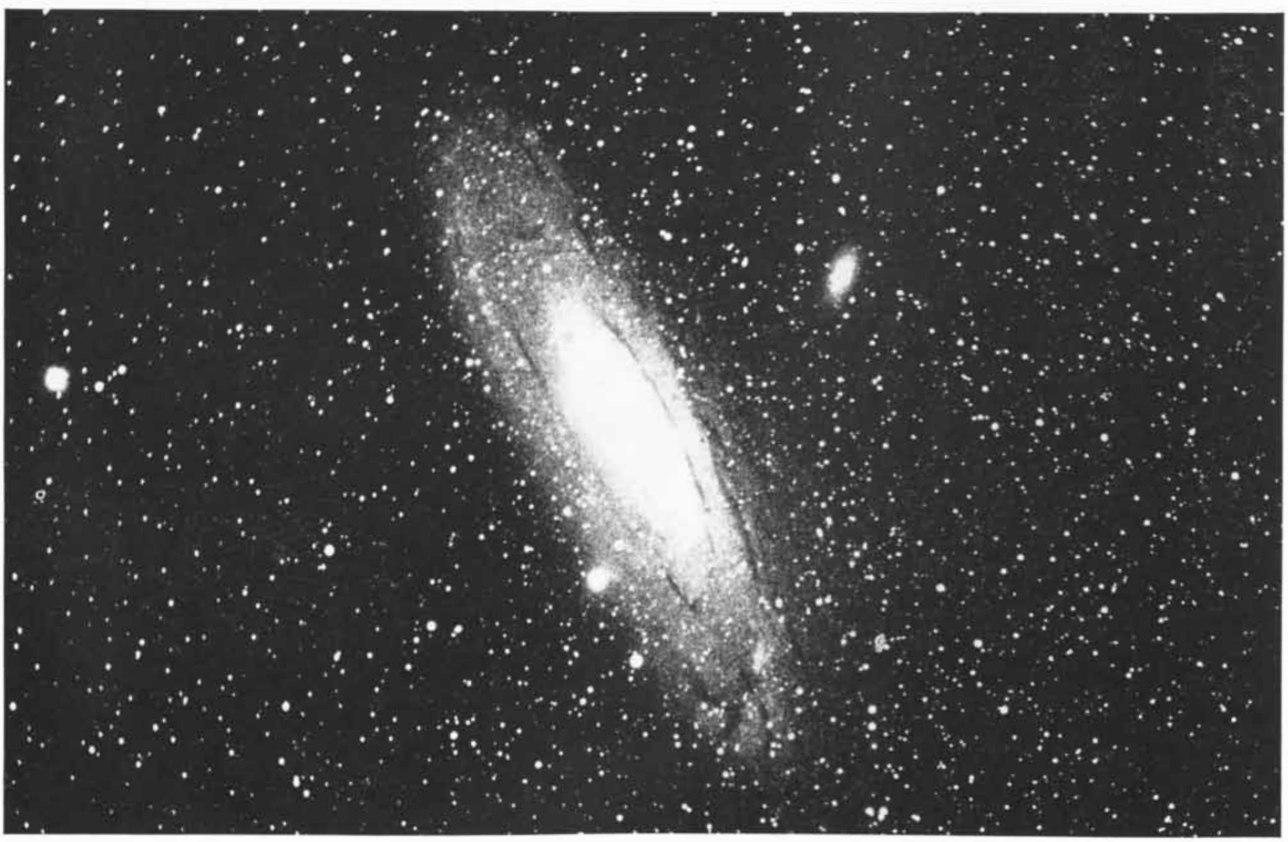
"When such drift is apparent during an interval of less than 10 minutes, I shift the azimuth of the telescope base in either a clockwise or a counterclockwise direction and again observe the guide star. If the altered position has accelerated the drift, I next rotate the base in the opposite direction. When no drift is evident in 10 minutes, I make my exposure. Drift in right ascension is easily corrected by altering the speed of the telescope's motor with the variable-frequency oscillator. The azimuth adjustment must again be altered if the telescope is directed to higher or lower angles of the sky because of variation in the refraction of the atmosphere.

"I always use the highest possible magnification for observing the guide star. Actually the magnification should be increased in direct proportion to the focal length of the camera lenses. I also use a rheostat for controlling the illumination of the cross hairs, a useful provision when guiding on a faint star.

"Incidentally, few commercially available camera lenses are well corrected for blue light at full aperture. Blue rays do not focus sharply at the lens setting that is correct for yellows



Horsehead Nebula in Orion, photographed with 500-millimeter lens



Great Nebula in Andromeda, photographed with 500-mm. lens and reds. I minimize this effect by stopping all lenses down to at least $f/5$ when making exposures with black-and-white film. This is not always necessary in the case of color film, which appears to have better antihalation qualities. Some good color shots have been made with openings as large as $f/2.8$."

While Robert Little was learning how to make deep-sky photographs the editor of this department was spending most of his free time experimenting with the helium-neon laser previously described here [September, 1964]. Lasers of this type are in effect electromagnetic oscillators. Essentially they consist of an amplifier tube and a resonant cavity. They emit continuous beams of intense coherent light at 6,328 angstrom units and open new experimental opportunities for amateurs in several disciplines. My own interest in recent months has centered on improving the performance of the apparatus—particularly by increasing the useful life of the amplifier tube—without substantially increasing the cost over that of the unit I had originally constructed.

The amplifying portion of my apparatus consists of a straight gas-discharge tube, equipped with cold electrodes, that contains a mixture of helium and neon in the ratio of seven to one at a pressure of 1.8 to 2.7 torr, depending on the diameter of the tube. The ends of the tube are closed by plane windows set at an angle equal to the trigonometric cotangent of the index of refraction of the window material, which may consist of any clear pure glass or of fused quartz. The windows are attached to the tube by epoxy cement. The resonant cavity consists of a pair of dielectric mirrors of spherical curvature mounted to face each other at a distance equal to approximately 95 percent of their radius of curvature and adjusted so that their optical axes coincide. The amplifier tube is positioned coaxially between the mirrors.

When an electric field of sufficient potential to ionize the gas is applied to the electrodes, excited atoms of helium collide with and transfer energy to the neon atoms, raising the neon atoms to one or another of their higher energy

Nebulae in Sagittarius: Trifid (left) *and Lagoon* (right); *500-mm. lens* levels. Subsequently the neon atoms spontaneously drop to one or another of the lower energy levels they naturally occupy and simultaneously emit light of the wavelength that is characteristic of the energy released. Some transitions occur between the levels that give rise to emission at the wavelength of 6,328 angstroms.

Some photons of this wavelength are emitted along the axis of the tube. The energy then oscillates between the mirrors. During each transit through the tube this oscillating energy stimulates neon atoms that happen to occupy the appropriate energy level to drop to the appropriate lower level and thus contribute their energy to the resonator.

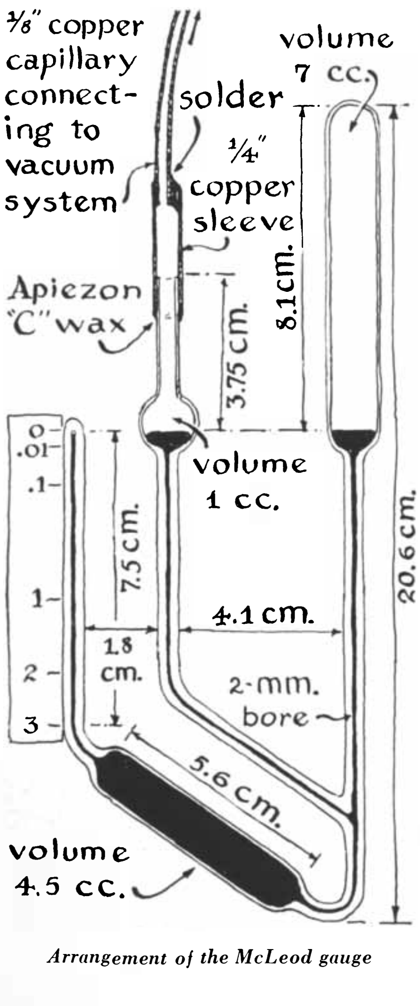
In lasers of this type the intensity of the oscillating light can increase as much as 5 percent during each transit through the amplifying tube. Although more than 500 million transits are made each second, energy stored in the resonator does not increase without limit. The efficiency of the amplifying action decreases as the stored energy increases. Efficiency is also impaired by the presence of impurities in the gases, departures from optimum gas pressure and changes in the ratio of helium to neon. In addition the stored energy is dissipated in various ways. Some is scattered by dust and imperfections on the surfaces of the mirrors and windows. Another portion is diverted by reflection from the surfaces of the windows. Ultimately less than two-tenths of 1 percent seeps through the mirrors. This small fraction constitutes the useful output of the laser.

The amplifying tube of the first apparatus I constructed operated only 15 hours before failing. That the laser worked at all was gratifying, of course, but I felt that I was entitled to a longer run for my pains. The immediate cause of failure was "sputtering," which is the erosion of the metal electrodes by the electrified gases. Metal thus eroded collects in part as a film on the glass walls and lowers the pressure of the gas by burying atoms of helium and neon in the debris. The lowered pressure accelerates the phenomenon, which soon leads to the destruction of the tube.

Some metals tend to sputter more

Milky Way photographed with 50-mm. lens readily than others. The destructive action can be minimized by coating electrodes with a metal such as barium that increases conductivity in the vicinity of the electrode, thereby lowering the velocity of the ions in the plasma and the consequences of their impact on the metal. Coated electrodes must be purged of the occluded gases when the tube is constructed. This is usually done by operating the tube for a time on current intense enough to heat the metal to redness. I omitted the step during my initial construction in an attempt to minimize the cost of the project. By trial and error I found that electrodes of aluminum foil resist erosion without having to be heated. The oxide coating naturally present on aluminum appears to retard the sputtering action for as long as 50 hours of operation if all other conditions are favorable.

Sputtering appears to be accelerated by a trace of almost any organic vapor. This became evident from the operation of the manometer I used originally for measuring gas pressure. The instrument employed phthalate as the indicating fluid. The vapor passed readily through a trap refrigerated by a slurry of dry ice and acetone and eventually contaminated the entire vacuum system. From then on even aluminum electrodes sputtered severely after an hour of operation, and no tube gave as many as five hours of service.



