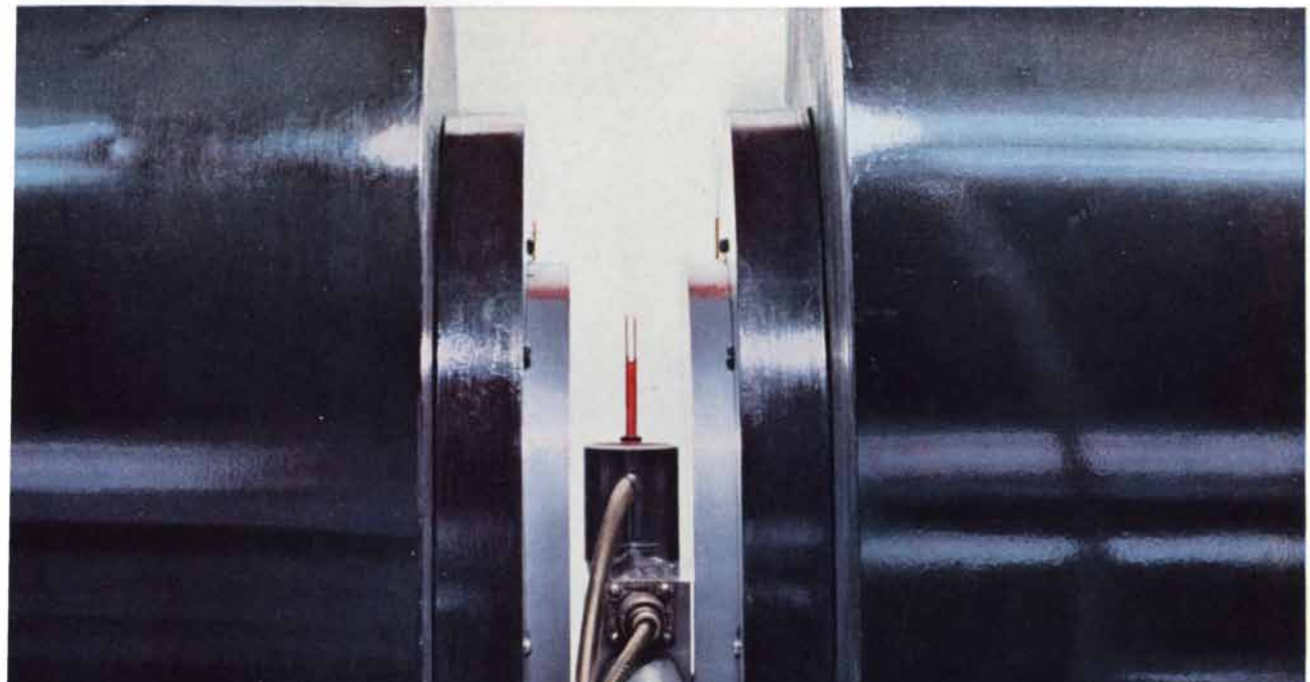
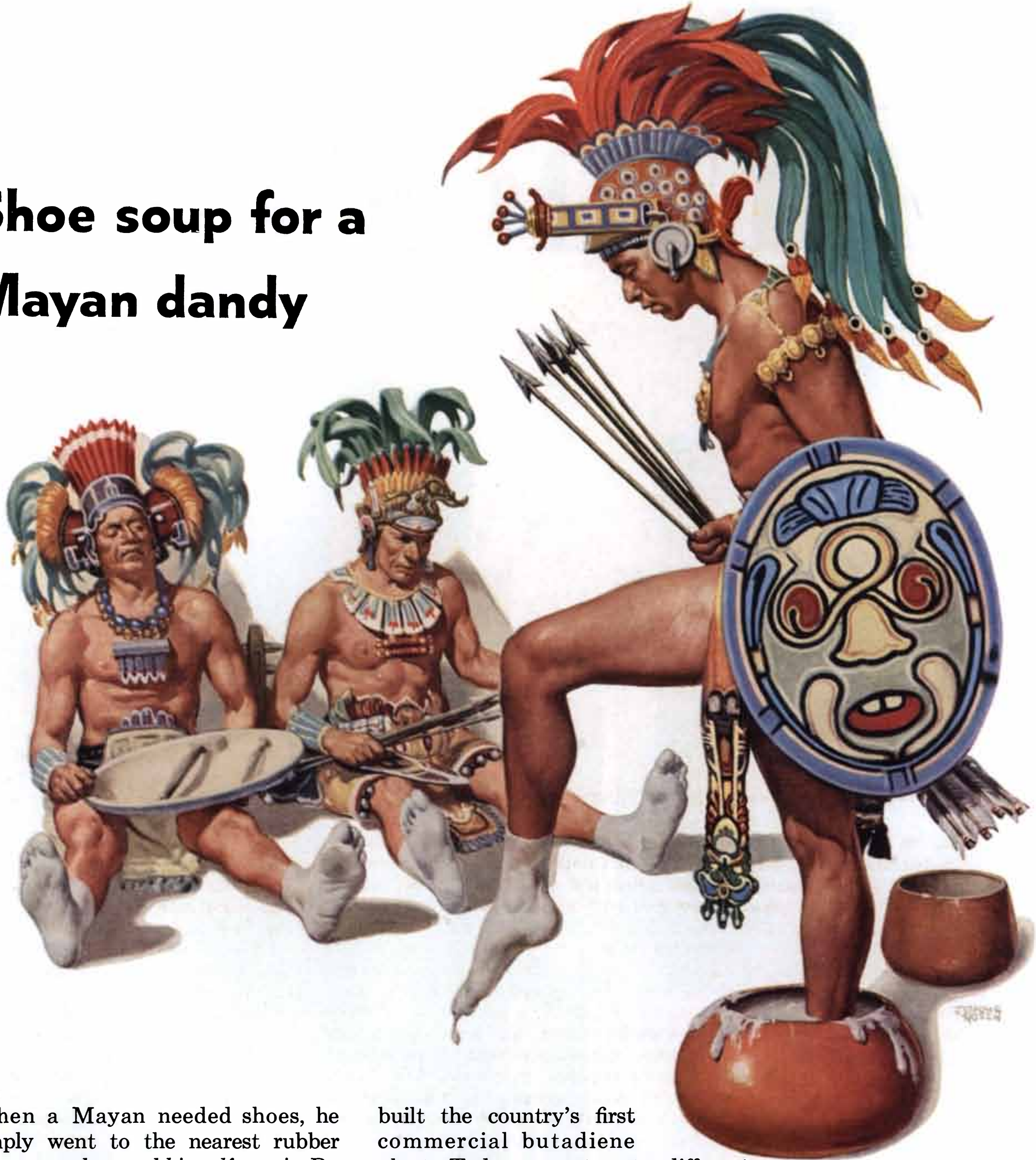
SCIENTIFIC AMERICAN



MAGNETIC RESONANCE

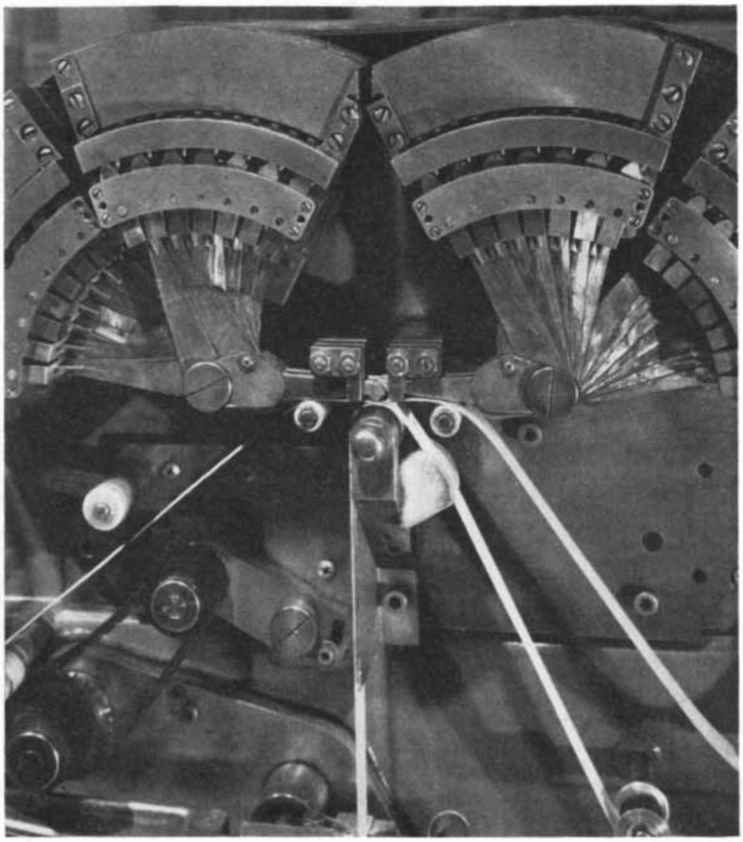
FIFTY CENTS

August 1958



Kodak reports on:

for whom the styli have not vibrated . . . color movie film that duplicates better



See the 28 vibrators poised over the paper tape? Each time a vibrator hits the paper it makes a black dot. The black dots form letters and numerals. The letters and numerals spell out names and addresses at 10 per second. Eastman Kodak Company developed and built this punch-card-obeying machine.* Recently, an hour or so of its time was used to address a copy of **Eastman Organic Chemicals List No. 41** to everybody who has ever written us of a continuing need for an up-to-date compendium of research compounds, analytical reagents, indicators, and solvents for the laboratory. There are some 3700 in all—with their package sizes, prices, structural formulas, BP's or MP's, and a few useful tabulations. Predecessors to List No. 41 are obsolete. If by the time you read this you have not yet received your copy, you must assume that the impulses representing YOU never motivated the styli. If you want the catalog anyway and will accept an ordinary typewritten address, please inform Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).

*Inquiries about the machine should be made to Addressograph-Multigraph Corp., 1200 Babbitt Road, Cleveland 17, Ohio.

A green look

We used to make a 16mm product designated Kodachrome Commercial Film. If you loaded it into a camera, exposed it according to directions, had it properly processed, and projected it, the result would look bad. The colors would be weak and washed out. The film wasn't intended for projection. It was intended only to serve as an original from which numerous copies could be reproduced. The copies were excellent, much better than duplicates from the more familiar *Kodachrome Film.* Obviously, every movie studio had to have some of this, but who else?

Strange as it may seem to those who ignore certain long-range trends in the way man earns his daily bread, Kodachrome Commercial Film found many hundreds of customers.

Now we have something better for the same purpose. We have the new *Ektachrome Commercial Film, Type 7255.* It looks green in projection instead of just washed out. The reason for the green makes an invigorating little mental workout for minds that don't have to think about it all day long.

Theory requires each of the three layers of the film to emerge from processing with its originally unexposed areas in a color complementary to the color to which that layer responds. (You can prove this to yourself with your own doodles on a scratch pad.) Only theoretical dyes do this perfectly. Real dyes that can be formed *in situ* by combination of coupler compounds in the emulsion with the reaction products of the development process don't quite make it. It is possible, however, by fudging a little in the selection of all three dyes to play the errors off against each other and wind up convincing the color receptors in the human eye that nature is being simulated.

But the color receptors in a second piece of film are not the same as the color receptors in the eye. What convinces one does not convince the other. The film needs a little sharper gradient of response to red light than the eye needs. Thus it works out that what looks right to the film on which you are copying looks green to the eye.

What's the advantage of Type 7255 *over Kodachrome Commercial? Improved speed, graininess, sharpness, latitude, and quality in the release prints. Who cares? Not just studios but movie technicians who learn such things from Eastman Kodak Company, Motion Picture Film Division, Rochester 4, N. Y., and work for organizations that understand how lucidly a 16mm projector can report on work in progress. Some R&D contracts even carry clauses specifying this form of lucidity.*

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

Established 1845 **SCIENTIFIC AMERICAN** August, 1958 Volume 199 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a close-up view of a nuclear magnetic-resonance spectrometer (*see page 58*). The smallest, innermost cylinders at left and right of the central structure are magnet poles. The larger cylinders are water jackets. Magnetic resonances are detected by slowly varying the field of the magnet. The sample being studied is the red liquid in the glass tube. The tube extends into the holder, where it is surrounded by a coil carrying a radio-frequency current. This current produces a rotating magnetic field which tips the spinning nuclei in the sample. A second coil picks up the signal they send out. This instrument, made by Varian Associates, was photographed at Esso Research and Engineering Company in Linden, N. J.

THE ILLUSTRATIONS

Cover photograph by Paul Weller

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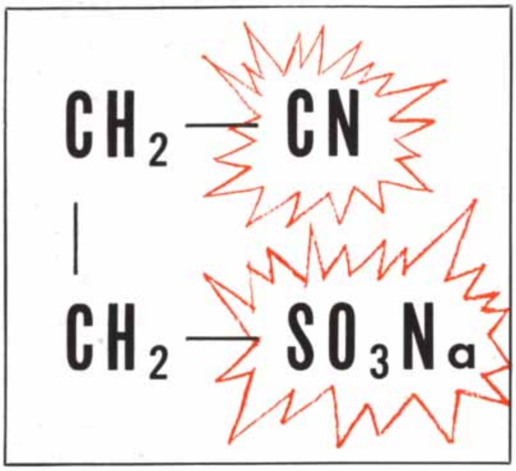
Life on the Chemical Newsfront

NEW IDEAS IN BEAUTY are transforming bathroom design and decoration with the help of modern FORMICA® *laminated plastics.* Especially popular is the Vanitory, combining the countertop lavoratory, makeup bar, cabinets and other units with FORMICA wall surfacing for distinction and convenience. FORMICA laminates provide color and pattern variety, durability and economy, resistance to stains, easy cleaning and warm, smooth touch through qualities imparted by LAMINAC® *laminating resins.* (The Formica Corporation)

SPRAYS AWAY ITCHING AND PAIN. The annoying itching and pain of insect bites, poison ivy, poison oak and minor skin irritations are quickly relieved by RHULISPRAY® *analgesic-anesthetic.* Combining an effective analgesic-anesthetic formula with zirconium, it soothes affected areas instantly and dries the rashes of poison ivy or poison oak. Sprayed easily and cleanly over the skin, it is quick-drying and non-staining. (Lederle Laboratories Div.)

LOSS OF COAL OR MINERAL FINES through wind and rain erosion during shipment in open railroad cars or in open storages is sharply retarded by AEROSPRAY* 52 *binder.* Applied as a spray, this water emulsion polymerizes and forms a tough protective crust in the upper layer of fines. While the crust does not prevent percolation of water, it is insoluble and not destroyed by rain. AEROSPRAY can also be used on stockpiled mineral or coal fines, chemicals or silt to prevent wind loss or objectionable dusting. (Organic Chemicals Division)



A NEW BIFUNCTIONAL DERIVATIVE of acrylonitrile, *sodium β-sulfopropionitrile* is now available in experimental quantities from Cyanamid. Melting at 243-244° C, soluble in water, hot methanol and glacial acetic acid, this interesting chemical combines the functionality of a nitrile group and a sulfonic acid group. It offers a synthetic route to a variety of molecules of interest in pharmaceuticals, surfactants and other fields. Potentially, sodium β-sulfopropionitrile could be produced commercially in the bulk chemical price range. If you would like to explore its possibilities, write for additional information. **(Market Development Department)**

MAILING RATES ARE UP, but mailing costs need not rise proportionately. With low basis weight paper made opaque with UNITANE® 0-110 *titanium dioxide,* publishers can save weight and still maintain good readability. The uniform particle size, high refractive index and maximum water dispersion of UNITANE provide excellent opacity which is preserved from dry sheet to printed page, unlike ordinary clay-filled sheets which lose opacity when printed. **(Pigments Division)**

NEW ECONOMY IN CRACKING UNITS — AEROCAT® 2000 *fluid cracking catalyst,* designed for "problem" operating conditions (such as heavy metals contamination) in catalytic cracking units, has just been introduced by Cyanamid and is now commercially available. AEROCAT 2000 provides activity stability with greater economy than other low-cost catalysts. It offers an octane advantage, superior attrition resistance, and lower production of coke. It has controlled bulk density for better fluidization properties. Extensive testing on principal types of gas oils show the new catalyst to have outstanding catalytic properties. **(Industrial Chemicals Div.)**

*Trademark

CYANAMID

AMERICAN CYANAMID COMPANY
30 ROCKEFELLER PLAZA. NEW YORK 20. N. Y.

For further information on these and other chemicals, call, write or wire American Cyanamid Company

LETTERS

Sirs:

In view of A. G. McNish's letter to the editor in the June issue of *Scientific American*, it seems important to have the true facts set forth to avoid confusing the interested but nonspecialist reader. [Editor's note: Dr. McNish took issue with a statement in this magazine that the international meter bar might soon be replaced by the wavelength of a line in the spectrum of krypton.]

The Comité Consultatif pour la Définition du Mètre met on three occasions between September 23 and September 25, 1957, to consider the question of re-establishing the International Metre on a wavelength basis. The following resolution was adopted by a unanimous vote (which included that of the American delegate) for submission to the Comité International des Poids et Mesures:

"The Advisory Committee for the Definition of the Metre, after having heard the report of the director of the International Bureau of Weights and Measures confirming that the international platinum-iridium prototype of the metre no longer meets the demands of the most precise metrology, and after having studied carefully the reports from the principal national laboratories (*grands laboratoires*) and the International Bureau on the question of the metrological suitability of radiations that can be pro-

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

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

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duced at the present time, states that it is sufficiently informed to set forth a firm recommendation consistent with Proposition II adopted by the Advisory Committee in 1953.

"In consequence the Advisory Committee for the Definition of the Metre recommends that the metre be defined by means of the radiation corresponding to the transition between the levels 2 p_{10} and 5 d_5 of the atom of krypton 86.

"From the concordant results obtained on the basis of the procedures set forth in Proposition III adopted by the Committee in 1953 it is of the opinion that the metre ought to be defined as equal exactly (*par convention*) to 1,650,763 .73 times the wavelength of this radiation in vacuum.

"This recommendation was unanimously adopted."

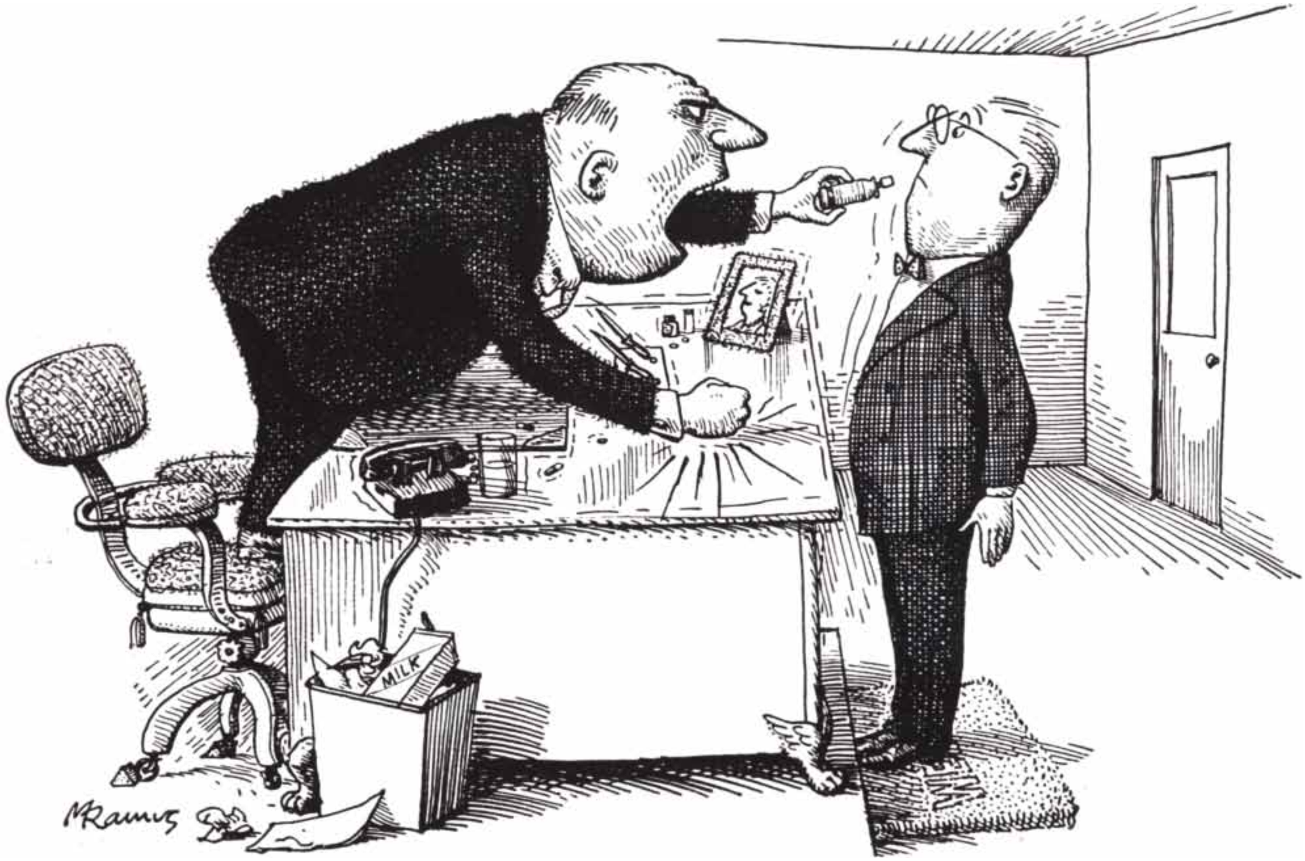
This resolution will be considered by the Comité International des Poids et Mesures at its meetings starting October 29, 1958, and if the Comité International concurs the resolution will be recommended for adoption to the XI Conférence Generale des Poids et Mesures which meets in 1960 at Sèvres.

It will be noted that these facts are in general agreement with the original note in the March issue of *Scientific American*, unless one takes seriously the jocular reference to the melting down of the present platinum-iridium standard for wedding rings.

Some facts with respect to the accuracy of the International Metre may be of interest. The International Metre is currently maintained with a precision of approximately 2 parts in 10^7 at the Bureau International at Sèvres by means of the platinum-iridium prototype. If the International Conference of 1960 accepts the recommendation of the Comité Consultatif, the precision with which the International Metre will be preserved by interferometric techniques will be increased by a factor between 10 and 100 —probably closer to the latter figure. This would lead to a considerable improvement in the precision of material standards of length, but it is doubtful whether this precision will approach the precision with which the International Metre can be defined on the basis of the krypton wavelength.

L. E. HOWLETT

Président
Comité Consultatif
pour la Définition du Mètre
Division of Applied Physics
National Research Council
Ottawa, Canada


MILK

Du Pont Announces

A new synthetic rubber unequalled fuels, solvents and chemicals at

The addition of VITON to the Du Pont family of elastomers (neoprene and HYPALON®) corresponds to the increased need for flexible construction materials with higher heat resistance.

The outstanding property of VITON is its ability to withstand temperatures of 400° F. and up in contact with most oils, chemicals, solvents and fuels. In addition, VITON also has good mechanical properties plus excellent resistance to ozone, oxygen and weathering.

VITON resists temperatures up to 450° F. in continuous service and up to 600° F. in intermittent service. This kind of heat resistance, coupled with VITON'S resistance to most fluids at these temperatures, makes VITON serviceable where other commercial elastomers would fail rapidly.

VITON'S mechanical properties are good for any elastomer and excellent for one that is highly resistant to heat and fluids. Notable among these properties are low compression set and good tensile

"VITON" RESISTS CORROSIVE FLUIDS

Data were obtained by immersing VITON vulcanizates for 7 days and measuring the effect on properties shown.

		Tensile Strength Retained %	Hardness Change Points	Volume Increase %
SOLVENTS	Carbon tetrachloride, 75° F.	85	+2	1.3
	Ethyl alcohol, 75° F.	97	+2	1.7
	Aniline, 75° F.	100	−1	3
	Tricresyl phosphate, 300° F.	93	−11	24
	Acetone, 75° F.	—	−11	271
FUELS AND LUBRICANTS	JP-5 petroleum aircraft fuel, 75° F.	100	+1	0.4
	Ref. fuel B (70 isooctane, 30 toluene), 75° F.	93	+1	2.5
	ASTM No. 3 oil, 300° F.	95	−1	4.3
	Turbo oil No. 15 diester lubricant (Mil-L-7808), 400° F.	60	−6	19.6
HYDRAULIC FLUIDS	Transmission fluid, Type A, 212° F.	77	−1	1.5
	Oronite 8200 silicate ester, 400° F.	93	0	1.8
	OS-45 silicate ester, 400° F.	62	−3	11.1
	Skydrol 500 phosphate ester, 300° F.	—	−32	270
ACIDS AND BASES	Sodium hydroxide, 46.5%, 75° F.	75	+1	2.1
	Sulfuric acid, fuming, 75° F.	58	−4	4.8
	Hydrofluoric acid, 48%, 75° F.	98	+2	4.8
	Hydrochloric acid, 36.5%, 75° F.	81	−8	7.3
	Nitric acid, red fuming, 75° F. (*Special acid-resistant compound*)	—	—	16
	Acetic acid, glacial, 75° F.	—	−10	61.6

VITON

TRADEMARK

Synthetic rubber

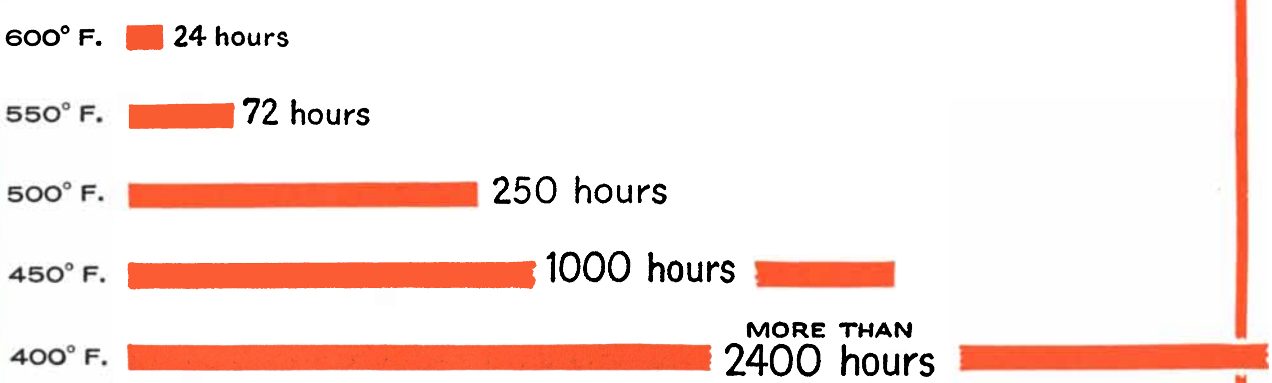
for service in oils, temperatures over 400° F.

strength. VITON specimens compressed 25% and held 70 hours at 250° F. recover to within 90 to 97% of their original dimension—making them good seals at high temperatures. VITON, tested at room temperature, has a tensile strength in the range of 2000 to 3000 psi and ultimate elongation varies from 100 to 400%, depending on hardness. (Vulcanizates of VITON can be made in any hardness from 60 to 95 durometer.)

With VITON, it is possible to obtain high heat, fluid resistance in close tolerance components due to VITON'S easy processability. VITON is being put to use in precision seals, diaphragms, coated fabric, linings and other critical applications. If you have need for a flexible material highly resistant to both heat and corrosive fluid, ask your rubber supplier about VITON. For a free booklet describing VITON'S many useful properties write to E. I. du Pont de Nemours & Co. (Inc.), Elastomer Chemicals Dept. SA-8. Wilmington 98, Delaware.

In Canada: Du Pont Company of Canada (1956), Ltd., Box 660, Montreal

"VITON" RESISTS HEAT



Periods of time for which VITON vulcanizates have remained usefully elastic when oven aged in air at the temperatures shown.

DU PONT REG. U. S. PAT. OFF. VITON

Better Things for Better Living . . . *through Chemistry*

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1908: "It is not often that a measure of such startling character as the Daylight Saving Bill is introduced into the English House of Commons. The fact that the momentous changes advocated by the bill are proposed by William Willett, a member of the Royal Astronomical Society, suggests that the measure may not be so chimerical as might be supposed. It is proposed, during part of the spring and autumn and the whole of the summer, to advance the clocks throughout the country, moving the working day forward, with a view to including within the working hours a longer stretch of daylight. The advantage of a long daylight evening for such sports as yachting, rowing, golf, tennis and automobiling is indisputable."

"The great distance of Jupiter's eighth satellite from the planet, and its retrograde motion, which are matters of profound interest to the astronomical world, have led Prof. George Forbes, F.R.S., to advance an interesting and reasonable suggestion in regard to this celestial object. 'While speculation is premature,' says Prof. Forbes, 'it is impossible to resist the conjecture that this new satellite is really the long-lost Lexell's comet, discovered in 1770. In August, 1779, this comet approached Jupiter within .01 of the earth's mean distance from the sun, and has not been again observed.'"

"Upon the termination of the Glidden tours on July 23, after three more days of running from Boston to the Rangeley Lakes in Maine and thence to Bethlehem, N.H., and Saratoga, three teams, five runabouts, and 14 other touring cars finished the 1,700-mile reliability test with perfect scores. The teams that tied for the trophy were the Buffalo team of three Pierce-Arrows, the Columbus team of three Peerless cars, and the Chicago team consisting of two Hayneses and one Oldsmobile."

"After the painful accident he met with on the Fourth of July, when a bursting water-pipe caused him to scald his hand, it is somewhat remarkable that Mr. Wilbur Wright was able, in a trifle over a month, to guide his new aeroplane in its first flights in France. The scene of Mr. Wright's current endeavors is a disused racetrack near Le Mans. The series of flights was terminated for a time on August 13 when, after a splendid flight lasting eight minutes and 52 seconds (during which Mr. Wright made seven complete turns of the field at a height greater than the tops of the trees) he, at the end of a second two-minute flight, struck one wing in landing, while attempting to make a sharp curve, and damaged the machine to a slight degree."

"'Neossin,' the Chinese edible bird's nest, has been studied by E. V. McCollum, who finds that it is a gluceoproteid. It gives Millon's, Adamkiewicz's, the biuret and xanthoproteic reactions. It contains 2 per cent of sulphur, 9.69 per cent of nitrogen and no phosphorus. Hausmann's method showed the nitrogen to be distributed as follows: NH_3, 1.3 per cent; humus, 1.27 per cent; phosphotungstic acid precipitate, 1.59 per cent; amino acids, 5.53 per cent."

"The International Motor Boat Race for the Harmsworth trophy was held in Huntington Bay on Long Island Sound, August 3. The trophy was successfully defended for the U. S. by the *Dixie II* of E. J. Schroeder, which completed the run of 10 nautical miles just 49 seconds ahead of the *Daimler II*, a British racer of double her power. On the succeeding day *Dixie II* was put through a series of speed trials which amply establish her as the fastest motorboat in the world. In four runs over the course, two with and two against the tide, the *Dixie II* made an average speed of 31.05 knots. The times were taken at one end of the course by Messrs. J. Frederick Tams and Ernest E. Lorillard of the Regatta Committee of the New York Yacht Club, and at the other end by the yachting editors of the New York *Sun* and SCIENTIFIC AMERICAN."

"SCIENTIFIC AMERICAN shares sincerely in the universal sympathy which has been expressed for that indomitable inventor, Count Zeppelin, in the sudden and absolute destruction of his great airship. The *No. IV* was forced, owing to loss of gas, to alight at Echterdingen, near Stuttgart, about noon on August 5. The airship was anchored in a large field, and was guarded by a detachment of soldiers. While Count Zeppelin was at lunch at a nearby inn, a storm sud-

Courtesy Mount Wilson Observatory

FROM BEYOND THE SKY TO BENEATH THE SEAS

In the field of communications, two extraordinary events have occurred within a short span of time. One was the linking of Europe to America by the submarine telephone cable. The other was the sending of radio signals from U. S. satellites in outer space.

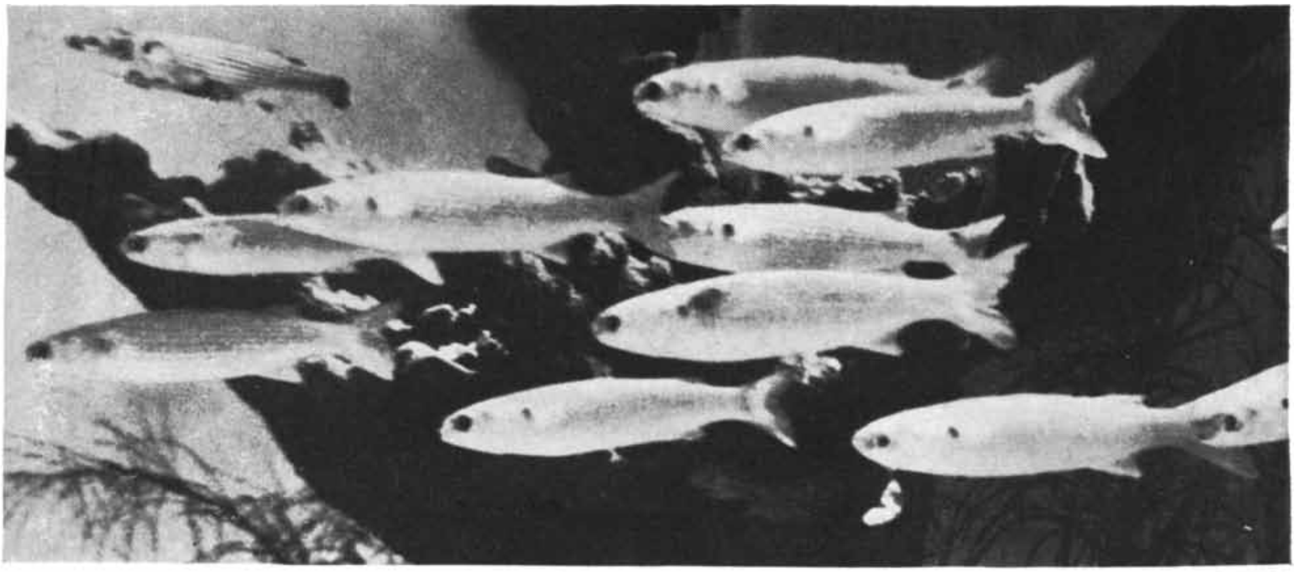
Both achievements depended on developments from Bell Telephone Laboratories. The cable was made possible by development of long-life electron tube amplifiers able to withstand crushing pressure on the ocean floor. The satellites derive their radio voices from transistors—products of basic research in semiconductor physics.

The deep sea amplifier and the transistor illustrate the wide range of work at Bell Telephone Laboratories. Here, over 3000 professional scientists and engineers explore and develop in physics, mathematics, electronics, chemistry, mechanical engineering, even biology—in every art and science which can help improve electrical communications.

Through this work, Bell Telephone Laboratories has helped make your telephone service the world's finest—and will keep it so.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

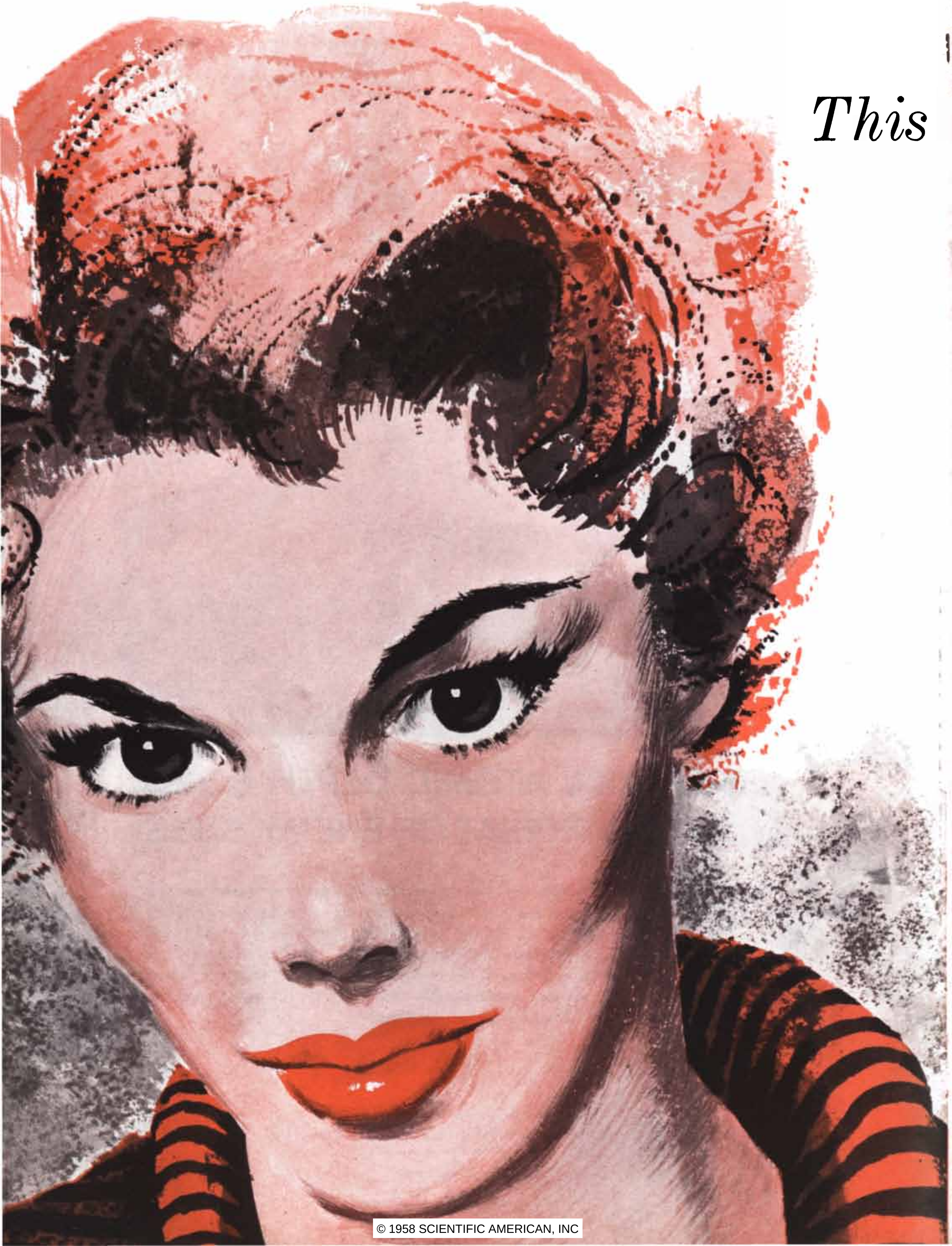


denly arose and buffeted the airship so heavily that it broke away and burst. The hydrogen ignited in some mysterious manner, and the colossal airship was quickly destroyed."