Arrangement of the McLeod gauge

The difficulty was overcome by substituting for the manometer a gauge of the McLeod type, which uses mercury as the indicating fluid. The version of the gauge that I made consists of three joined capillary tubes, each of which contains a bulb [*see illustration on this page*]. One bulb terminates in a closed capillary about 7.5 centimeters long. The middle leg contains a small spherical bulb that is connected to the vacuum system by means of a coil of copper tubing. The third leg terminates in a bulb substantially larger than the other two.

The glass structure is supported on a fixture improvised of plywood and pipe fittings that allows the assembly to be rotated through an angle of about 100 degrees for transferring the mercury by gravity from the largest bulb, in which it is stored, to the other two legs of the gauge. Normally the gauge is kept in the standby position with the mercury in the large bulb. To make a reading the assembly is rotated to the upright position. This causes the mercury to run into the other legs. A specimen of the gas under measurement is trapped and compressed in the closed capillary, limiting the height to which the mercury can rise in the tube.

When the system is fully exhausted, mercury rises to the top of the closed capillary, indicating zero pressure. Simultaneously the metal rises to the same level in the bulb of the middle leg as well as in the reservoir. When the system is not fully exhausted, compressed gas prevents the mercury from rising to the end of the closed capillary. The distance between the closed end and the meniscus, or curved top, of the mercury is a measure of the pressure. In effect the gauge acts as a closed-end manometer.

A vertical scale, plotted in torr, is adjacent to the closed capillary, the zero graduation coinciding with the closed end. Graduations representing higher pressures are plotted at appropriate distances below the zero graduation. Only two quantities must be determined to compute the locations of the graduations: (1) the volume of the closed capillary plus the volume of the bulb to which it is attached and the volume of the capillary that connects this bulb to the middle leg of the gauge, (2) the cross-sectional area of the closed capillary.

To measure the volume, first weigh the glassware (to a tenth of a gram), then fill the volume to be determined with mercury and weigh it again. Subtract the weight of the glass from that of the glass and the mercury combined to determine the net weight of the mercury. Divide the net weight of the mercury by .0135 to determine the volume of the glassware in cubic millimeters. The cross-sectional area of a two-millimeter capillary is approximately three square millimeters.

To determine the distance in millimeters at which mercury will stand below the zero graduation for any pressure first multiply the volume just measured by the given pressure. Then divide this product by the cross-sectional area of the closed capillary. The square root of this quotient is equal to the distance in millimeters. For example, assume that the position of the graduation is desired for a pressure of 1.5 torr, that the volume of the closed capillary and its associated bulb and connecting tubing is 4,500 cubic millimeters and that the cross-sectional area of the closed capillary is three square millimeters. The distance between the zero graduation and the desired graduation is then equal to the square root of $1.5 \times 4{,}500/3$, or 47.4 millimeters. To compute the entire scale, make a list of selected pressure intervals, such as .1, .5, 1, 1.5 and so on, and do the arithmetic. Plot the resulting distances in millimeters as graduations on a cardboard scale and cement it to the closed capillary with the zero indication adjacent to the closed end. If the volume of the closed capillary, its associated bulb and connecting tubing is approximately 4,500 cubic millimeters, a 75-millimeter scale will span the range of pressure from zero to three torr. Helium-neon lasers operate within this range.

The useful life of the amplifier tube is also reduced by the release of gases naturally present in the metal of the electrodes. Such gases can be dislodged by repeatedly filling the tube with the helium-neon mixture to a pressure of a torr or so and energizing it with an alternating current of 18 milliamperes, the rated output of the neon-sign transformer from which the tube operates. This is a time-consuming business, however. I now use direct current at 120 milliamperes for heating, and thus driving the gas out of, electrodes of metals other than aluminum. The current is supplied by a General Electric constant-current transformer (Model 916Y11) that develops 15,000 volts at 60 milliamperes. The unit is energized from the 120-volt power line through a variable-voltage transformer. The secondary of the constant-current transformer is tapped at the center of the secondary winding and grounded to the case by the manufacturer. The output of the secondary is converted to direct current by a conventional full-wave rectifier circuit that employs silicon diodes.

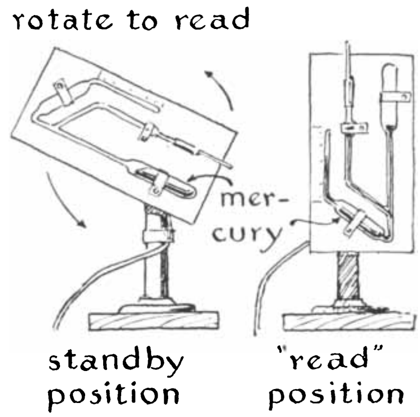
To outgas the electrodes the amplifier is first filled with about three torr of the helium-neon mixture. Power is then applied. The discharge current is gradually increased from minimum to 120 milliamperes during an interval of about 30 seconds. Ion bombardment heats the cathode to redness and the released gases change the color of the plasma from red to blue. Power is then shut off and the tube is pumped down. The procedure is repeated until the electrode is fully outgassed, that is, until the plasma retains its red color. The polarity is reversed for similarly processing the second electrode. Getters are assembled in a sidearm that serves as a reservoir for stabilizing the pressure of the gas. The glass of the reservoir and inner wall of the envelope of the amplifier tube is outgassed by initiating a discharge on alternating current at 18 milliamperes between the getters and the electrodes.

I am now experimenting with iron electrodes in the form of a cylinder, the inner wall of which is coated with barium strontium carbonate, and also with similar electrodes of titanium foil. The titanium is coated by evaporating barium inside the cylinder from a conventional getter of the KIC type. Tubes with coated electrodes of iron have operated from 50 hours to more than 100. Thereafter they can be reconditioned. (Coated-iron electrodes, barium getters, McLeod gauges and other supplies for experimenting with helium-neon lasers can be procured from Henry Prescott, 150 Main Street, Northfield, Mass. 02118.)

To open a spent amplifying tube for replacing the gas or for some other repair, crack the filling tube by heating the tip of the glass in a sharp flame. After an hour or two, when the amplifier has reached atmospheric pressure, the cracked tip can be removed. The slow leak prevents an inrush of air from depositing dust on the windows. If electrodes are also replaced, the glassblower must insert a desiccator in the blow hose to prevent moisture from condensing on the windows. I use an air filter charged with anhydrous calcium sulfate. Smudged windows seriously reduce the output.

A simple procedure for aligning the mirrors of the resonator has been described in the *American Journal of Physics* for March by K. L. Vander Sluis, G. K. Werner, P. M. Griffin, H. W. Morgan, O. B. Rudolph and P. A. Staats. The alignment tool consists of a square of white cardboard of any convenient size that is blackened on one side. A pair of fine diagonal lines are ruled on the white side of the card, which is pierced with a half-millimeter pinhole at the point where the lines intersect. A quarter-inch square of red gelatin (roughly the color of an Eastman Wratten No. 29 filter) is placed over the pinhole on the black side and cemented in place at the edges.

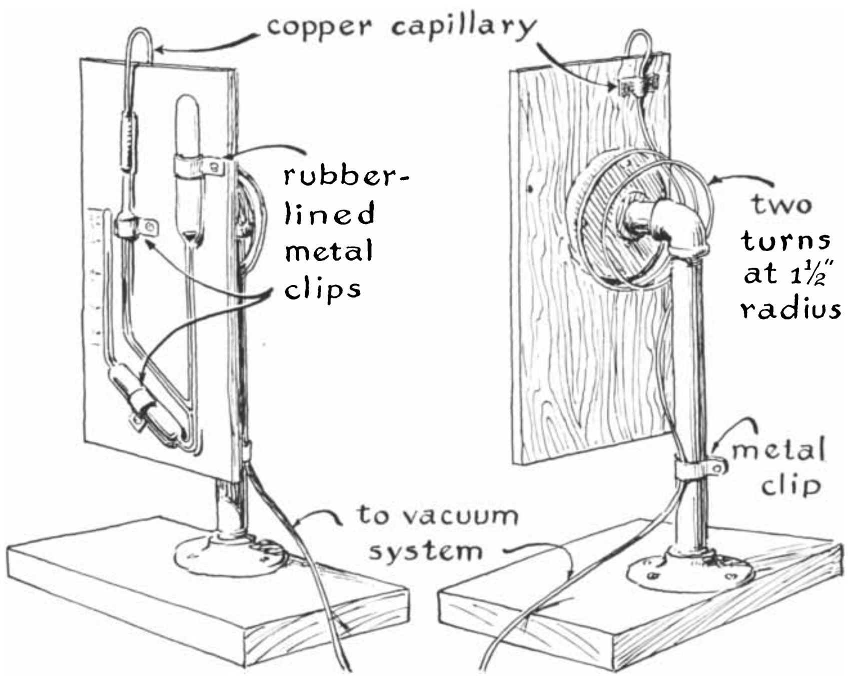
To align the resonator a small sheet of glass, such as a microscope slide, is placed at approximately right angles to the axis of the tube between one mirror and its facing window. This "spoiler" glass prevents the laser from generating a beam. The experimenter now energizes the amplifier tube and, from the blackened side of the card, looks through the pinhole and either of the mirrors into the capillary of the amplifier tube. The position of the eye is changed until the distant end of the capillary appears