AUGUST, 1858: "The Atlantic Cable is laid! All hail to Anglo-Saxon genius! and two nations' heartfelt thanks to the noble—aye, and mighty—men of science, capital and energy, whose untiring zeal and indomitable perseverance have linked the hemispheres with the electric cord! But a month ago we announced the third failure in this enterprise, but we did not groan and lament. Cyrus W. Field, Professor Morse and all connected with the enterprise are great pacificators, great civilizers. The telegraph fleet met at mid-ocean on Wednesday, July 28th, and made the splice at 1 p.m. on Thursday, the 29th, and then separated—the *Agamemnon* and *Valorous* bound for Valentia, Ireland, and the *Niagara* and *Gorgon* for Trinity Bay, Newfoundland, where they arrived on August 4th. It is 1,698 nautical miles between the two telegraph houses, and for more than two thirds of this distance the water is over two miles in depth. On August 16th the first telegram, directed from Queen Victoria to President Buchanan, was received. On the evening of the 17th inst., New York and many other cities were brilliantly illuminated, fireworks were let off, and the people generally had a good time of it throughout the country; and here, to celebrate the event properly, the cupola and upper story of our City Hall were burned."

"F. Yeiser of Louisville, Ky., has invented a new engine, in which electro-magnetism is to be the motive power. The invention consists in a certain system of balanced beams or frames carrying soft iron bars at each end, to be operated upon alternately by two series of electro-magnets in such a manner as to receive an oscillating motion, and having combined with them mechanisms, through which their oscillating motion is caused to produce the rotary motion of a shaft."

"An ingenious instrument called the ophthalmoscope, by the aid of which the eye may be internally examined, has recently been introduced to the notice of the scientific world."



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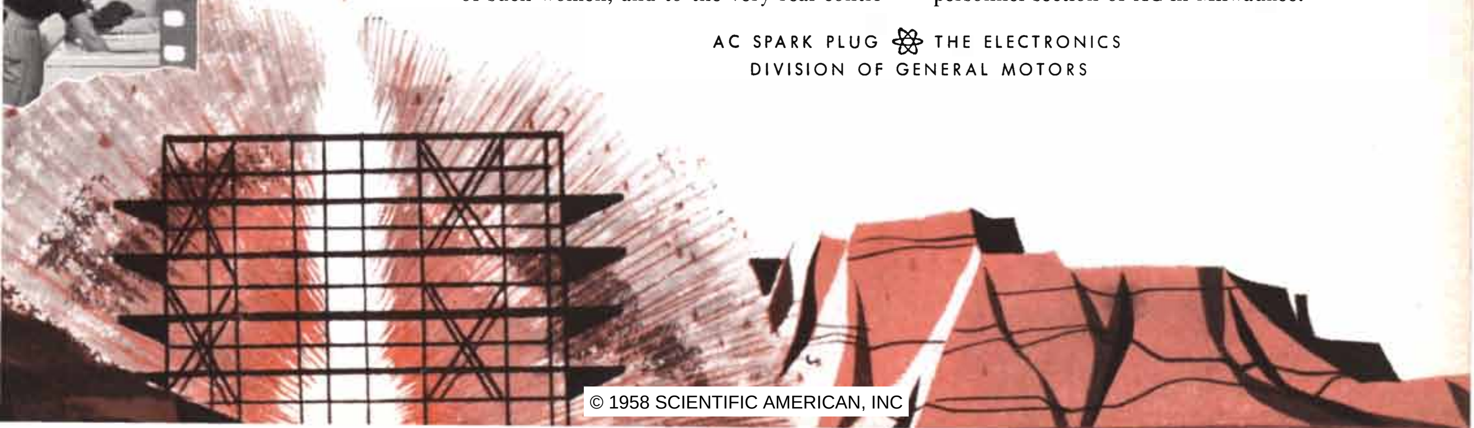


THE AUTHORS

JACK SCHUBERT ("Beryllium and Berylliosis") was trained in physical chemistry at the University of Chicago and is now a senior chemist at the Argonne National Laboratory. There he applies the concepts of physical chemistry to the study of biology. Schubert's article "Radioactive Poisons" appeared in SCIENTIFIC AMERICAN's issue of August, 1955. Since then he and Ralph E. Lapp have published their popular book *Radiation*, which is being translated into several languages. Schubert is presently at work on a textbook about ion exchange. In 1955 he was a U. S. delegate at the Geneva "Atoms for Peace" conference, and in 1956 and 1957 he held a senior fellowship of the National Science Foundation, which sent him to study chelates at the Swiss Federated Institute of Technology in Zurich.

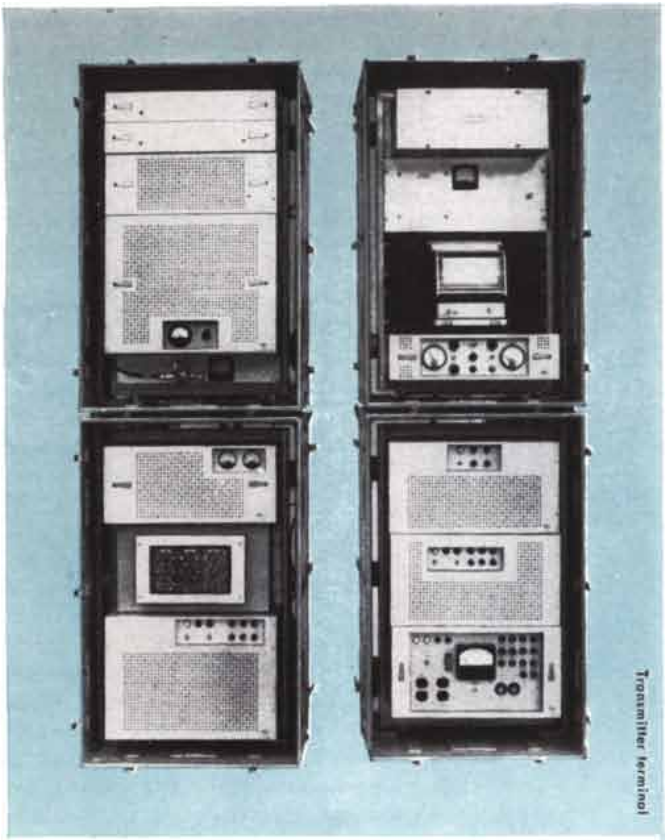
HAROLD ZIRIN ("Hot Spots in the Atmosphere of the Sun") is an astronomer at the High Altitude Observatory of the University of Colorado. Like many other astronomers, he began his career as an amateur; when he was a Boston high-school student he built an eight-inch reflecting telescope and volunteered for duty with the American Association of Variable Star Observers. The Westinghouse Science Talent Search of 1946 took him to Washington, where he met Bart J. Bok of the Harvard College Observatory and was pursuaded to enter Harvard. Zirin got through Harvard on Westinghouse and Pepsi-Cola scholarships, graduating *magna cum laude*. After a year with the Rand Corporation he returned to Harvard as an Agassiz Fellow, receiving his Ph.D. there under the direction of Philip M. Morse of the Massachusetts Institute of Technology. Zirin has been with the High Altitude Observatory since 1955.

E. G. F. SAUER ("Celestial Navigation by Birds") is an ornithologist at the University of Freiburg, near the German Black Forest region in which he grew up and acquired his interest in the habits of birds and other animals. Sauer was born at Mannheim in 1925 and studied zoology and physical sciences at the universities of Freiburg and Heidelberg, where he conducted research on play behavior in animals, the navigation of birds and the question of inheritance *v.* learning in bird songs. He was made *dozent* in the natural science faculty at Freiburg last year.

GEORGE E. PAKE ("Magnetic Resonance") was Edward Purcell's graduate student at Harvard University when Purcell was just beginning his Nobel-prize-winning work on magnetic resonance. Pake, who is now professor of physics at Stanford University, has been investigating magnetic resonance ever since. Pake grew up in Kent, Ohio, where his father taught English at Kent State University. As a student in the University's "laboratory" high school for teacher training, he had access to the University library, and there his interest soon turned from baseball and model airplanes to physical science. With the help of Kent State's faculty, Pake received a head start in physics which served him well when, as a Westinghouse Scholarship student at the Carnegie Institute of Technology, he received his B.S. and M.S. degrees just 32 months after matriculating. "My undergraduate career whizzed by in a kind of blur," Pake reports. "I often think I would never have survived the concentrated dose of studies had it not been for my music and the opportunity to play French horn in the Carnegie Tech orchestra." Pake worked at Westinghouse Research Laboratories for a year, then went to Harvard, where he received his Ph.D. in 1948. Four years later, at the age of 28, he became chairman of the physics department at Washington University in Saint Louis. He has been at Stanford since 1956.

IRVIN ROCK ("Repetition and Learning") is associate professor of psychology at New York's New School for Social Research, where he received his Ph.D. in 1952. Rock was born in New York and went to the now-defunct Townsend Harris High School, the only accelerated three-year high school for bright students in the U. S. Rock studied physics briefly, then transferred to psychology, which he studied at the College of the City of New York. He has taught psychology at the University of Kansas and C.C.N.Y. as well as on the graduate faculty of the New School.

MARTIN D. KAMEN ("A Universal Molecule of Living Matter") was the co-discoverer of carbon 14—an event which turned him from a physical chemist into a founder of the science of tracer studies in biology. Now a professor at Brandeis University, he studied at the University of Chicago and at the Radiation Labora-



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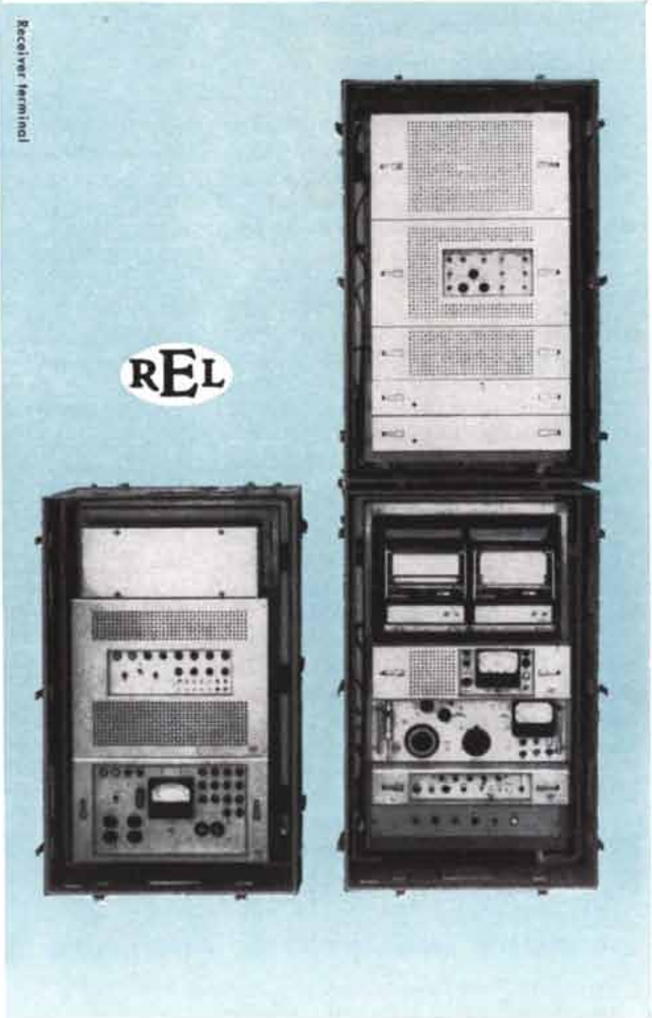

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Canadian representative: AHEARN & SOPER CO · 384 BANK ST · OTTAWA tory of the University of California, then did wartime work in the Manhattan Project and taught at Washington University in Saint Louis.

RAY S. SNIDER ("The Cerebellum") is professor of anatomy at the Northwestern University School of Medicine. Trained at Washington University in Saint Louis, he received his Ph.D. in medicine there in 1937, then worked for five years at the Johns Hopkins University, where his research with the electroencephalograph led to the unexpected discovery of perception centers in the cerebellum. From 1944 to 1946 Snider took part in the work of the Manhattan Project at the University of Chicago; he was senior biologist at the Bikini atomic bomb test. Since then he has taught at Northwestern and renewed his studies of the cerebellum.

S. H. HUTNER and JOHN J. A. McLAUGHLIN ("Poisonous Tides") are microbiologists at the Haskins Laboratories in New York City. Hutner was born in Brooklyn and graduated from the College of the City of New York. "My interest in marine microbiology goes back to undergraduate days," he says, "when I spent many weekends rowing in and around Jamaica Bay and the Rockaways, and saw marvels such as beaches bright green with sand-encrusting flagellates and drainage ditches red and purple with masses of photosynthetic bacteria. I resolved then to learn to cultivate such creatures. One needs, I discovered, a polychromatic rather than a green thumb!" After acquiring a Ph.D. in microbiology from Cornell University, Hutner worked for the New York State Department of Health, then joined the Haskins Laboratories in 1941. McLaughlin, also a New Yorker, studied at St. Francis College and St. John's University in Brooklyn after completing a wartime stint with the 14th Air Force in China. He has earned a Ph.D. from New York University and is assistant professor of biology at St. Francis College.

GEORGE GAYLORD SIMPSON, who reviews the new edition of Darwin's autobiography in this issue, is professor of vertebrate paleontology at Columbia University and curator of fossil mammals and birds at the American Museum of Natural History. He has done extensive field work in North and South America in search of early mammals and is the author of a number of well-known books, including *The Meaning of Evolution* and *Life of the Past.*

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Lucretius...on discovering truth

"...no fact is so simple that it is not harder to believe than to doubt at the first presentation. Equally, there is nothing so mighty or so marvellous that the wonder it evokes does not tend to diminish in time. Take first the pure and undimmed lustre of the sky and all that it enshrines: the stars that roam across its surface, the moon and the surpassing splendor of the sunlight. If all these sights were now displayed to mortal view for the first time by a swift unforeseen revelation, what miracle could be recounted greater than this? What would men before the revelation have been less prone to conceive as possible? Nothing, surely. So marvellous would have been that sight—a sight which no one now, you will admit, thinks worthy of an upward glance into the luminous regions of the sky. So has satiety blunted the appetite of our eyes. Desist, therefore, from thrusting out reasoning from your mind because of its disconcerting novelty. Weigh it, rather, with discerning judgment. Then, if it seems to you true, give in. If it is false, gird yourself to oppose it."

—Lucretius, 1st Century B.C.

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Beryllium and Berylliosis

Extracted from beryl, a crystal which is almost identical with emerald, this light metal has found glamorous applications in modern technology. It is also capable of causing a serious disease

by Jack Schubert

Injury and death to hundreds of American workers during the 1940s might have been averted if the prescient advice given a decade earlier by an Italian physician had been heeded. On the basis of animal experiments and known human cases, Stefano Fabroni gave the name berylliosis to an illness which followed soon after the inhalation of dust and fumes of irritating salts of the relatively obscure metal beryllium. He wrote: "In view of the important practical applications of beryllium in industry . . . which all indicate that the importance of this metal will continue to grow, we feel it is of interest now to call the attention of scientists to the picture of berylliosis . . . so that there will be the chance of timely development of measures to prevent this grave malady of the lungs from being added to the catalogue of industrial diseases."

The story of berylliosis is one of the most fascinating, contradictory, infuriating and controversial episodes in medical history. Some medical people argue even now that beryllium is incapable of causing disease. One writer in *The Lancet*, the esteemed British medical journal, invoked sheer sentimentality: "Beryllium seems to be the Admirable Crichton of metals. . . . To charge such an admirable metal with having poisonous properties is about as distasteful as accusing a trusted butler of stealing the family plate."

When one examines the clinical, biochemical and toxicological evidence, however, one cannot escape the fact that beryllium has caused at least 500 cases of poisoning in the U. S. alone during the past two decades. Particles of the metal or its compounds, wherever they are deposited, but especially in the lungs and skin, do extensive local damage to the tissues; reduction in respiratory capacity and general systemic debility have terminated in death in 10 to 30 per cent of all the cases.

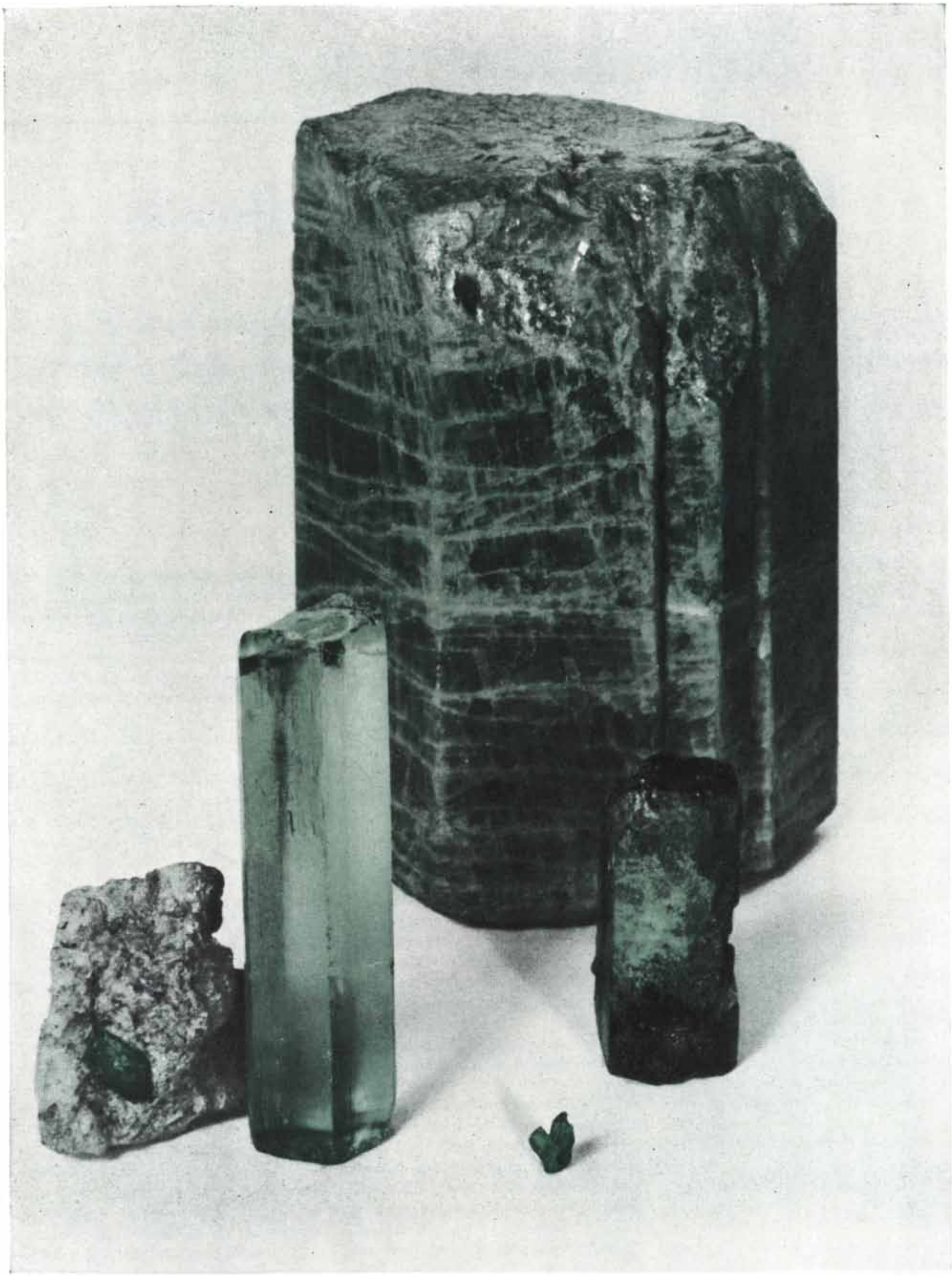
Beryllium performs heroic functions in hundreds of everyday products even though its total annual production is measured in pounds. A little beryllium goes a long way, especially in the alloys which account for most of its consumption. It is a glamorous newcomer to metallurgy, one of a number of rare metals now brought into wide use by virtue of highly specific properties which technology has only recently learned to appreciate.

Beryllium has special glamour because it is the element that distinguishes the crystal structure of the precious emerald. The discovery of beryllium in 1798 stemmed from the observation by the French mineralogist René Just Haüy that the optical properties of the emerald were identical with those of the more common mineral beryl. He asked Louis Nicolas Vauquelin to make a chemical analysis. Vauquelin proved that both substances had the same composition and contained a new element. Since the salts of beryllium are sweet-tasting, the new element was first called glucinium. The name beryllium was given by Friedrich Wöhler in Germany in 1828, when he succeeded in isolating the pure metal. With an atomic weight of nine, it is one of the lightest elements.

The emerald is a transparent, intensely green variety of beryl. The hexagonal crystals of beryl itself may be greenish, bluish or rosy, but in the field they tend to assume the color of the granitic rocks with which they are generally associated. Occasionally they attain gigantic size, up to two or three feet in diameter and several feet in length, weighing several tons. Some 60-ton crystals have been found.

Beryl is the single industrially significant beryllium-bearing mineral. The small size of the beryllium ion favored its diffusion as a minor constituent in numerous minerals, and discouraged the formation of high-concentration beryllium minerals. The world resources of beryl are estimated at four million tons, the principal deposits being in Brazil. Miners have to move, on the average, about 100 tons of rock in order to hand-pick half a ton of beryl crystals. A ton of beryl, which sells for $400 to $500, yields about 70 pounds of beryllium, worth about $4,200. (Emerald is worth some $25 billion per ton!) For better or worse, the production of beryllium will always be measured in pounds.

As a light element, beryllium should be a great deal more abundant on earth. It appears, however, that the beryllium nucleus is easily destroyed by collision with high-energy protons, as in the sun and other stars. In the cold reaches of



BERYL closely resembles emerald and aquamarine. The large crystal is beryl. At left in foreground is limestone containing emeralds. Second from left is an aquamarine. Third and fourth are emeralds. Specimens are in the American Museum of Natural History.

interstellar space, where such collisions are rare, beryllium occurs in much higher relative concentration. The scarcity of beryllium on earth, then, indicates that our planet passed through a stage of stellar temperature. Curiously the cosmic ray bombardment of the earth's upper atmosphere results in the transformation of nitrogen and oxygen into beryllium 7 and beryllium 10, two radioactive isotopes of the element. The latter has a half-life of 2.5 million years; incorporated in snow and ocean sediments, it fills an important gap in geological age measurement.

The principal uses of beryllium stem from the discovery in the 1920s that the addition of only 2 per cent of beryllium to copper forms an alloy six times stronger than copper. Beryllium-copper alloys stand up at high temperatures, have great hardness, show resistance to corrosion, do not spark and are nonmagnetic. One finds them used in the critical moving-parts of aircraft engines and in the key components of precision instruments, mechanical computers, electrical relays, switches and camera shutters. Springs made of these alloys retain their springiness almost indefinitely. Beryllium-copper hammers, wrenches and other tools are employed in petroleum refineries and other plants where a spark from steel against steel might ignite an explosion or a conflagration.

The peculiar virtues of its alloys brought a sudden expansion of beryllium production during World War II. The needs of war machines were so specialized and urgent that it was easier to expand the supply of this rare element than to look for substitutes. Moreover, it happened that beryllium was destined for a special role in the development of the atomic weapons.

When beryllium atoms are bombarded with alpha particles (*e.g.*, from radium), their nuclei disintegrate and yield a profusion of neutrons. This reaction led James Chadwick to the discovery of the neutron itself in the early 1930s, and a radium-beryllium source provided the neutrons for the historic experiments of Enrico Fermi that led to the discovery of uranium fission. Beryllium is one of the most efficient materials for slowing down the speed of neutrons; it is also an excellent neutron reflector. The Manhattan Project overnight created a big new market for beryllium. Incidentally, one of the physicists working in the program is numbered among the first clearly diagnosed cases of berylliosis in the U. S.

Beryllium remains today an important material in nuclear technology. At least one U. S. atomic submarine went to sea powered by a beryllium-moderated reactor, and a reactor in the U.S.S.R. has a beryllium moderator and reflector. Last year the Atomic Energy Commission invited proposals for the supply of about 100,000 pounds of "reactor-grade" beryllium a year for five years. This amounts to roughly a 30-per-cent increase in production.

Presently the makers of advanced aircraft, missiles and of space ships to come are developing ambitious plans for beryllium. The metal has much higher rigidity and heat stability than the other light metals, qualities that commend it for use in airframes and rocket bodies. The oxide has a higher heat conductivity than any known ceramic and looks like a promising material for re-entry cones. Were it not for its toxicity and scarcity beryllium might make the ideal rocket fuel; it packs more energy per unit volume than any other element.

The general public first became acquainted with beryllium as an ingredient in the phosphors that give fluorescent lamp tubes their glow. Until 1949 nearly all fluorescent tubes were coated with beryllium phosphors. It was this use of beryllium that first exposed large numbers of industrial workers and the general public as well to the hazard of berylliosis. Most of the cases have been traced to exposure to the phosphor dust, either in the manufacturing process or in the disposition and incidental destruction of old fluorescent tubes. By 1949 the list of cases had grown to such alarming proportions that the major manufacturers of fluorescent tubes decided in consultation with officials of the U. S. Public Health Service to discontinue the use of beryllium phosphors.

The ill effects of beryllium compounds on workers who handled them were first observed in the U. S. in 1940 by Howard S. Van Ordstrand and his colleagues at the Cleveland Clinic. The workers were employed in processing beryllium ores; one of them died late in 1940. Not long afterward the first cases involving workers exposed to beryllium phosphors were recorded in Pennsylvania. Suspicion of beryllium was allayed at this early stage, however, by medical literature dealing with similar cases in Europe. Beginning in 1933 there had been reports from Germany, Italy and the U.S.S.R. of an occupational disease peculiar to beryllium workers. Because the victims were exposed to fluorine and other acid-forming compounds of the metal, and because the symptoms so closely resembled the effects of wartime poison gases in which fluorine was the active ingredient, the trouble was laid to the corrosive action of acids, not to beryllium. The clinical picture of the Ohio and Pennsylvania cases fitted precisely the symptoms described in the European literature: a first stage of chills, fever and profuse perspiration, then progressive involvement of the lungs, shortness of breath, a painful cough and an X-ray picture suggesting tuberculosis. Accordingly the U. S. physicians adopted the European diagnosis and exculpated beryllium, even though some of the victims, those working with beryllium phosphors, were exposed to beryllium oxide, which forms no acids.

By 1945 Van Ordstrand had reported on 170 cases of illness in beryllium workers. These patients exhibited damage to the skin as well as to the lungs. The findings were typical: 42 of the patients had severe skin ulcers with the most intense reaction occurring on the hands, arms, face and neck. When exposure to beryllium compounds was terminated, the dermatitis subsided and cleared up. Some ulcers persisted. In these cases a minute crystal of beryllium or a beryllium compound was invariably found entrapped within the skin; healing followed removal of the crystal.

In 1946 the hazard that threatened beryllium workers developed an alarming new aspect. Most of the cases reported up to that time had been acute attacks arising during exposure to beryllium compounds. Two physicians associated with the Massachusetts industrial hygiene office, Harriet L. Hardy and Irving R. Tabershaw, now reported on 17 cases of chronic illness arising long after exposure had ceased. All these patients had been engaged in the manufacture of fluorescent lamps in a plant in Massachusetts, and had worked an average of 17 months in the building where the phosphors were compounded. Their illness did not become noticeable until six months to three years after they had quit working in the building and had ceased to have contact with beryllium.

The beryllium compounds involved in these cases had no fluorine or other acid-forming element to divert concern away from beryllium itself. The recipe for phosphors called for pure beryllium oxide, mixed with silica and the oxides of other metals and fused in a furnace at temperatures in excess of 2,000 degrees Fahrenheit. After firing, the rock-like batch of phosphors had to be pulverized for coating the inside of the lamp tubes. The operation was at times a dusty one and exposed the skin and respiratory system of the workers to beryllium compounds in powdered form.

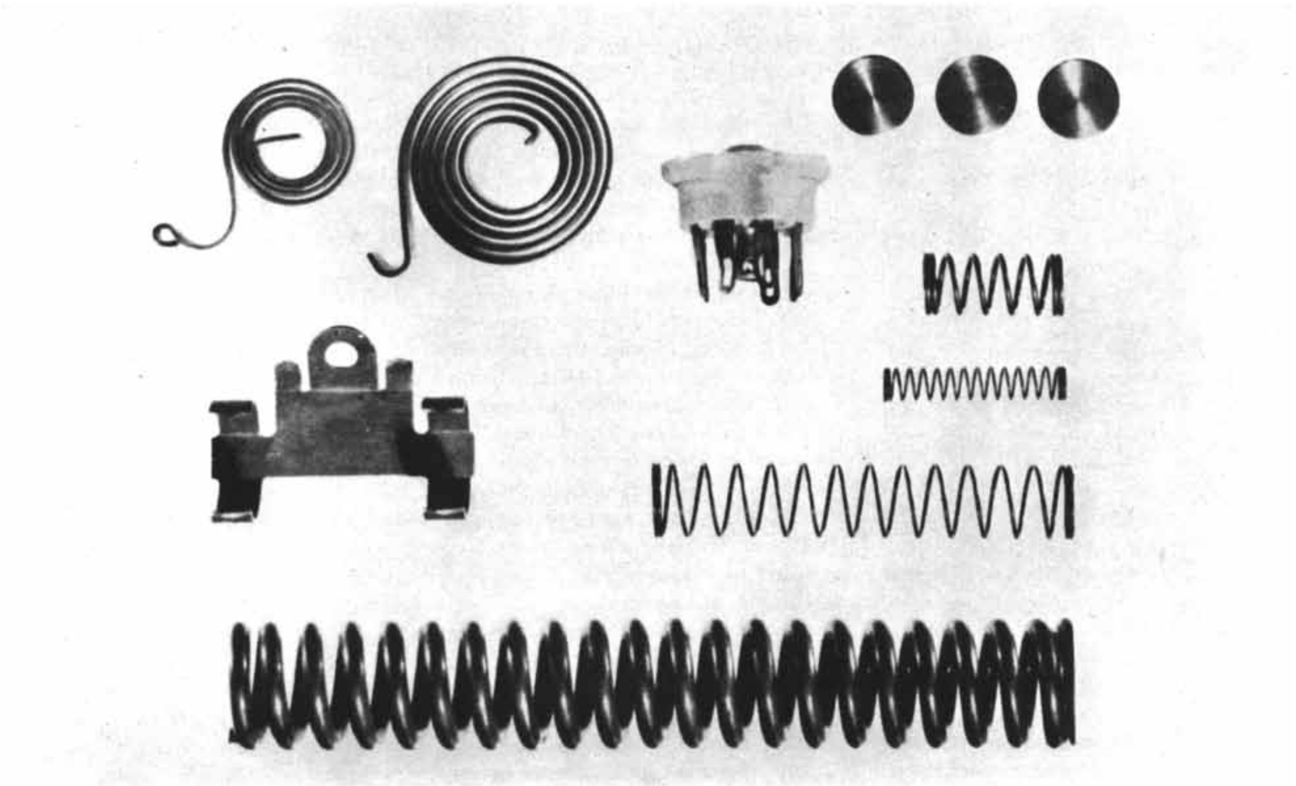
The cases of delayed or chronic illness clearly implicated beryllium itself as the poison. The principal distinction between the various beryllium compounds now appeared to be merely their relative solubility in the body fluids. The acid-forming compounds are the most soluble; in the Cleveland ore-processing plant they produced immediate illness. The lesions in the lungs and skin in these cases were only incidentally complicated by the action of acids. In its oxide, beryllium appears to be somewhat less soluble, and in its silicate phosphor-compounds even less so. These compounds produced the delayed illness among the fluorescent-lamp workers.

The chronic form of berylliosis is distinguished from the acute chiefly by the delay between the exposure to beryllium and the onset of symptoms. The case of the Manhattan Project physicist mentioned earlier typifies the course of the chronic disease. His exposure began in 1938 at Columbia University, where on several occasions he handled finely powdered pure beryllium metal in making up neutron sources. Later at Chicago, where he was engaged in assembling the world's first nuclear reactor, he handled beryllium-oxide bricks. The first sign of his illness was not detected until 1946, when a routine chest X-ray yielded the finding "the lung fields are diffusely granular in appearance and look subjectively like silicosis." At that time he felt in good health, and nothing was done about his condition. In the summer of 1948, however, he went to the hospital, suffering general debility and with his weight down 20 pounds.

There are 35 similar cases, in which symptoms were not noted until more than 10 years after exposure. Chronic berylliosis is difficult to diagnose. The symptoms of shortness of breath, lowered vitality, weight loss and reduction in respiratory capacity are typical of many debilitating illnesses. The chest X-ray, which is said at times to give the appearance of a sand- or snow-storm, may be mistaken for tuberculosis and other diseases. Unless the physician has special experience and instruction he may misdiagnose a case of chronic berylliosis such as still turns up occasionally among persons who were exposed a decade ago, before the disease and its cause were adequately recognized.

Just as in the delayed form of the lung disease, the skin lesions caused by the less-soluble beryllium compounds do not appear until several months after exposure. This was a hazard particularly for the unwary consumer when beryllium was used in fluorescent-lamp phosphors. A typical case was that of a 12-year-old boy who was admitted to a Boston hospital with small painless swellings around the angle of the jaw on the right side. His story was that three months previously he had been playing with some friends at a dump. One of the boys, deciding an old fluorescent lamp tube would make an excellent baseball bat, hit a bottle with it. The tube broke, and pieces of phosphor-coated glass hit the patient on the right side of the neck. About eight weeks later small lumps began to appear beneath the scars on his face and neck. Upon analysis the tissue was found to contain several micrograms of beryllium. With the complete removal of the beryllium from the tissue, the condition cleared up.

The epidemiology of berylliosis assumed a truly bizarre character in the discovery of the so-called "neighborhood" cases of the chronic disease in 1947 in a Midwestern city. Not one of these people had ever worked with beryllium or handled it in any form. All of them, however, had lived within three quarters of a mile of a plant which pro-

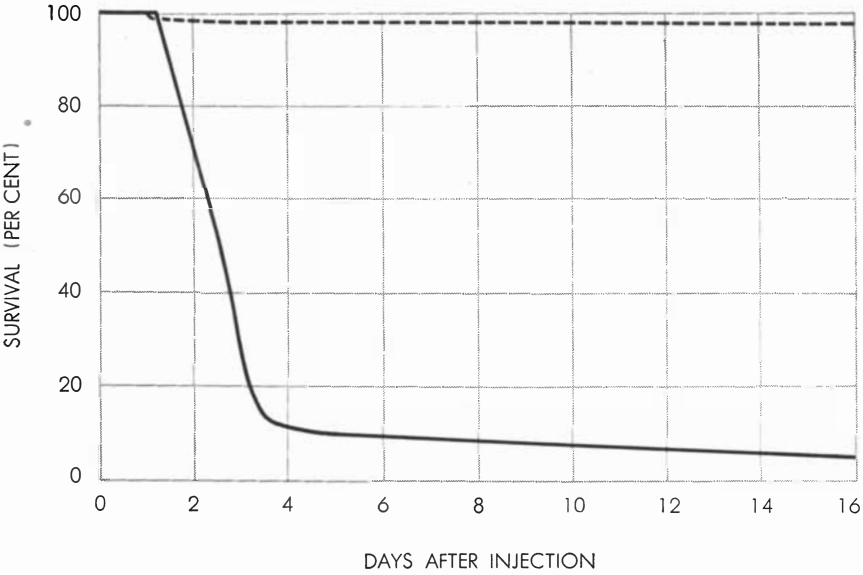


METAL PARTS are made of beryllium and its alloys. At upper right are three small disks of pure beryllium, used as windows for X-ray tubes. All the other metal parts shown here are made of beryllium-copper alloy, which is six times stronger than copper.

duced beryllium compounds from ore. When physicians in the community learned about these neighborhood cases, they soon discovered others in their records of undiagnosed lung disease. The apprehensive plant management instituted a chest X-ray survey; among 10,000 persons examined, two additional cases of berylliosis were discovered. It turned out that traces of beryllium were being emitted from the plant in the stack gases. Altogether more than 40 such neighborhood and nonoccupational cases of beryllium poisoning have been recorded. One woman lived nearly two miles from a beryllium plant; her husband worked in the plant, and she received her exposure from the dust she inhaled while washing his work clothes!

The registry of cases kept by Harriet Hardy at Massachusetts General Hospital in Boston shows that about 40 per cent have been of the chronic type, with a mortality rate of about 30 per cent. About 15 cases have involved individuals working in atomic-energy developments during the war years—an ironic fact in view of the extreme measures taken to protect workers from radioactive poisons. The Atomic Energy Commission has since led the way in the establishment of safe working conditions in the beryllium industry.

While beryllium alloys as commonly used appear safely nontoxic, one laboratory experience is instructive. During World War II a group of surgeons, testing various alloys for repair of massive bone damage, tried one alloy containing 1.6 per cent beryllium. They fixed plates of the alloy in dog skulls with screws made of the same alloy. After six months they were startled to find that the screws had loosened and that the screw holes and tissues in contact with the plate were lined with inflamed lesions.



MICE WERE INJECTED with a beryllium salt at Argonne National Laboratory. An hour later half of them were injected with aurintricarboxylic acid (ATA). Broken line shows survival of mice injected with ATA; solid line, survival of those not injected.

As yet the biochemistry of beryllium poisoning is little understood. The ion of the metal, dissociated from the oxide or salt in solution with the body fluids, appears to be the active principle. We know also that the chemical reaction of beryllium ions in the body invariably involves a hydroxide group (OH) attached to a benzene ring. Such phenolic hydroxide groupings, as they are called, are found in the amino acid tyrosine, which in turn undergoes metabolic transformation to such compounds as adrenalin which react with beryllium ions.

In the test tube beryllium inhibits the action of many enzymes. Injection of tiny amounts of its compounds in experimental animals causes massive damage to the cells of practically every organ with which the compounds come in contact. Similarly in human victims, upon autopsy, lesions are found scattered throughout the organs of the body as well as in the lungs. Beryllium poisoning is now accepted as a general disease, and it is recognized that the patient is sicker than the lung picture would suggest.

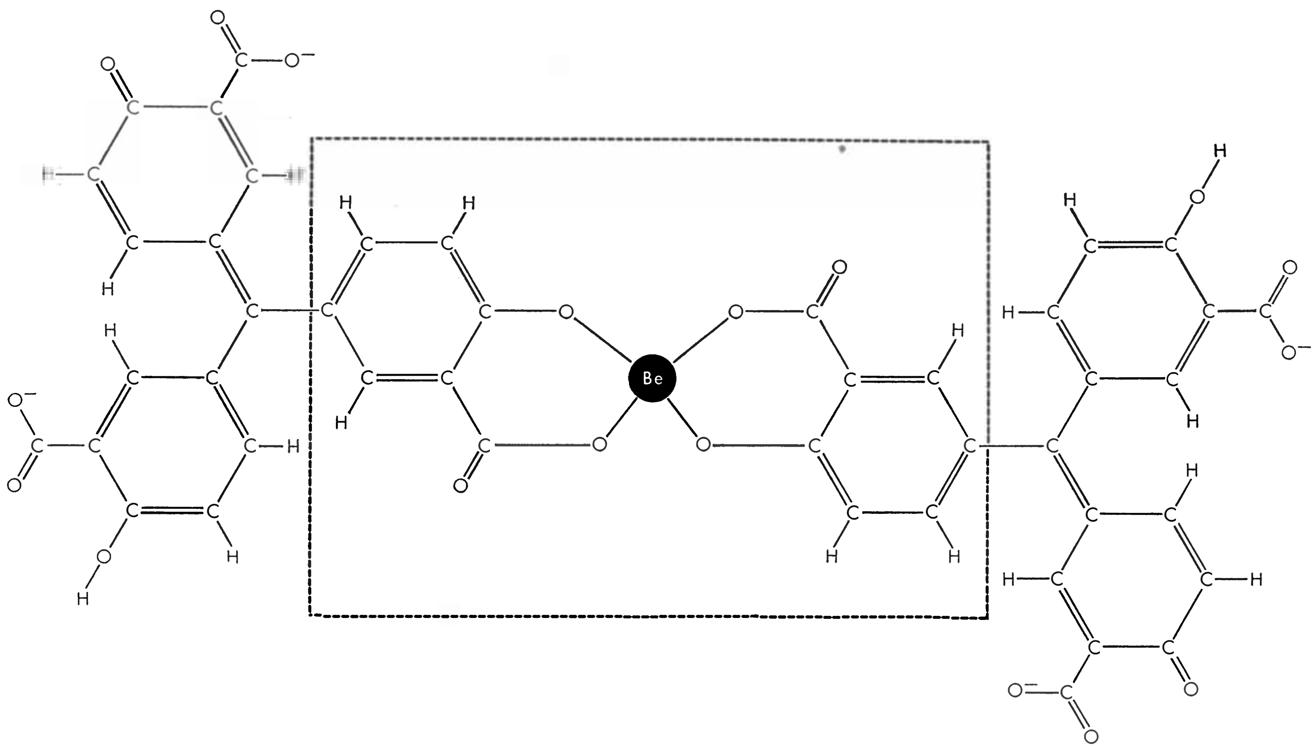
Examination of the lumps and nodules that form in the tissues suggests that beryllium possesses some power to cause the growth and proliferation of cells. This suspicion has been supported by the discovery that beryllium may induce cancer in experimental animals. The late Leroy Gardner of the Saranac Laboratory showed in 1946 that the intravenous injection of beryllium compounds in rabbits led to bone cancers. This finding has since been confirmed and extended to various animals, including guinea pigs and rats. Lung cancers also have been produced repeatedly with beryllium compounds. The investigators conclude: "These studies pose the grave question whether beryllium may not ultimately prove a factor in the genesis of certain cases of human lung cancer."

The question how beryllium acts on the tissue cells leads into the whole general problem of the role of trace metals in the processes of life. M. B. Hoagland at Harvard University has demonstrated that the growth-stimulating effect of beryllium is a general one, acting on algae and higher plants as well as on animal tissues. When he supplied a very small amount of beryllium salt to the nutrient of a tomato plant that had been stunted by depriving it of magnesium, the growth of the plant immediately showed a marked acceleration.

Ignorant as we are about the toxicity of beryllium, investigators have made one significant finding which already facilitates diagnosis and may lead to the discovery of an effective treatment. Patients invariably exhibit a kind of allergic response to beryllium compounds. It would seem, therefore, that beryllium must combine with protein in the body to form an antigen. The antigen stimulates the formation of beryllium-specific antibodies. As a result, in all cases of active berylliosis a small amount of any beryllium compound placed on the skin produces a local allergic reaction. This "patch test" is now a valuable aid in the diagnosis of beryllium poisoning. The finding that beryllium forms compounds with protein suggested in turn that the logical approach to treatment is to look for a way to tie up beryllium chemically so that it can no longer react with substances in the body.

With this in mind, our group at the Argonne National Laboratory began a search for a specific antidote to beryllium poisoning. At first we studied the possibility of injecting materials into experimental animals which would hasten the elimination of beryllium. However, we soon learned that it is nearly impossible to eliminate the poison once it has been deposited in the tissues.

We then determined to look for a drug



ACTION OF ATA is explained. The molecular structure of ATA is given in the diagram at left. ATA is a chelating agent, *i.e.*, a substance which chelates or sequesters a metal ion within a larger structure of atoms. In this case the metal ion is beryllium (Be). The

which would seek out beryllium deposited in the body and form an insoluble compound, thus inactivating the metal. Such an agent, we thought, might be found among the chelates, an interesting class of dyestuffs which have the power to incorporate various metal ions selectively in their structures [see "Chelation," by Harold F. Walton; Scientific American, June, 1953].

We did not have to search long. There is a deep-red dye, well known to analytical chemists, which is used for the analysis of aluminum and to a lesser extent for beryllium and which, on paper, seemed to meet our requirements. This dye is known by the trade name "aluminon," and by the chemical name aurintricarboxylic acid, or simply ATA. In the first test of ATA we injected mice with enough beryllium salt to kill them within a few days. We then injected half the animals with a small dose of ATA and left the others untreated. The results were dramatic: virtually every animal treated with ATA survived and lived on normally, while all of the untreated animals died. We have repeated this experiment with hundreds of animals of different species, with the same high degree of protection.

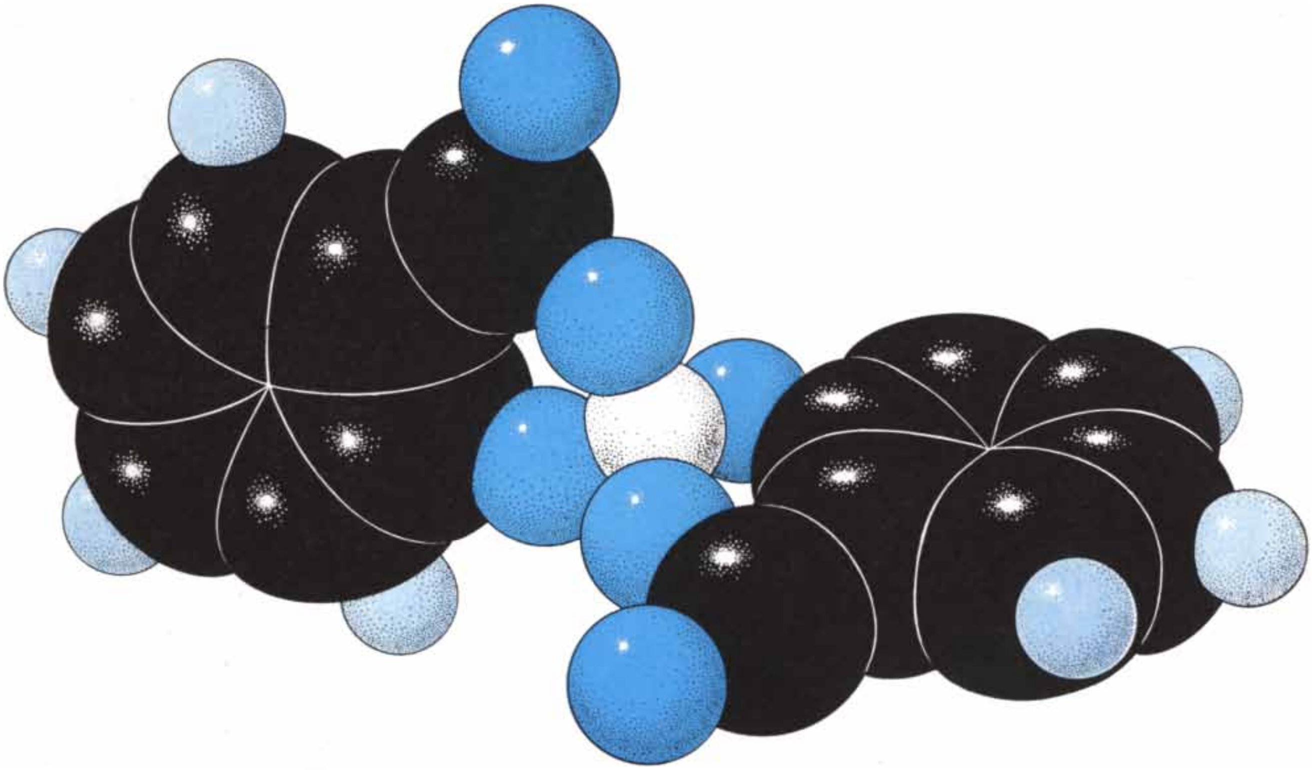
We checked the conclusions suggested by this experiment by injecting the animals with radioactive beryllium and with ATA tagged with tracer atoms. The picture that emerged was clear and unambiguous: ATA was found in practically every cell where beryllium was present. Previously damaged cells recovered, and within a few days could not be distinguished from the normal tissue. Nor could any abnormality be detected a year or more later, despite the fact that the beryllium-dye combination remained in the tissues.

We have tested many other compounds and found none as completely effective as ATA. Some of them have demonstrated a high affinity for beryllium in the test tube, yet have failed completely when injected in the experimental animal. Capacity to tie up beryllium does no good if the compound is unable to make contact with the beryllium in the tissues. All the compounds that failed have chemical groups which render them more water-soluble. As a result, they tend to remain in the water of the body and are rapidly excreted.

It is too early to say whether ATA will prove to be successful for the treatment of human beings. Clinical tests are being made. The main problem is to promote contact between ATA and beryllium. One approach involves the use of a special aerosol generator which breaks down the ATA into extremely small particles to insure that the material penetrates deep into the lung spaces. Intravenous injections will be tried along with the aerosol treatment. On the theory that ACTH and cortisone might render the lumps and nodules in the tissues surrounding the beryllium more permeable, these drugs may also be used in combination with ATA. As to the toxicity of ATA, physicians report they "are satisfied beyond any doubt that the ATA preparation is nontoxic, easy to administer and well tolerated by the patient."

Meanwhile, treatment of berylliosis patients with ACTH or cortisone has shown some success. Just why these drugs are helpful remains unknown. Certainly they have no effect on the beryllium itself. They do, however, provide many patients with some or with considerable relief. In the case of the Manhattan Project physicist described earlier, treatment with ACTH restored him to almost full activity.

Can the beryllium hazard be controlled? Is it possible to work with beryllium compounds in safety? The answer is a somewhat qualified "Yes." The problem reduces itself to one of good industrial housekeeping, which means keeping the levels of beryllium low. But how low is low? One important factor to be taken into account is that different forms of the same beryllium compound



three-dimensional structure of the atoms within the broken rectangle at left is shown in the illustration at right. When ATA is injected into body fluids containing beryllium, it sequesters the beryllium ions so that they cannot exert their poisonous effects.

may have radically different degrees of toxicity, depending upon particle size as well as solubility. On the basis of extensive tests the AEC early in 1950 concluded that all known cases of the acute disease could be attributed to air concentrations of soluble salts in excess of 100 micrograms per cubic meter, and that when the air level exceeded 1,000 micrograms of beryllium, nearly everyone developed acute beryllium poisoning. To minimize the risk of the chronic disease, on the other hand, the AEC found it necessary to recommend a limit of two micrograms per cubic meter. The strictness of this standard can be appreciated when it is realized that the corresponding limits for dusts of other metals such as lead, mercury, arsenic and cadmium range from 100 to 500 micrograms per cubic meter. As to the air in the neighborhood of a beryllium plant, the recommended limit is one hundredth of a microgram per cubic meter. To the best of our knowledge, no cases of beryllium poisoning have appeared in or around plants which have adopted these rigid standards.

These limits are, in fact, so low that they raise the general and sinister question whether the natural occurrence of beryllium in the environment might not at times be sufficient to induce beryllium lung disease in hypersensitive individuals. The tissues of most persons contain negligible amounts of beryllium, actually less than a microgram in the entire lungs, for example. Ordinary outdoor air contains about a thousandth of a microgram or less of beryllium per cubic meter. Beryllium, however, is concentrated by some plants, especially those growing in areas where the soils contain higher-than-average amounts of beryllium. The ashes of wheat straw are reported to contain as much as 2 per cent beryllium. Again, its concentration in certain coal ashes goes as high as 2 per cent. Another site of high concentration is forest litter. Examination of the lungs of coal miners has shown beryllium usually present in amounts far in excess of normal and in many instances greater than in known berylliosis cases. Yet the lungs of these miners had no lesions suggesting the disease. It must be emphasized that the severity of berylliosis does not necessarily reflect the amount of beryllium in the lungs. The total amount is not as important as the fractional amount present in an active form. It seems, therefore, we do not have to worry that we might fall victim to chronic beryllium poisoning merely from breathing outdoor air.

I say "seems" because physicians remain puzzled by some 1,800 cases of sarcoidosis, a lung malady, discovered among troops from the southeastern states during World War II. Their condition resembles berylliosis. The soil of their granitic native countryside has a higher than average beryllium content. Recently investigation has shown that the pollen dust of local evergreens carries lipid compounds similar to lipids found in tubercle bacilli. But the case is not yet closed.

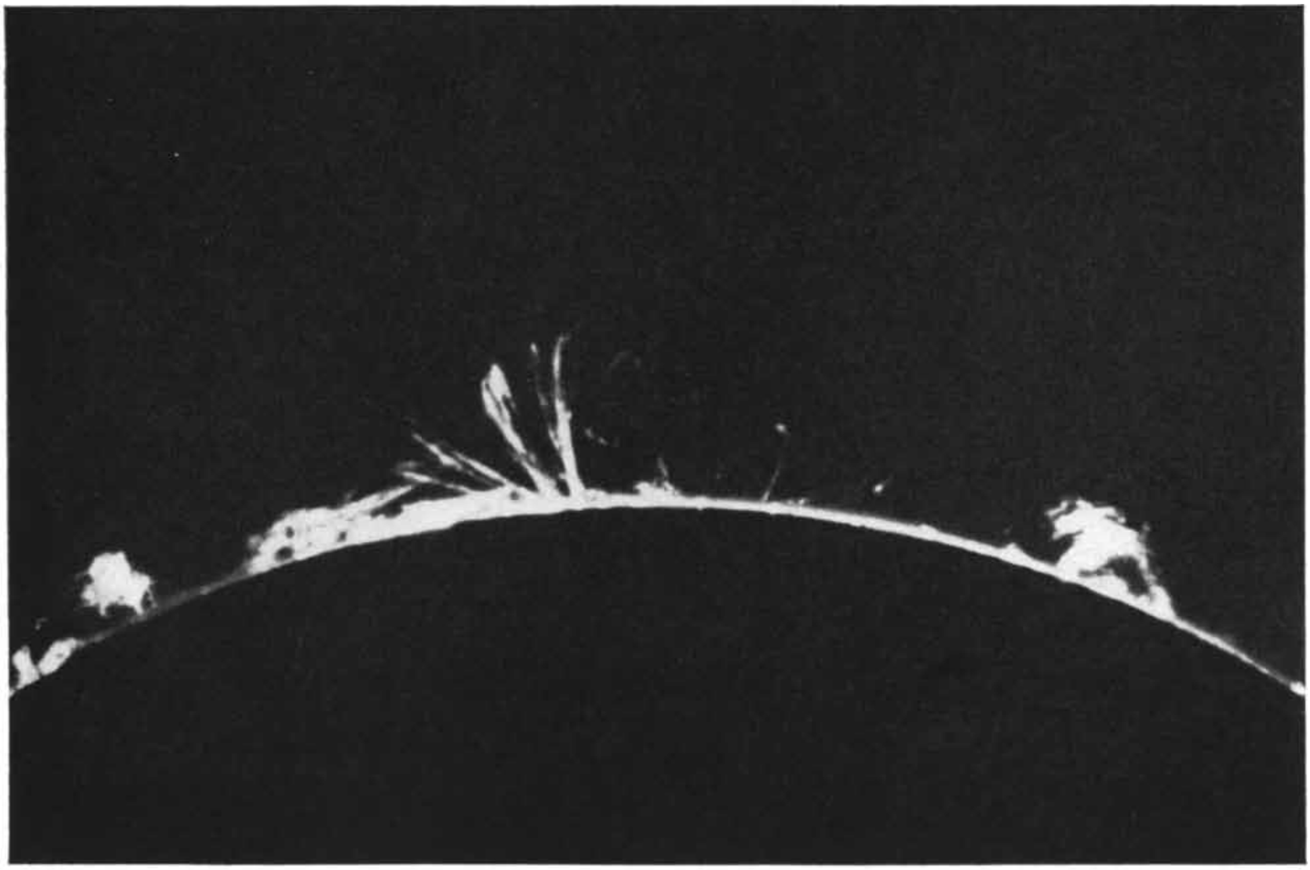
More than 250 years ago Bernardino Ramazzini, the great student of industrial diseases, wrote that when physicians have a working man as a patient they should inquire into all the details of his occupation, because without this information a correct diagnosis cannot be made. The story of beryllium highlights the whole problem of occupational disease in the present era. Advances in technology now develop so rapidly that the rare material of yesterday becomes the widely used material of today. The beryllium mishaps teach the lesson that the harmlessness of a material cannot be taken for granted; a new material must be regarded as harmful until proved otherwise. Industrial medicine must provide safe working conditions before harm results; public health agencies must see that the public is not exposed to fumes from industrial processes until safe tolerances are known.

Hot Spots in the Atmosphere of the Sun

Regions in the sun's corona appear to be as much as 1,000 times hotter than its surface. They may be the long-sought connection between sunspots and disturbances in the atmosphere of the earth

by Harold Zirin

Galileo's 16-century contemporaries rejected his report that he had seen spots on the face of the sun. His *Letters on the Solar Spots,* they said, were full of "damnable matter," heretically contrary to the dogma that "this most lucid body" must be without blemish. But knowledge of the existence of sunspots was inescapable. Centuries before Galileo trained his telescope on the sun, sky watchers in China had beheld them with unaided eyes. Galileo's successors in astronomy brought the sun under close surveillance and, after two or three centuries, established that the spots fluctuate in number in a regular 11-year cycle. Simple observation showed this cycle to be synchronized with a corresponding fluctuation in the number of displays of the aurora borealis. Men began to suspect that the sun-



LOOP PROMINENCES appear in the center of this photograph made with the coronagraph of the High Altitude Observatory of the University of Colorado. The coronagraph artificially eclipses the sun's disk so phenomena in its lower atmosphere can be observed.

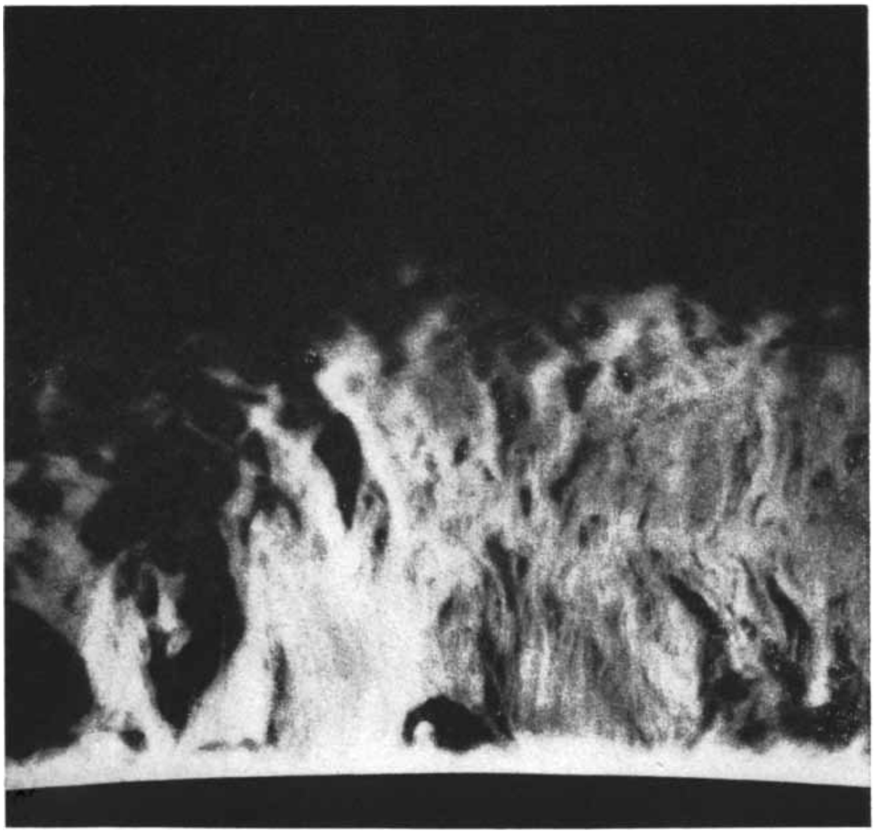
spots exert profound effects on our planet. It was discovered that the passage of spots across the face of the sun is associated with violent storms in the earth's magnetic field; with the arrival of radio it was found that these storms were accompanied by widespread blackouts of radio communication.

Now we are at the beginning of the next significant advance in knowledge of the sun. Though the statistical coincidence of solar activity and geomagnetic storms is conclusive, physicists have been unable to describe a process connecting events on the solar surface with the earth's high atmosphere. The ionized layers of our atmosphere, and the storms which perturb them, require a source of high-energy radiation and highly energetic particles. Obviously the sun is this source. But just as the earth's atmosphere shelters us from the hard radiation and cosmic particles raining in upon it, so the sun's own atmosphere absorbs and blocks the shorter wavelengths of energy and the particles that radiate from the solar surface. A crucial link was missing between the physics of the sun and that of the earth. Recent advances in instrumentation, however, have made it possible for solar astronomers to turn from the face of the sun to investigate the solar atmosphere. There, thousands and even millions of miles out in space above the sunspots, they have found clouds of gas with temperatures in the millions of degrees, far hotter than the 4,000-degree surface of the sun.

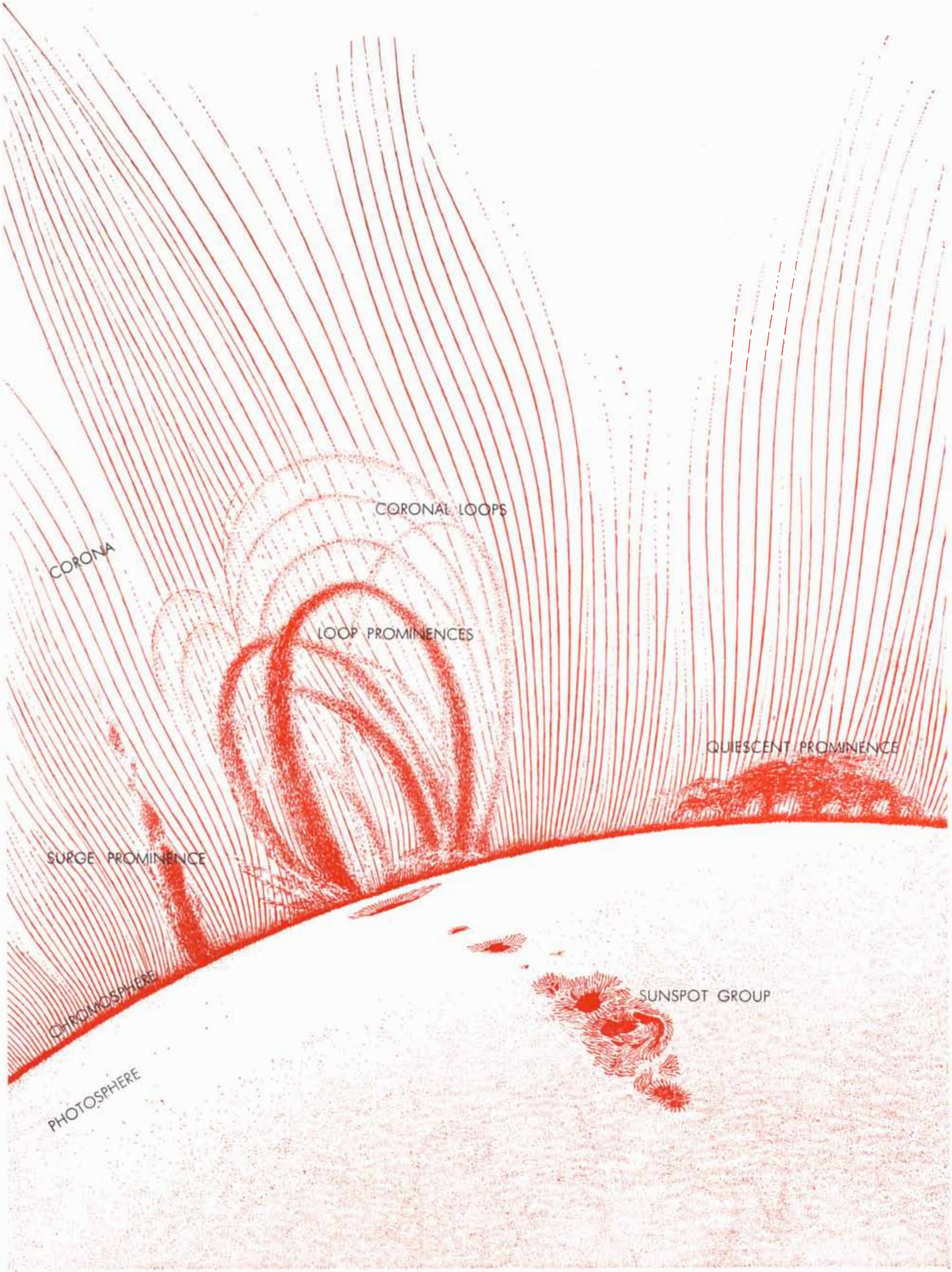
These hot spots in the solar atmosphere are a major focus of interest in the world-wide program of observation concerted by the International Geophysical Year. The time is propitious, for this effort was scheduled to take advantage of the present sunspot maximum, and it has turned out to be the most active maximum in the history of solar astronomy. Rapidly accumulating evidence points to the conclusion that the hot spots in the solar atmosphere furnish the connection between the spots on the surface of the sun and the effects we experience on our small planet.

For many years astronomers who wanted to observe the sun's atmosphere had to wait for the infrequent opportunity of a solar eclipse, when the moon for a few moments blots out the photosphere (the sun's surface seen in ordinary light). The dazzling light of the photosphere, containing all the wavelengths of the visible spectrum, overwhelms at other times the faint light

SURGE PROMINENCE shoots upward 120,000 miles at a speed of 120 miles per second. Unlike surge prominences, loop prominences appear to condense out of the sun's atmosphere.



QUIESCENT PROMINENCE billows up from the surface of the sun at relatively low speed. This coronagraph picture was made by R. B. Dunn at the Sacramento Peak Observatory.



LAYERS OF THE SUN'S ATMOSPHERE are (1) the photosphere, which is synonymous with the sun's surface as it is seen in white light; (2) the chromosphere, which is some 6,000 miles deep; (3) the corona, which extends outward for millions of miles.

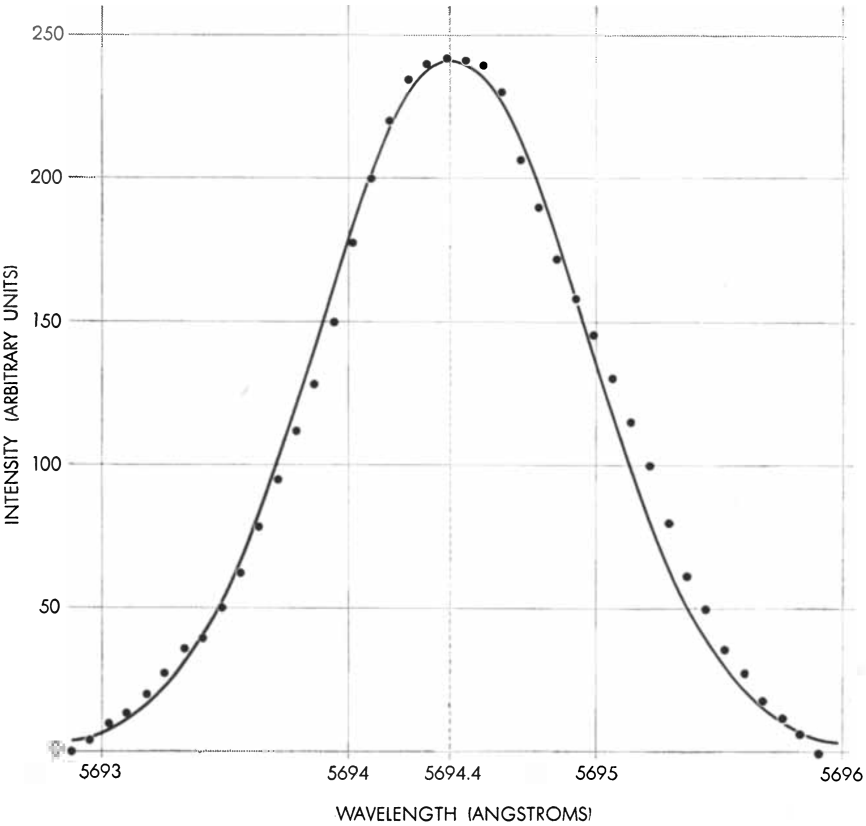
radiated in a number of distinct wavelengths by the gases in the atmosphere. Today, thanks to the genius of the late Bernard Lyot, astronomers are able to keep a day-to-day watch on the sun's atmosphere. Lyot invented the "coronagraph" to make an artificial eclipse. This specialized telescope cuts out the light of the sun's surface with an occulting disk and employs an elaborate train of optics to get rid of scattered light. Lyot furthermore devised a filter which selectively admits narrow regions of the spectrum. With the Lyot coronagraph and filter we can observe the processes that go on in the solar atmosphere; by attaching a spectrograph we can determine which components of the atmosphere are involved, and under what physical conditions their light is emitted.

Just above the photosphere we see the "chromosphere," the lowest layer of the atmosphere, which appears as a bright rim around the solar disk about 6,000 miles deep. Beyond the chromosphere the sun's corona, a diffuse gaseous envelope, stretches several million miles into space—perhaps even as far as the earth. At the bottom of the corona luminescent gas clouds, the solar "prominences," appear. They may take the form of very large, quiescent masses, active loops, or fast jets called surges. A time-lapse motion picture provides an exciting view of the behavior of the prominences, especially the beautiful loops. Most of the time these appear to condense right out of the corona. First a small horizontal arc will appear, growing downwards until it forms a complete loop reaching into the chromosphere. Incandescent material pours down the arms of the loop, and more loops continually form. The motion of the material is obviously governed by a local magnetic field related to a nearby sunspot. A Lyot filter passing the light of the strongest spectral line emitted by the corona reveals a diffuse loop structure paralleling the sharp prominence line. Associated with the loops we see the spectacular surge prominences that stream upward with velocities of 60 to 120 miles per second—sometimes even 600 miles per second. Most of the material that goes up in these surges seems to come down, so we are at a loss to account for the material that moves downward in the loop prominences, except for the possibility that hot invisible material somehow streams upward from the surface and becomes visible when it cools and descends.

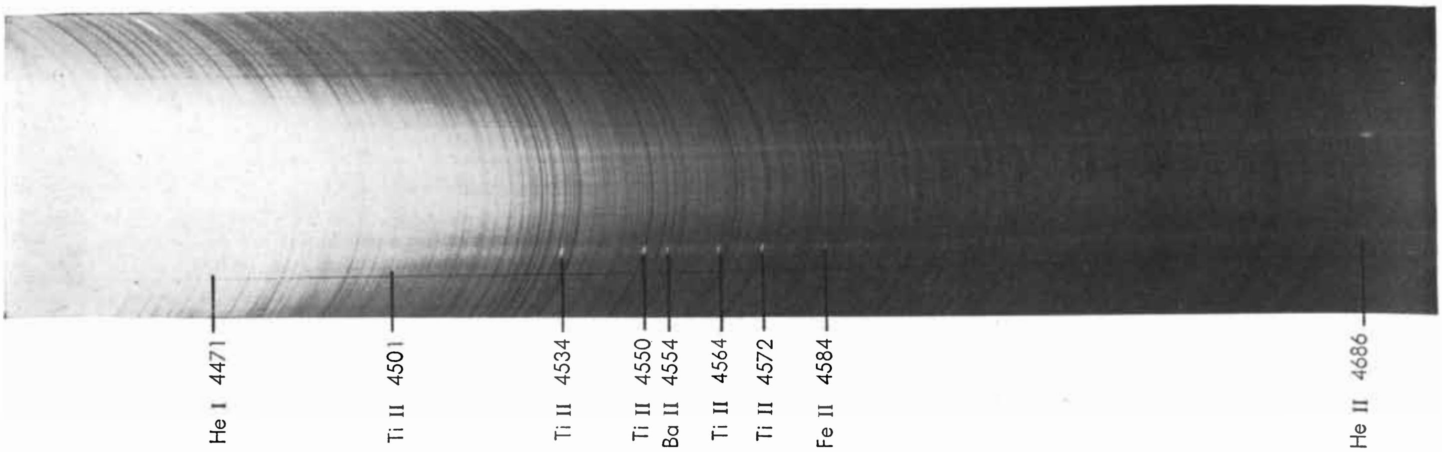
Surge and long prominences are almost always associated with sunspots. Observers accordingly keep closer watch on the east edge or "limb" of the sun: the appearance of prominences there often presages the appearance of spots, which become visible a day or two later as the sun wheels around in its 27-day rotation. West-limb prominences are frustrating, for they soon turn out of sight, leaving us guessing until the region reappears at the east limb two weeks later. Some sunspots, however, endure for several rotations.

When we look directly at the trillion square miles of solar surface, we can no longer see the loop prominences and the corona. These are visible only at the edge of the sun against the dark background of space. With the help of the Lyot filter, however, we can see the quiescent prominences as dark clouds against the surface. We see also the bright clouds, called plages or faculae, that accompany sunspots, floating low in the atmosphere. Occasionally one of these plages brightens strongly and rapidly. This brightening is almost invariably accompanied by a dark surge prominence. Such an event is a solar flare. On the rare occasions when we have managed to see flares in profile through the coronagraph, they look like surge or loop prominences which brighten suddenly and intensely, high in the atmosphere above the altitude at which the plages occur. Because the coronagraph occults the photosphere it is difficult to observe the low- and high-altitude components of a flare simultaneously. The composite picture, however, is confirmed by the fadeouts of short-wave radio communication that accompany a major flare seen either on the disk or at the limb. Flares are the most spectacular phenomenon of the solar atmosphere. Their effects on earth are so significant that a 24-hour-a-day (weather permitting) around-the-world flare patrol is being maintained throughout the International Geophysical Year.

With a spectrograph we can identify the elements whose radiation makes up the light from the solar atmosphere, since the atoms of each element absorb and emit energy only at sharply defined characteristic wavelengths. But we can



YELLOW LINE in the spectrum of Ca XV (calcium atoms from which 14 electrons have been removed) is shown in profile by the dots in this chart. The solid curve shows the distribution of wavelengths which would be expected from ionized atoms radiating at a temperature of four million degrees absolute. The broadening of the line is due to the Doppler shift in the light from atoms moving at high speed toward or away from the observer.



SPECTRUM OF LOOP AND QUIESCENT PROMINENCES shows the difference in their temperature. The lines of the spectrum are curved because the slit of the spectrograph is curved to fit the edge of the sun. The dark lines are due to sunlight scattered by the sky. The upper row of bright spots was made by the loop prominence; the lower row, by the quiescent. The labels indicate the wave-

also use the spectrograph to measure the temperature of the atmosphere. When an orbital electron is knocked free by a high-energy photon or particle and an atom is ionized, the characteristic line pattern of its radiation shifts. It takes a great deal of energy to ionize an atom, and so a high degree of ionization indicates an extremely high temperature. Indeed, the temperature of certain parts of the solar atmosphere goes so high that some elements are entirely stripped of electrons. Since they then cease to radiate, they become invisible as far as the astronomer is concerned.

Measurement by spectrograph gives a temperature for the prominences of the order of 30,000 degrees absolute (degrees centigrade above absolute zero). Hydrogen and helium continue to radiate their characteristic spectral lines, although most atoms of both species are already ionized. The same is true of the other elements. The spectra of the quiescent prominences indicate temperatures of around 10,000 degrees, perhaps even less. These large, long-lived prominences occur at some distance from sunspots and do not share their great activity, although they certainly have some role in the process. Their spectra show lines of neutral and singly ionized metals (with one electron removed) as well as lines of neutral helium and hydrogen.