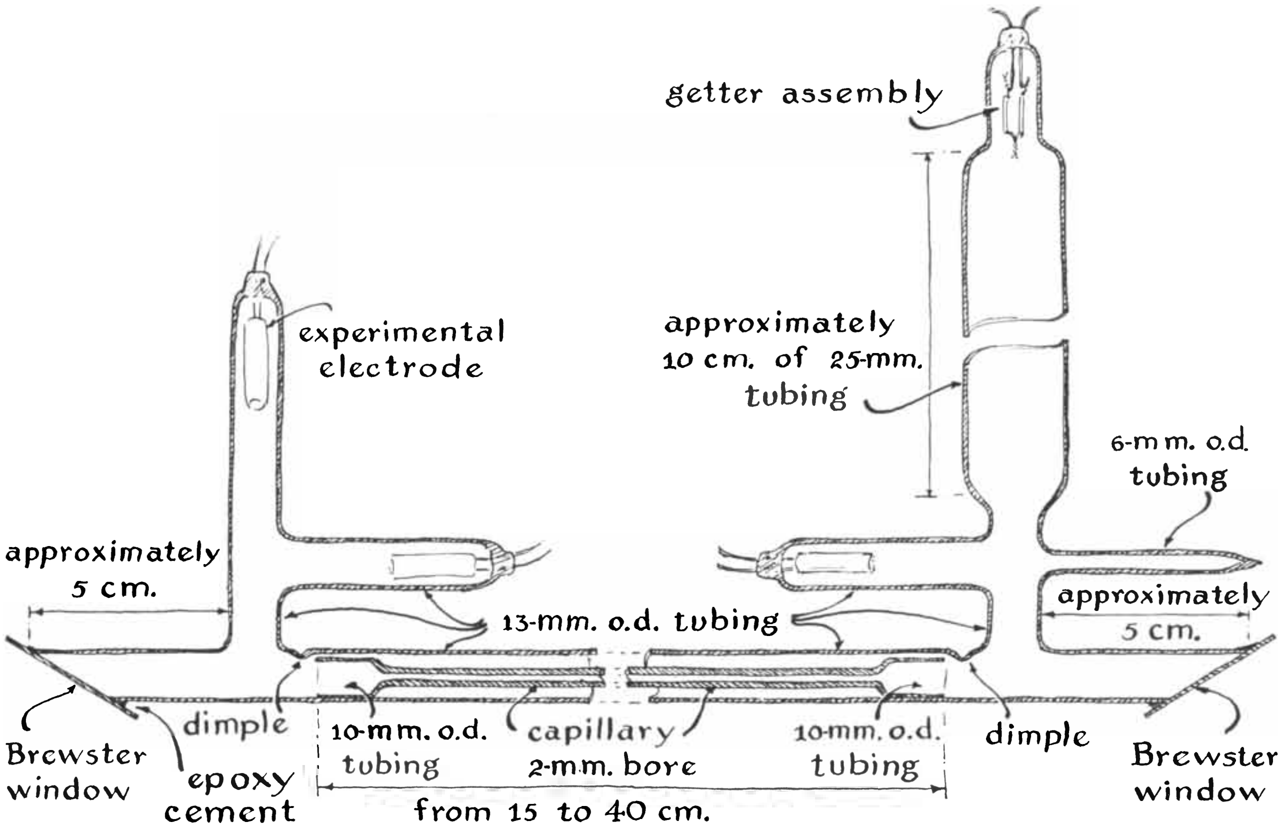
Reading the gauge

as a concentric circle inside the larger circle, which is the near end of the capillary. While the eye is in this position the adjustment screws of the mirror cell are manipulated until the image of the crossed lines, which is reflected by the near side of the mirror, is brought precisely to the center of the inner circle. The second mirror is then similarly adjusted.

The screws are now carefully rocked a degree or so in each direction. At some point a crescent of bright light will appear at the edge of the inner circle, resembling the rising moon. The screws are then gradually manipulated to produce a full moon. The second mirror is similarly adjusted for the full-moon condition. When the spoiler glass is re-



Mounting of the gauge

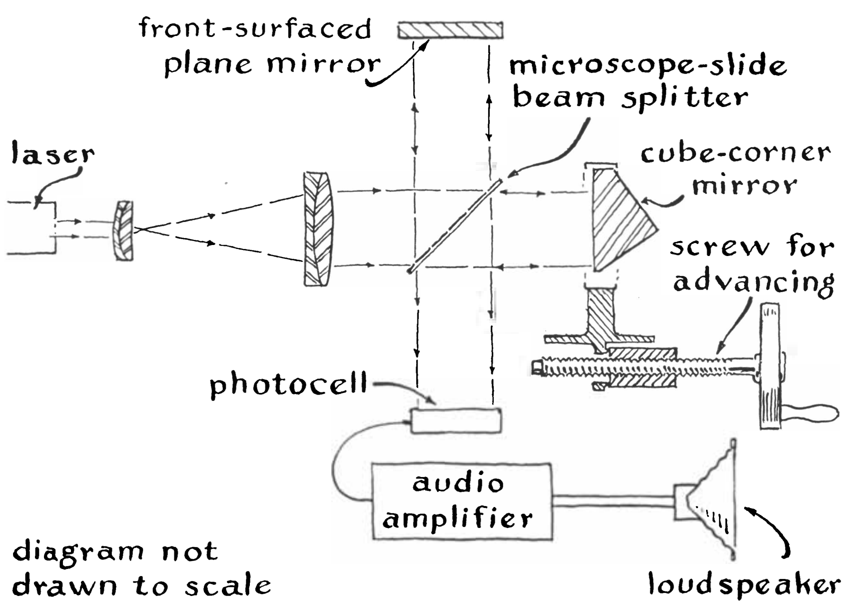


Arrangement of an experimental helium-neon laser tube

moved, the apparatus will "lase." The adjustment is now trimmed for maximum output. Caution: *Never adjust the mirrors by this method unless the spoiler glass is in position.* The beam may form and permanently damage the experimenter's eye.

I have recently repeated a fascinating experiment with the laser that was described in the *American Journal of Physics* for May, 1964, by David Dutton, M. Parker Givens and Robert Hopkins. The experiment suggests a number of applications for the apparatus, among them the detection of microscopic movements of an object at distances up to 100 feet. The beam is first collimated by a microscope objective with a focal length of approximately eight millimeters; it projects the rays to a lens of two-centimeter aperture and proportionately longer focal length. The collimated beam is then directed into a Michelson interferometer, the beam splitter of which can be an unsilvered microscope slide. One portion of the split beam proceeds a few centimeters to a plane front-surfaced mirror of optical quality; the other portion, which is transmitted at right angles by the beam splitter, is projected to a distant mirror of the cube-corner type.

Both the plane and the corner mirror are adjusted to return the reflected rays to the beam splitter, where they combine and interfere. The interference fringes are picked up by a photocell that acts as the input to an amplifier and a loudspeaker [*see bottom illustration on this page*]. When the corner mirror is moved at velocities of less than approximately one centimeter per second, the fringes modulate the photocell and a tone is emitted from the loudspeaker that varies in pitch in proportion to the velocity. The loudspeaker emits a rumbling sound even when the corner mirror is apparently at rest. This is explained by random vibrations, including microseisms, as well as by varia-



Schematic arrangement of interferometer tions in the refractive index of the air. Numerous possible applications come to mind for the apparatus, including strain seismographs, the precise determination of length and the accurate monitoring of distant positions.

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION (Act of October 23, 1962; Section 4369, Title 39, United States Code). *1.* Date of filing: October 1, 1965. *2.* Title of publication: Scientific American. *3.* Frequency of issue: monthly. *4.* Location of known office of publication: 415 Madison Avenue, New York, N.Y. 10017. *5.* Location of the headquarters or general business offices of the publishers: 415 Madison Avenue, New York, N.Y. 10017. *6.* Names and addresses of publisher, editor and managing editor: Publisher, Gerard Piel, 415 Madison Avenue, New York, N.Y. 10017. Editor, Dennis Flanagan, 415 Madison Avenue, New York, N.Y. 10017. Managing Editor, none. *7.* Owner: Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Atwell & Co. (for Edwin H. Baker Pratt), 45–47 Wall Street, New York, N.Y. 10005; Janet Rosenwald Becker, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Cudd & Co. (for John Crisona, Successor Trustee u/a 10/15/51 F.B.O. Robert L. Rosenwald), c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Dengel & Co. (for Elinor Gottlieb Manucci), c/o Fiduciary Trust Company, 1 Wall Street, New York, N.Y. 10005; Richard E. Deutsch, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Bayard Ewing, 15 Westminster Street, Providence, R.I. 02903; Sidney R. Garfield, M.D., 1924 Broadway, Oakland, Calif. 94612; Nathan W. Levin, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Frasier W. McCann, 10 Rockefeller Plaza, New York, N.Y. 10020; Piel & Co., c/o Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Barbara K. Rosenwald, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Julius Rosenwald II, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Lessing J. Rosenwald, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Rowe & Co. (for Rhode Island Charities Trust), c/o Industrial National Bank of Rhode Island, Trust Department, 100 Westminster Street, Providence, R.I. 02901; I. M. Scott, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Joan Rosenwald Scott, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Harry Snellenburg, Jr., c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Helen Rosenwald Snellenburg, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Sydney S. Spivack, Far Hills, N.J. 07931; John Hay Whitney, 110 West 51 Street, New York, N.Y. 10019. *8.* Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: none. *9.* Paragraphs *7* and *8* include, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, also the statements in the two paragraphs show the affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner. Names and addresses of individuals who are stockholders of a corporation which itself is a stockholder or holder of bonds, mortgages or other securities of the publishing corporation have been included in paragraphs *7* and *8* when the interests of such individuals are equivalent to 1 percent or more of the total amount of the stock or securities of the publishing corporation. *10. A.* Total number of copies printed (net press run): average number of copies each issue during preceding 12 months, 438,228; single issue nearest to filing date, 486,458. *B.* Paid circulation: *1.* Sales through dealers and carriers, street vendors and counter sales: average number of copies each issue during preceding 12 months, 79,334; single issue nearest to filing date, 110,129. *2.* Mail subscriptions: average number of copies each issue during preceding 12 months, 319,669; single issue nearest to filing date, 320,500. *C.* Total paid circulation: average number of copies each issue during preceding 12 months, 399,003; single issue nearest to filing date, 430,629. *D.* Free distribution (including samples) by mail, carrier or other means: average number of copies each issue during preceding 12 months, 19,688; single issue nearest to filing date, 25,181. *E.* Total distribution (sum of *C* and *D*): average number of copies each issue during preceding 12 months, 418,691; single issue nearest to filing date, 455,810. *F.* Office use, leftover, unaccounted, spoiled after printing: average number of copies each issue during preceding 12 months, 19,537; single issue nearest to filing date, 30,648. *G.* Total (sum of *E* and *F*—should equal net press run shown in *A*): average number of copies each issue during preceding 12 months, 438,228; single issue nearest to filing date, 486,458. I certify that the statements made by me above are correct and complete. Donald H. Miller, Jr., Vice-President and General Manager.

BOOKS

An annual survey of books about science addressed to young readers

by James R. Newman

With each December issue this department launches a flotilla of brief reviews of books for young readers about science, technology, medicine and related matters. The reviews follow.

Physical Sciences

THE ELEMENTARY MATHEMATICS OF THE ATOM, by Irving Adler. The John Day Company Inc. ($4.50). Some years ago an English schoolmaster, Clement Durell, wrote a small book called *Readable Relativity* that achieved the seemingly impossible: a clear, rigorous, simple explanation of the theory, using nothing more than elementary algebra. Durell's book is a gem; in its field it has no equal. Here, however, is an achievement that, if not fully up to Durell's, deserves high praise. Adler, a practiced and versatile explainer of science and mathematics for younger readers, has written an excellent account of modern atomic theory, not merely in general descriptive terms but in mathematical detail, the mathematics being wholly within the grasp of any thoughtful student who has had one year of high school algebra. He describes the fundamentals of the molecular theory of matter, explains the basic relations of motion, electricity and light, develops the Bohr model of the atom with its planetary electronic orbits and as a climax lays before the reader an admirably lucid exposition of quantum and wave mechanics. One has to see this done to appreciate the author's exceptional skill and to enjoy his gift for reducing the most difficult and esoteric concepts of modern physics almost to ABC. Many readers will be grateful to Adler for bringing within their reach matters they could not have hoped to understand—in the sense of actually following the reasoning—without such a book as this. Highly recommended for high school students and any interested adult.

SCIENCE EXPERIMENTS WITH WATER, by Sam Rosenfeld. Harvey House, Inc. ($5). This book for young teen-agers consists of 19 experiments with water that are intended to exhibit important laws of physics and chemistry. The experiments deal with specific gravity, Pascal's law, surface tension, adhesion and capillary action, soap bubbles, the nature of solutions, the refraction of light, the impossibility of perpetual motion, electrolysis and so on. In addition to describing the procedures and explaining their results the author furnishes portraits, together with brief biographical notes, of famous scientists (for example Archimedes, Dalton, Pasteur, Descartes, Pascal and Newton) who discovered or contributed to the physical laws the experiments demonstrate. A better than average book of its kind.

STRING, STRAIGHTEDGE, AND SHADOW, by Julia E. Diggins. The Viking Press ($5). The story of geometry in ancient times, from Thales and the surveyors of the Nile valley to Eratosthenes and Euclid. Miss Diggins discusses the measurement of the height of the pyramids, the first recorded studies of the properties of triangles, Pythagoras' invention of his famous theorem, the study of the regular solids, the unexpected and catastrophic appearance of the first irrational number, Eudoxus' reflections on the golden mean, Menaechmus' and Archimedes' epochal discovery of the conic sections, Eratosthenes' measurement of the circumference of the earth. In spite of imaginary conversations, occasional coyness and similar foibles, she handles her subject well; the book will give satisfaction to youngsters aged about 11 to 14, that is, to those in this category who are willing to read more about mathematics than what is strictly required of them in school. Useful illustrations.

THE RISE AND FALL OF THE SEAS, by Ruth Brindze. Harcourt, Brace & World, Inc. ($3.50). The story of the tides: how they affect the land and its inhabitants, the action of the moon and sun in commanding them, how tides are predicted, the nature of whirlpools and other tidal hazards, harnessing the power of the tides. Competent and unpretentious. Illustrated by photographs and diagrams. For readers of age 12 and up.

ELECTRICITY IN YOUR LIFE, by Irving Adler. The John Day Company Inc. ($3.95). From electrons to radar, a reasonably satisfactory introduction to theories and applications. Illustrations in color and photographs. For children of 11 and up.

THE NEW GOLDEN BOOK OF ASTRONOMY, by Rose Wyler and Gerald Ames. Golden Press, Inc. ($3.95). A revised edition of a sound, colorful first reader in astronomy, updated so as to tuck in information about space flight and radio astronomy, which has piled up since the first edition appeared in 1955. For youngsters of 10 and up.

BIOGRAPHY OF AN ATOM, by J. Bronowski and Millicent E. Selsam. Harper & Row Publishers ($2.95). This book, based on an article by Bronowski that originally appeared in *The New York Times*, tells the story of a single carbon atom from its birth in a star billions of years ago until it finally becomes a part of a human being. For ages nine or 10 to 12. Diagrams and photographs.

LOGIC FOR BEGINNERS, by Irving Adler. The John Day Company Inc. ($3.95). Here the attempt is made to teach the elements of the art and science of reasoning by means of a selection of games, jokes and puzzles. The lessons begin badly with such features as "little moron" jokes, double meanings, painful puns, drawings in which you are supposed to find hidden animals and other stale trivia that will not cause the youthful mind to tintinnabulate. There is a marked turn for the better when Adler introduces the theory of logical sets and then, with the help of the usual symbols and diagrams, explains syllogisms, simple and compound propositions, relations of things and fundamentals of the structure of reasoning. For readers of age 12 and up.

MAN PROBES THE UNIVERSE, by Colin A. Ronan. The Natural History Press ($4.95). A profusely illustrated history of astronomy that presents information about the men who made the science, their theories and their discoveries. For teen-agers.

ALL ABOUT THE UNIVERSE, by David Dietz. Random House, Inc. ($1.95). A quick visit to Palomar Mountain, followed by thimble-sized sketches of some of the main features of modern astronomy, all under the guidance of a veteran journalist of science. Nothing here will tax the mind or, for that matter, significantly extend it. For ages 11 to 13.

Biological Sciences

THE CRAB THAT CRAWLED OUT OF THE PAST, by Lorus and Margery Milne. Atheneum Publishers ($3.50). A fascinating account of the horseshoe crab, a marvelous relic of the past that first appeared on the earth about 500 million years ago and still flourishes in different parts of the world. Everything about the horseshoe crab contributes to its survival: an armor-plated exterior, a spiny tail with which it is able to right itself if it is turned over, antibiotics in its blood that prevent bacteria from growing in it, its compound eyes, its method of locomotion, its omnivorousness, its mating habits, its prudent choice of homes (along the shore and in protected shallow water when the crab is very young, in deeper places in the ocean as it grows older and larger, and then back to shallow water to mate). Altogether a creature both moderate and modestly versatile, brave but not too brave. The Milnes have written many books, large and small; this is one of their best. Highly recommended for adolescents and grown-ups.

FOURSCORE ... AND MORE, by S. Carl Hirsch. The Viking Press ($4). Better a short life and a merry one but better yet a long and useful life without too many bodily discomforts. The ancients pictured life as a bridge spanning a river; the life-span became the term to describe the full duration of life, with man trying to make the crossing. Until the 1850's most people died before the age of 40. Today the average life expectancy in the U.S. is past the 70-year mark, twice as long as it was only 150 years ago. This book deals with both the lengthening of the human life-span and the life-span of other organisms. Giant tortoises have been known to live 200 years and more (a specimen Captain Cook found in the 1770's and gave as a gift to the Queen of the Tongan Islands is reported to be still alive); the mayfly has only a single day in the sun; the mouse, with a heart that beats between 520 and 780 times a minute, lives about three years, during which the heart beats almost a billion times; the elephant, with a heart that beats 25 to 28 times a minute, lives no more than about 65 years, during which its heart also beats about a billion times. A billion heartbeats seems to be the limit for many other large and small animals, including the rabbit, the cow, the shrew and the lion, but there is no universal magic about the number: the average man lives for about three billion heartbeats. There are living things without hearts that can live for thousands of years; for example, a flourishing bristlecone pine has been found in the Sierra Nevada that botanists estimate is 4,600 years old. For readers of 12 and older.

ANIMALS OF THE ARCTIC, by Gwynne Vevers; THE BIG CATS, by Desmond Morris; THE CURIOUS WORLD OF SNAKES, by Alfred Leutscher. McGraw-Hill Book Company ($2.95 each). For eight-to-12's, an acceptable group of natural-science picture books by British specialists. Each volume runs to 32 pages, usually has at least one illustration on every page, is plainly written and should appeal to young readers of average curiosity.

BIONICS, by Vincent Marteka. J. B. Lippincott Company ($4.25). Bionics—a word not to be found even in the science-conscious third edition of *Webster's International*—is, this book says, the name of a new science that studies biological systems for the purpose of imitating some of their features. These include animals' timekeeping mechanisms, navigational skills, echo location, compound eyes and the like. It appears that among those who are interested in this kind of thing are the military, who have funds for whatever will help to make armies and navies as alert as bats and frogs. For adolescents.

BIOLUMINESCENCE, by H. Arthur Klein. J. B. Lippincott Company ($4.25). A popular account of the study of how plants and animals produce light. It describes, among the various bioluminescent organisms, bacteria, plankton, sponges, corals, glowworms and millipeds; it explains the nature of the lighting machinery itself, considers the biological purposes of bioluminescence and tells what can be learned from it that may be helpful to progress in other scientific disciplines. For young adolescents. Drawings and photographs.

ALL ABOUT ELEPHANTS, by Carl Burger. Random House, Inc. ($1.95). Almost any new book about elephants is welcome. This one (for ages 10 to 15) concerns three particular animals—imaginary but typical of elephants leading the kind of life described in each story. Sirdar is a wild elephant whose life is spent in the forests of India. Po Sein is a working elephant, who with his oozie (trainer and master) moves and stacks teak for a lumber company. Begum begins her career as a maharaja's pet; she is first used in ceremonial processions and then in hunts but fails because she is gun-shy, is sold to a circus and, after a time, to a zoo, which is said to be (not by elephants) an elephant's idea of heaven. Burger describes the evolution of elephants, how they are trained, the uses to which they have been put, particularly in wars. (One learns that they did better on the Burma Road in the 1940's than in crossing the Alps with Hannibal.) He recounts sundry myths and truths about elephants, including the danger of their extinction unless further conservation measures are not only enacted but also rigorously enforced. Photographs and drawings.