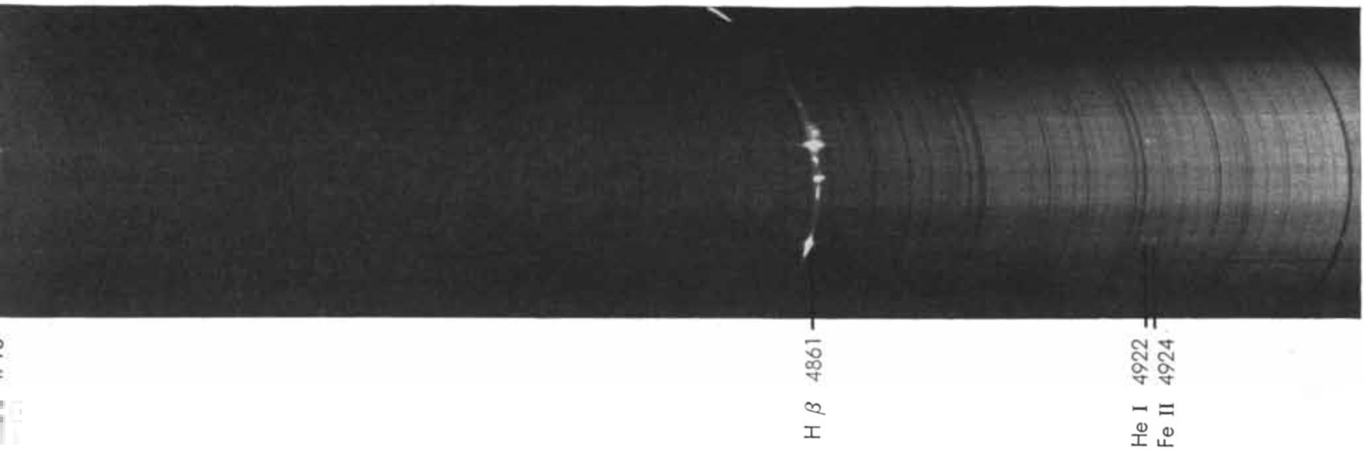
The spectrum of a loop prominence, such as the one at the top of these two pages, indicates a higher temperature. The metals have all lost two or more electrons, and no longer radiate their characteristic wavelengths. Ionized helium, producing light with a wavelength of 4,686 angstrom units, radiates strongly. The 4,686 line is an excellent tell-tale of high temperatures since the atoms emitting it require a great deal of energy for excitation, about 50 electron volts as compared to about five volts for atoms emitting the usual line. Ionized helium radiates strongly only at temperatures above 30,000 degrees. The solar flares appear at the limb to be dense, hot, bright prominences. They radiate the same spectrum as an ordinary loop prominence, but much more brightly.

The corona presents a quite different picture on the spectrographic plate, and for many years it mystified astronomers. The lines of its spectrum corresponded to no known elements. Furthermore, they were extremely broad and diffuse, as compared to the relatively sharp lines of the prominences. In 1940 Walter Grotrian of the Potsdam Observatory pointed out that one of the two brightest lines of the coronal spectrum, the red line with a wavelength of 6,374 angstroms, corresponded exactly to an energy level midway between two excitation states of the Fe X ion (*i.e.*, iron with nine electrons removed).

This suggestion was confirmed in 1942 in a brilliant paper by Bengt Edlén, a Swedish astrophysicist. Edlén identified a whole host of coronal lines as coming from jumps between energy levels of a number of incredibly highly ionized atoms. Some of these ions he had actually registered in electrical discharges in his laboratory; for the spectra of others he made theoretical predictions. In this remarkable work Edlén also analyzed the physical conditions under which these ions could exist and radiate the coronal lines. The corona, he concluded, must have a temperature of the order of 700,000 degrees. The exact temperature, as we shall see, is still not determined.

A remarkable physical process accounts for the coronal lines. In every atom the circling of the electrons around the nucleus makes an effective electrical current, which in turn produces a small magnetic field. At the same time the spinning of the electrons on their own axes produces another small magnetic field. The two magnetic fields interact in varying degrees depending on the inclination of the spin axis to the plane of the orbit. This "spin-orbit" interaction causes a slight change in the total energy of an atom. Thus the atoms can assume any of a number of different energy levels, according to the orientation of the spin axis to the orbit. The spacings between energy levels are extremely small in normal atoms, perhaps .001 electron volts. In highly ionized atoms, however, the spacings increase to several volts because of the powerful charge of the unshielded nucleus. The probability of transitions between these levels is so low that the radiations they emit are called "forbidden" lines. The state of the atoms in the corona is such that these forbidden transitions show up as the coronal lines. Edlén did not observe the forbidden lines in his laboratory. However, he did observe jumps from other atomic states to the levels in question and from these he determined the energies involved and predicted the wavelengths of the coronal lines.

The spectrograph thus pictures the corona as an extremely hot region where some uncommon atomic processes occur. Hydrogen and helium are completely ionized and do not radiate. The other atoms are so highly ionized that



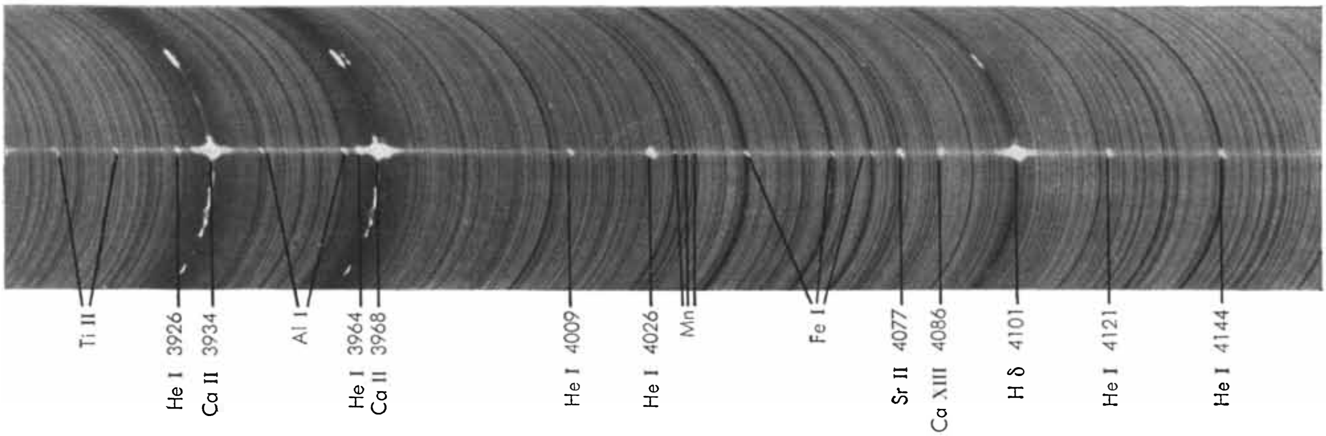
length (in angstroms) of the spots and the elements which made them: helium (He), titanium (Ti), barium (Ba), iron (Fe) and hydrogen (H). The numeral I means that the atom is neutral; II, that it has one electron removed, and so on. The spot for the loop prominence at 4686 angstroms (He II) is brighter than that for the quiescent, indicating that the former is hotter than the latter.

their radiation is all in the invisible ultraviolet, except for a few forbidden lines.

By watching the shifts and changes in the lines of the coronal spectrum over the past 15 years solar physicists have begun to see the dim outline of the processes in the corona that accompany the sunspot cycle. During the minimum sunspot activity the visible light of the corona is largely concentrated in the red line of Fe X, indicating the corona is at a relatively low temperature. As the level of activity rises, the Fe X line fades out, and the green line radiated by Fe XIV (iron with 13 electrons removed) grows stronger, showing up all around the edge of the sun. According to Edlén's calculations this indicates an ascent in the average coronal temperature to 800,000 degrees.

Against this general background, gas clouds in the corona above sunspots give evidence of even greater excitation. Most of the time we see sharp brightening in the Fe XIV line. But on occasion in the active coronal region above the sunspot the Fe XIV line fades, and we see the exciting yellow line of the Ca XV ion (calcium with 14 electrons removed). More energy is required to produce this ion than any other yet observed by man. It takes 814 electron volts to remove an electron from Ca XIV and make Ca XV; it takes only 13.6 volts to ionize hydrogen and 390 electron volts to remove an electron from Fe XIII. The appearance of the Ca XV line therefore indicates extreme heat, so great that even the green line of Fe XIV has been extinguished and the iron atoms have been raised to higher states of ionization which do not radiate so well. The yellow line of Ca XV tells us that the hot spots in the corona must reach temperatures of at least 2.5 million degrees!

An alternate method of measuring temperatures in the corona gives somewhat different results. This method utilizes the Doppler effect—the shift of the spectral lines toward the red or the blue end of the spectrum depending upon whether the emitting atoms are moving away from or toward the earth. If the atoms move in many different directions, the spectrograph will register a shift toward both ends of the spectrum, which shows up as a broadening of the lines. Since the random motion of atoms increases as temperature increases, temperature can be measured as a function of line width. Many workers have made these calculations, all with similar results. Donald E. Billings at the High Altitude Observatory of the University of Colorado has probably measured more coronal-line profiles than anyone else. He finds temperatures around 1.7 million degrees for the red line of Fe X and 2.2 million degrees for the green



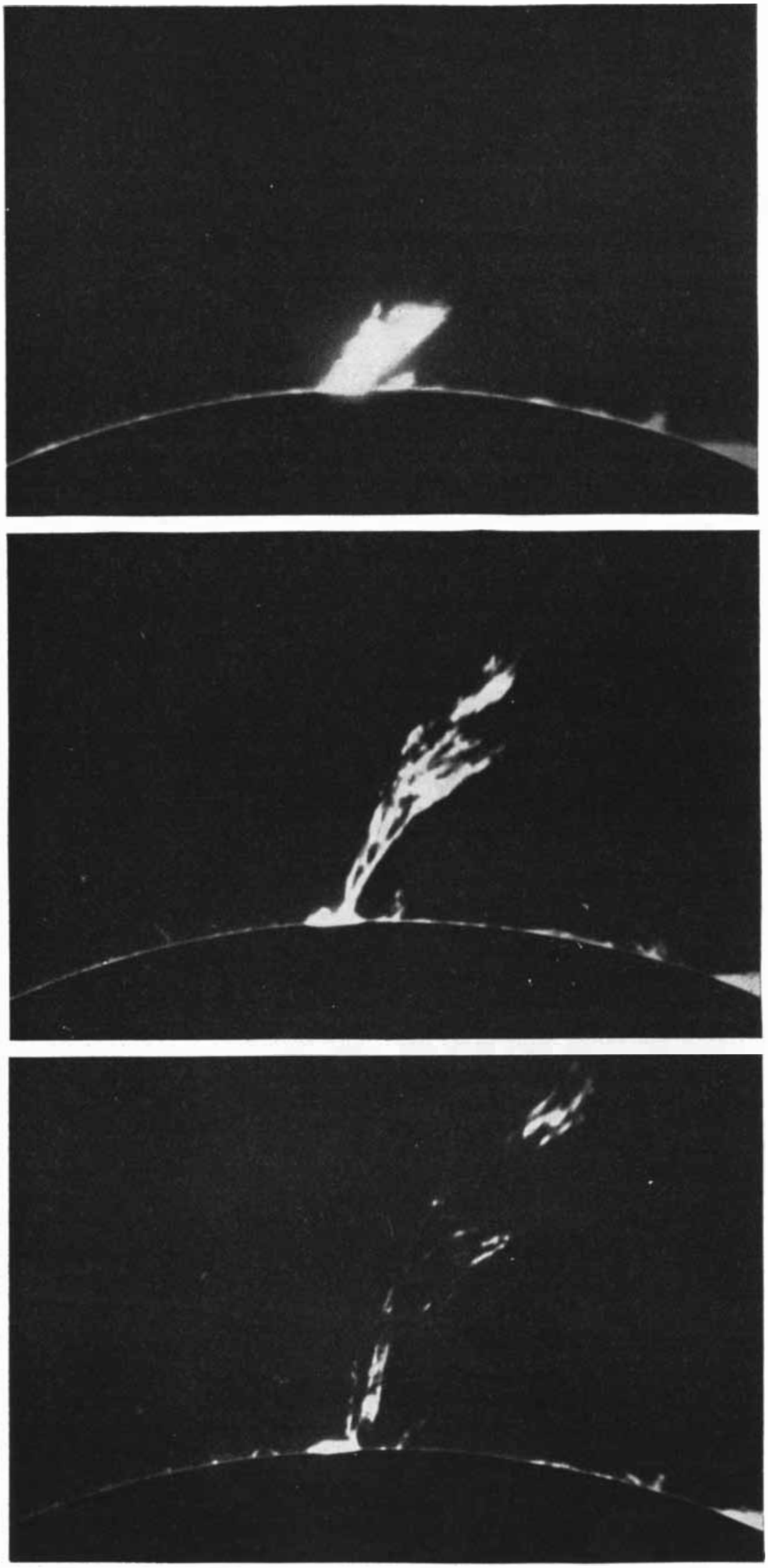
SPECTRUM OF FLARE indicates a still higher temperature. The elements responsible for these spots, in addition to those in the spectrum at the top of these two pages, are: calcium (Ca), aluminum (Al), manganese (Mn) and strontium (Sr). The relatively fuzzy spot at 4086 angstroms is caused by Ca XIII (calcium with 12 electrons removed) not in flare but in intertwined corona.

line of Fe XIV. Measurements of the Ca XV line by both Billings and myself, as well as by others, range from 2.7 to 4.5 million degrees. In the excited region of the corona associated with the limb flare of December 18, 1956, we observed an especially intense yellow line with Doppler broadening that corresponded to four million degrees.

The gap between Edlén's ionization measurements and those made by the Doppler effect is thus considerable. At the High Altitude Observatory we tend to credit the higher temperatures indicated by the Doppler profiles; calculations now in progress may bring the estimates from ionization into line. Since the temperatures are high to begin with, it might seem immaterial whether the normal coronal temperature is 800,000 or two million degrees, or whether hot spots reach 2.5 million or 4.5 million degrees. But the exact value has great significance in understanding the solar atmosphere, and in particular in estimating the amount of ultraviolet and X-ray radiation which originate there.

We still have much to learn about the interaction between the corona and other parts of the solar atmosphere. Flares, for instance, are generally accompanied by a sharp increase in the intensity of the yellow line from the associated coronal region, as Lyot himself observed. But which comes first, flare or yellow line? In the case of the December 18, 1956, flare the yellow line appeared faintly three hours before the beginning of the flare; it reached its greatest intensity at the flare maximum and faded with the flare. Unfortunately there were no yellow-line observations at the very onset of the flare, so we do not know if flare and corona brighten simultaneously. The important fact is that the coronal radiation comes from a four-million-degree furnace, and the flare radiation comes from a region of only 30,000 degrees. The portion of the flare we observe certainly cannot produce the hot spot, because it is too cool. For a variety of reasons the converse is also true, unless external forces are involved. This leaves one feeling that another agent causes both.

The question of temperature is crucial also to understanding how the high excitation of the solar atmosphere induces high excitation in the atmosphere of the earth. The two-million-degree temperature of the corona explains, for example, the large amount of energy radiated by the sun in the far ultraviolet around a wavelength of 50 angstroms. At this



FLARE is photographed. The photograph at the top was made at 6:05 a.m. Mountain standard time; the one in the middle, 10 minutes later; the one at the bottom, 25 minutes later.

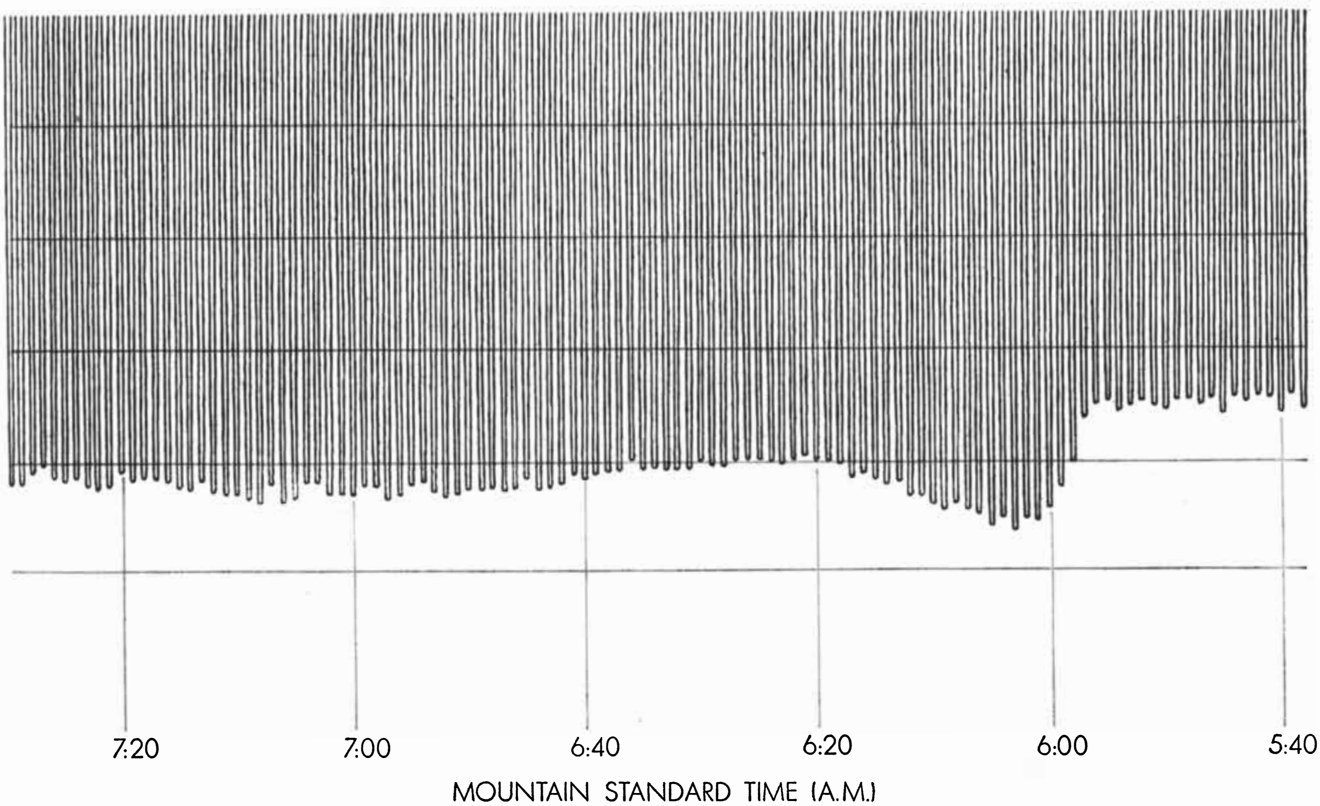
temperature the electrons have an average kinetic energy of 165 volts; they give up part of this energy in ultraviolet radiation when they are decelerated by the electrostatic attraction of naked nuclei in the coronal gas cloud. This radiation, called *brehmsstrahlung*, contributes substantially to the ionization of the E layer, one of the lower layers of the earth's ionosphere, occurring at heights 60 to 90 miles above the earth. The electron density in the E layer of the ionosphere varies closely with the temperature of the corona, for the rate of radiation rises sharply with temperature. There also appears to be a relation between coronal activity and the F layer, the highest layer of the ionosphere.

The solar hot spots also produce important effects in the lowest layer of the ionosphere: the D layer. The turning of the earth in the ultraviolet radiation of the chromosphere produces a daily variation in the ionization of the D layer which is augmented by the waxing and waning of hot spots. In addition, solar flares bring sharp increases in D-layer ionization which show up as sudden short-wave fadeouts, sudden diminution of cosmic radio noise, sudden enhancements of static and other phenomena.

When the sun is observed with a radio telescope tuned to 10 centimeters, the hot spots in its atmosphere stand out brilliantly. In wavelengths around two meters there is often an intense "radio-noise storm" lasting for several days when a hot region crosses the face of the sun. Studies of sunspots show that those with strong loop-prominence activity are particularly apt to produce radio-noise storms. Since the corona tends to block the shorter radio waves, these signals must originate at least 25,000 miles above the surface. This is the altitude of the loop prominences. Solar flares themselves produce extremely intense short-lived outbursts which must originate from hot spots at the same height. Indeed, the sources of this radiation have been observed to move radially outward from the flare at great velocities.

The high temperatures of the corona, especially its hot spots, offer at present the most promising lead to an explanation of the sun's production of cosmic rays. In at least five cases recorded since 1942, showers of cosmic rays have been traced to large flares. The sharp time agreement makes the origin of the cosmic rays in the flares virtually certain. But a 30,000-degree flare looks like a poor generator of cosmic rays. On the other hand, the concurrent production of a coronal hot spot in the million-degree range provides a source of moderate-energy ions for a cosmic-ray accelerating mechanism. At this point we enter the realm of arid speculation: we have devised no mechanism to explain the process.

With solar activity at its biggest and best during the International Geophysical Year, astronomers are studying the solar hot spots by their visible radiation, forbidden and permitted; by their ultraviolet radiation as it affects the terrestrial ionosphere; and by their intense radio emissions. Perhaps these studies will lead us to understand why such intensely hot regions occur above the relatively cool surface of the sun. The artificial earth satellites are also providing truly promising new information. We are taking a long step toward better understanding of the sun.



COSMIC RADIO NOISE sharply decreased at the time of the flare shown in the photographs on the opposite page. In this reproduction of the radio record, which should be read not from left to right but from right to left, the dip at right corresponds to the decrease. The decrease was due to the fact that the D layer of the ionosphere was heavily ionized by the radiation from the flare.

CELESTIAL NAVIGATION BY BIRDS

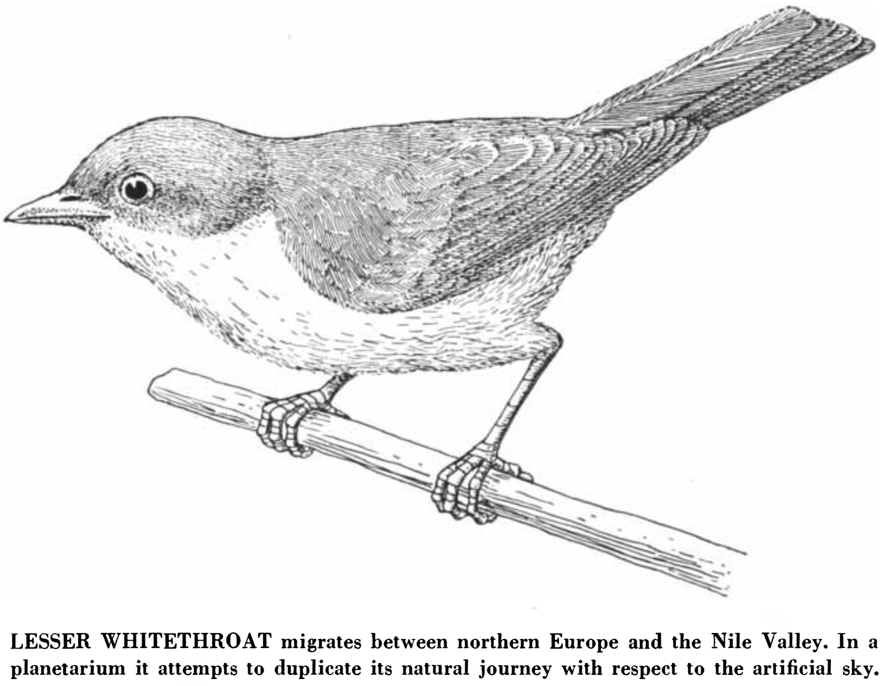
A remarkable series of experiments shows that migratory birds navigate by the stars. In a planetarium their flight direction is controlled by the position of the stars in the artificial sky

by E. G. F. Sauer

In spring and summer the songbirds known as the warblers are familiar residents in the countries of northern Europe. City dwellers know them well, for the small, gray birds find a home to their liking in the shrubs and hedges of gardens and small parks. During the spring breeding season the air is filled with their loud, melodic singing as each male establishes a small territory for himself in noisy battle with a rival. Once the claims are decided, the truculence and the songs subside; the birds proceed to mate, to raise their young, to feed amicably on elderberries and blackberries, to flit about in peace among the bushes. Then in August the birds begin to grow restless; their migratory instinct stirs. Suddenly, in one night, the whole resident population is off and away. The next morning the bushes are filled with a new lot of warblers that have flown in from more northern areas; they stay for a few days and then they too fly on to the south. Through the weeks of September and October there is a continuous coming and going of hordes of the migrating warblers. Gradually the number passing through diminishes. The species called the garden warblers disappears first, then the whitethroats, after them the lesser whitethroats and finally the blackcaps.

Where do they go? Ornithologists know exactly where the warblers go, for they have banded these birds for many years and followed them to their winter homes. The warblers travel to various parts of Africa. Some of them migrate as far as from Scandinavia to the southern part of Africa—a distance of thousands of miles. In the spring the birds migrate back to the very same place that they left in the fall.

Most remarkable of all is that each bird finds its own way to its destination! The warblers do not follow a leader or make the journey as a group; they navigate individually. And young birds making their first migration reach their goal as surely as the experienced travelers. Somehow, purely by instinct, the warblers know exactly how to set their course. Since they fly only at night, we are impelled to ask: Do the warblers navigate by the stars?



LESSER WHITETHROAT migrates between northern Europe and the Nile Valley. In a planetarium it attempts to duplicate its natural journey with respect to the artificial sky.

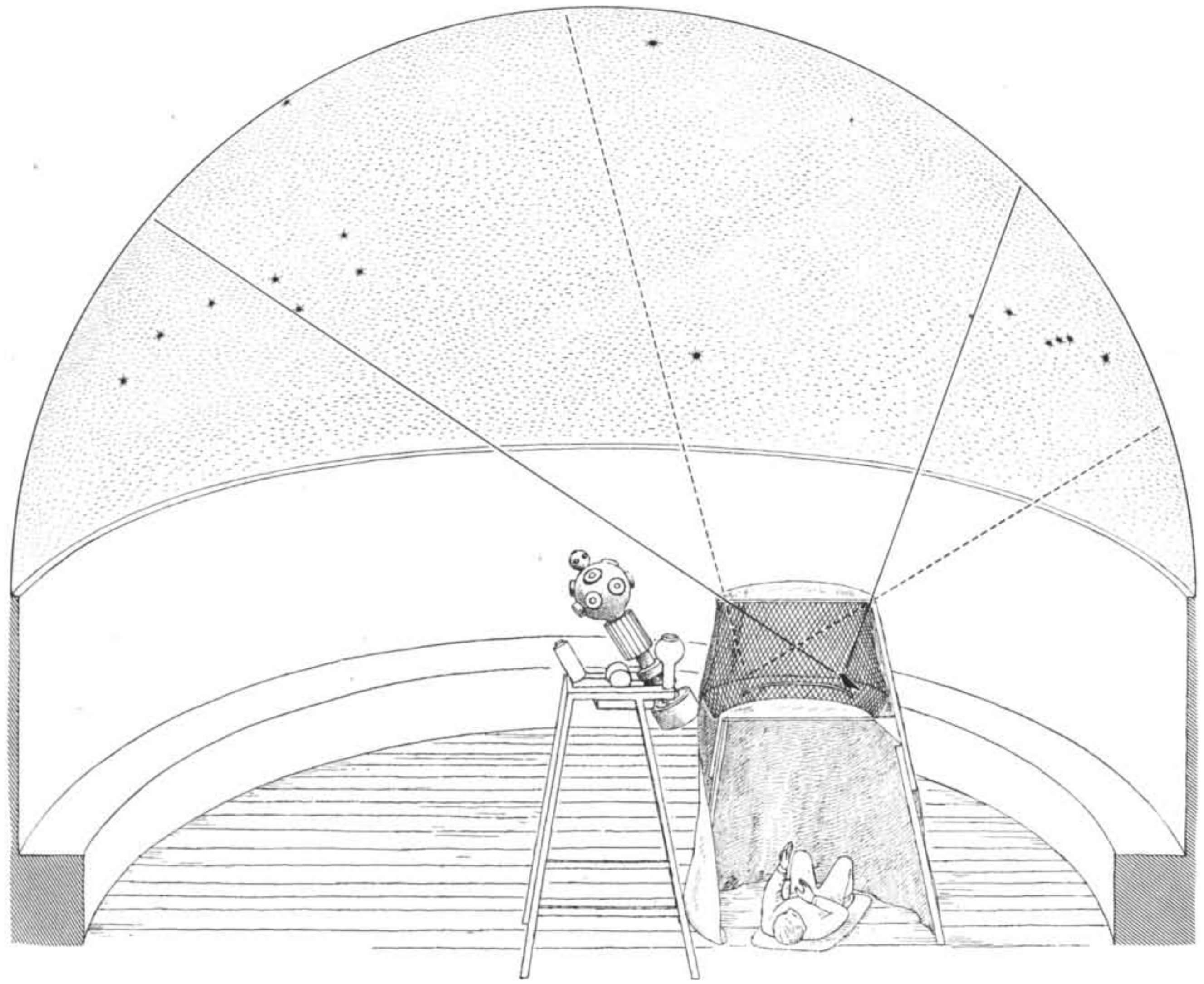
The navigation powers of birds have fascinated investigators for more than a century. By now there is a large literature of well-documented testimony to their amazing performances. The late Werner Rüppell of Germany, one of the leading experimenters on bird migration, found that starlings taken from their nests near Berlin and carried away to all points of the compass would find their way back to their nesting places from as far as 1,250 miles away. The Manx shearwater, a sea bird, has astonished investigators with still more spectacular feats; one shearwater, taken from the west coast of England and flown by plane to Boston, was back in its English nest in 12 days, having winged its own way 3,067 miles across the unknown Atlantic. The North American golden plover migrates each fall from its breeding grounds in northern Canada to its winter home in the Hawaiian Islands. This bird, lacking webbed feet, cannot rest on the water as waterfowl do; it must fly on steadily for several weeks to reach its destination over thousands of miles of ocean. If it wandered only slightly off course, it would become lost and exhausted in the vast Pacific, but it finds its way unerringly to Hawaii.

Until recently attempts to explain the incredible navigation feats of birds were almost entirely a matter of speculation [see "The Navigation of Birds," by Donald R. Griffin; SCIENTIFIC AMERICAN, December, 1948]. Various theorists proposed that the birds were guided by the earth's magnetic field, by the Coriolis force arising from the earth's rotation, by landmarks, and so on. But more and more ornithologists have been driven to the conclusion that birds must rely mainly on celestial navigation—the sun by day, the constellations by night.

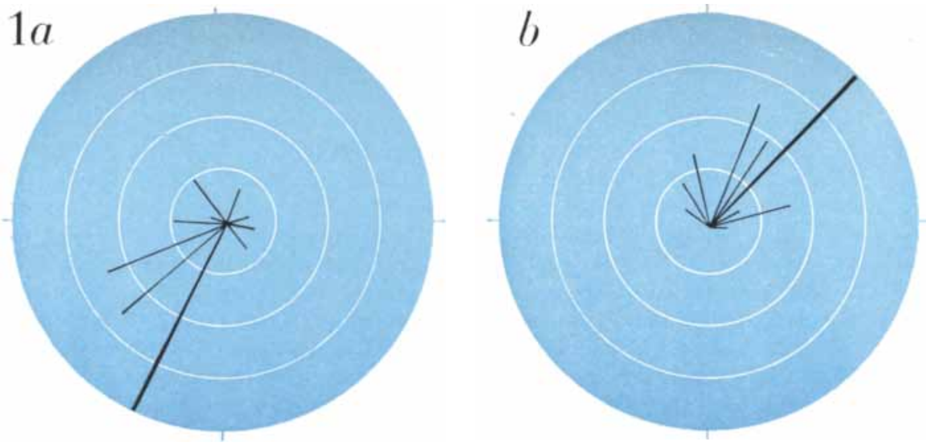
The idea that birds are guided by the sun was suggested as long as half a century ago, but it was not taken seriously until the early 1950s, when experimenters began to turn up some interesting evidence. Gustav Kramer in Germany and G. V. T. Matthews in England discovered independently that homing pigeons and wild birds can use the sun as a compass and that they possess a "time sense" which allows them to take account of the sun's motion across the sky. Other zoologists have confirmed these findings. It has now been proved, in fact, that our warblers can orient themselves by the sun.

But the warblers fly mainly at night. What sort of system do they use to steer their course in their nocturnal migrations nearly halfway around the globe? Several years ago we started a systematic laboratory study of this question by means of specially designed cages in our aviary at Freiburg.

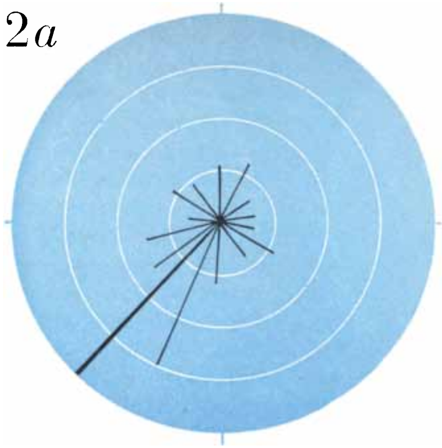
We had already seen laboratory proof of the stirring of the migratory instinct in these small world-travelers and of a seasonal time sense that governed this urge. We had hatched and raised warblers in completely closed, soundproof chambers where they lived in the illusion of eternal summer, year in and year out. Yet, although they had no outward cues of the yearly rhythm of nature, in the autumn the birds would begin to flit restlessly from branch to branch or flutter continually over their perches, night after wakeful night. They kept this up for many weeks—about the length of time it would have taken them to fly to Africa. Then they went back to sleeping again at night. In the spring, about the time that warblers migrate back from Africa to their European homes, our birds again had a spell of restless, wakeful nights. It was as if they had an inner clock which told them



PLANETARIUM EXPERIMENT is performed under a 20-foot dome. Dome and bird cage are shown in cross section. A felt cloth from the bottom of the cage to the floor cuts out light from below. Sector of sky visible to the bird is indicated by solid lines. The sector visible from the opposite side of the perch is shown with broken lines. "Flight direction" means direction in which bird faces.



FLIGHT DIRECTIONS taken in the planetarium by a garden warbler under a fall sky are plotted at left, and by a blackcap under a spring sky at right. North of artificial sky is at top. Full radial lines are principal directions of flight. Lengths of other lines, compared to the length of a full radius, indicate fractions of principal flight time spent in these directions.



VARIOUS SKY PATTERNS produced the flight directions shown in these four diagrams. For 2*a* the projector was set for 9 p.m. (Greenwich time) September

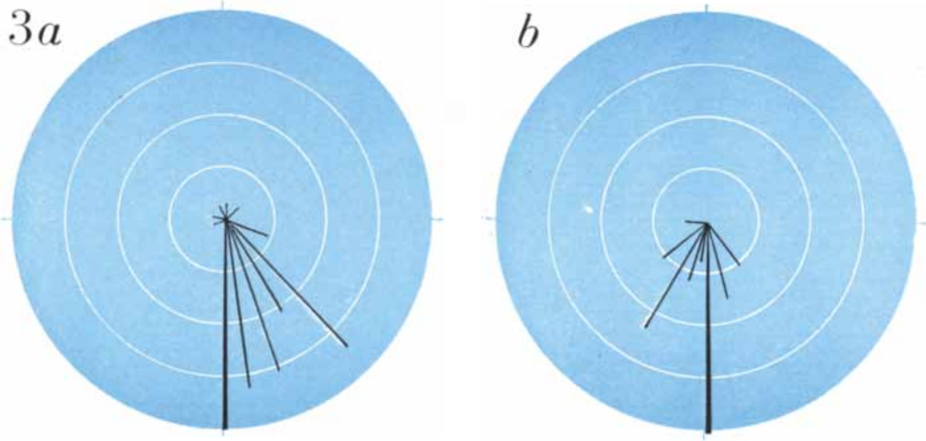
when the time had come to take wing for distant parts.

To explore the orientation question we now placed warblers in a cage with a glass opening at the top, so that they could see part of the sky (but nothing else of their surroundings). At the season of migration the birds would begin to flutter and, peculiarly enough, each would take up a position pointing in a particular geographic direction, like the needle of a compass. Even when we tried to turn the birds away by rotating their perches, they stubbornly turned back to the preferred direction. The direction in each case was characteristic of the species: the garden warblers, the whitethroats and the blackcaps all pointed toward the southwest, the lesser whitethroats toward the southeast (that is, in the fall; in the spring these directions were reversed). Now these are precisely the directions in which the respective species start their migrations from central Europe to Africa! The lesser whitethroats start southeastward, flying across the Balkans, and then turn south up the Nile Valley; the other species all take off southwestward and fly to Africa by way of Spain and Gibraltar.

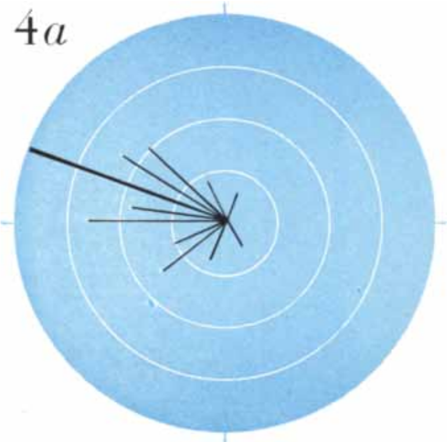
Experienced or inexperienced, the birds invariably took up the appropriate direction of flight in the cage. How did they know the direction? Seemingly the only clue available to them was the starry night sky overhead. To explore this theory further we now put them through a series of tests. We found that when the stars were hidden by thick clouds, the birds became completely disoriented. They were likewise confused when only diffuse and strongly polarized light came through their skylight. To adopt and keep to a definite direction they needed a look at the starry sky. Indeed, the birds watched the sky so intently that meteors made them change their direction momentarily.

For still more rigidly controlled experiments we proceeded to test the birds in a cage placed in a planetarium: that is, with a dome showing an artificial replica of the natural starry sky. Again, when the dome was merely illuminated with diffuse light (showing no stars), the warblers were unable to choose a preferred direction. But when the planetarium sky matched the night sky over Germany, the birds took up the proper direction just as if they were seeing the natural sky.

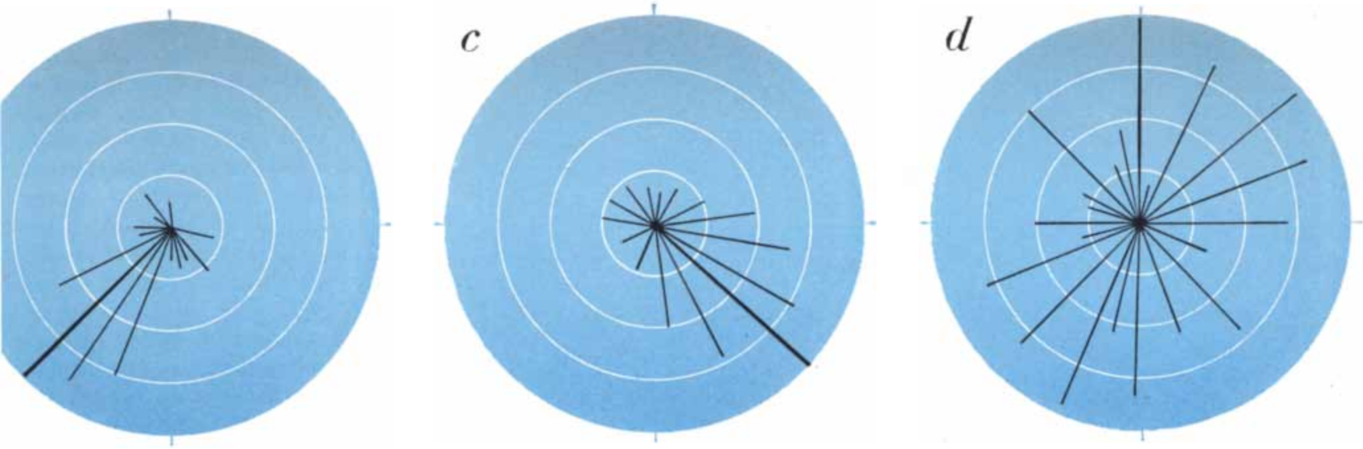
Now our artificial dome permitted us to shift the stars and constellations about. By changing the north-south declination (height) of the stars we could change the apparent geographical lati-



FALL MIGRATION of the lesser whitethroat was simulated in the experiments plotted here. For 3*a* the sky was appropriate to a latitude of 20 degrees north; for 3*b*, 10 degrees north.



EASTWARD DISPLACEMENT of the planetarium sky resulted in the flight



25, and a latitude of 40 degrees north. For 2*b* the setting was for 11 p.m. October 1, and 50 degrees north. For 2*c* it was set for 10 p.m. September 10, at a latitude of 50 degrees north. For 2*d* no stars were projected on the planetarium dome. The bird then took up a random series of flight directions. The actual dates of the experiments were the same as the planetarium dates, or one day before or after. The birds used in these experiments were a blackcap in 2*a*, a garden warbler in 2*b* and a lesser whitethroat in both 2*c and* 2*d*.

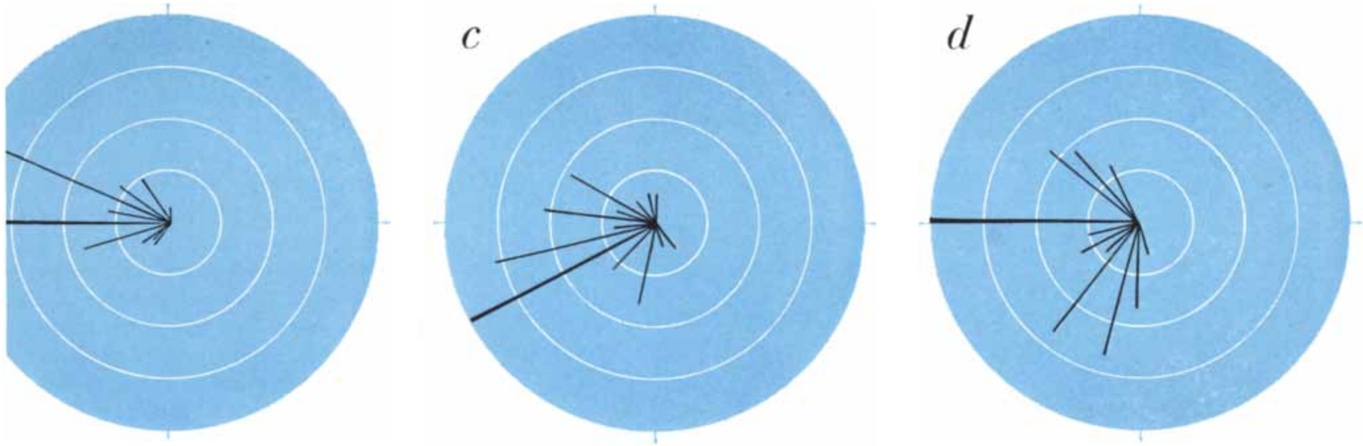
tude, making the birds believe that they were farther south or north than they actually were. Similarly by shifting the sky in the east-west direction we might mislead the birds about their position in longitude. How would they behave under these circumstances?

To illustrate the results I shall describe some experiments with a lesser whitethroat warbler which we will call "Johnny." Recall that the lesser whitethroat normally first travels southeastward across the Balkans and then turns due south, flying along the Nile to its winter home in the region of the Nile headwaters. In our experiments it turned out that as long as the planetarium sky was adjusted to the approximate latitude of Germany (40 to 50 degrees north), Johnny took up the expected flight position facing southeast. But as we shifted the sky, simulating more southerly latitudes, the bird tended to turn more and more toward the southern direction, until, at the latitude of 15 degrees, it set its course due south!

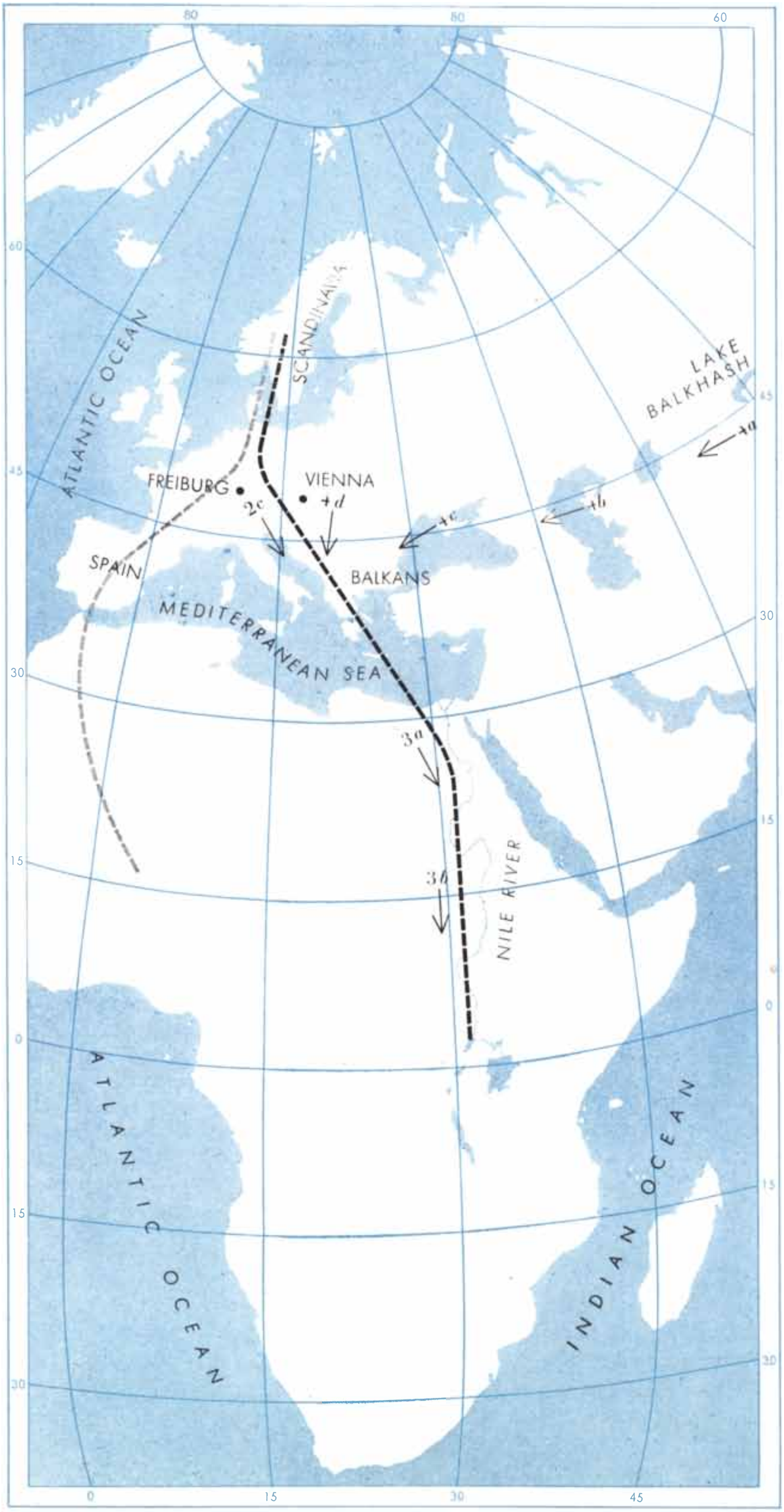
In other words, Johnny, a bird which had spent all its life in a cage and never traveled under a natural sky, let alone migrated to Africa, still displayed an inborn ability to use the guidance of the stars to follow the usual route of its species, adjusting its direction nicely at each given latitude. Earlier investigators had supposed that these birds used landmarks to find their route: for example, that the coastline at the eastern end of the Mediterranean was the cue which told them to turn south. But our experiments proved that the birds are guided only by the stars.

Now let us see what happened when we shifted the planetarium sky to change the longitude. One night, while Johnny was flapping its wings and heading in the southeast direction, we suddenly presented the bird with a sky shifted back to the configuration five hours and 10 minutes earlier than the local time; in other words, the apparent geographical position of the cage then corresponded to a point about 77 degrees eastward in longitude at this particular time. The bird at once showed that it was deeply disturbed. It looked excitedly at the unfamiliar sky and for almost a full minute stood irresolutely. Then it suddenly turned and took wing in the westward direction. According to the sky, its position at the moment corresponded to a point near Lake Balkhash in Siberia; Johnny, to correct its displacement, was heading directly toward the usual migration starting point in Germany!

As we reduced its displacement, the



paths shown here. For 4*a* the displacement was five hours and 10 minutes; for 4*b*, three hours, 26 minutes; for 4*c*, one hour, 41 minutes; for 4*d*, one hour, 10 minutes. In experiment 4*d* the bird headed east at first, but shifted eventually to almost due south.



PATHS OF MIGRATION of warblers are indicated by broken lines. Route of the lesser whitethroat is in black; of other species, in gray. Arrows show the headings taken by birds in planetarium experiments when the sky was adjusted for the positions shown on the map. Numbering of arrows corresponds with numbering of diagrams on the preceding two pages.

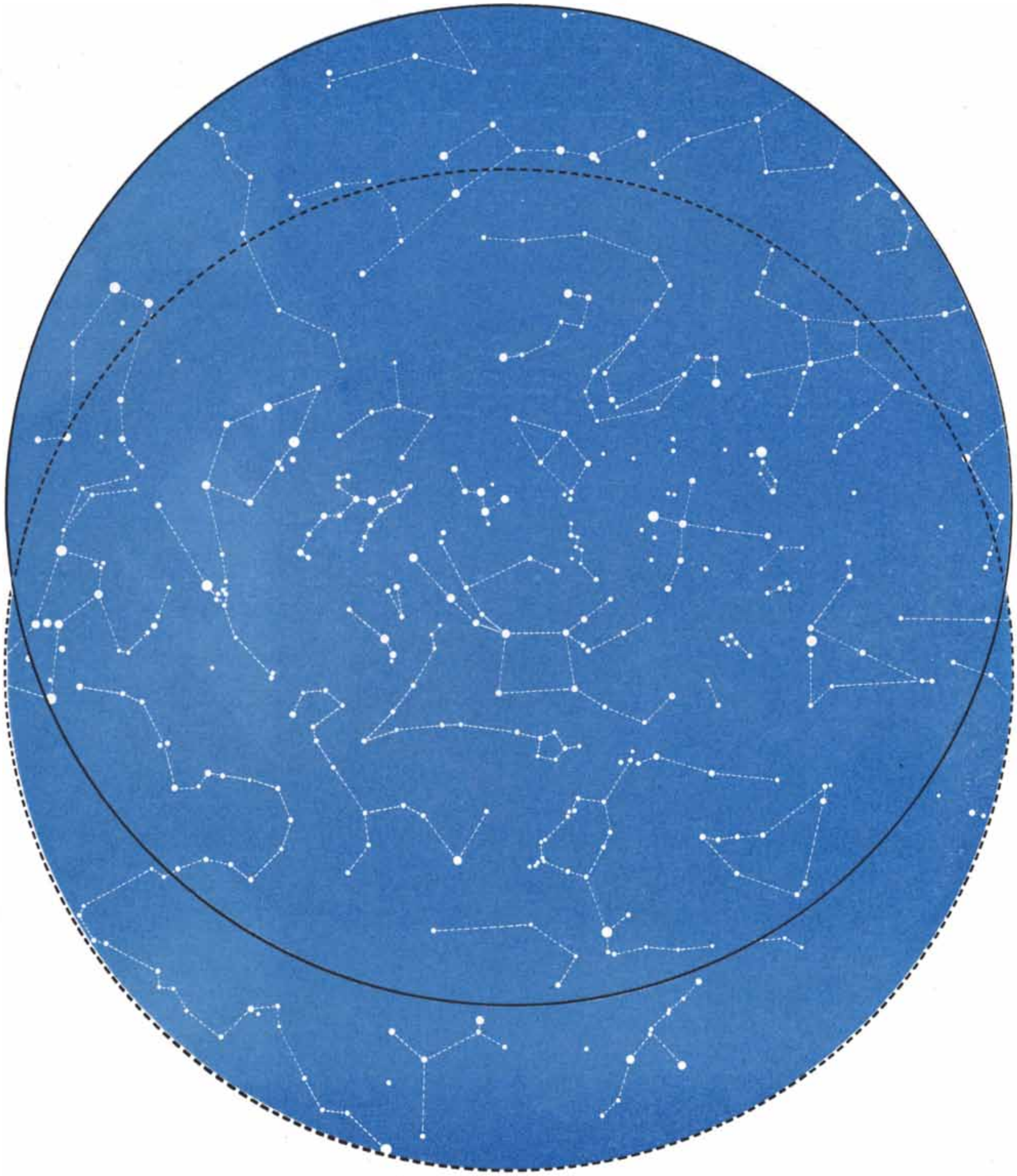
bird shifted its heading more and more from due west toward the south. When the displacement was only an hour, corresponding to a position near Vienna, Johnny headed south; when the canopy of stars was restored to the correct configuration at our locality for the season and time of night, the bird took up the normal heading toward the southeast.

Johnny's behavior, confirmed by experiments with other birds, leaves no doubt that the warblers have a remarkable hereditary mechanism for orienting themselves by the stars—a detailed image of the starry configuration of the sky coupled with a precise time sense which relates the heavenly canopy to the geography of the earth at every time and season. At their very first glimpse of the sky the birds automatically know the right direction. Without benefit of previous experience, with no cue except the stars, the birds are able to locate themselves in time and space and to find their way to their destined homes.

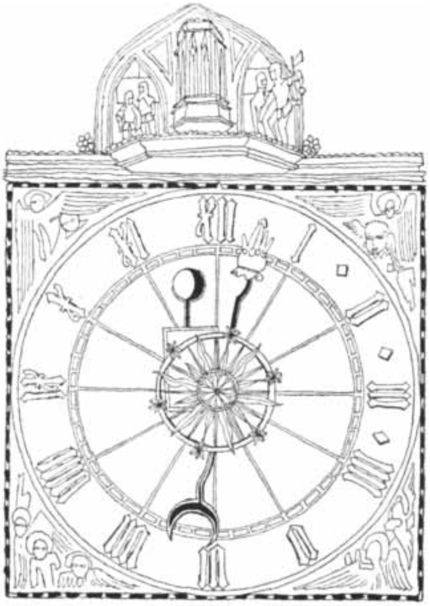
To be sure, the warblers do not have to rely solely on the constellations. In daytime they can guide themselves by the position of the sun. On cloudy nights they get some guidance from mountain ranges, coastlines and river courses gleaming in the pale night shine. Only in almost total darkness, when thick clouds utterly hide the sky, are the birds in trouble: they circle helplessly and sometimes are drawn to lighthouses.

We are going on to study the warblers' orientation system in more detail, systematically removing constellations or stars from our planetarium sky one by one to see if we can reduce the guidance cues to a basic pattern. One very interesting puzzle is the fact that the birds must somehow be able to make adjustments to astronomical evolution, for in the course of time the pattern of constellations in the sky is slowly but constantly changing. Even more difficult to explain is the mystery of how the birds ever came to rely on celestial navigation and to develop their skill in the first place. We know that the warblers are not the only creatures possessing this gift: other birds, insects, crabs and spiders have been found by experiment to be capable of guiding themselves by the sun or stars. But there are many other guidance mechanisms and signposts available on earth. What evolutionary process was it that endowed these animals with the highly sophisticated ability to read the stars?

Whatever the answer, we cannot help marveling at the wondrous celestial instinct of the warblers. When fall comes, the little garden warbler, weighing barely three quarters of an ounce, sets off one night on an unbelievable journey. All alone, never in the collective security of a flock, it wings its solitary way southwestward over Germany, France and Spain and then swings south to its distant goal in southern Africa. It flies on unerringly, covering a hundred miles or more in a single night, never once stopping in its course, certain of its goal. In the spring it takes off again and northward retraces its path to its nesting place in a German or Scandinavian thicket—there to give birth to a new generation of little warblers which will grow up, without being taught, with the self-same capacity to follow the same route across continents and oceans by the map of the stars.



STAR MAP shows the sky as it appears at an early evening hour in late October. The solid circle encloses the stars that can be seen at a latitude of 50 degrees north, and the broken circle encloses those that are visible at a latitude 20 degrees farther to the south.



SCIENCE AND

Conserving Moondust

The crash of the first rocket on the moon, which will signal man's intrusion into the ecology of space, may seriously hinder the study of the origin of life. So say Joshua Lederberg, chairman of the department of genetics at the University of Wisconsin, and Dean B. Cowie of the Carnegie Institution of Washington. In an article in *Science* they point out that the moon is covered with cosmic dust, collected during the long history of the solar system. Examination of this material should help decide two important questions: (1) whether living spores exist in space, as one theory holds, and (2) how the first, pre-living organic molecules were synthesized out of the atoms of the universe. But if moondust is polluted by terrestrial organisms that find their way into rockets, the test will be inconclusive.

The situation will be even more serious for planets with climates more hospitable to life than that of the moon. Contamination could "distort the microbiology" of such a planet, and might even start the growth of living things on a previously sterile planet.

Extraterrestrial life, if it can be observed in its "wild state," will throw light on some of the deepest problems of evolution, the authors observe. All presently known forms of life transmit genetic information by means of nucleic acids. Do Martian plants, if any, also contain DNA? If so, does it mean they are descended from the same ancestor as earthly plants, or is DNA "a unique solution to the requirements of genetic replication"? If Martian genes are made of other compounds, is this "an independent solution or an evolutionary divergence"?

Since there will be a considerable lag between the time when rockets can be sent to the moon and planets and the time when material can be collected and brought back to earth, "we urgently need to give some thought to the conservative measures needed to protect future scientific objectives," the authors conclude.

No Safe Radiation

The eminent geneticist Milislav Demerec has settled a much-debated issue concerning the effects of radiation. The question: Will radiation cause mutations at any dosage, however small, or is there a "safe" threshold? Demerec and a coworker, Joan Sams, in the Department of Genetics of the Carnegie Institution of Washington, tested the question by exposing cells to graded doses of X-rays, and they found that the smallest doses they could administer still produced mutations.

Working with altered strains of the common bacterium *Escherichia coli,* they measured the effects of the radiation by the rate at which the cells reverted to the original "wild" type. Their smallest X-ray doses, about eight roentgens (barely more than the amount at the skin of the jaw in a dental X-ray), caused mutations to rise above the usual rate in nature (about 10 cells in 10 billion). And as the dose was increased, the mutation rate rose in proportion.

Interferon

A possible new weapon against virus disease has been discovered. It is a substance called "interferon," which seems to exercise a general shotgun action against many kinds of viruses, instead of the specific action of the usual vaccine. The research was reported in the British magazine *The New Scientist* last month by Alick Isaacs and Derek C. Burke of the British National Institute for Medical Research.

It has been known for some time that infection by one kind of virus often produces immunity to a totally different type. The British workers cultured an immunity-conferring virus, then killed the virus and succeeded in extracting from the culture a substance which interferes with the growth of various viruses. Chemical tests indicate that the substance is a protein. It is produced in greatest quantity when the virus is killed by a moderate dose of ultraviolet radiation—a treatment known to damage nucleic acids, the hereditary material. The British workers conjecture that damage to the virus's nucleic acids causes the invaded cell to make interferon instead of some normal general protein required for the reproduction of viruses.

The virologists are now proceeding to investigate whether injections of interferon will safely attack a virus disease in a living animal. They point out that even if interferon itself should prove useless as a drug, its discovery has brought to light "a weak point" in the growth cycle of viruses which should be vulnerable to attack in some way.

Pacific River

A great submarine "river" which flows for at least 3,500 miles across the equatorial Pacific has been discovered by scientists of the Scripps Institution of Oceanography and the U. S. Fish and Wildlife Service. The current is 250 miles wide and about 100 to 800 feet below the ocean surface. Roger Revelle, director of the Scripps Institution, described it as "one of the great oceanographic discoveries of our time," comparable in importance to the discovery of jet streams in the upper atmosphere.

The river flows eastward at about three knots. It is sandwiched between two slow westward-flowing currents, the South Equatorial Current on the surface and another current below 800 feet. So far the river has been traced westward to a point north of the Marquesas Islands, but it may originate several thousand miles farther west off Indonesia. Its eastern terminal lies near the Galápagos Islands, where the current dissipates. The volume of its flow is comparable to that of a thousand Mississippis.

The Warming Antarctic

It has been known for some time that the Arctic is growing warmer; now investigations in the International Geophysical Year have established that the

Antarctic also is warming up. According to measurements made in a 1,000-foot shaft drilled into the ice of Antarctica, the warming process has been going on for at least 10 centuries. Records at Little America indicate that the average annual temperature there has gone up about five degrees in the last 50 years.

Antarctica is still pretty cold. A Soviet I.G.Y. team recorded a low of 114 degrees below zero. And reports from a number of I.G.Y. groups show that the Antarctic icecap is up to 10,000 feet thick. In many places the bottom of this ice sheet is below sea level, which suggests that the "continent" either has many frozen lakes and fjords or perhaps is actually a chain of islands rather than one land mass.

Antarctica's frigid climate makes its land surface a botanical desert, but the surrounding waters are rich in plant life. Divers wearing plastic suits report that the waters off Palmer Peninsula are considerably richer in plant life than those in the Arctic regions. Some species of marine plants even manage to thrive in the lightless waters beneath the shelf ice.

Gout Chemistry

A new lead in the search for the cause of gout was reported last month by Leonard Laster of the National Institutes of Health. Sufferers from gout have an abnormally large amount of free uric acid in the blood [see "Gout and Metabolism," by DeWitt Stetten, Jr.; SCIENTIFIC AMERICAN, June]. Uric acid is known to be a product of the metabolism of proteins; Laster now finds that it may also be released from sugar. He discovered an enzyme which splits uric acid from its combination with sugar. He also demonstrated that this enzyme's action is inhibited by colchicine, the drug long used as a treatment for gout.

Biggest Dish

The U. S. Office of Naval Research announced last month that it will build the world's largest radio telescope near Sugar Grove, W. Va. Its site is about 25 miles from that of the National Radio Observatory, now under construction in the West Virginia hills.

The Navy's telescope will be a parabolic reflector at least 400 feet in diameter. Details of the design will be worked out by tests on a 60-foot model.

The giant instrument, costing $60 million, is expected to penetrate six billion light years into space—three times the range of the 200-inch telescope on Palomar Mountain. It will be used also for radio communication, transmitting jamproof signals by reflection from the moon and planets.

The largest radio telescopes now in operation are a 250-foot instrument at Jodrell Bank in England and a 350-foot reflector in the U.S.S.R.

Cellulose Chromatography

Chromatography, the remarkably convenient technique for quick separation of difficult-to-separate substances, has evolved into several forms—the resin column, paper chromatography, gas chromatography and so on. Two workers at the National Cancer Institute, Elbert A. Peterson and Herbert A. Sober, have now developed a new version which is particularly well suited to the delicate job of separating proteins. Their method employs powdered cellulose—from wood or cotton—packed in a glass column.

In this adsorbing column biological substances, including viruses, come through without damage and without losing their activity. Peterson and Sober have successfully separated blood-serum proteins, substances of the tobacco mosaic virus, hormones and nucleic acids.

Their ion-exchanging material is prepared by mixing purified cellulose with a strong solution of sodium hydroxide, treating the mass with ionizing substances and then drying the product to a white powder. It is very stable and can be used over and over again.

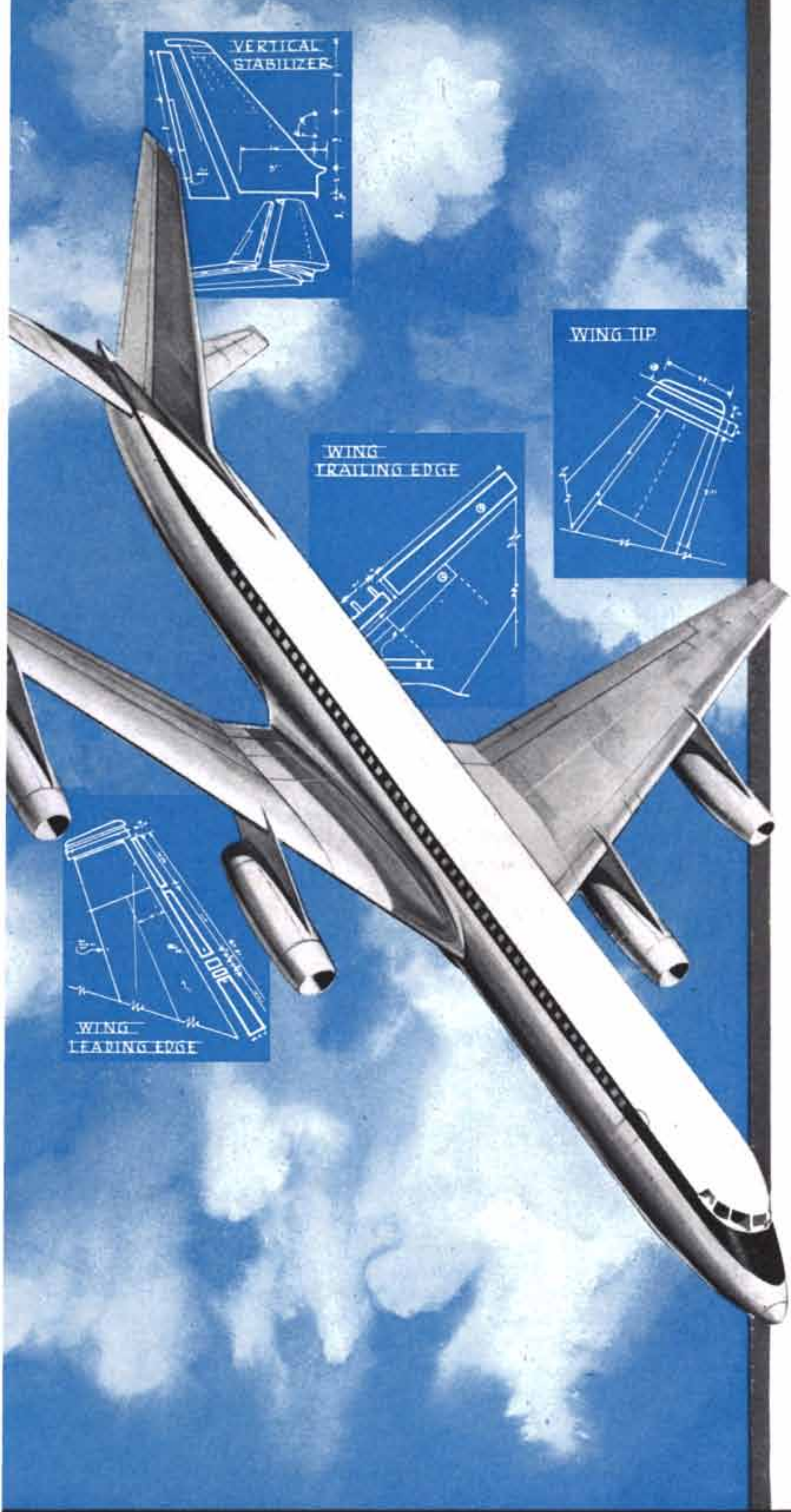
The AEC

President Eisenhower has appointed John A. McCone, California industrialist and shipping executive, to replace Lewis L. Strauss on the Atomic Energy Commission. McCone, an Air Force undersecretary in 1950 and 1951, has served on a number of government advisory committees.

The other members of the AEC are Harold S. Vance, also an industrialist; John F. Floberg, an attorney; John S. Graham, a financial consultant, and the chemist Willard F. Libby.

Peaceful Atoms

The International Atomic Energy Agency, set up to develop peaceful uses of the atom, has started its first major project. It will be launched in Latin America. A four-nation team of experts, after a survey covering nearly every Latin American country, is preparing a program for training experts and



Crosley helps CONVAIR JET 880 to keep a date

Soon the Convair Jet 880 will take to the skies as one of the world's fastest jetliners. Sleek, smooth and strong—the luxurious jet will race the sun at 615 miles per hour!

Convair has chosen Crosley to design and produce many of the 880's components. And while actual construction progresses, a Crosley team of engineers is "on site" at the plant to help insure speedy transition from design to production to maiden flight date.

Crosley's contributions to airframe construction include all of the conventional types of assembly in addition to the newer methods of honeycomb, metal bond, and chem-milling. Equally important are Crosley's contributions to safety in flight, represented by such developments as Volscan—the electronic air traffic control system, or airborne navigation and communications equipment, embodying advanced concepts of electronic application.

For further information on Crosley's airframe and other capabilities write to the Vice President—Customer Relations, Avco Manufacturing Corporation, Crosley Division, 1329 Arlington Street, Cincinnati 25, Ohio.

Avco // Crosley

developing nuclear power in South America.

The mission was headed by Norman Hilberry, director of the Argonne National Laboratory; it included specialists from the U. S., France, Brazil and Great Britain.

Neanderthal Surgery

In the "Big Cave of Shanidar" in northern Iraq Ralph S. Solecki of the Smithsonian Institution has found the skeleton of a Neanderthal man who apparently had his right forearm amputated 45,000 years ago. This skeleton is one of several which Solecki has discovered in the ancient site [see "Shanidar Cave," SCIENTIFIC AMERICAN; November, 1957].

T. D. Stewart, a co-worker with Solecki, assembled the bones of the skeleton and discovered that the right arm, which was atrophied, extended only to the elbow. After consulting orthopedic surgeons, Stewart deduced that the arm had been paralyzed by a birth injury and that it was later deliberately cut off below the elbow. Examining the teeth, Stewart found them worn in a way which suggested that the Neanderthal had used them to help him hold objects.

The skeleton has other distinctions. Although the skull as a whole is unmistakably Neanderthal, its rear section might be taken for that of a more advanced human type. This raises the possibility that other well-known fossils have been misclassified. Swanscombe man, represented only by the rear portion of the skull, has been generally considered a very old example of a rather modern man. Stewart thinks he too may have been Neanderthal.

Tall Japanese

The short stature of the Japanese, long thought to be genetically determined, actually must be attributed largely to their diet and other environmental factors, according to William W. Greulich of the Stanford University School of Medicine. Writing in the *American Journal of Physical Anthropology*, he reports that American children of Japanese ancestry are consistently taller, heavier and more advanced skeletally than Japanese children of the same age.

On the other hand, the short legs of the Japanese (a trait which they share with some other Oriental peoples) seem to be a hereditary characteristic: the legs of teenage Nisei children in the U. S. are about the same length as those of teenagers in Japan.

Even in Japan children are taller today than in 1900, probably because of improvements in diet and other factors. The increase in height is particularly marked among girls: Japanese teenage girls are almost as tall as their American-born counterparts. Greulich believes that the girls' greater response to an improved environment "provides additional evidence of the functional superiority of the human female" over the male [see "The Mortality of Men and Women," by Amram Scheinfeld; SCIENTIFIC AMERICAN, February].

Physics Teachers

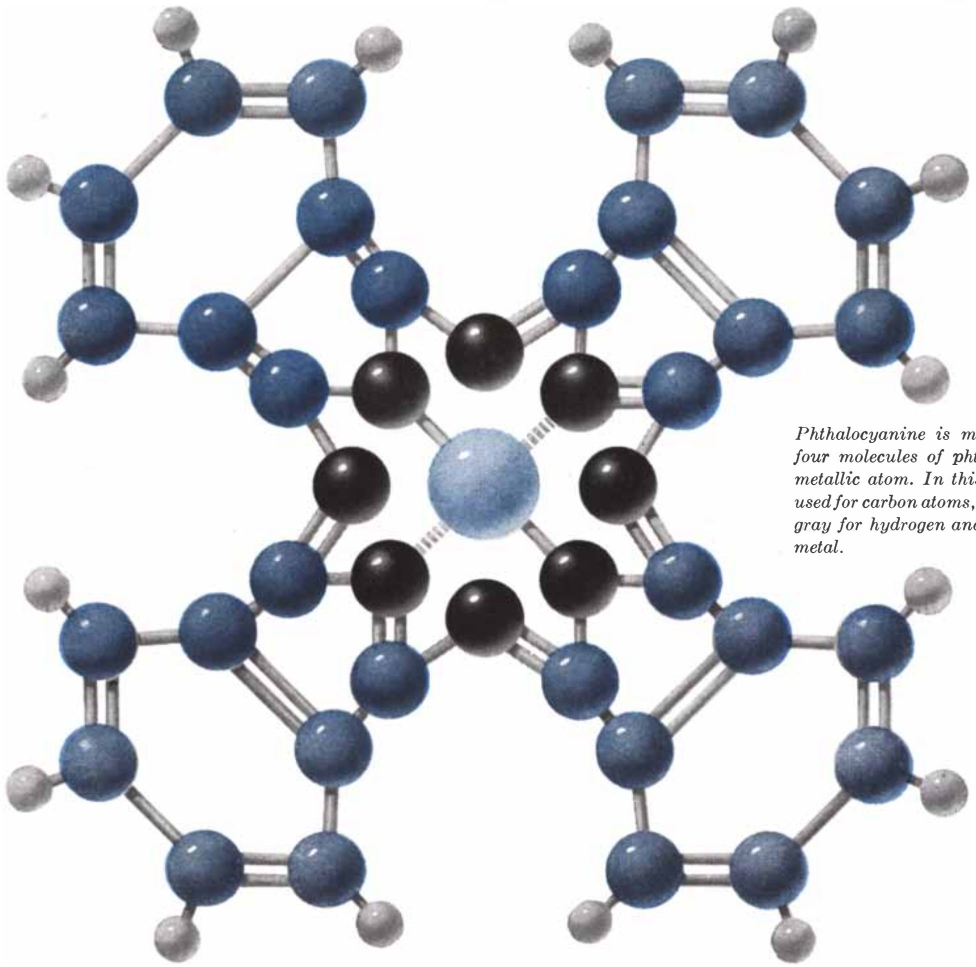
More than 90 per cent of U. S. colleges and universities are short of physics teachers, according to a recent survey by the American Institute of Physics. In some cases they have had to drop physics courses.

The 490 schools that replied to the Institute's questionnaire need a total of 688 more physics teachers with Ph.D.'s; they now have 2,720. This year they were authorized to hire 403 new teachers but could find only 254. Small colleges with six or fewer physics teachers have the most difficulty in attracting instructors, because their salaries are low and they offer little opportunity for research.

The Invisible Sell

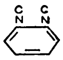
For years psychologists have been experimenting with "subliminal" stimulation—exposing subjects to stimuli which are too faint or too fleeting to be noticed consciously but which nevertheless evoke a response. The technique has become a public issue since a commercial research firm announced that it can be used to sell popcorn and Coca-Cola to movie theater audiences. Last month three psychologists of the University of Michigan presented their views on the technology and ethics of subliminal advertising in *The American Psychologist*.

The authors, James V. McConnell, Richard L. Cutler and Elton B. McNeil, dismiss the theater test as vague and uncontrolled. According to the subliminal experimenters, they caused people to buy by flashing the words "Eat popcorn" and "Drink Coca-Cola" on the screen at subliminal speeds during the showing of a film. But no account of this experiment has been given in a psychological journal, and the psychologists are skeptical. They ask: "Did members of the audience rise like automatons during the course of the movie . . . to



Phthalocyanine is made by combining four molecules of phthalonitrile with a metallic atom. In this diagram, blue is used for carbon atoms, black for nitrogen, gray for hydrogen and light blue for the metal.

Phthalonitrile: petals of a dye molecule

In a kind of chemical hoedown, phthalonitrile molecules  *form a ring around an atom to create a flower-like dye molecule. This unique reaction is but one of the fascinating properties that make phthalonitrile so promising commercially.*

Take a benzene ring and replace two adjacent hydrogen atoms with CN radicals and you have *phthalonitrile*, now commercially produced by Plastics and Coal Chemicals Division, Allied Chemical Corporation. Probe more deeply and you will find the mark of a good intermediate. Those CN radicals have a talent for hooking up with passing molecules, yielding enough new and different compounds to keep your applications lab busy for months.

Given the chance, phthalonitrile molecules will join to form a ring around a central atom of copper or some other metal. (You see it happening in the kaleidoscope pattern above.) This reaction results in a resonating structure of remarkable stability and inertness, and can be used to create a whole family of fast blue-green pigments and dyes—the *phthalocyanines*. Their formidable tinting power and unfading brilliance have been gratefully seized upon by color makers in the printing, plastics, paint and other industries. Now—just as they are coming into widespread use—along comes phthalonitrile to provide a simple, labor-saving method of manufacture.