BIRDS WITH BRACELETS, by Susan F. Welty. Prentice-Hall, Inc. ($3.50). For youngsters aged 10 to 13, an engaging little book on birdbanding. This practice was started more than 2,000 years ago by the Greeks and Romans and is pursued today in many countries of the world, 600,000 birds being banded annually in the U.S. alone. Birdbanding by government departments and by thousands of bird lovers furnishes a great deal of information about bird migrations, navigational powers, endurance, longevity and kindred matters.

THE STORY OF BIRDS OF NORTH AMERICA, by Ruth Lellah Wheeler. Harvey House, Inc. ($3.95). Of bird books for youngsters there is, to say the least, a surfeit; nevertheless, this short volume deserves notice because it is unassuming and well organized. Mrs. Wheeler discourses on the structure of a bird, the variety of feathers and their special uses, the different kinds of bird nests, how birds learn to fly, their songs and calls, their remarkable migrations, bird refuges, how birds help the farmer, how the farmer and others can help birds. Youngsters of 10 to 12 or so will find this palatable.

DNA LADDER OF LIFE, by Edward Frankel. McGraw-Hill Book Company ($2.95). An entry into molecular biology, concerned mainly with deoxyribonucleic acid and the genetic code. For younger high school students.

GENETICS IN THE ATOMIC AGE, by Charlotte Auerbach. Oxford University Press ($2.50). A revised edition of Dr. Auerbach's popular introduction to genetics, which as a brief popularization —clear, succinct and authoritative—is without a peer. For high school students and adults.

WINDOWS ON THE WORLD, by Anne Terry White and Gerald S. Lietz. Garrard Publishing Co. ($2.07). About man's senses: the nature of taste and smell, the working of the eye and ear, the way instruments have stretched man's vision and extended the reach of his communication. Colored illustrations. For ages about 11 to 13.

CYPRESS COUNTRY, by Marjory Bartlett Sanger. The World Publishing Company ($3.50). A gracefully written account of a spring day in a great Southern cypress swamp, with its varied plant and animal life, by the author of *Mangrove Island* (reviewed in these columns in 1963). A sensitive book. For ages nine to 14.

ANIMALS ON THE MOVE, by Ann and Myron Sutton. Rand McNally & Company ($3.50). About the migrations of birds, fishes, whales, caribous, turtles, lemmings, crabs, springboks and other creatures: why they migrate, their speed of travel, their methods of navigation, where and when they go, the routes they follow, the dangers they encounter. For ages nine to 12.

Social Sciences

ARCHAEOLOGY, EXPLORING THE PAST, by Edith Whitney Watts. The Metropolitan Museum of Art ($2.95). TREASURES OF YESTERDAY, by Henry Garnett. The Natural History Press ($5.95). Two likable books on digging up, interpreting and reconstructing the past. Miss Watts's elegantly illustrated primer, addressed to children of junior-high and early high school age, is short but opens a number of doors. She explains how things get buried, how much care and skill is needed to find them and when necessary to put them together, the sudden destruction of ancient cities by natural disaster or siege, the information that has already been found or may still be found in graves and tombs, underwater archaeology, how archaeologists know where to dig, the tools they use, how records are kept, the various methods of dating. Garnett's survey, designed for high school readers, is much more comprehensive and covers several of the major archaeological feats from the time of Johann Winckelmann's pioneering investigations of Pompeii in the 18th century. Among the topics treated are Heinrich Schliemann's excavations at Troy, Sir Arthur Evans' monumental work at Knossos on the island of Crete, the reconstruction of the civilizations of Central and South America, the digging up of treasures in Egypt, the study of the mounds of Mesopotamia, Sutton Hoo and its buried king's ship, Jean-François Champollion's brilliant deciphering of the Rosetta stone (a story that Garnett tells uncommonly well), the Dead Sea Scrolls, the scientific techniques used in archaeology. Every page of this volume is illustrated with the help of photographs, diagrams, paintings in color and other visual material. For parents as well as children.

BLACK MAGIC, WHITE MAGIC, by Gary Jennings. The Dial Press, Inc. ($3.95). A wonderfully varied company of strange beliefs and superstitions, of priests, wizards, soothsayers, fortunetellers, alchemists, warlocks and witches inhabits these pages. Magic produced the cave paintings of the Stone Age and is responsible for the aura that still surrounds the number 13. The gargoyles that project from cathedral roof eaves are monuments to magic. Phrenology and palmistry are magical pseudosciences. Good-luck charms, emblems, symbols—even national flags—are offspring of magical beliefs. Over its long history magic has done much harm, has led men into paths of folly, cruelty and destruction. It has also inspired works of art, literature, poetry and music and has led, if only by serendipity, to advances in medicine, chemistry, astronomy and other rational endeavors. Full of curious and unexpected items, this book will entertain almost any reader of 12 or over.

THE MINOANS OF ANCIENT CRETE, by G. L. Field; SUMER AND BABYLON, by H. E. L. Mellersh. Thomas Y. Crowell Company ($3.50 each). For youngsters aged about nine to 11, these books by British writers furnish an acceptable introduction to the civilizations of the Fertile Crescent and of Crete. They discuss wars and conquests, how the cities looked, the ancient works of art, the archaeological discoveries that shed the light of modern times on peoples, places and ways of the past.

ANTHROPOLOGISTS AND WHAT THEY DO, by Margaret Mead. Franklin Watts, Inc. ($3.95). Miss Mead has written at least one very good book about anthropology addressed to young readers; one might therefore have expected this to be a work of merit. Unfortunately it is pretty much of a nonbook made up of scrappy interviews with museum curators and teachers of anthropology and a couple of essays by Miss Mead that describe the kind of work she does in the office and in the field. There is also an appendix containing practical information on how to pursue a career in anthropology. Disappointing.

Technology

THE PAPERMAKERS, written and illustrated by Leonard Everett Fisher; THE PRINTERS, written and illustrated by Leonard Everett Fisher. Franklin Watts, Inc. ($2.65 each). These two volumes in an attractive series on colonial American craftsmen tell the stories of printing and papermaking in the colonies from the early 17th century to the latter part of the 18th. Each volume is nicely illustrated and tells its story so directly and so well that any reader aged 11 to 13 will, with little effort, gain a grasp of the fundamentals of these two great crafts. Recommended.

BIG DREAMS AND SMALL ROCKETS, by Patricia Lauber. Thomas Y. Crowell Company ($3.75). A short history of space travel, which touches on the work of Isaac Newton (third law of motion), William Congreve (whose rockets' red glare Americans have had to sing about for so long), Jules Verne (who forecast voyages to the moon that were less expensive than those now in preparation), Konstantin Tsiolkovsky (the Russian who was the first to suggest liquid fuel and liquid oxygen for a space rocket), Robert Goddard (who considerably advanced the technique of rocket construction), Hermann Oberth and Wernher von Braun. For youngsters of 10 to 12 who like that kind of thing.

COMPUTERS, by Shirley Thomas.

Holt, Rinehart and Winston, Inc. ($2.50). Although Miss Thomas may be known—according to the jacket copy—as the "first lady of space," she is evidently not the first lady of popularization. Her book, which is supposed to explain the history and present applications of computers, is mainly concerned with touting the engineering skills and genius of sundry manufacturers and the members of their staff. It is awestricken and not very instructive.

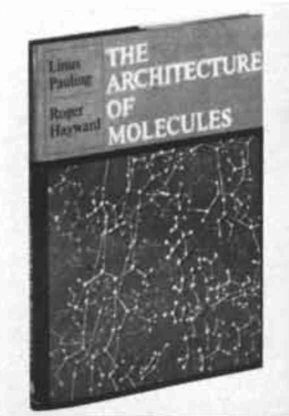
Medicine

MEDICINE FROM MICROBES, by Beryl Williams and Samuel Epstein. Julian Messner ($3.95). The story of antibiotics skillfully narrated by an experienced husband-wife team. They trace the evolution of the search for the causes of disease from the time of Galen, which makes the medical triumphs of the present century seem freshly exciting. For young adolescents.

EXPLORER OF THE UNCONSCIOUS: SIGMUND FREUD, by Adrien Stoutenburg and Laura Nelson Baker. Charles Scribner's Sons ($3.95). A biography for young teen-agers. It does not succeed in making altogether clear what Freud accomplished; it lacks focus and has a fair share of dubious interpretations and outright errors of fact (for example, Ernest Jones was not an "American psychoanalyst"). It also indulges in a number of implausible reconstructions of events in Freud's youth about which nothing is known. Still, it is not an uninteresting book, and if it leads the reader to some of Freud's letters and other writings, as well as to Ernest Jones's biography, it serves a purpose.

Biography

THE UNIVERSE OF GALILEO AND NEWTON, by William Bixby. Harper & Row Publishers ($3.95). Galileo founded the modern science of mechanics; it was he who discovered how things move. Thus he laid the foundations for the stupendous achievement of Isaac Newton in formulating the great law that explains the working of the universe. This fine book sketches the lives of both men and describes their labors. Galileo's studies of the pendulum, of falling bodies and of motion on the inclined plane, his remarkable astronomical discoveries, his practical inventions, his brilliant and daring writings (which offended the church and cost him his liberty) are skillfully presented. The chapters devoted to Newton follow the



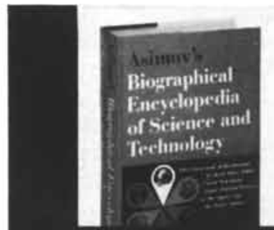
Choose any 3 of these books

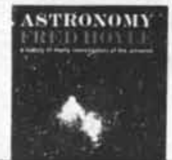
(VALUES TO $56.90)

for only $4.95

with professional membership in

The Library of Science





1. THE ARCHITECTURE OF MOLECULES. A uniquely beautiful book. Nobel Prize-winner Linus Pauling's lucid, authoritative guide to the world of electronic structure, coupled with 57 full-page drawings in full color by distinguished illustrator Roger Hayward. *List Price $10.00*

2. MASERS AND LASERS, *by M. Brotherton.* What impact will masers and lasers have on the physical, medical, and communication sciences? This brilliant book provides the answer—and reviews basic principles and applications. *List Price $8.50*