Phthalonitrile also has some tantalizing properties of its own. Its buff-colored crystals have been suggested as a pesticide and, when hydroxylated, as a desensitizer and preserving agent for photographic developers.

You take it from there. Tell us what you need to investigate phthalonitrile. Write on company letterhead for prices, sample, or developmental quantities.

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satisfy a sudden craving for popcorn? Or did they wait until [some time later] to do their purchasing? . . . What if the message had been 'Buy Christmas seals?' "

The psychologists concede that there are well-authenticated demonstrations of subliminal stimulation in the literature of psychological studies. Experimenters have found that subjects sometimes respond to electric shocks they cannot "feel," to whispered sounds they cannot "hear" and to pictures they cannot "see." The stimuli are always more effective the closer they approach the threshold of noticeability. Also, the threshold may depend on how the subject feels: a hungry man is more sensitive than a sated one to words about food.

But the controlled laboratory experiments fall far short of telling the subliminal advertiser what he needs to know. They do not show what range of behavior can be influenced, how long a subliminal message needs to be or how often it can be repeated before subliminal annoyance sets in.

The authors point out that the psychologist's code of ethics forbids him to use psychological techniques for "devious purposes." They also observe that through "a kind of guilt by association" psychologists may come into disrepute because of the public revulsion against subliminal advertising.

The Color of Eggs

Why is a robin's egg blue? Why isn't it white, like the hen's egg? Why is the thrush's egg speckled? David Lack, the noted University of Oxford ornithologist, was so intrigued by these almost-too-obvious questions that he went on a field hunt for the answers. He thinks he has succeeded in unscrambling the egg-color code.

The coloring, he found, tends to be associated with the nesting site. Birds that lay their eggs in a shallow nest or a niche produce speckled or blue eggs which blend into the surroundings. Similarly, the eggs of species that nest in bushes are blotched, often with shadow-marks. Eggs laid on the ground or on ledges tend to be brown, gray or olive. White eggs usually belong to species that deposit their eggs in deep holes, where concealment is unnecessary and the white color helps the parents find the eggs in dim light.

Lack found no evidence for the notion that eggs are sometimes conspicuously colored as a warning of bad flavor. The palatability of eggs is associated with their size rather than with their coloring.

Whenever you

remember

Taillight lenses molded for Oldsmobile
by Guide Lamp Division of General Motors Corporation,
using Tenite Butyrate plastic.

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his new use for Tenite Butyrate

Simple applications often do the best job of illustrating the many advantages of Tenite plastics.

Take the taillight lenses of the 1958 Oldsmobile as an example. They're a new use for Tenite Butyrate.

Reasons for the choice were many. Weather resistance, of course, was of primary importance. Transparency and good optical properties were other requisites. Impact resistance was needed, too, to take the shock of hard knocks...and toughness, which would serve to prevent cracking around the bolt holes should mounting bolts be drawn up too tightly.

Expanding use of higher octane gasolines imposed still another "must": resistance to the aromatic solvents that give the new gasolines their extra power.

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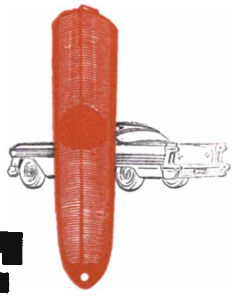

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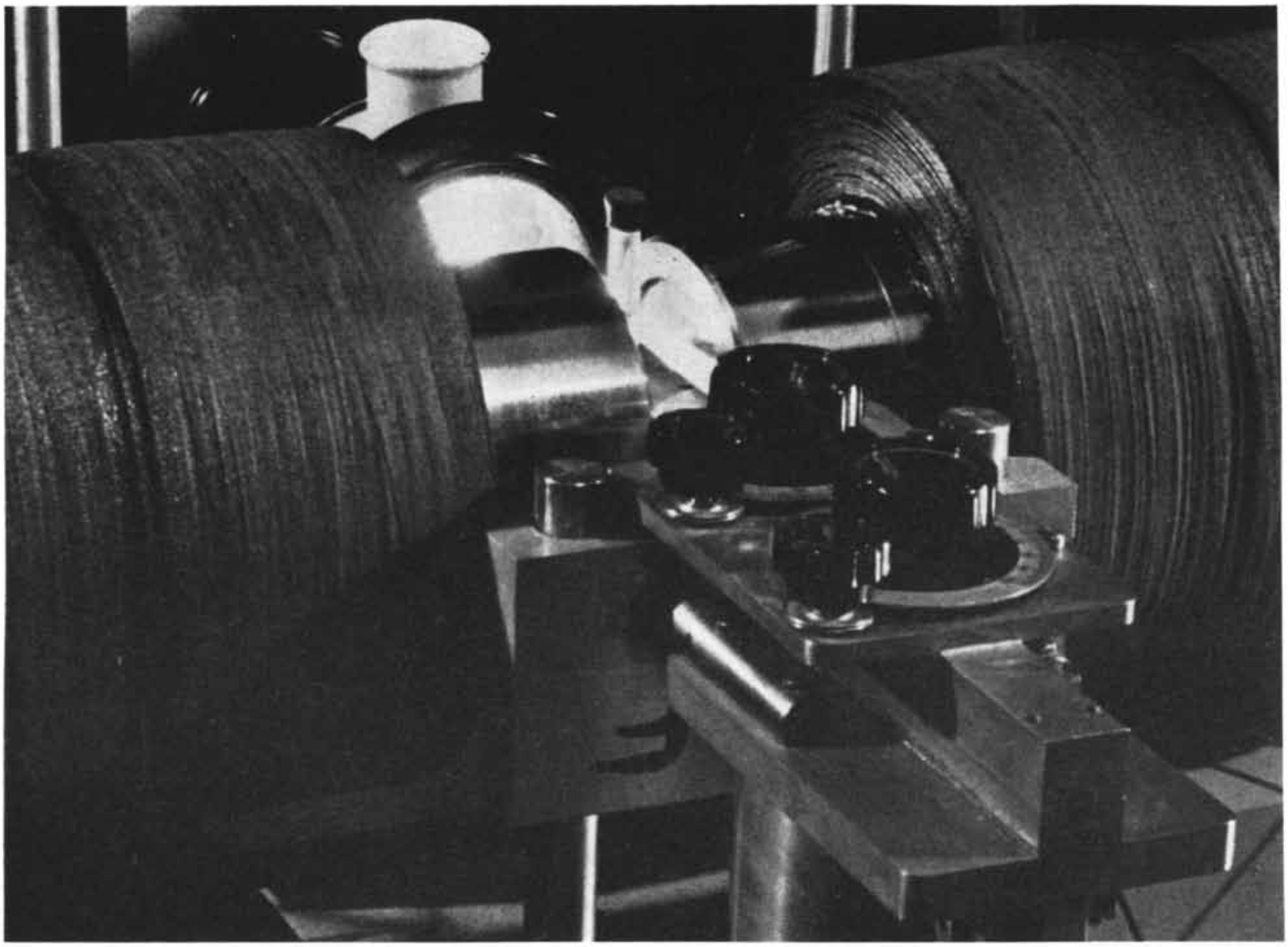
MAGNETIC RESONANCE

Atomic nuclei and electrons, which spin on their axes like tops, can be tipped over by magnetic fields. The technique furnishes much information about complex molecules and chemical reactions

by George E. Pake

Early in 1946 Edward Purcell at Harvard University and Felix Bloch at Stanford University announced, almost simultaneously, an interesting discovery in physics. They had found a way to tune in on the magnetic fields of the spinning nuclei of atoms. The work was important enough to win the 1952 Nobel prize in physics for Purcell and Bloch.

It is doubtful that many people outside the field of nuclear physics were much excited by or even took notice of these experiments at the time they were announced. But by now the phenomenon in question, called magnetic resonance, has become a matter of very wide interest indeed. Scientists in various distantly separated lines of work—geologists, chemists, biologists—are, if anything, even more excited about the discovery



MAGNETIC-RESONANCE EXPERIMENT on electrons in chlorophyll demonstrates that photosynthesis involves free radicals. The sample of chlorophyll is in the upright tube in the center, between the poles of the magnet. The light source which illuminates sample is behind magnet. This photograph was made in the laboratory of Barry Commoner at Washington University in Saint Louis.

than nuclear physicists. For it has led unexpectedly to the development of a sensitive tool useful for a multitude of purposes, from prospecting for minerals in the earth to analyzing the chemistry of living organisms.

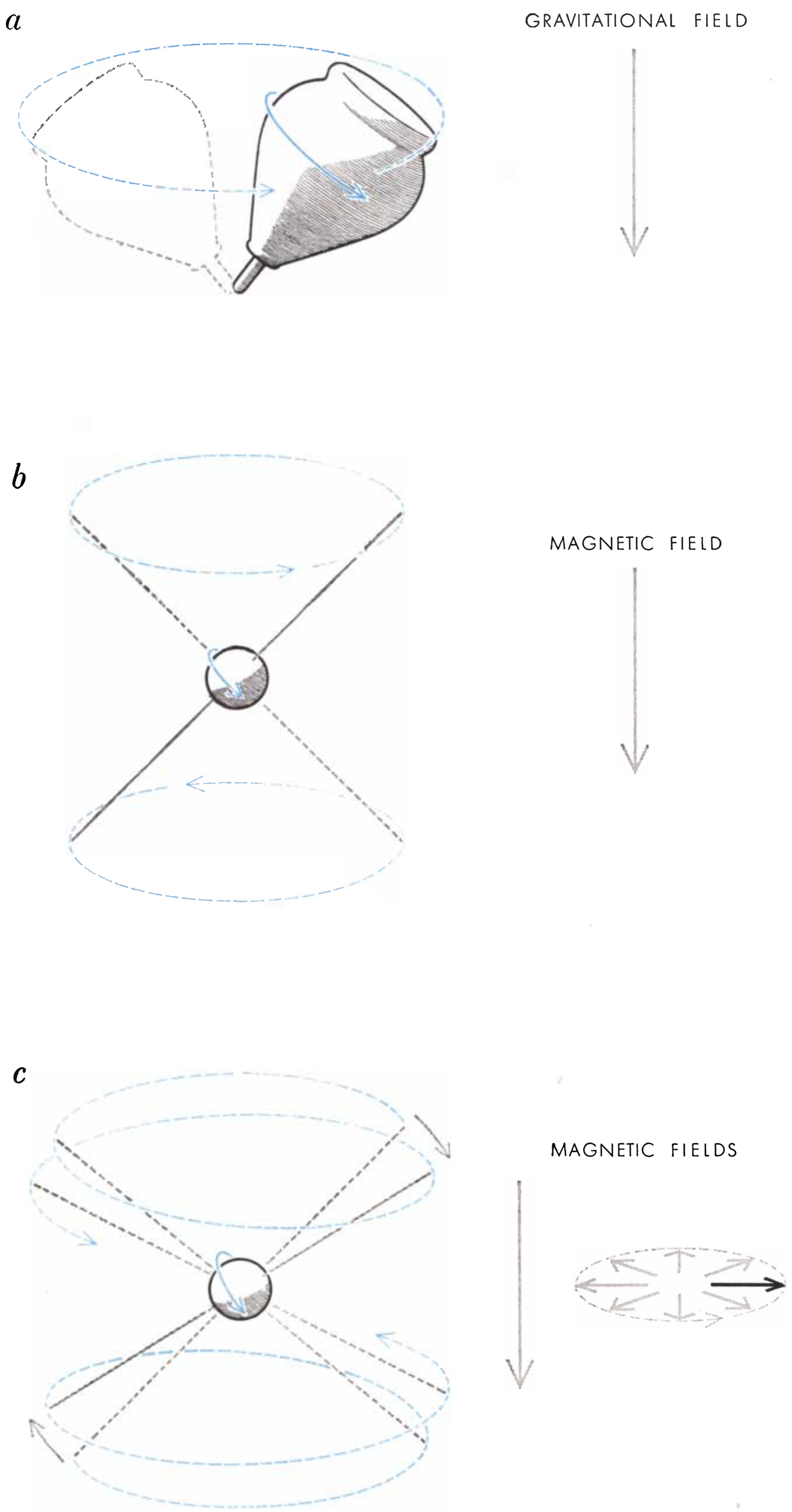
We must start this story by giving thought, as Purcell and Bloch did, to the spinning behavior of the proton. Like the rotating earth, a proton constantly spins around its axis (as do all the other elementary particles of the atom). It spins eternally with a certain momentum, reckoned in the proton's case as one-half unit. Since the proton carries an electric charge, its spin generates a magnetic field; in other words, the proton is a tiny magnet. Now we can ask ourselves the intriguing question: What will happen if we apply an outside magnetic field to this little magnet? Purcell and Bloch fell to wondering (independently) whether it would be possible to use a magnetic field to manipulate the spinning protons in a piece of matter: say, flip them over so that their north and south poles were reversed.

Here it is useful to think of an ordinary spinning top or a gyroscope. As everyone knows, a gyroscope tipped from the vertical does not fall down; instead its upper end circles slowly (precesses) around the vertical. That is to say, the downward gravitational pull of the earth acts to swing the axis of the spinning gyroscope around rather than to tip it further. Similarly, if we apply magnetic force to a spinning proton it will make the proton precess, not tip over. Brute force, in the form of stepping up the strength of the magnetic field, will avail us nothing: it will merely cause the proton to precess faster.

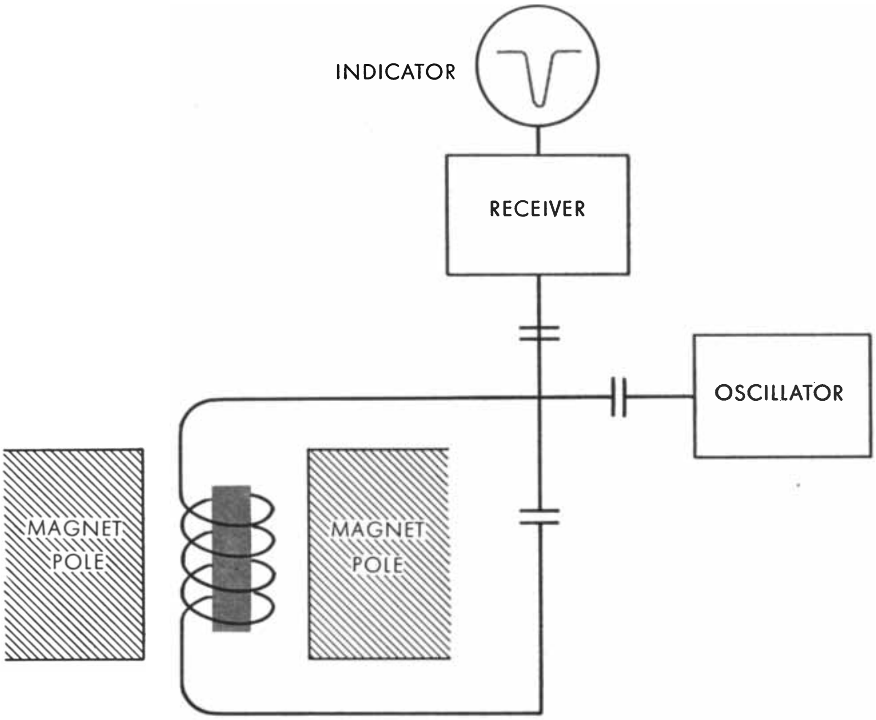
But there is a way to outwit the spinning particles. Suppose we apply a second magnetic field at right angles to the main field. Theory says that if we make the second field rotate around the first (by means of an alternating electric current in a coil), and if we time the rotation so that it coincides exactly with the rate of the proton's precession, we should be able to tip the proton over. In short, with proper tuning (at radio frequencies) the feat may be achieved by a magnetic-resonance effect.

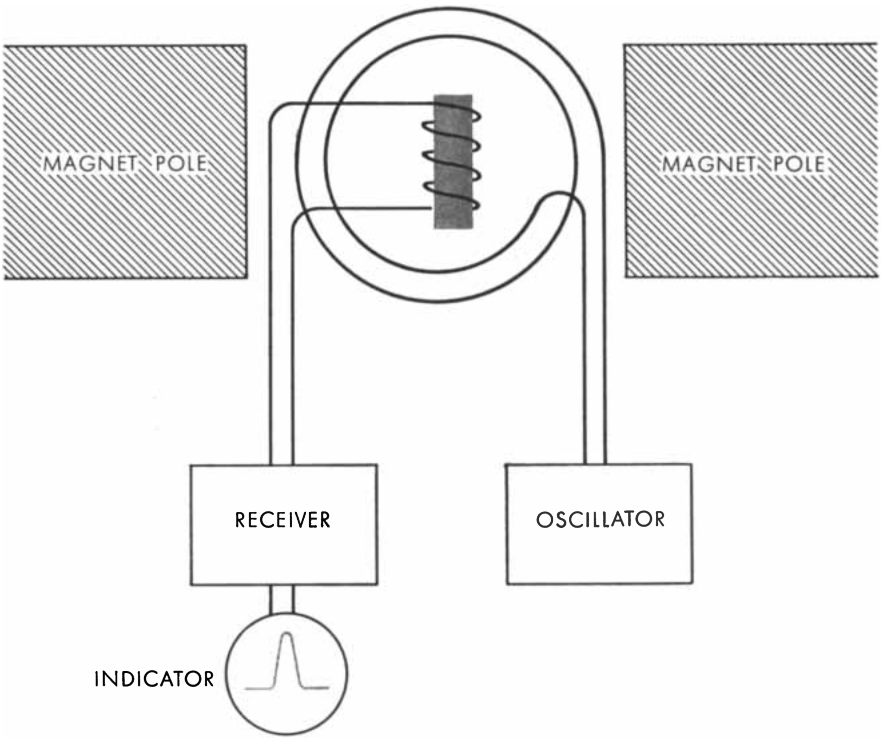
A New Spectroscopy

The problem, then, was to find the resonance frequency and to detect the effect on the protons. Purcell and Bloch employed different methods to look for the effect. In Purcell's apparatus the sample of matter was placed between



GYROSCOPIC ACTION of a spinning top or particle causes it to revolve or precess around a vertical field tending to tip it over. Particle can be tipped, as shown in the diagram at the bottom, by applying in addition a rotating horizontal magnetic field (*right*), which revolves at exactly the same rate as the axis of the precessing particle in the vertical magnetic field.





NUCLEAR-RESONANCE DEVICES designed by Edward Purcell and Felix Bloch are diagrammed schematically. In Purcell's arrangement (*top*) a single coil passes radio waves from oscillator into sample (*gray bar*) and feeds into receiver. Resonance is indicated by a dip in received energy. In Bloch's apparatus (*bottom*) a separate coil picks up energy from tipping particles. Resonance shows up as an increase in energy reaching the receiver.

the two poles of a magnet and surrounded with a coil which produced the second, rotating field [*see upper diagram at left*]. When the frequency was just right, energy passing along the coil was absorbed by protons in the sample of matter as they flipped over; this absorption of energy was recorded by a sudden dip in the strength of the signal reaching a radio receiver. Bloch's group, on the other hand, devised an instrument which recorded the event by induction of a voltage. As the protons flipped over, the motion of their magnetic fields induced a voltage in a second coil, and this signal was registered on an oscilloscope [*see lower diagram at left*].

The electron, like the proton, is a charged particle; it, too, spins and has a magnetic field—far stronger than the proton's, because it spins much faster. The electron also exhibits magnetic resonance. Since it is a stronger magnet and much lighter than the proton, it precesses much more rapidly in a given magnetic field. Whereas the proton is probed with radio waves in the range of a few megacycles per second (near the frequencies of ordinary home radio), for electrons the frequencies employed are in the microwave range, around 10,000 megacycles per second.

The magnetic resonance of protons and electrons makes it possible to learn many things about atomic nuclei, atoms and molecules. The magnetic probe amounts, in effect, to a new kind of spectroscopy. This brings us to the varied uses of the discovery in chemistry and biology.

The Structure of Molecules

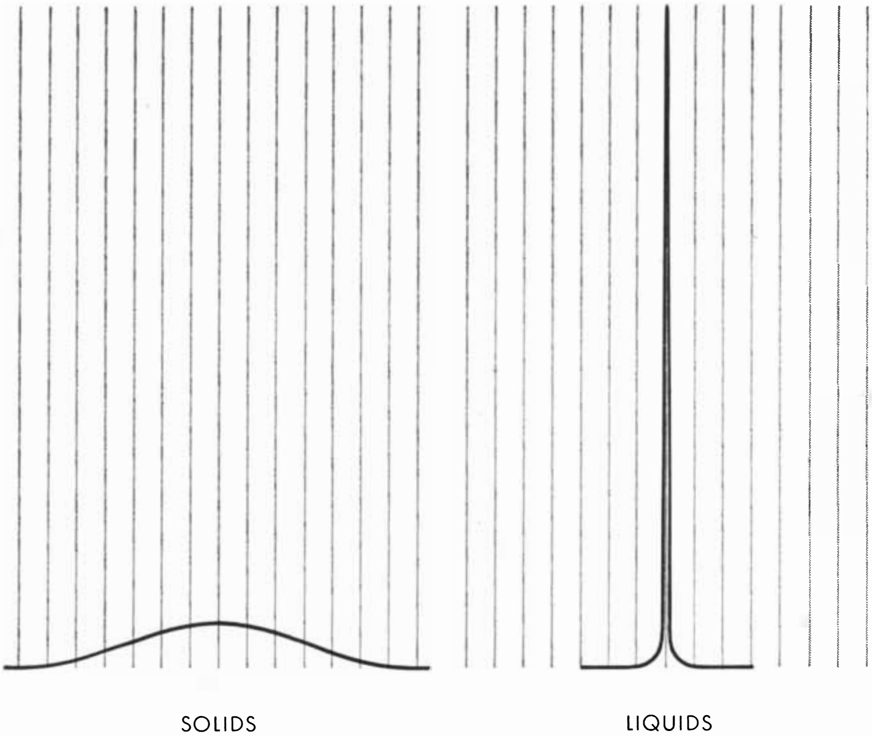
Let us look, for example, at an organic compound such as cyclohexane (C_6H_{12}). We shall examine its resonance spectrum by means of nuclear magnetic resonance (NMR). We measure the substance's resonance in terms of the precession speed at which the nuclei flip over. That is, instead of tuning in to the resonance by varying the frequency of the rotating magnetic field, we use a fixed frequency and vary the strength of the main magnetic field, which controls the precession speed; when the nuclei flip, the resonance reading is taken as the strength of the magnetic field at that point (measured in gauss or oersteds).

When we subject a sample of cyclohexane at room temperature to the proper magnetic field, we get a sharp resonance reading. The compound's hydrogen nuclei flip simultaneously at a certain field strength (the carbon atoms are not affected). Now the sharpness of this response has to be explained. In any collection of atoms we must reckon not only with the applied magnetic field but also with the little nuclear magnets of the atoms themselves. Each nucleus is subject to the magnets of its neighbors as well as to the applied field. The total magnetic field acting on a nucleus must vary from place to place in the material, because of the varying orientation of the nuclear magnets that happen to surround it. As a result of these variations, the responses to the external field should vary: it should take a slightly stronger applied field to flip some nuclei than others. This means that the resonance range for the whole group of nuclei should be a broad band rather than a sharp line. However, in a liquid the local variations are so short-lived, because of the rapid random motions and mixing of the molecules, that in effect all the nuclei are subject to about the same average field. Thus cyclohexane, a liquid at room temperature, gives a sharp magnetic-resonance line.

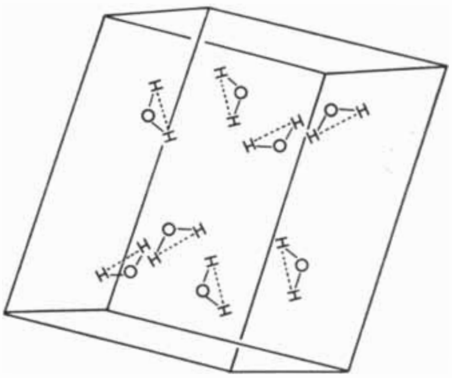
The situation is different in a solid. Because the molecules occupy fixed positions, there are persisting local differences in the magnetic field, and accordingly solids tend to have a broad resonance. The resonance band may be as wide as 20 gauss, as against a sharp line as narrow as one 10,000th of a gauss for some liquids. But here cyclohexane offers an unusual and illuminating case. When it is frozen to the solid state, it still has a sharp resonance down to a temperature of 90 degrees centigrade below its freezing point. This tells us that the molecules in the solid must be in some kind of motion. Evidently they rotate around their positions in the crystal lattice, so that the magnetic field averages out to uniformity.

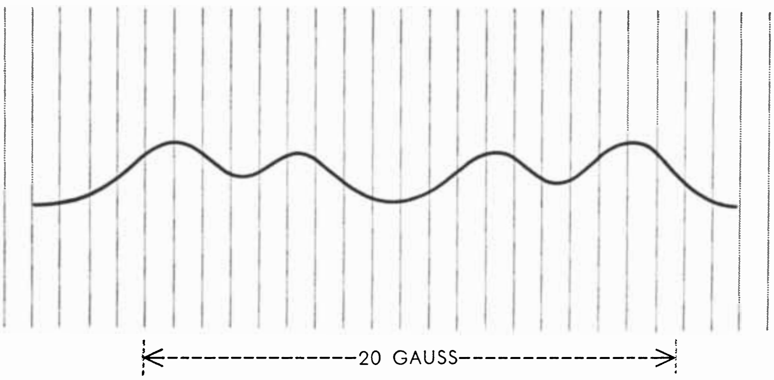
More detailed study of various substances, solid and liquid, leads to still more interesting developments. In 1947, while working as a graduate student with Purcell at Harvard, I found that the resonance of the hydrogen nuclei in gypsum was split into four distinct lines [*see chart below*]. Clearly these must reflect certain definite variations of the magnetic field within the gypsum crystal. By a theoretical analysis it was possible to translate the information into a picture of how the hydrogen atoms lie in the crystal structure. Here, then, was a new tool for analyzing the structure of crystals—a supplement to probing them with X-rays and neutrons. It is particularly useful for locating light atoms such as hydrogen and lithium, which deflect X-rays only weakly. Nuclear magnetic resonance has now been applied to the study of crystals by scientists in many parts of the world.

From crystals it was a logical step to go on to study the structure of giant molecules, such as rubber, polyethylene and other plastics. One of the problems in analyzing such molecules is to find out how much of their structure is orderly, or crystalline [see "Giant Molecules," a special issue of SCIENTIFIC AMERICAN; September, 1957]. C. W. Wilson, III, one of my graduate students at Washington University in Saint Louis, was able to show that nuclear magnetic reso-

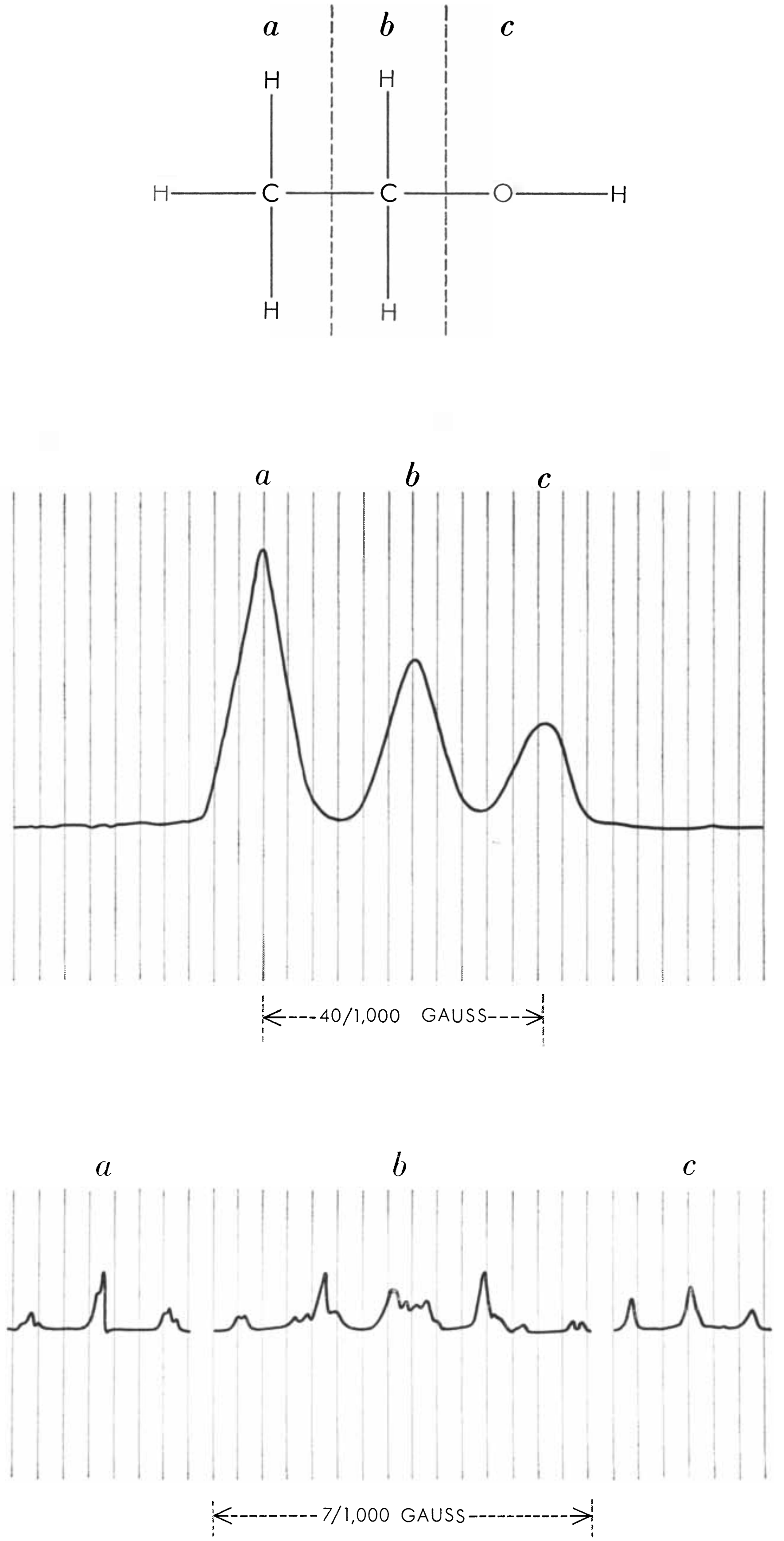


NUCLEAR-RESONANCE CURVES are broad for solids, narrow for liquids. The difference is actually greater than indicated here: the ratio of widths may be as great as 100,000 to 1.





GYPSUM CRYSTAL contains molecules of water, indicated in drawing at left as H-O-H. From the shape of the nuclear magnetic resonance (NMR) spectrum of gypsum (*right*) the positions of the water molecules in the structure of the crystal can be calculated.



ETHYL ALCOHOL, whose chemical formula appears at top, has a three-peaked NMR spectrum (*center*) when examined with a uniform magnetic field. Letters match hydrogen atoms in various sections of the molecule with their corresponding resonance curves. With a still more uniform field the central part of each curve splits further, as shown at bottom.

nance could be used to examine the structure of these huge molecules.

Fingerprints of Molecules

It is in liquids rather than solids, however, that the technique of nuclear magnetic resonance has achieved its most important triumphs of structural analysis. As we have seen, liquids show sharp resonances, because the magnetic field through the material is almost completely uniform. But a few irregularities can be detected when a liquid compound is examined under a very uniform applied field. Under these circumstances it becomes possible to read the resonance spectrum as a "fingerprint" of the structure of the molecule.

For example, James Arnold and Martin Packard at Stanford University, working with an extremely uniform applied field, were able to resolve the resonance of the hydrogen nuclei in the ethyl alcohol molecule (CH_3CH_2OH) into three separate resonances [*see upper chart at left*]. These singled out the three different groups that make up the molecule: CH_3, CH_2 and OH. The explanation is that the hydrogen nuclei in the three groups respond differently to the applied magnetic field because of a shielding effect of the atoms' electrons. The electrons themselves show no magnetism, for in a molecular combination electrons usually are paired off so that each cancels its partner's magnetic field. But an applied magnetic field slightly alters the motions of electrons around their atomic nuclei; the induced motions of the electrons in turn produce weak magnetic fields opposed to the applied field; this "diamagnetism" partly shields the nuclei from the external field. The amount of shielding differs in the different groups of a molecule, and this explains why the hydrogen atoms in the three groups composing ethyl alcohol have different resonances.

With higher resolution (*i.e.*, under a still more uniformly controlled magnetic field) the magnetic spectrum of the ethyl alcohol molecule splits up into an amazing array of separate resonances [*see lower chart at left*]. The spectrum is a fingerprint of the molecule which not only identifies it but also tells much about its structure. Indeed, from such a fingerprint a chemist can sometimes predict the behavior of a molecule.

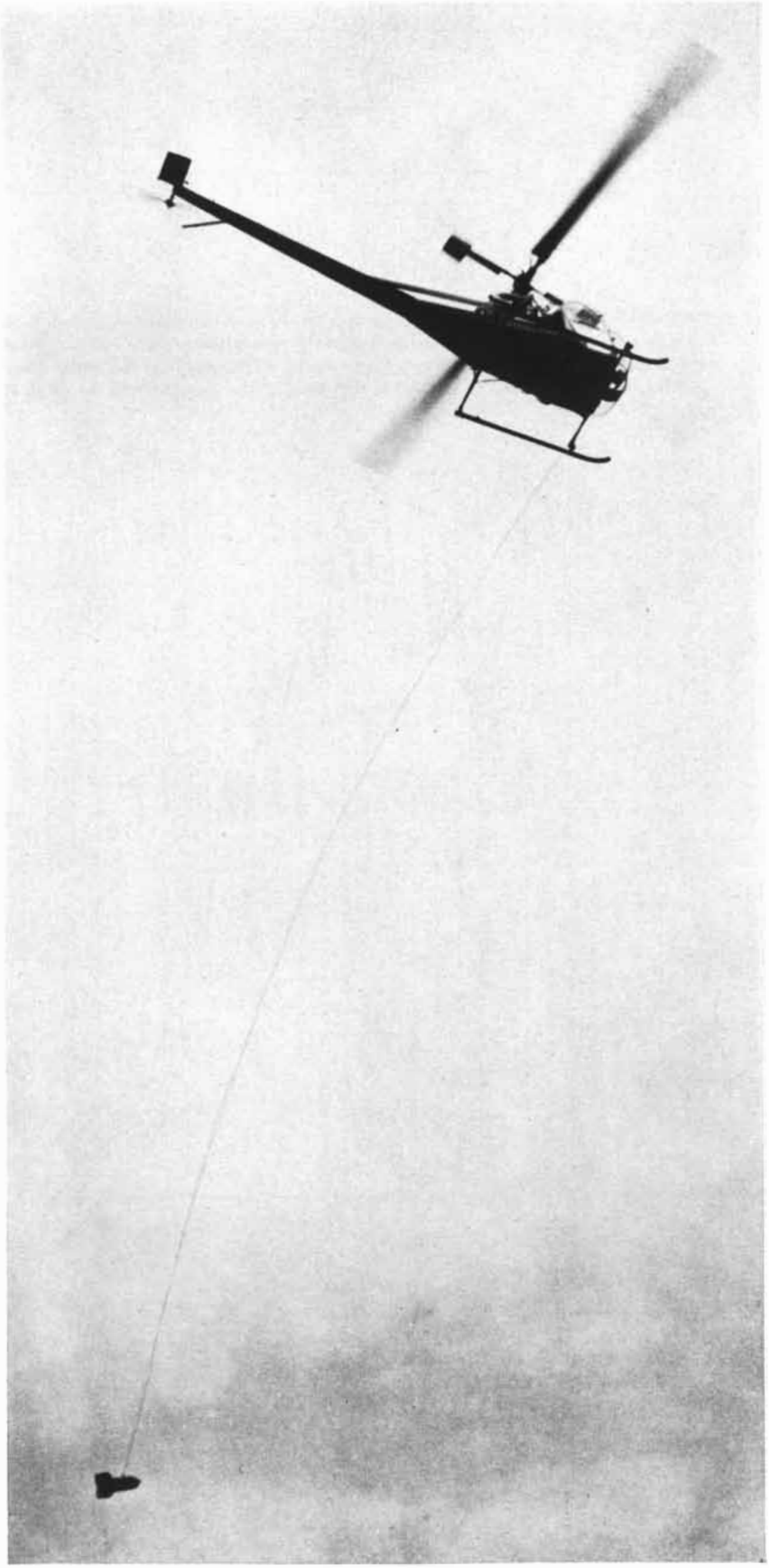
Chemists in all branches of their discipline are now busily employing nuclear magnetic resonance to unlock the secrets of structure of many kinds of substances, from soap and motor oil to the extremely complicated molecules of living matter. One of the virtues of this new analytical tool is that it does not destroy the chemical under analysis. The chemist simply puts the sample in a coil, turns on the radio waves and the magnetic field, records the resonance spectrum and then takes out the sample intact.

Measuring the Earth's Field

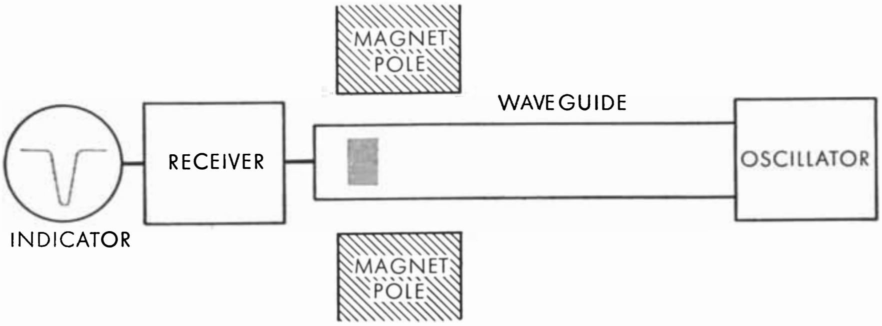
As a final illustration of the versatility of NMR let us look at a very different use—namely, exploring the earth's magnetic field. If very sharp precision in the strength of the applied field is needed to hit the resonance of a liquid, why not reverse the procedure and use resonance for precise measurement of magnetic fields? The difficulty about the earth's field is that it is extremely weak—only about half a gauss. To measure this by the resonance phenomenon, which previously had been studied in the laboratory with fields of thousands of gauss, posed quite a challenge. But Russell Varian and Packard, now with the Varian Associates, have solved the problem with an ingenious device.

Their instrument first lines up the protons in a sample of liquid with a moderately weak magnetic field. The protons are all oriented in one direction so that the whole sample, in effect, is a weak magnet. Then the polarizing field is suddenly switched off; the magnetic rug is pulled out from under the group of protons, so to speak. The nuclear magnets, which have been lined up in a direction *not* parallel to the earth's field, now begin to precess around the axis of this field. Their alignment rapidly breaks down, but in liquid benzene it lasts up to 20 seconds. This is long enough to measure the strength of the earth's magnetic field to an accuracy approaching one part in 10 million. The measurement is made simply by tuning in to the precession rate of the group of protons: since the earth's field produces the precession, the rate is a measure of the strength of the field.

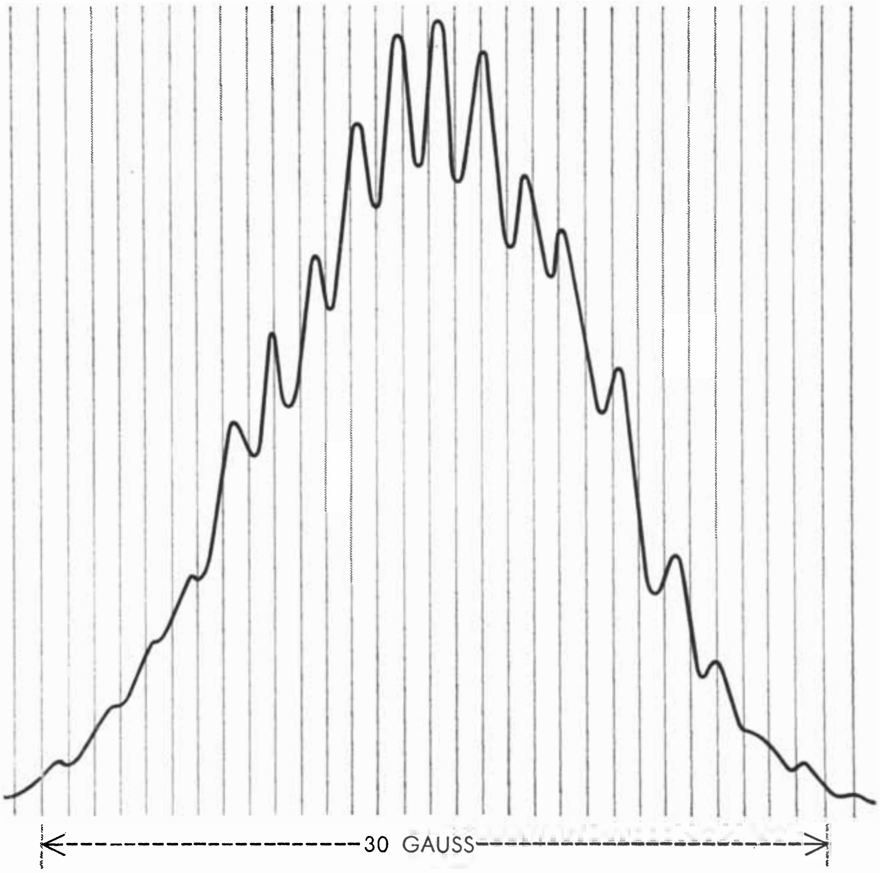
Varian and Packard named their instrument the proton precessional magnetometer. Obviously this amazingly sensitive device could serve to measure variations in the earth's magnetic field. It has already been put to use in prospecting for mineral deposits, from the air and on the ground [*see photograph at right*]. The instrument has also been shot in rockets to measure the strength of the earth's field at various heights above the surface. A magnetometer of this type is scheduled to go up in

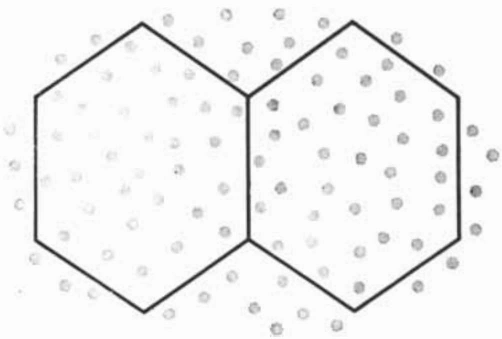


MAGNETOMETER based on nuclear magnetic-resonance principle measures small variations in the earth's field. Here it is towed by a helicopter in a mineral-prospecting survey.



ELECTRON-RESONANCE APPARATUS operates on the same principle as Purcell's circuit shown on page 60. A microwave oscillator sends three-centimeter radio waves through the waveguide. The sample (*gray rectangle*) is mounted on the inside of the guide. Resonance is indicated by a decrease in the power delivered by the waveguide to the receiver.





HYPERFINE STRUCTURE (jagged splitting) of an electron-paramagnetic-resonance (EPR) spectrum indicates various positions of the unpaired electron in a free-radical molecule. This curve comes from naphthalene radicals. Gray dots in the structural outline of the radical at bottom indicate that the free electron wanders over many parts of the molecule.

one of the U. S. artificial satellites soon. Surely Purcell and Bloch could hardly have foreseen that their exploration of the magnetism of the proton would lead to such developments.

The Resonance of the Electron

Let us turn now to the magnetism of the electron. The magnetic resonance of this particle was discovered by a Soviet physicist, E. K. Zavoisky, in 1944, before Purcell and Bloch tuned in on the proton. But curiously enough the Russians apparently were not as quick to exploit the discovery as physicists in the U. S., Great Britain and the Netherlands. At all events, the electron's resonance, called electron paramagnetic resonance (EPR), has now been forged into a tool as important in its area of usefulness as nuclear magnetic resonance.

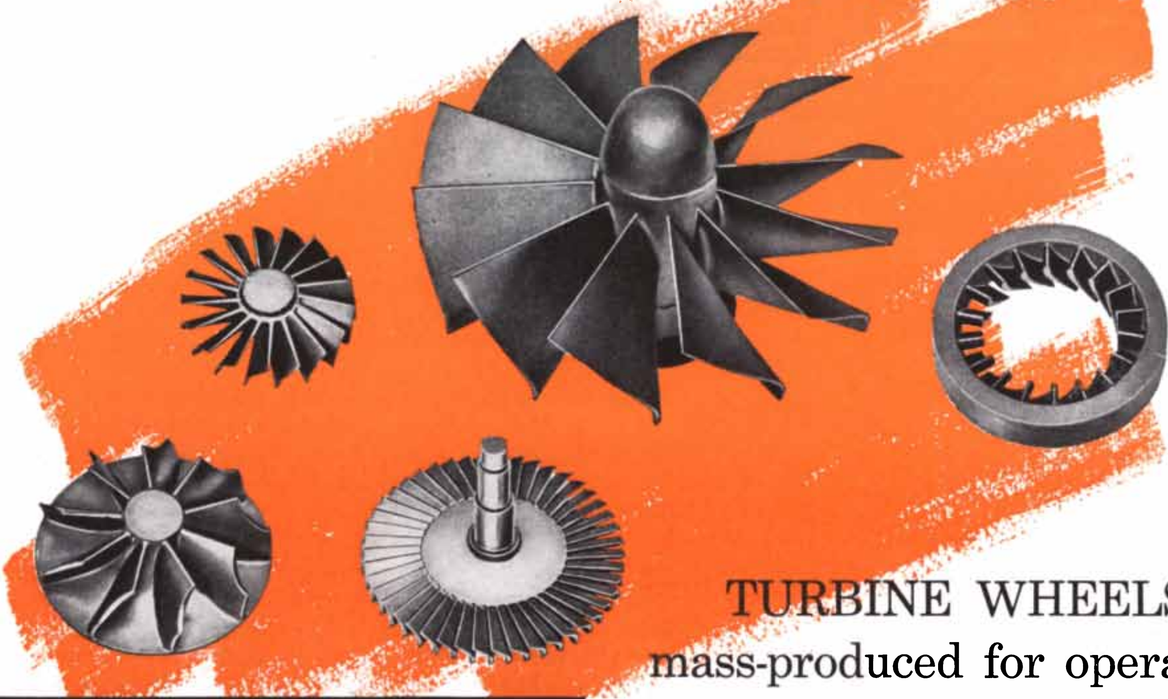
As we have seen, the electron, because of its smaller mass and faster spin, is a much stronger magnet than a proton. As a result, a given magnetic field makes it precess far more rapidly. Its precession rate in the standard laboratory magnetic field is in the range of the frequency of radio microwaves—that is, about 10,000 megacycles per second, or a wavelength of about three centimeters.

When microwaves travel down a rectangular waveguide (the tube used to conduct such waves), they produce a rotating magnetic field at any fixed point. This field can serve to flip over the electron magnets in matter, just as a rotating field in a coil flips protons. The experimenter may place the sample of material on a side wall of the waveguide, turn on the radio waves and apply an external magnetic field to make the electrons precess. When the precession rate reaches the resonance value and the electrons flip, they extract energy from the radio waves, and the reading on a receiver at the end of the tube dips accordingly.

Now this technique obviously can tell us nothing about substances in which the electrons are all paired, *i.e.*, where the electrons' magnetism is neutralized. But it has proved very helpful indeed in studying material with unpaired electrons. Electron resonance was first applied to investigate crystals containing elements with unfilled electron shells (therefore unpaired electrons)—elements such as manganese and iron. Much has been learned about substances of this kind, particularly about those used for "magnetic" cooling of matter to very low temperatures.

But more exciting has been the discovery that electron resonance can be used to investigate free radicals, the

HAYNES investment casting solves the *tough* design problems



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Special inspection equipment guarantees accuracy. Examinations by Gamma Ray (above) is one of a number of inspection methods used at Haynes Stellite Company's plant to insure top quality control.

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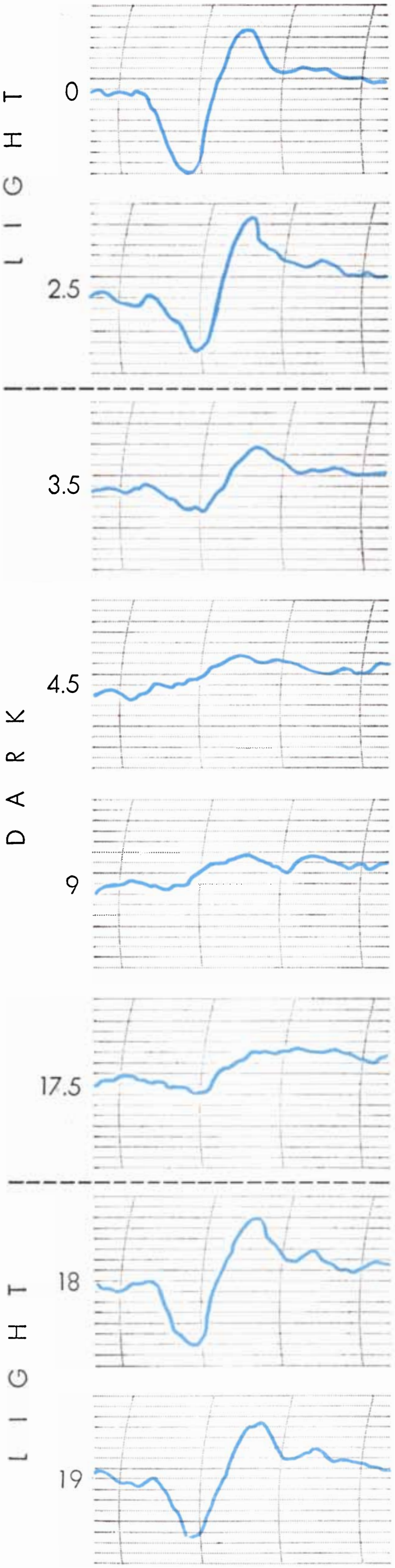


CHLOROPHYLL SAMPLE gives sharp EPR spectrum when irradiated with light. This proves that free radicals are involved in photosynthesis. Numbers at left indicate minutes from the start of the experiment.

transitory molecular fragments that play a crucial role in many chemical processes, including the chemical activities of living cells [see "Free Radicals," by Paul D. Bartlett; SCIENTIFIC AMERICAN, December, 1953]. Free radicals, of course, have unpaired electrons, and with the electron-resonance technique it is sometimes possible to detect these fleeting substances and to learn something about their structure and behavior.

At first thought one might suppose that the resonance spectrum of the unpaired electron in a free radical should always be the same—one free radical indistinguishable from another. But this is not the case. The electron is affected by the magnetic field of the nuclei in whose neighborhood it happens to be, and as the free electron wanders about in the molecular fragment, it is subjected to varying magnetic fields. As a result its resonance may be split into a "hyperfine structure" [*see chart on page 64*]. From the splitting we may learn where the electron spends its time and at what rate the free radical is likely to enter into chemical reactions.

Such studies are not limited to natural free radicals. With high-energy particles from an accelerator it is possible to break a molecule into fragments, and the fragments can sometimes be frozen in their tracks, so to speak, by keeping the sample at a very low temperature. We can then see what has happened to the molecule by examining the electron resonances of the fragments. This kind of investigation could be useful for studying the chemical effects of radiation on certain plastics; irradiation is known to strengthen some plastics by causing them to form new chemical bonds. Magnetic resonance also looks promising as a tool for investigating the free radicals that catalyze the synthesis of high polymers such as rubber or polyethylene [see "How Giant Molecules Are Made," by Giulio Natta; SCIENTIFIC AMERICAN, September, 1957].

Resonance in Living Cells

To illustrate the interest of biologists in magnetic resonance, I shall close this account with an episode that began in Saint Louis one evening in 1951. After attending a chamber music concert, a few members of the Washington University faculty repaired to someone's home for coffee, and the conversation turned (probably to the wives' chagrin) to shop talk. Barry Commoner of the botany department fell to discussing the theory that free radicals play an important role in the processes of oxidation and reduction in living cells, and he remarked how difficult it was to detect free radicals in living systems. I suggested that electron resonance might be helpful, and offered to help Commoner and his group learn how to use the method. Thus began a most interesting series of experiments.

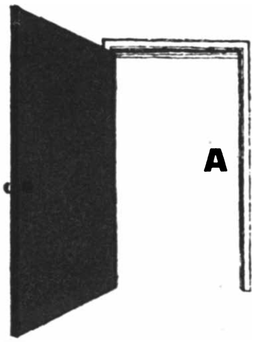
The first results were disappointing. Since the experiments involved cultures of cells (yeast and other organisms), there was moisture in the microwave apparatus, and moisture absorbs microwaves. This absorption of course masked the dip in radio energy produced by magnetic resonance. Even so, the experimenters finally detected a weak resonance from yeast and found that its intensity varied with the rate at which oxygen was consumed by the yeast cells. Then a resonance was discovered in green leaves ground up and quickly freeze-dried to eliminate the absorption by moisture.

To study the active process of photosynthesis in its necessary moist environment, however, called for a much more sensitive apparatus. Jonathan Townsend of the physics department succeeded in devising one, and it became possible to work with living cells. The cells selected contained chloroplasts—the small, green, chlorophyll-packed bodies which are thought to carry out most if not all the steps of photosynthesis.

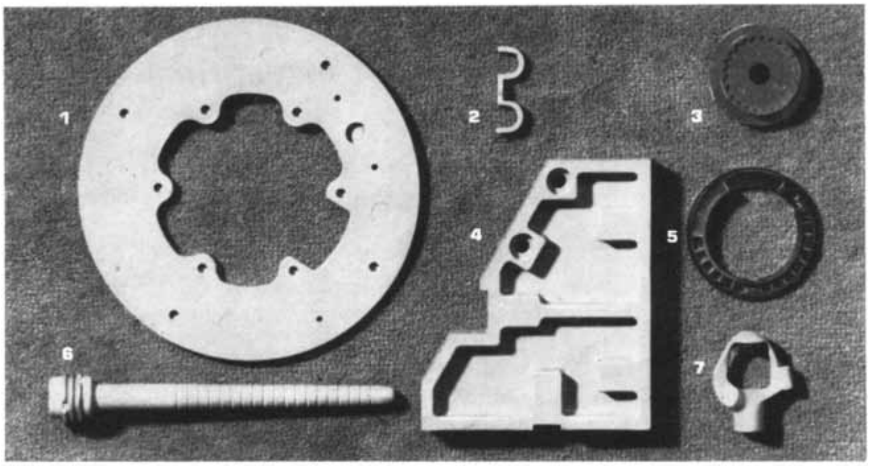
The cells were placed in the sensitive magnetic resonance apparatus and were simultaneously irradiated with white light from a 50-candle-power lamp. The chloroplasts immediately showed a dramatic resonance spectrum [*see charts at left*]. When the light was turned off, the resonance soon weakened or disappeared entirely. Next the cells were exposed to light of various specific wavelengths; it turned out that the resonance appeared at the very same range of wavelengths of light that produces photosynthesis.

Commoner and Townsend have gone on to further experiments which not only have linked free-radical activity firmly to photosynthesis but have also indicated that free radicals are involved in the metabolism of cancer cells. And biological investigators in many other laboratories have begun to adopt electronic resonance as a tool in their researches.

That basic discoveries in science invariably bear fruits which cannot be foretold is an old story to scientists. Even so it has been a great thrill to see what has grown out of the work of Purcell, Bloch and Zavoisky, who were seeking only to get a better understanding of the magnetism of the particles in the atom.



A DOOR IS OPENED... TO NEW DEVELOPMENTS IN PLASTICS



NEW USES FOR PLASKON ALKYD MOLDING COMPOUNDS: 1. Motor guard; 2. Cable bracket; 3. Fishing reel part; 4. Support bracket; 5. Azimuth ring; 6. Textile bobbin; 7. Fire sprinkler head.

Our headline doesn't mean that we are going to tell you about a revolutionary new *kind* of plastic material. Instead, what follows is more in the nature of a letter from some old friends—namely, Alkyd, Urea and Nylon. It tells you what these characters are up to these days and may contain a hint or two about why it may pay *you* to keep in touch with *them.*

ALKYDS. Developed some years ago, alkyd molding compounds began their career in a specialized field—electrical and electronic insulating components. They did a fine job, too—and why not? They have the best electrical properties of any plastic molding compound we know. Their arc and heat resistance are excellent, and they are extraordinarily strong and dimensionally stable.

More recently, however, *Plaskon* Alkyds have broadened their careers to find many uses in fields other than the electrical. Customers from all kinds of businesses are coming to us with a host of different applications in mind. (The illustration above shows some of these and you can see they are as diverse as fishing reel parts and textile bobbins.)

It's not hard to account for the present popularity of alkyds. Besides excellent electrical properties, these compounds offer a combination of strength, dimensional stability and rapid cure that can "open a door" to many profitable new applications for those who make or use plastic parts.

WOOD-FILLED UREA. When is a 25-year-old plastic "new"? Look at it this way: woodflour-filled urea has been a popular molding compound in England for a quarter of a century. American producers have never pushed it—as we think it deserves to be pushed. Now—through our new facilities—Allied is making a major effort to bring this low-cost, general-purpose compound into wide use in this country. *Plaskon* Wood-filled Urea is excellent for high-speed automatic operations. It offers color-fastness, superior electrical properties and resistance to solvents. Parts molded from it have hard, scratch-resisting, nonelectrostatic surfaces. Uses? Closures and wiring devices chiefly—and at present; but innumerable applications may be expected as American industry becomes increasingly aware of this economical plastic "workhorse."

EXTRUDED NYLON. Those familiar with the advantages of tough, thermoplastic nylon for *molded* parts will immediately appreciate the possibilities in *extrudable* nylon. *Plaskon* Nylon for extrusion is a special form of polycaprolactam ("Nylon 6"). It can be extruded as tubing, tape or film. As instrumentation tubing, for example, it may replace copper in many applications, costing less both from a raw material and an installation point of view. As tape, covered with leather or otherwise reinforced, it promises a new high in thin, strong tapes. (Power transmission belting is now under development.) As film —transparent, strong and resistant to high heat—it becomes a kind of "Tiffany" plastic. Example: as a wrapping for frozen food which is to be cooked right in the pack.

Allied Chemical

IF YOU WOULD LIKE INFORMATION *or literature on any of these plastics developments from our* Plastics and Coal Chemicals Division, *just write us on your company letterhead. In addition to* Plaskon *alkyd, urea, nylon and melamine molding compounds, we make polyester, industrial and coating resins. Perhaps information on one or more may "open a door" to profits or progress in* your *business. Address: Allied Chemical, Dept. 88-S, 61 Broadway, New York 6, N.Y.*

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Repetition and Learning

Is drill necessary in rote learning? The author's experiments indicate that we form mental associations instantly. The role of repetition is to help us retain what we have already learned

by Irvin Rock

Every school child, past and present, knows the pain and humiliation of learning by drill and repetition. In the prevailing opinion of teachers and psychologists this procedure is inescapable. Rote learning—the forming of mental associations between two (or more) initially unrelated entities—is held to be akin to the process of conditioning in laboratory animals that associates the buzzer and the flow of saliva.

On the other hand, we fix many associations in our mind with ease. We associate a name with a face, a word with its meaning, and so it goes with much of the "by-heart" learning that attends daily life. Many psychologists hold that all learning is by association. Such generalization is probably unwarranted. School children also know the pleasanter experience of learning by understanding and thinking, and it can be argued that this involves something more. Nonetheless it must be conceded that understanding requires the forming of associations and that these associations also often seem to form upon the instant. Why then does some rote learning call for drill? Perhaps we can go so far as to ask whether repetition is ever really necessary to learning.

It is an ancient tradition that exalts drill as a method of learning. Of all the many notions from the past, two in particular have a firm place in modern learning theory. One of these is the principle of contiguity: we can associate two things only if we experience them at approximately the same time. The second is repetition: we form associations only through repeated experience. Various schools of psychology have put forward other factors in learning, such as motivation (the intention or "set" to learn), reinforcement (the presence of reward or punishment) and grouping (whether or not the items to be learned are perceived as a unity). Different theories assign different weights to these additional factors, but all agree on the central importance of contiguity and repetition in the forming of associations.

Contiguity is obviously the *sine qua non* of learning. We associate thunder and lightning, for example, because they occur close together. If they were separated by several hours, we would almost certainly not associate them unless investigation had taught us that they were related. Even when we associate a past experience with a new one, contiguity is at work. We evoke the memory of the past experience (or its presumed physiological "memory trace" in the nervous system) contiguously with the direct sensation of the new experience.

Repetition acquired its equally paramount position in modern experimental psychology thanks to the work of the pioneer German investigator Hermann Ebbinghaus. He published a now-classic monograph on the subject of learning in 1885 in which he described experimental procedures that are the prototypes of those used today. Ebbinghaus made up random lists of nonsense syllables and set out to learn them, keeping records of his progress. He used nonsense syllables to be sure that his items of learning would have no prior associations attached to them. Syllables of this sort are still widely used by experimental psychologists. Ebbinghaus would read them aloud, over and over, testing himself after each reading by trying to recite the entire list after reading only the first syllable. When he could do this without error twice in a row, he considered the list learned. By this procedure Ebbinghaus explored such problems as the connection between length of lists and the number of repetitions required to learn them, and was able to measure also the rate at which he forgot what he had learned. From the latter experiments he was able to plot the first "curve of forgetting" [*see illustration on page 70*].

Ebbinghaus considered repetition basic to rote learning, and almost all psychologists and educators today agree with him. The accepted theory holds that a single experience of two contiguous items establishes only a partial connection between them in the nervous system, one that the learner cannot as yet articulate. Additional experience strengthens this connection to the point where the subject, upon exposure to one item, can respond with the other.

Now repetition often does seem necessary to learning; this is no doubt the genesis of the theory in the first place. In the typical laboratory experiment most subjects require repeated exposure to the list of items to be learned.

On the other hand, the repetition theory fails to account for the many associations in daily life that seem to be established by a single experience. One explanation of the meaning of a new word is often enough (this is particularly the case with children, who learn new words all the time). One introduction to a person often suffices to teach us his name. Even in laboratory experiments most subjects, though they require many repetitions to learn the entire list, learn at least a few items on the first trial. These apparent exceptions to the principle of repetition suggest that we might well re-examine the principle itself.

Let us, for the sake of argument, adopt

1	2	3	4	5	6	7	8
GAC QET	BIH XIR	CEZ MUN	TOF LAH	GEY NUR	KAR WEH	DUP TEZ	FAX SOQ
BIH XIR	FAX SOQ	BIH XIR	KAR WEH	FAX SOQ	TOF LAH	GAC QET	DUP TEZ
TOF LAH	GAC QET	TOF LAH	DUP TEZ	CEZ MUN	DUP TEZ	KAR WEH	GAC QET
FAX SOQ	CEZ MUN	DUP TEZ	GAC QET	TOF LAH	GEY NUR	FAX SOQ	KAR WEH
GEY NUR	TOF LAH	KAR WEH	FAX SOQ	GAC QET	BIH XIR	GEY NUR	CEZ MUN
DUP TEZ	GEY NUR	GEY NUR	CEZ MUN	BIH XIR	FAX SOQ	TOF LAH	BIH XIR
KAR WEH	DUP TEZ	FAX SOQ	BIH XIR	DUP TEZ	GAC QET	CEZ MUN	GEY NUR
CEZ MUN	KAR WEH	GAC QET	GEY NUR	KAR WEH	CEZ MUN	BIH XIR	TOF LAH

1	2	3	4	5	6	7	8
POY CES	QOZ YAT	BOP YIT	QAT BUP	ZEB DUF	YUL TAJ	YUR FEG	LUZ VAB
KOB RUV	XAN NAC	QOZ YAT	YUR FEG	QAT BUP	NUV DAK	YUL TAJ	FEC RIQ
QAT BUP	CEG YOW	JEP BOZ	KIB JUY	KAM JIR	YUR FEG	JAL MEP	KOR GOP
WEM NIR	JEP BOZ	NOH FEJ	FEC RIQ	YUR FEG	QAT BUP	QAT BUP	QAT BUP
FAH VAQ	ROF FAZ	LUJ ZEN	LEQ GEZ	FEC RIQ	FEC RIQ	KOR GOP	YUR FEG
JEP BOZ	YOB FAP	QAT BUP	SIQ HAX	JEP BOZ	KOR GOP	FEC RIQ	YUL TAJ
ZAM VOM	QAT BUP	DAF VUT	TOC JEV	KOR GOP	DOJ YAF	JEP BOZ	NOK MIJ
XUN BEW	TIS KED	FEC RIQ	JEP BOZ	BOQ YUG	JEP BOZ	NAJ QUN	JEP BOZ

1	2	3	4	5	6	7	8
FAX SOQ	KAR VAQ	JED NUR	POV LUB	GEY VAQ	FAX SOQ	JED SOQ	KAR SOQ
GEY NUR	SOH LUB	FAH ZIM	WOB PEQ	POV LUB	WOB PEQ	FAX GIZ	JED VAQ
JED LUB	FAX WEH	POV LUB	SOH WEH	WOB PEQ	GEY ZIM	FAH NUR	FAX GIZ
WOB PEQ	POV ZIM	FAX VAQ	KAR ZIM	FAH NUR	JED VAQ	GEY ZIM	SOH WEH
SOH GIZ	JED NUR	GEY WEH	FAX GIZ	KAR SOQ	KAR GIZ	SOH WEH	WOB PEQ
POV ZIM	GEY SOQ	KAR GIZ	GEY VAQ	FAX ZIM	POV LUB	KAR VAQ	FAH NUR
FAH VAQ	WOB PEQ	SOH SOQ	JED NUR	SOH WEH	FAH NUR	WOB PEQ	POV LUB
KAR WEH	FAH GIZ	WOB PEQ	FAH SOQ	JED GIZ	SOH WEH	POV LUB	GEY ZIM

LEARNING RECORDS show the progress of typical subjects in three experiments made under different conditions. In the control group (*top*) subjects saw new pairs of nonsense syllables (*light type*) on the first trial; these were repeated (*heavy type*) on subsequent trials, in a different order. In the experimental group (*middle*) only the pairs learned on previous trials (*light color*) were repeated; unlearned pairs were replaced with new ones. In the second experimental group (*bottom*) unlearned pairs had their syllables interchanged each time (*underlined*). Subjects occasionally forgot pairs previously learned (*colored bar*). All benefited from "overlearning" (*dark color*) of pairs already learned; the pairs learned on early trials were remembered best after a lapse of time.

the contrary hypothesis and declare that repetition has nothing to do with the forming of associations. We will explain the necessity for repetition in psychological experiments not on the ground that associations are built up gradually but simply because the list is too long to be mastered on one trial. If this reasoning is correct, items on the list which are not learned do not leave behind any increment of associative strength. People should be able to learn items which they have never seen just as easily as items which they have seen but not learned.

During the past few years I have performed a number of experiments to test this hypothesis. In the first of these experiments two groups of subjects undertook to learn eight pairs of nonsense syllables. Each subject was shown the pairs in succession, and was then tested by being shown the first syllable in each pair to see if he could respond with the second. I chose this "paired-associates" technique because it seems to isolate the basic element of associative learning—the individual association—more effectively than Ebbinghaus's linking together a series of items. In both learning and testing the syllable pairs were presented in random order.

Subjects in the control group were repeatedly shown the same eight pairs until they had learned all of them—the traditional procedure in learning experiments [*see illustration on preceding page*]. Subjects in the experimental group, however, were shown a changing series of pairs. Pairs which they learned on the first trial were kept on the list, but those which they failed to learn were replaced by new pairs. This procedure was followed on each trial until the subject had learned eight pairs, most of which were not on the original list. Thus these subjects had to learn their pairs on one trial or not at all: they had no chance to build up associations gradually. The control subjects, on the other hand, saw the same eight pairs from beginning to end and had the benefit (if any) of associative increments.

What was the difference in the performance of the two groups? The answer is: There was none! Both groups learned at about the same rate [*see illustration on page 72*], requiring on the average about eight trials to learn eight pairs. An experiment using letters paired with numbers instead of pairs of syllables gave the same result.

Perhaps, however, the control group was under some special disadvantage as compared with the experimental group. Some control subjects, for example, instead of simply failing to learn a particular pair learned it incorrectly, recalling GAC-QET, say, as GAC-XIR. These subjects obviously had to unlearn such incorrect associations before they could learn correct ones. The experimental subjects did not have this disadvantage, since the pairs which they learned incorrectly were stricken from the list, and they could start afresh on new pairs.

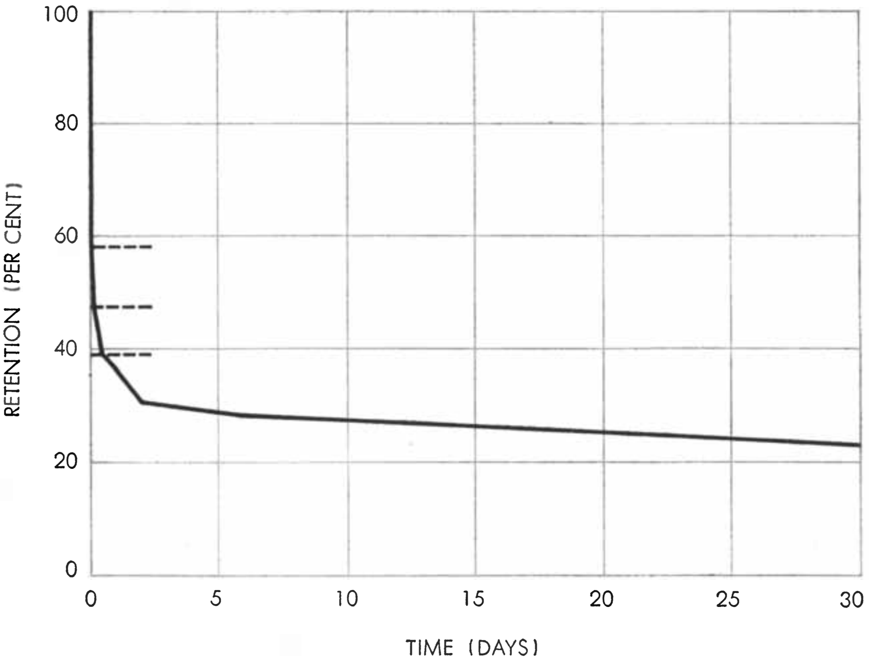
To test this possibility I undertook a further experiment in collaboration with Walter Heimer. This time we did not strike out unlearned pairs, but reshuffled them, pairing the first syllable of one pair with the second syllable of another. For example, if a subject failed to learn FAX-SOQ and GEY-NUR the first time, or mislearned them, he might see them the next time as FAX-NUR and GEY-SOQ; if he still failed to learn them, they would be reshuffled in a different way. We thus made sure that if any partial bonds were established they would be incorrect bonds which the subject would have to overcome before he could form the correct association.

Despite this seeming further disadvantage, the third group did just as well as the other two. Moreover, almost no subjects in this group noticed the reshuffling. This fact further strengthened our conclusion that pairs which are not learned leave little if any trace in the memory.

It could be argued that the experimental group enjoyed other possible advantages that offset the absence of repetition. For example, one could say that the control group has an increasingly difficult task since the people in it are left with pairs which, for one reason or another, they find hard to learn, whereas the experimental group is confronted with new pairs of average difficulty. It is also possible that some future variation in experimental design will show that our experiments were weighted in some other way against the control procedure (although we found no such weighting in testing several designs not discussed here). But even if it could be shown that the traditional control procedure promotes faster learning, the excellent performance of the experimental groups shows that at the very least a considerable portion of learning in the traditional procedure occurs on one trial.

If associations are formed in one trial, as these results indicate, how is it that none of our subjects learned more than a few items on any one trial? To answer this question we must contend with another factor which I have not mentioned: interference.

Ebbinghaus himself discovered that the presence of a great many items in a list interfered with the learning and retention of any of them. He found that as he increased the length of his lists the time needed to learn them increased far more rapidly. A list of 10 items might require 52 seconds, or a little more than five seconds per item, while a list of 36 items might require 792 seconds, or



CURVE OF FORGETTING shows that material is forgotten most rapidly soon after learning. Broken lines show (*top to bottom*) retention after 20 minutes, one hour, and nine hours.

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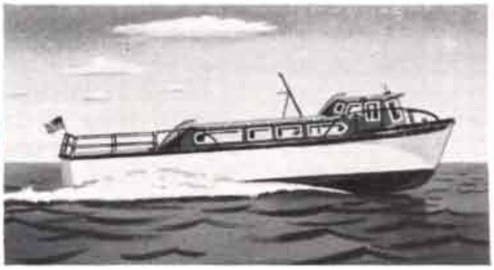

Two V-drive Solar Jupiter® turbines produce 1000 hp in this aluminum-hulled 52 ft work boat. Dry weight is 31,000 lbs. It will carry 25 passengers and crew at speeds better than 40 mph.

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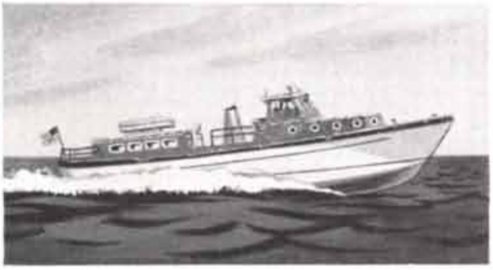

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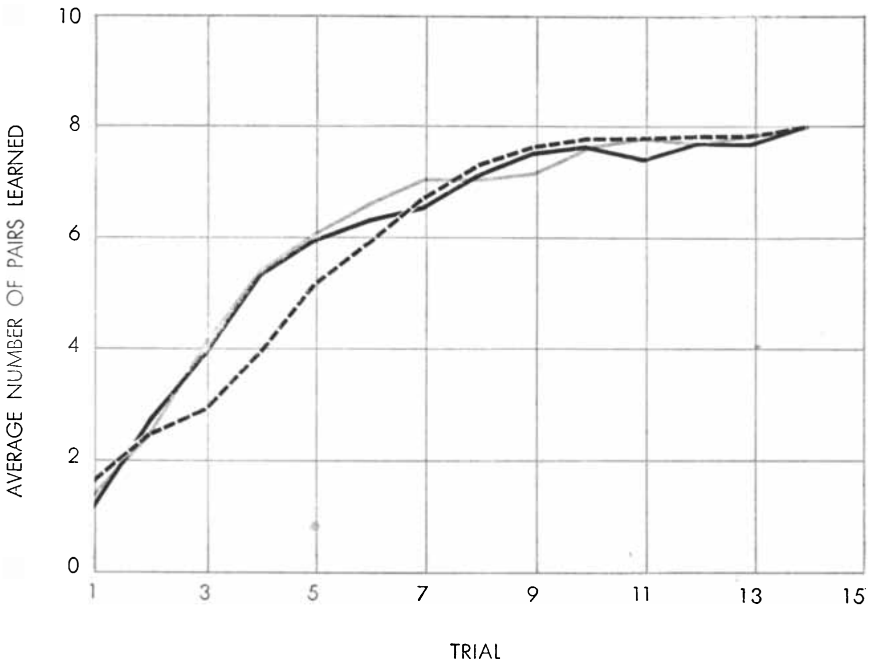

LEARNING CURVES show the average progress of three groups of subjects under the different conditions charted on page 69. The control group (*solid line*), experimental group (*broken line*) and "interchange group" (*gray line*) all learned at about the same speed.

22 seconds per item. Interference shows up in another way in an experiment which the reader can try for himself. A subject is exposed to a number of digits and asked to repeat them back; he may be able to repeat as many as eight digits correctly. If he is exposed to nine or 10 digits, however, he will often not even get eight. As the number of digits increases beyond a certain critical point, the number of correct responses invariably decreases.

These experiments confirm a common experience of daily life. It is easy to learn one person's name in a single introduction, but most of us will remember few names or none by the time we have been introduced to the last guest at a social gathering.