3. ASTRONOMY, *by Fred Hoyle.* One of the most highly regarded books on the subject. A beautiful, strikingly illustrated volume portraying the full panorama of astronomical achievement over the centuries. "Fitting introduction to the space age."—*N. Y. Times. List Price $12.95*

4. A STYLE MANUAL FOR TECHNICAL WRITERS AND EDITORS, *edited by S. J. Reisman.* A practical, easy-to-follow guide to every aspect of organizing, planning, writing, editing, designing and printing technical materials of all kinds. Many illustrations, cartoons, charts, and diagrams. *List Price $8.00*

5. INTRODUCTION TO THE THEORY OF SETS, *by Joseph Breuer.* "The most encompassing idea of modern mathematics" is cogently explained in this sound book for the non-specialist. Covers all points from finite sets to paradoxes. *List Price $8.00*

6. HUMAN BEHAVIOR, *by Bernard Berelson* and *Gary Steiner.* Already famous as an extraordinary "inventory" of scientific knowledge, this book contains an item-by-item account of 1,045 essential facts about how we behave in vital experiences. *List Price $11.00*

7. CHAMBERS' TECHNICAL DICTIONARY, *edited by Tweney and Hughes.* The leading technical dictionary—a comprehensive, 1,028-page volume that defines and pronounces over 60,000 terms in 120 branches of science and technology. *List Price $7.95*

8. THE SEX LIFE OF THE ANIMALS, *by Herbert Wendt.* A remarkable account of the vast and often incredible processes of reproduction in the animal world, from the amoeba to the elephant. With over 100 striking photographs and drawings. *List Price $7.95*

9. ASIMOV'S BIOGRAPHICAL ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY, *by Isaac Asimov.* One of the nation's leading science writers offers a unique history of science, told through biographies of its leading practitioners. *800 pages, over 1,000 entries. List Price $8.95*

10. THE ANCIENT SUN KINGDOMS, *by Victor W. von Hagen.* In one lavish, 620-page volume—all the lost splendor and magnificence of the Aztec, Inca, and Maya civilizations, recreated in vivid prose and breathtaking illustrations. *List Price $15.00*

11. THE AMBIDEXTROUS UNIVERSE/ELEMENTARY PARTICLES. *A Dual Selection.* Martin Gardner's superb exploration of the "downfall" of parity in physics—*plus* a highly readable account of atomic structure by the Nobel Prize-winner Chen Ning Yang. *List Price $9.45*

12. MATHEMATICS DICTIONARY, *by James & James.* This indispensable reference work contains definitions of over 70,000 terms, concepts, and relationships in mathematics. Tables, formulas, symbols, much more. *List Price $15.00*

13. HISTORY OF TECHNOLOGY, Volume 5, *edited by Singer and others.* A wide-ranging volume covering all technological developments of the late 19th century. With sections on the rise of the chemical, electrical, and other industries. *530 illustrations. List Price $26.90*

14. ELEMENTARY MATRIX ALGEBRA, *by Franz E. Hohn.* A virtually encyclopedic introduction to matrix algebra and its many applications in atomic physics, game theory, industrial "transport" problems, other areas. *List Price $8.00*

15. PUZZLES AND PARADOXES/A MISCELLANY OF PUZZLES. *A Dual Selection.* Two delightful volumes for devotees of recreational mathematics. Thomas O'Beirne's fascinating exploration of many kinds of puzzles—*plus* Stephen Barr's remarkable collection of entertaining problems, invented by the author. *List Price $9.25*

16. ASTRONOMY OF THE 20TH CENTURY, *by Otto Struve and Velta Zebergs.* A sweeping history of modern astronomy—and a guide to the glittering figures of astronomy's Golden Age. With over 200 photographs and diagrams. *List Price $12.50*

17. THE NATURE OF THE CHEMICAL BOND, *by Linus Pauling.* A revised and enlarged edition of the famous book that fully conveys the scope, fascination, and power of the field of structural chemistry. *List Price $8.95*

18. THE GREEK STONES SPEAK/THE MUTE STONES SPEAK, *by Paul MacKendrick. A Dual Selection.* Two copiously illustrated companion volumes that recreate and revitalize ancient Roman and Greek cultures and offer insights into the nature of classical man. *List Price $15.00*

19. PROBABILITY THEORY AND ITS APPLICATIONS, *by William Feller.* The single most important introduction to probability theory and its fundamental concepts — extensively illustrated with typical problems. *List Price $10.75*

20. MATHEMATICS FOR THE PHYSICAL SCIENCES, *by Herbert S. Wilf.* A unique integration of seven major mathematical disciplines that bear directly upon central problems and issues in the physical sciences. Covers each method from theory to computational techniques. *List Price $7.95*

Which 3 of these valuable books may we send you?

THE LIBRARY OF SCIENCE S12
59 Fourth Avenue / New York 10003

Please enroll me as a member and send me at once the 3 Selections circled below, for which you will bill me only $4.95, plus postage. As a member, I need take as few as 3 more Selections during the next 12 months, always at reduced Member's prices. I will receive a free Bonus Book of my choice after every fourth Selection.

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	

NAME . . . .

ADDRESS . . . .

CITY . . . . STATE . . . . ZIP CODE

Please be sure to insert correct zip code.

Library of Science Members Enjoy These Advantages:

• largest selection of outstanding books covering new developments and innovations in every major branch of science and technology • free monthly Reports on selections, featuring reviews by such distinguished authorities as Warren Weaver, Harlow Shapley, Gerald Wendt, and Martin Gardner • reduced Member's Prices—*with savings up to 40% on all books* • *free* Bonus Books after every fourth book purchased • no fees or dues. Members need accept as few as three more selections during the next twelve months, from over 200 significant works to be made available.

same course, focusing attention on his theory of light, on the composition of his masterpiece the *Principia,* on his controversies with Robert Hooke, on his personal life and idiosyncrasies—which matched his prodigious intellectual powers. Many excellent paintings, drawings and documents. Highly recommended for high school students.

GALILEO, by Arthur S. Gregor. Charles Scribner's Sons ($3.50). The story of Galileo's life and work, recounted with the help of much imaginary (and unconvincing) dialogue. The scientific part is unobjectionable. The drawings are few and almost useless. For children of about nine to 12.

MENDELEYEV AND HIS PERIODIC TABLE, by Robin McKown. Julian Messner ($3.25). A satisfactory biography of the gifted, immensely prolific, wild-and-woolly-looking Russian chemist who at the age of 35 developed the periodic table, which played a profoundly important part in the advances of modern physics and chemistry. For readers about 12 to 14.

ENGINEERS, INVENTORS AND WORKERS, by P. W. Kingsford. St. Martin's Press ($4.95). Biographical accounts of British inventors and engineers from Abraham Darby I (the 18th-century ironmonger and blast-furnace builder) to Frank Whittle (the inventor of the jet engine). The major merit of this book is that it gives, by means of many quotations from contemporary sources, a vivid picture of the conditions under which inventions and discoveries were made, how they affected the lives of the workers and led to new skills and crafts, and how the exploitation of workers led to the formation of trade unions. Ably written. For adolescents and grown-ups.

THE WORLD OF COLUMBUS AND SONS, by Genevieve Foster. Charles Scribner's Sons ($5.95). A discursive historical view of the world at the end of the 14th century and the beginning of the 15th. The method, which the author has used in other books, is to describe episodes in which leading figures play a part and weave these together into a kind of contemporary tapestry. Among those in addition to Columbus who figure in it are Mohammed II (the sultan of Turkey who captured Constantinople), Johann Gutenberg, Prince Henry the Navigator, Leonardo da Vinci, Lorenzo de' Medici, Henry Tudor, Queen Isabella, Michelangelo, Erasmus, Martin Luther, Savonarola, John Cabot, Vasco da Gama, the young Copernicus and Magellan. Many illustrations by the author. For readers aged 12 to 16.

Various

BRITANNICA JUNIOR ENCYCLOPEDIA. Encyclopedia Britannica, Inc. ($149.50). The 1965 printing of the 15-volume *Britannica Junior* reports changes in about 5 percent of its text, the revision or rewriting of about 200 articles and the addition of some 400 illustrations. A major article—16,000 words long—that has been entirely revised covers the U.S.S.R. Articles on scientific topics, either new or revised, include "Electricity," "Electronics," "Gravitation," "Capillary Action," "Evaporation," "Ion Migration" and "Isaac Newton." The *Britannica Junior* is, on the whole, a satisfactory compendium for younger children through the first couple of junior high school years. The writing, although often no better than pedestrian, is inoffensive; the illustrations, of which there are many, are not striking—this is particularly true of the scientific diagrams, which are much inferior to those one can find in good textbooks and other encyclopedias accessible to young readers. There are, it is almost unnecessary to say, much better encyclopedias for older children and for general family use, but the *Britannica Junior* is certainly not without merit; boys and girls of elementary school age can dig a great deal of information out of it quickly and relatively painlessly.

A MISCELLANY OF PUZZLES, by Stephen Barr. Thomas Y. Crowell Company ($3.50). MATHEMATICAL PUZZLES AND PASTIMES, by Aaron Bakst. D. Van Nostrand Company, Inc. ($5.50). PUZZLES AND PARADOXES, by T. H. O'Beirne. Oxford University Press ($5.75). Good mathematical puzzles are still around and give the newcomer as much fun as they ever did, but very few new ones of genuine originality are being invented. What appears on the market consists mainly of old themes embroidered to the point of inane complexity or recreations with numbers and lines that afford no true recreation. In one way or another this batch of books supports the indictment. Barr offers a variety of items based on topology, geometry, exercises in folding and cutting paper, problems of cryptarithmetic and odds and ends such as crossword puzzles, mental-arithmetic japes and conundrums. It is thin stuff. The late Aaron Bakst's book is a second edition of a volume first published in 1954. It presents puzzles of number, time, line and area, problems of combinatorial mathematics and a chapter on methods of solving mathematical puzzles. The most difficult of the three books is O'Beirne's, which concentrates on elaborations of stock problems such as ferrying mixed groups (wolf, goat and cabbage; jealous husbands and wives) across rivers, weighing counterfeit coins, pouring fluids from one container to another, arranging cubes by color, playing the game of nim. O'Beirne's puzzles are fairly difficult and, on the whole, artificial and dull unless one is a demon puzzle solver. A desirable feature of his book is that he works out solutions as he goes along so that the reader can follow the reasoning. Any of these books is, in part at least, accessible to the understanding of adolescents and adults, although the harder problems in the Bakst and the O'Beirne place rather severe demands not only on one's powers of concentration but also on one's appetite.

INSIGHT, by J. Bronowski. Harper & Row Publishers ($5.95). Bronowski made a television series on the B.B.C. a few years ago, on which this book is based. It roams a broad area, touching on ideas of modern science from the architecture of matter and the evolution of life through genetics, topology, statistics, the nature of time, relativity and the language and behavior of animals. Trained as a mathematician, Bronowski is a man with many interests, a lively imagination and a rare gift for making hard things simple. The lectures are lighted by his insights and on the whole do well by the attentive reader. On occasion they are more exciting than instructive—hard ideas are often displayed without being adequately explained—and the photographic illustrations are wretchedly muddy. Even when Bronowski is not at his best, however, he offers delights. For readers of high school age and older.

SECRETS OF INLAND WATERS, by Boris Arnov, Jr. Little, Brown and Company ($4.50). In the hydrologic cycle there is every year an exchange between atmosphere and earth of more than 80,000 cubic miles of water. About 15,000 cubic miles of this water comes from lakes and the land and about 24,000 cubic miles returns to the land, the difference coming from the sea. The water that falls on the land or is stored there makes life possible; our origins were the sea but it is on fresh water that we depend. The study of fresh water is a science called limnology, a word that has Greek roots in the term for "marshy lake": *limnē*. Although the earth's streams, rivers, lakes and ponds have had the attention of natural philosophers since ancient times, limnology as a professional discipline is less than 100 years old. In 1869 a Swiss, F. A. Forel, began a systematic investigation of his country's lakes and published a book that is considered the starting point of the modern discipline of limnology. Since then much has been learned about almost every aspect of the earth's fresh water: the living organisms that dwell in it, its physical and chemical properties, how bodies of water are formed, the increasing use of water and growing shortages, the way water resources have been tainted and wasted, measures to tap new supplies. Arnov surveys the subject knowledgeably in an easy narrative style quickened by many unusual and little-known facts. Recommended for both teen-agers and adults. Photographs.

The Third Book of Experiments, by Leonard de Vries. The Macmillan Company ($3.95). A varied collection of mildly amusing and modestly instructive experiments from burning a candle underwater to repeating, in somewhat modified form, Becquerel's famous experiment on radioactivity. Some of the experiments are much too difficult for the ordinary youngster, some involve tinkering with the electric circuits in one's home and may have disagreeable results; moreover, the book is clumsily translated from the Dutch and is obviously addressed to British readers in requiring certain types of equipment (flat batteries, for example) that are not easy to get in this country. All the same De Vries has an infectious enthusiasm, and quite a few of his experiments earn their keep. Numerous illustrations. The book has something for everyone at almost any age.

Mathematics Illustrated Dictionary, by Jeanne Bendick and Marcia Levin, with Leonard Simon. McGraw-Hill Book Company ($4.50). Definitions, descriptions, explanations and many illustrations of some 2,000 mathematical terms, together with a few charts, tables, collections of formulas and brief biographical notes about noted mathematicians. That students of both junior high school and high school age will find this compendium helpful is undoubtedly true, but there are omissions and disproportions in coverage that are as puzzling as they are disappointing. The entry for probability, for example, is altogether inadequate, whereas there are no fewer than three entries on the paradoxes of Zeno: explaining Achilles and the tortoise, the arrow in motion and the stadium. Quételet gets more space than Clerk Maxwell or even Gauss; game theory is poorly explained and includes a reference to Monte Carlo methods without bothering to define them; Vannevar Bush and Lewis Carroll get biographies but not Kurt Gödel.

The First Book of Salt, by Olive Burt. Franklin Watts, Inc. ($2.65). The Chinese were boiling brine for salt some 5,000 years ago. The most famous salt mine in the world is near Kraków in Poland; it has been in operation for more than 1,000 years and runs some 80 miles underground. Salt mines were long notorious for their brutal working conditions, which led to the contemporary phrase "Back to the salt mines." Salt has been used as money and has been so severely taxed as to have become the cause of social upheavals. Many places in the world began as salt cities; the English towns ending in "wich" (such as Norwich, Ipswich, Greenwich) had this beginning, "wich" being Saxon for "a place where salt is dug." Facts of this kind together with descriptions of how salt is made today fill Mrs. Burt's entertaining primer. Illustrations. For readers of 10 to 12.

Steamboat up the Colorado: From the Journal of Lieutenant Joseph Christmas Ives, edited by Alexander L. Crosby. Little, Brown and Company ($4.50). In 1857 the War Department sent Lt. Joseph Christmas Ives of the Topographical Engineers to explore the Colorado River from the Gulf of California to the head of navigation. Ives, only 29 years old when he took charge of the expedition, started up the river in a small paddle steamer (which had been prefabricated in Philadelphia, dismantled, shipped to the West and then reassembled), got as far as the Black Canyon (where the Colorado breaks through the Black Mountains), then explored further by rowboat and after making additional surveys took a mule train east to Fort Defiance on the border of what is now New Mexico. He kept a journal of his travels and adventures, a shortened version of which is offered here. Although the account is not to be compared with the classics in this field of literature such as John Wesley Powell's description of his voyage down the Colorado, it is simple, unaffected and graphic. For any adolescent or grown-up. Illustrated by Lorence Bjorklund.

WORLD BENEATH THE OCEANS, by T. F. Gaskell. The Natural History Press ($4.95). A well-illustrated popularization of oceanography that describes, among other things, how the oceans were formed, how men have journeyed to the bottom, the carpet of marine sediments and the rocks under them, the anatomy of waves, the currents of the sea and the movement of the tides, the minerals of the sea, what feeds on what in the great chain of ocean life. For high school readers.

OCEANOGRAPHY, by Warren E. Yasso. Holt, Rinehart and Winston, Inc. ($2.50). An introduction to the chemistry of seawater, the circulation of the oceans, the structure of the earth, the topography of ocean basins and marine biology. Simply written; good photographs and other illustrations; a glossary. For adolescents from 14 up.

HOW SCIENTISTS FIND OUT, by William D. Lotspeich. Little, Brown and Company ($3.95). A collection of stories about discoveries in medicine and biology: the work of Henrik Dam on vitamin *K*, Otto Loewi's study of the chemical transmitters of nerve impulses, Fleming and penicillin, and so on. The theme is to show the respective roles of chance, purposeful planning, tenacity, imagination and other factors in the advance of scientific knowledge. For teen-agers.

TO SAVE THE SOIL, by Naomi Talley. The Dial Press, Inc. ($2.95). A brief account for youngsters in the nine-to-12 group of man's waste and abuse of the soil in the U.S., the steps that have been taken to repair the damage and to institute a comprehensive program of soil conservation. Good photographs. A good book.

THE SHATTERED SKULL: A SAFARI TO MAN'S PAST, by Carol Morse Perkins. Atheneum Publishers ($3.25). A short, illustrated account of a visit by the author and her husband (who is the director of the St. Louis zoo) to Olduvai Gorge, where L. S. B. Leakey and his wife found the skull of *Zinjanthropus* and hundreds of other fossils. A pleasant enough book for readers of eight to 12, the main emphasis being on the trip to the gorge rather than on what the Perkinses learned when they got there.

INDEX OF ADVERTISERS

DECEMBER 1965

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1965. Also indexed are "Mathematical Games," "The Amateur Scientist" and the principal book review in each issue.*

AUTHORS

ARTICLES

MATHEMATICAL GAMES

THE AMATEUR SCIENTIST

BOOKS

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

THE "UNTOUCHABLES" OF INDIA

CASTE & CLASS IN INDIA. G. S. Ghurye. Bombay, 1957.

THE CHANGING STATUS OF A DEPRESSED CASTE. Bernard S. Cohn in *Village India: Studies in the Little Community,* edited by McKim Marriott. The University of Chicago Press, 1955.

RELIGION AND SOCIETY AMONG THE COORGS OF SOUTH INDIA. M. N. Srinivas. Oxford University Press, 1952.

THE MECHANISM OF MUSCULAR CONTRACTION

A DISCUSSION OF THE PHYSICAL AND CHEMICAL BASIS OF MUSCULAR CONTRACTION. Organized by A. F. Huxley and H. E. Huxley in *Proceedings of the Royal Society,* Series B, Vol. 160, No. 981, pages 433–542; October 27, 1964.

ELECTRON MICROSCOPE STUDIES ON THE STRUCTURE OF NATURAL AND SYNTHETIC PROTEIN FILAMENTS FROM STRIATED MUSCLE. H. E. Huxley in *Journal of Molecular Biology,* Vol. 7, No. 3, pages 281–308; September, 1963.

FILAMENT LENGTHS IN STRIATED MUSCLE. Sally G. Page and H. E. Huxley in *The Journal of Cell Biology,* Vol. 19, No. 2, pages 369–390; November, 1963.

THE STRUCTURE OF F-ACTIN AND OF ACTIN FILAMENTS ISOLATED FROM MUSCLE. Jean Hanson and J. Lowy in *Journal of Molecular Biology,* Vol. 6, No. 1, pages 46–60; January, 1963.

X-RAY DIFFRACTION FROM LIVING STRIATED MUSCLE DURING CONTRACTION. G. F. Elliott, J. Lowy and B. M. Millman in *Nature,* Vol. 206, No. 4991, pages 1357–1358; June 26, 1965.

VIOLATIONS OF SYMMETRY IN PHYSICS

QUESTION OF PARITY CONSERVATION IN WEAK INTERACTIONS. T. D. Lee and C. N. Yang in *Physical Review,* Vol. 104, No. 1, pages 254–258; October 1, 1956.

EXPERIMENTAL TEST OF PARITY CONSERVATION IN BETA DECAY. C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes and R. P. Hudson in *Physical Review,* Vol. 105, No. 4, pages 1413–1415; February 15, 1957.

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON. J. H. Christenson, J. W. Cronin, V. L. Fitch and R. Turlay in *Physical Review Letters,* Vol. 13, No. 4, pages 138–140; July 27, 1964.

INVARIANCE PRINCIPLES AND ELEMENTARY PARTICLES. J. J. Sakurai. Princeton University Press, 1964.

UNITARY REPRESENTATIONS OF THE INHOMOGENEOUS LORENTZ GROUP INCLUDING REFLECTIONS. E. P. Wigner in *Group Theoretical Concepts and Methods in Elementary Particle Physics,* edited by Feza Gürsey. Gordon and Breach Science Publishers, Inc., 1964.

FLEAS

FLEAS, FLUKES & CUCKOOS: A STUDY OF BIRD PARASITES. Miriam Rothschild and Theresa Clay. Collins, London, 1952.

PLAGUE. R. Pollitzer. World Health Organization, 1954.

THE RABBIT FLEA AND HORMONES. Miriam Rothschild in *Endeavour,* Vol. 24, No. 93, pages 162–168; September, 1965.

THE AURORA

THE AURORA. S. Akasofu, S. Chapman and A. B. Meinel in *Handbuch der Physik: Vol. XLIX.* Springer-Verlag, Inc., in press.

AURORAL PHENOMENA. B. J. O'Brien in *Science,* Vol. 148, No. 3669, pages 449–460; April 23, 1965.

DYNAMIC MORPHOLOGY OF AURORAS. Syun-Ichi Akasofu in *Space Science Reviews,* Vol. 4, No. 4, pages 498–540; June, 1965.

POLAR AURORAS. V. I. Krasovskij in *Space Science Reviews,* Vol. 3, No. 2, pages 232–274; 1964.

RHEUMATIC FEVER

THE HEMOLYTIC STREPTOCOCCI. Maclyn McCarty in *Bacterial and Mycotic Infection of Man,* edited by René J. Dubos and James G. Hirsch. J. B. Lippincott Co., 1965.

RHEUMATIC FEVER. Maclyn McCarty in *Cecil-Loeb Textbook of Medicine,* edited by Paul B. Beeson and Walsh McDermott. W. B. Saunders Company, 1963.

RHEUMATIC FEVER: DIAGNOSIS, MANAGEMENT AND PREVENTION. Milton Markowitz and Ann G. Kuttner. W. B. Saunders Co., 1965.

THE STREPTOCOCCUS, RHEUMATIC FEVER AND GLOMERULONEPHRITIS. Edited by Jonathan W. Uhr. The Williams & Wilkins Co., 1964.

HEAT TRANSFER IN PLANTS

CONVECTION PHENOMENA FROM PLANTS IN STILL AIR. David M. Gates and Charles M. Benedict in *American Journal of Botany*, Vol. 50, No. 6 (Part I), pages 563–573; July, 1963.

ENERGY EXCHANGE IN THE BIOSPHERE. David M. Gates. Harper & Row, Publishers, 1962.

HEAT TRANSFER BETWEEN THE PLANT AND THE ENVIRONMENT. K. Raschke in *Annual Review of Plant Physiology*, Vol. 2, pages 111–126; 1960.

RADIATION AND CONVECTION IN CONIFERS. E. C. Tibbals, Ellen K. Carr, David M. Gates and Frank Kreith in *American Journal of Botany*, Vol. 51, No. 5, pages 529–538; May–June, 1964.

THE PHYSICS OF THE PIANO

NORMAL VIBRATION FREQUENCIES OF A STIFF PIANO STRING. Harvey Fletcher in *The Journal of the Acoustical Society of America*, Vol. 36, No. 1, pages 203–209; January, 1964.

QUALITY OF PIANO TONES. Harvey Fletcher, E. Donnell Blackham and Richard Stratton in *The Journal of the Acoustical Society of America*, Vol. 34, No. 6, pages 749–761; June, 1962.

THE THEORY OF SOUND: VOL. I. John William Strutt, Baron Rayleigh. Macmillan and Co., Limited, 1929.

VIBRATION AND SOUND. Philip M. Morse. McGraw-Hill Book Company, Inc., 1948.

GAMES

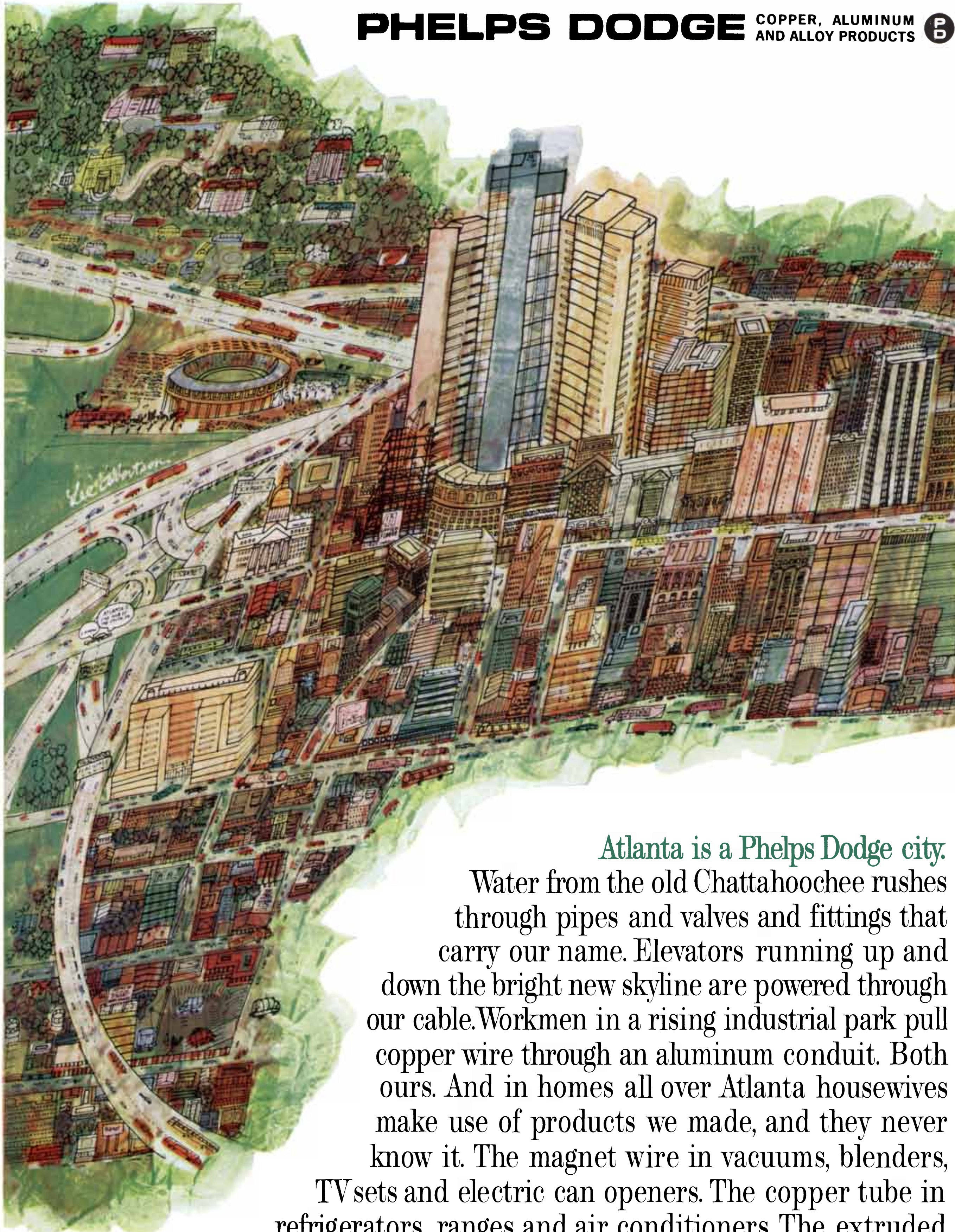
MAGIC CIRCLES, SPHERES AND STARS. W. S. Andrews in *Magic Squares and Cubes*. Dover Publications, Inc., 1960.

MAGIC NUMBER ARRANGEMENTS. Harry Langman in *Play Mathematics*. Hafner Publishing Co., Inc., 1962.

THE AMATEUR SCIENTIST

EXPERIMENTS IN PHYSICAL OPTICS USING CONTINUOUS LASER LIGHT. T. J. Perkins. Optics Technology, Inc., 1964.

PHELPS DODGE COPPER, ALUMINUM AND ALLOY PRODUCTS



Atlanta is a Phelps Dodge city.

Water from the old Chattahoochee rushes through pipes and valves and fittings that carry our name. Elevators running up and down the bright new skyline are powered through our cable. Workmen in a rising industrial park pull copper wire through an aluminum conduit. Both ours. And in homes all over Atlanta housewives make use of products we made, and they never know it. The magnet wire in vacuums, blenders, TV sets and electric can openers. The copper tube in refrigerators, ranges and air conditioners. The extruded aluminum in windows, awnings and a hundred and one other household and garden objects. You don't always see us. But in copper and aluminum, Phelps Dodge experience and imagination are at work, wherever you go.

shaping new links in
man/computer communications...

NEW REMOTE CALCULATOR brings high-powered computing to the individual scientist's desk

The Control Data Remote Calculator is an amazing new tool developed for *you*. It enables many scientists, mathematicians and statisticians to simultaneously use the CONTROL DATA® 6600—the world's most powerful computer—to get quick answers to problems stated in mathematical language. At the same time it frees the user from frustrating conventions, programming intermediaries and tedious waiting. This combination of power and convenience broadens your horizons—encourages experimentation, innovation and creativity.

Up to 2000 calculators can be installed remotely, via standard telephone channels, through the common-user dial network. Calculators can operate concurrently with normal processing and other types of remote terminals. This flexibility along with compact portability enables the calculator to be used for "homework." Whether at home or office, the user merely queries the computer from the calculator keyboard containing all conventional mathematical functions and symbols. Answers are shot back on the calculator's display panel.

Powerful computer systems, and the means for people to get at them the moment they need to, account for today's preference for Control Data computer systems in scientific research and development.

Talk over your requirements with your Control Data representative. Or write our Minneapolis address. Dept. E-125.

CONTROL DATA
CORPORATION

8100 34th AVE. SO., MINNEAPOLIS, MINNESOTA 55440