Evidently, then, it was interference that kept our subjects from learning all eight pairs on one trial. This suggests that if interference is kept to a minimum (*i.e.*, if the list is short enough), no repetition will be needed. Franklyn Springfield, at the New School for Social Research in New York, has tested this deduction by a simple experiment. He pretended to be giving a lecture on memory, and held up a pair of nonsense syllables on a card as an example of those which Ebbinghaus had invented. After different intervals of time, he tested the students. Virtually all of them had learned the syllables upon this single exposure, even though he had not asked them to do so.

Do these experiments mean that repetition plays no part in learning? By no means. Though repetition does not appear to help the forming of associations, there is ample evidence that it strengthens them once they are formed. If we meet a person only once, we may forget his name a week later. If we meet him repeatedly, however, we are likely to remember his name for years. Investigators from Ebbinghaus on have found that "overlearning"—the repeated recitation of already-learned material—minimizes forgetting.

Our own experiments bear this out. The control group provides a clear case. These subjects, as the reader will remember, worked on the same list of eight pairs from beginning to end—*i.e.*, they saw each pair the same number of times. Yet when we tested them after a lapse of time they recalled the pairs they had learned during the first trials much better than those they learned later. Evidently their learning of the first pairs had been strengthened by overlearning.

Thus repetition does not seem to help us learn. In the many situations where we have too much material to learn on one trial, it enters into learning, as such, only in the sense that it provides opportunity to see again the material not learned in earlier trials.

The real villain in memorizing, it seems, is interference. Cut down interference, and learning speeds up. If we have to learn a long list of items by heart, we will do well to concentrate on forming only one or two connections on the first trial. On the next trial overlearning will begin to strengthen our recollection of the first items learned, and we will be free to concentrate on learning a few more, and so on. If we try to memorize everything on each trial, we may well learn nothing at all.

It is undoubtedly too early to draw policy from these findings, but they do suggest a new approach to the learning of rote subjects. A teacher who is introducing the multiplication table, for example, might do well to present only a few numbers each day. She might even concentrate on one ($4 \times 5 = 20$, for example), present it in the context of a logical analysis of why 4×5 does equal 20, and let it go at that for the day. If the teacher took this approach to other rote subjects (spelling, for instance), she might devote shorter periods each day to a greater variety of subjects. There may be many good, practical reasons why this sort of curriculum would be undesirable. But it would certainly cut down the drilling.

The relationship of associative learning to more complicated types of learning, such as problem solving and learning by understanding, is still far from clear. But our finding that associations form instantly rather than gradually throws an interesting light on this question. Many psychologists (notably those of the Gestalt school) have stressed the importance of insight—the sudden flash of understanding often called the "aha" experience. Sudden insight may well be related to the sudden formation of associations. Indeed a number of experimenters have found that associative learning often involves the sudden discovery of some mnemonic device for linking together two items by means of some intermediate idea. This closely resembles the process by which we solve problems.

The reader may wonder why this article has said nothing about what goes on in the brain during learning. The fact is we simply do not know enough about how the brain works to say anything very helpful about the neurological basis of higher mental processes. Most investigators have preferred not to speculate about the physiology of learning but to explore it by means of psychological experiments. The knowledge we are gaining in this way will not of itself provide physiological answers, but should eventually enable us to tell the physiologist what to look for.

RARE EARTHS SERVE YOU EVERY DAY

A variety of common uses of these unique materials

a report by LINDSAY

We've often suggested on this page that you might find interesting and profitable uses for the rare earths in your manufacturing processes. Here are some of the common but none-the-less exciting applications of rare earths.

If you are a camera fan, you've probably heard about rare element glass developed by Eastman Kodak. It is called "rare" because it contains, among other things, lanthanum which is one of the rare earths.

Kodak utilized the principle that rare earth glass has a very high refractive index in relation to its dispersion. It, therefore, bends light more and spreads colors less. This permits production of lenses with shallower curves and, consequently, less inherent aberration. The result: higher quality lenses with fewer glass parts.

Rare element glass was perfected by Kodak for high precision military needs during World War II. The exciting part of the story is that Kodak's optical engineers have now found a way to produce rare earth element glass lenses in quantity at greatly reduced costs. That's why today you can get so fine a precision Kodak lens so economically.

Next time you get color slides with beautiful, needle-sharp images, shot with your favorite camera (Kodak, of course), you can thank the imaginative engineering of the people at Kodak . . . and think, too, of the amazing versatility of the rare earths.

IF YOU WEAR GLASSES

Chances are that your glasses were polished with ceria, a rare earth oxide preferred by many of the better optical firms. Cerium oxide is also widely used to polish high precision optical instruments, mirrors and other glass specialties. Speaking of versatility, certain of the rare earths are used to decolorize glass; others add the lovely, delicate colors so many people like in fine glassware.

HAVE A LIGHT

Top quality lighter flints are made of misch metal (an alloy of mixed rare earths). Rare earth metals are also used to create better alloy steels and magnesium alloys for high temperature service.

OUT OF THIS WORLD

Thorium, intimately associated with the rare earths, is literally out of this world — in the outer atmosphere! For thorium is an essential metal in the production of the alloy skin of the third stage of a rocket. Thorium has unique qualities which make it possible to produce a thorium-magnesium alloy which does not burn up at the fantastic speed of the rocket—up to 18,000 miles per hour.

AND A FEW MORE

More perhaps than you have suspected, *you* enjoy *every day* the benefit of the truly remarkable qualities of rare earths. They are used in the production of such widely diversified daily essentials (to name only a few) as movie projectors, textiles, ceramics, paint, TV picture tubes, petroleum, chrome plating, electrical resistance alloys, pharmaceuticals, ink, X-ray machines. Does all this give you an idea you can explore in your business?

THIS IS THE "COMMERCIAL"

As the TV announcer says, we pause for a brief announcement. If you are thinking about the possibility of using rare earths, even in the high purities, don't worry about availabilities. Most of them are available for prompt shipment in quantities of an ounce to a carload. How much do you need? Even more important, prices have been sharply reduced during recent years. You'll find the rare earths economically practical . . . and wonderfully useful.

So here's ample evidence that rare earths touch you in some way virtually every day. Certainly they are worth your own critical investigation. What helpful information would you like from us — today?

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Santay Corporation finds new ways to increase production of plastics products with the help of Socony Mobil

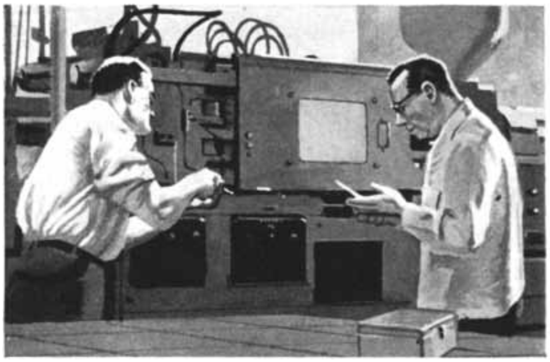
Competition is at its fiercest in the plastics business. Any unnecessary overhead costs can cut the heart out of profits. For this reason Santay management continually looks long and hard for ways to cut downtime, increase production.

In 1954 a Mobil Correct Lubrication Program was installed throughout the plant. This comprehensive engineering service had these results, according to Santay's plant engineer: "The reduction in downtime, three years after the Mobil program started, accounted for 27.1% increase in production *with no additional capital investment.*"

This outstanding result was achieved by close cooperation between Santay plant personnel and Mobil. Press operations were closely studied . . . lubrication procedures constantly improved . . . records prepared to show downtime and service frequency on every machine . . . cleanliness of lubricant carefully watched. All this help is *yours* when you rely on Mobil. Why accept less?

Problem: Downtime on a key press could result in a loss of $250 per hour in product sales. *Cause:* Maintenance follow-through not fully developed. *Solution:* Plant-wide Mobil Program that cut downtime over 25% in first year.

Oil Control saves 40% on oil purchases. Under Mobil Program, hydraulic oil is reconditioned . . . oil checked regularly for viscosity and contamination. *Result:* Oil purchases kept to minimum, maximum machine protection assured.

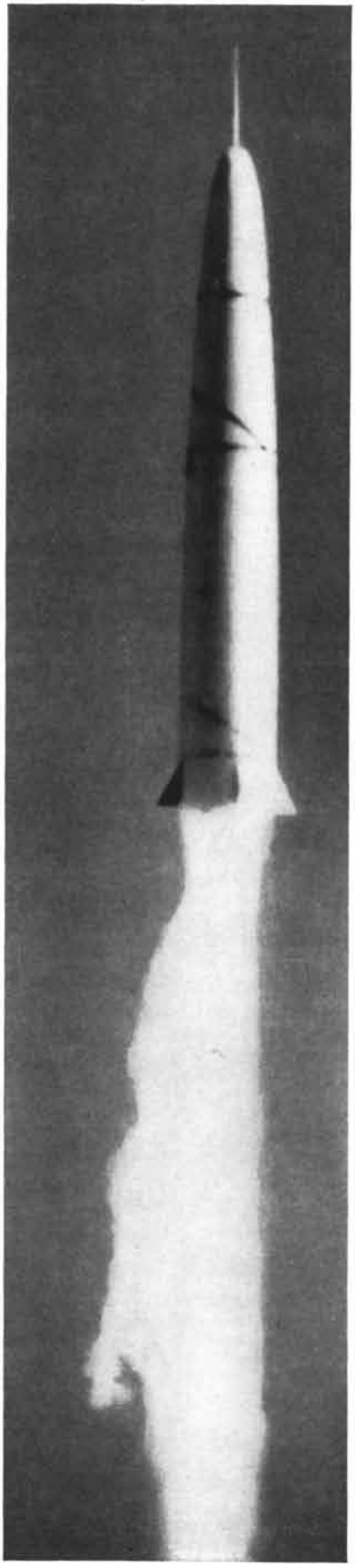


Problem: Matching molds on injection press worked out of alignment. *Cause:* Excessive wear on toggle pins and bushings. Lubricant didn't stick to wear surfaces. *Solution:* Mobil recommended oil that "stays put" . . . avoided $800 shutdowns.

Cost Control: Every machine has its control card. Alert watch is kept for press slowdowns, high maintenance. As a result, Santay maintenance personnel with Mobil assistance can move quickly to keep production high, costs low.

Correct Lubrication

Another reason You're Miles Ahead with Mobil!



A Universal Molecule of Living Matter

The tetrapyrrole ring, a chemical structure made up of four smaller rings, occurs in the chlorophyll of plants, the hemoglobin of blood and many enzymes which, like hemoglobin, take part in respiration

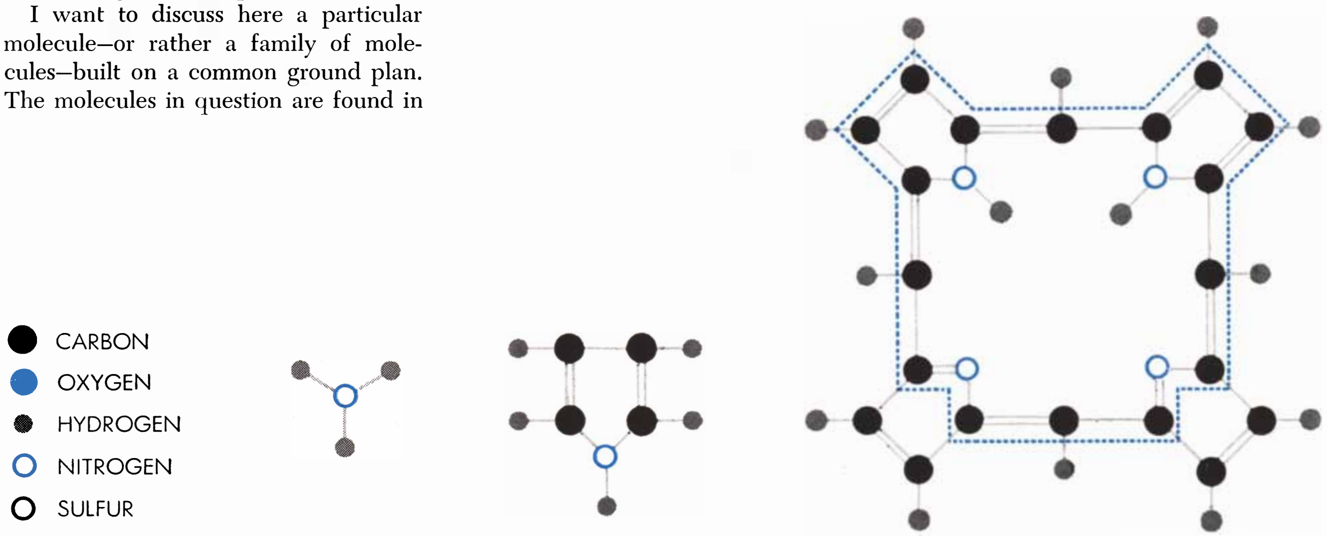
by Martin D. Kamen

In biology, as in politics, we are continually given fresh evidence of the truth of the French saying: "The more things change, the more they are the same." There are universal themes that run through all the forms of life on this planet, and nowhere is this more strikingly illustrated than in biochemistry. Chemically speaking, a lettuce leaf and an elephant are brothers under the skin. Their chemical substances show remarkable likenesses, and we can learn a great deal about the nature of living matter by studying the kinships. It is a growing appreciation of this fact—as much as powerful new tools such as radioactive tracers, tissue-culture methods and the electron microscope—that has produced the phenomenal progress made in the last two decades toward understanding the basic processes of life.

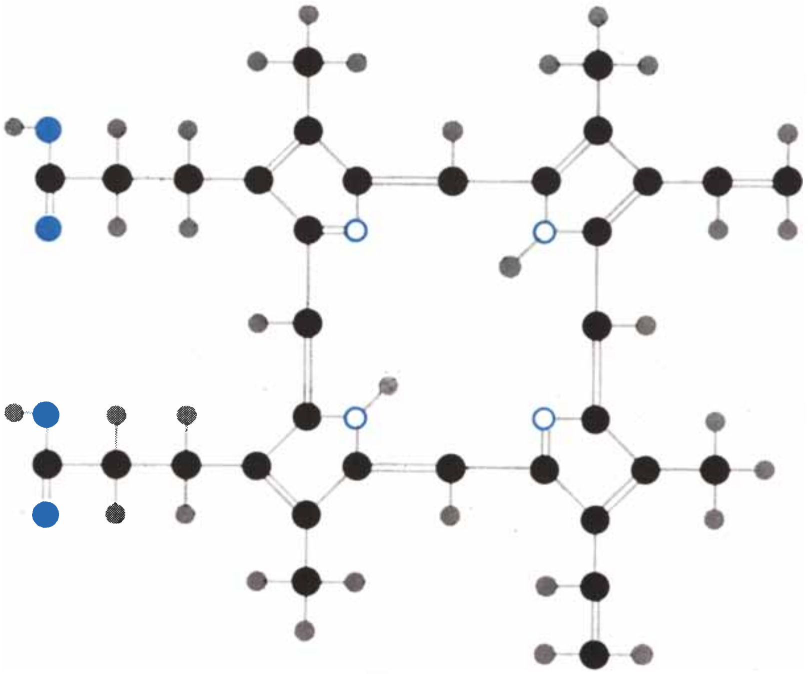
I want to discuss here a particular molecule—or rather a family of molecules—built on a common ground plan. The molecules in question are found in practically all living organisms, from bacteria to man. They differ from one another in comparatively minor details, like variations on a standard house-plan—a porch added here, a wing lopped off there, a stainless-steel kitchen instead of wood, a different lock on the front door. Yet these small modifications permit the same basic structure to perform an amazing variety of living functions: namely, distributing oxygen to an animal's tissues, converting food into energy, conducting the photosynthesis of plants. To be specific, chemical analysis shows that the hemoglobin of blood, the chlorophyll of plants and various enzymes involved in metabolism are all built on one basic blueprint!

To see how the structure is formed, let us begin with the simple ammonia molecule—a nitrogen atom surrounded by three hydrogens. If in place of the hydrogens we attach to the nitrogen a ring made up of four carbon atoms, we get a compound called pyrrole [*see diagram second from right below*]. Now let us take four pyrrole molecules, join them together with carbon atoms as links and coil them into a closed ring structure [*diagram at right below*]. We now have a brilliant-red substance named porphin. (Color is a characteristic property of molecules with a highly "conjugated" structure of this kind.)

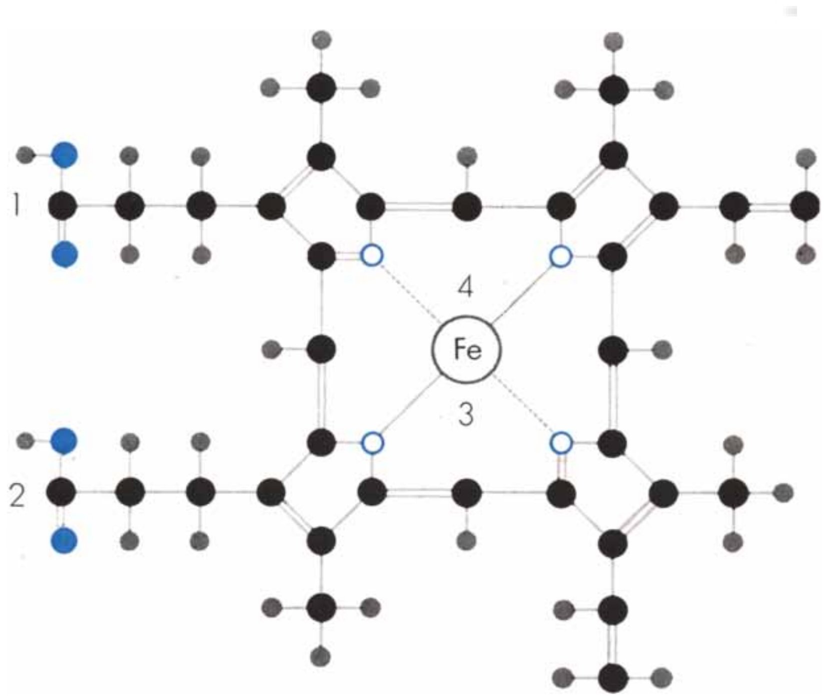
With porphin we have arrived at our central ground plan. One more step com-



TETRAPYRROLE RING is diagrammatically built up from ammonia (*molecular model at left*). If two of the three hydrogen atoms (*see key at far left*) of ammonia are replaced by a ring of four carbon atoms, the result is pyrrole (*model in middle*). If four pyrroles are joined in a ring, the result is porphin (*model at right*). The tetrapyrrole ring of porphin is indicated by the broken line.



PROTOPORPHYRIN IX has a tetrapyrrole ring to which smaller groups of atoms are attached. The key on the preceding page identifies the atoms in all diagrams in this article.



HEMOGLOBIN has a tetrapyrrole called heme which is identical with that of protoporphyrin IX except that two hydrogen atoms inside the tetrapyrrole ring are replaced by an iron atom (Fe). Protein (3) and water (4) are attached to the iron atom at right angles to the plane of the ring. Protein is also attached at 1 and 2. There are four hemes in the hemoglobin molecule. When hemoglobin performs its function of transporting oxygen, it is called oxyhemoglobin. In this substance oxygen is attached at 4 instead of the water.

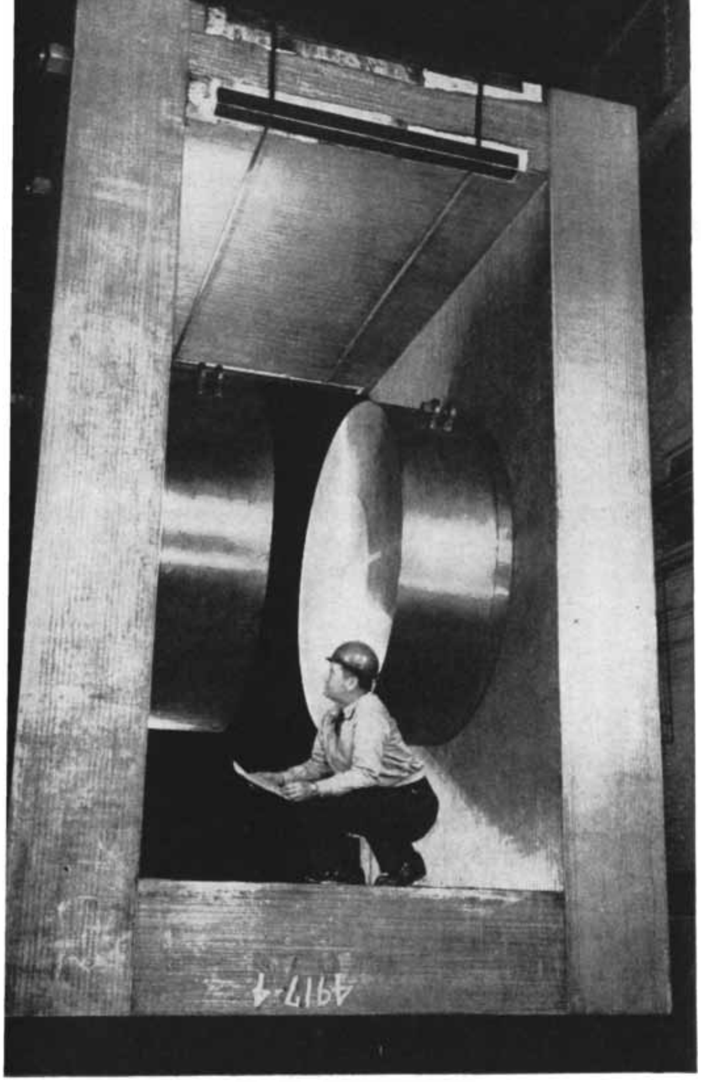
pletes the plan: we attach wings, or side groups, at certain points on the central ring [*top diagram at left*]. The structure is now called protoporphyrin IX, the number designating the fact that this is the ninth of 15 possible arrangements of the three larger side groups on the ring.

Here, then, is the framework of our universal molecule, or molecules. If we put an iron atom in the center, we have the compound called heme, and heme is the basis of the varieties of hemoglobin, of the cytochromes and of the various other catalysts involved in the oxidative metabolism of all mammals. Which of these it will be depends only on what specific protein is attached to the heme molecule [*bottom diagram at left and diagrams on page 80*].

But this is not all. If we put a magnesium atom in the center instead of iron and make a few minor changes in the side groups, we have chlorophyll, the great catalyst of photosynthesis by plants! Chemistry has few parallels to the versatility of the tetrapyrrole structure, to which nature has allotted so many tasks.

When we look at these molecules in a little more detail, we discover other remarkable facts about the chemistry of living matter. Consider the hemoglobin molecule. Its job is to pick up oxygen in the lungs and transport it via the bloodstream to the many organs of the body, where it releases the oxygen to the cells. The iron atom in the center of the heme structure is the carrier of the oxygen; it has one hook free for this purpose. But note now that the iron atom is in its "reduced," or oxidizable, form, which means that it should combine chemically with oxygen and not release it easily. Yet this iron refuses the normal chemical reaction with the oxygen and merely carries it as baggage, so to speak. Somehow the protein attached to the iron cools off the usual warm affinity between iron and oxygen. Just how it makes the iron inert to oxygen is still an unsolved mystery.

The hemoglobin molecule has another important carrier function; it picks up carbon dioxide from the tissues and carries it away as waste. Here again the structure does its work with beautiful efficiency, holding the carbon dioxide neatly in special "baggage racks" on the protein and dumping it in the lungs for expiration from the body. And there is a specialized form of hemoglobin which performs still another task. It is muscle hemoglobin, or "myoglobin," a heme-protein combination which holds oxygen



Why cyclotron magnet frames are made from steel forgings

Man is in a desperate race to learn more about magnetics. And for good reason. Already we see evidence that *very strong* magnetic fields may hold the secret of one of man's most sought-after dreams—power generation through sustained nuclear fusion.

And, if only a way could be found to increase the magnetic field strength by 20 times, one famous acres-big cyclotron could be reduced to the size of a steamer trunk.

However, the attainment of these highly desirable results presents formidable problems, due largely to the fact that when you double the strength of a magnetic field, the energy density or pressure increases *fourfold*. A not-uncommon 50,000 gauss magnetic field exerts a pressure of about 1,400 psi; but laboratory experiments have already created fields of 1½ million gauss for a few microseconds, and they confidently expect to hit *10 million* gauss before long!

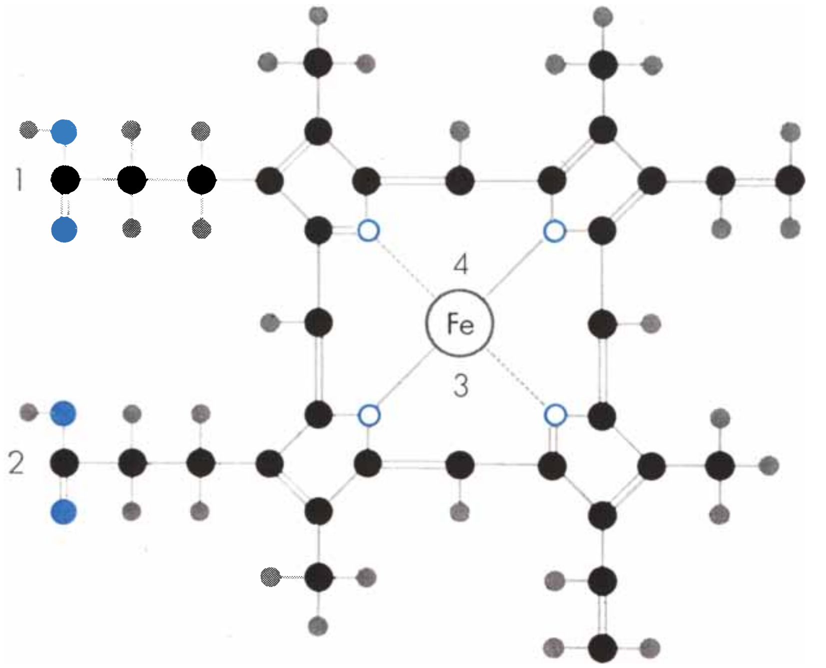
To contain the fantastic forces involved, designers of very large electromagnets turn to high-quality forged steel parts, and they very often come to United States Steel to ask for USS Quality Forgings.

The picture shows a cyclotron electromagnet frame that will go into service at Oak Ridge National Laboratory, Oak Ridge, Tennessee. It is made from six USS Quality Forgings that total 193 tons including the two cylindrical pole pieces. The pole pieces are machined to a .005″ flatness, and are parallel to within .005″. These tolerances are essential for close control over the bombarding particle beam—which often operates at velocities which approach 50,000 miles per second. All six forgings were melted, forged, machined, heat-treated and inspected at our Homestead Forgings Division.

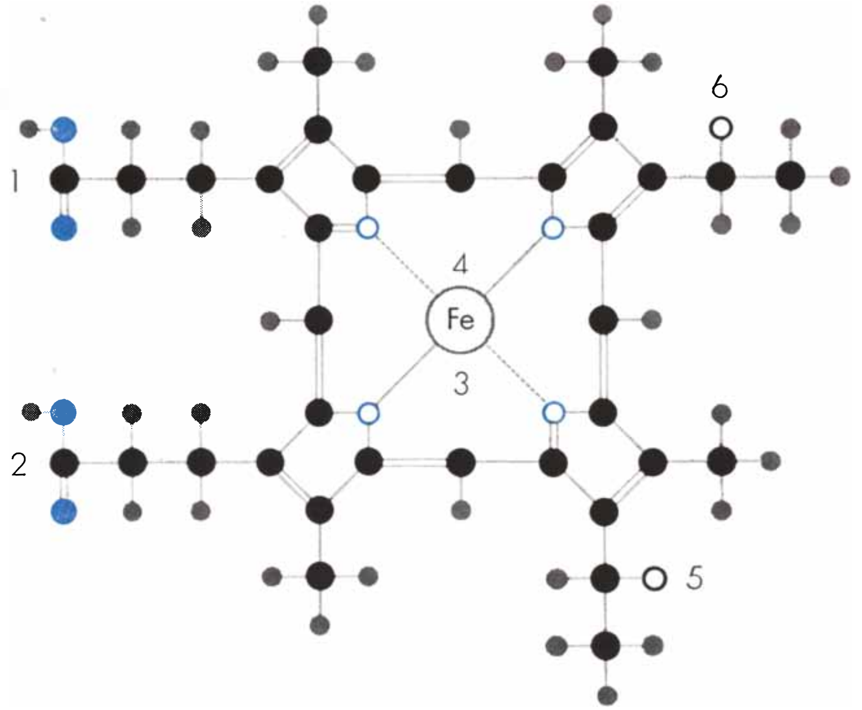
They are typical of the many cyclotron and nuclear reactor parts made from USS Quality Forgings to most exacting specifications. United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

USS **United States Steel**

TRADEMARK



CYTOCHROME B, one of a family of respiratory enzymes, has a tetrapyrrole which is identical with that of hemoglobin except for points at which protein is attached (1, 2, 3, 4).



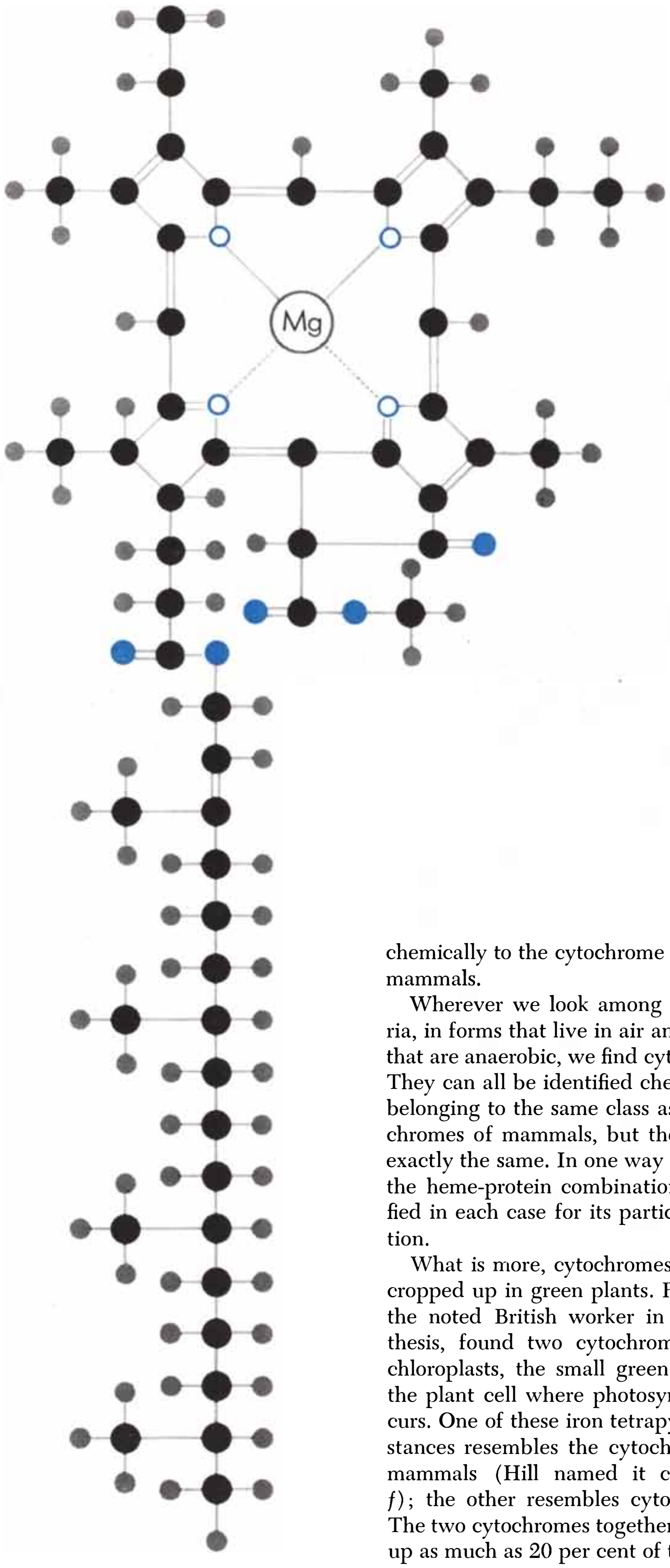
CYTOCHROME C, another member of the cytochrome family, has a tetrapyrrole which differs slightly from that of cytochrome *b*. Protein is attached to ring at 1, 2, 3, 4, 5 and 6.

as a reservoir and releases it to the muscle cells as they demand it.

Now we come to the cytochromes, the catalysts that play the key role in converting food into energy [see "Biological Oxidation," by David E. Green; Scientific American, July]. The job of the cytochromes is to carry out the oxidation of food substances in a series of finely controlled steps which finally produce packaged chemical energy in the form of adenosine triphosphate (ATP), with carbon dioxide and water as the waste products. Essentially this process involves transmitting electrons to the final products, by way of a chain of reductions and oxidations. Obviously, then, the carrier has to be a substance which can readily be reduced or oxidized. Strangely enough, nature has chosen for this job the very same agent that refuses to be oxidized in the hemoglobin molecule—namely, heme with its iron atom. The cytochromes, like hemoglobin, are built on heme as the active operator, but in their case the heme is attached to a protein which allows the iron atom to be oxidized, under precise control. Three different cytochromes, called *a*, *b* and *c*, perform the reduction-oxidation job in the cells of a mammal, and they are assisted by certain enzymes, named catalases and peroxidases, which likewise are built around heme.

Nature certainly shows a remarkable lack of imagination, or remarkable economy and flexibility, depending on your point of view. Here, monotonously repeating itself, it has made heme do the double duty of carrying oxygen to the cells and then helping the cell to use the oxygen. And nature's laziness—or brilliance—of invention does not stop there. Having hit upon a good thing, it finds still other employment for heme.

Until recently biochemists supposed that, because heme is particularly fitted for functions involving oxygen, it should be found only in air-breathing (*i.e.*, oxygen-using) organisms. But to their surprise, cytochromes, containing heme, have turned up in practically all living matter, including organisms that live without oxygen! For example, several years ago John Postgate in England and H. Ishimoto in Japan discovered a cytochrome in certain bacteria which use sulfur instead of oxygen for "oxidation"—that is, for accepting electrons. These organisms are extremely sensitive to oxygen: one part per million of this gas in their medium will kill them. The cytochrome in their case serves to transfer electrons to sulfur rather than to oxygen. Yet this cytochrome is very similar



CHLOROPHYLL A has a tetrapyrrole ring with a magnesium atom (Mg) in place of the iron atom of the tetrapyrroles of hemoglobin and cytochromes. It is also characterized by a long tail called a phytyl.

chemically to the cytochrome *c* found in mammals.

Wherever we look among the bacteria, in forms that live in air and in those that are anaerobic, we find cytochromes. They can all be identified chemically as belonging to the same class as the cytochromes of mammals, but they are not exactly the same. In one way or another the heme-protein combination is modified in each case for its particular function.

What is more, cytochromes have also cropped up in green plants. Robin Hill, the noted British worker in photosynthesis, found two cytochromes in the chloroplasts, the small green bodies in the plant cell where photosynthesis occurs. One of these iron tetrapyrrole substances resembles the cytochrome *c* of mammals (Hill named it cytochrome *f*); the other resembles cytochrome *b*. The two cytochromes together can make up as much as 20 per cent of the chloroplast's total protein content.

What do cytochromes have to do with photosynthesis? We know what role is played by their chemical relative, the green pigment chlorophyll: it absorbs sunlight as energy for the chemical building activities of the plant. But what function do cytochromes have to perform in plants?

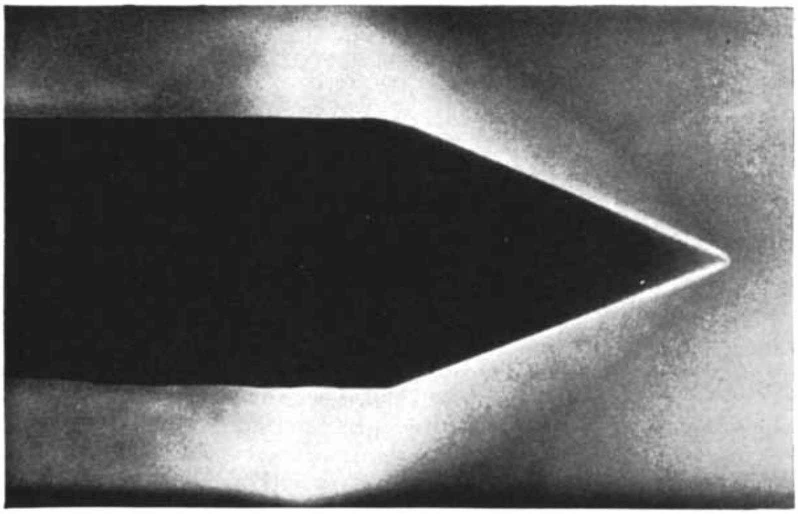
Several years ago at Washington University in Saint Louis, Leo Vernon and I began a series of researches on the chemistry of certain bacteria that carry on photosynthesis. We found that all of them contained large amounts of cytochromes of the *c* and *b* types, just like those Hill had found in green plants and algae. Particularly interesting was a new variant of the *c* which had not been found before. This molecule was able to react with oxygen without the help of a special enzyme, apparently because one or more of the protein bonds tying up the central iron atom was loosened or broken. It indicated, among other things, that the basic function of the cytochromes in plants, as in animals, is to promote oxidation, or at least to transport electrons. In any event, Hill's researches and ours show that chlorophyll and cytochromes always go together in the same part of the cell, and they suggest that the two form a close partnership in carrying out photosynthesis.

But most interesting is the fact that we are led to a provocative, if obvious, question about which no one has thought much heretofore. It has to do with color. We can easily understand what function color plays in chlorophyll, the magnesium tetrapyrrole: the molecule has to be a pigment to absorb sunlight. But why should the iron tetrapyrroles—hemoglobin, cytochromes and the rest—be brightly colored? Color certainly does not help them in their job of transporting oxygen or electrons. Chemically or physiologically, there is no reason why blood needs to be red or any other color. Is the high coloring of heme and its relatives a mere accident, or does it tell us something about the nature of these immensely useful molecules which are so beautifully designed for their manifold functions?

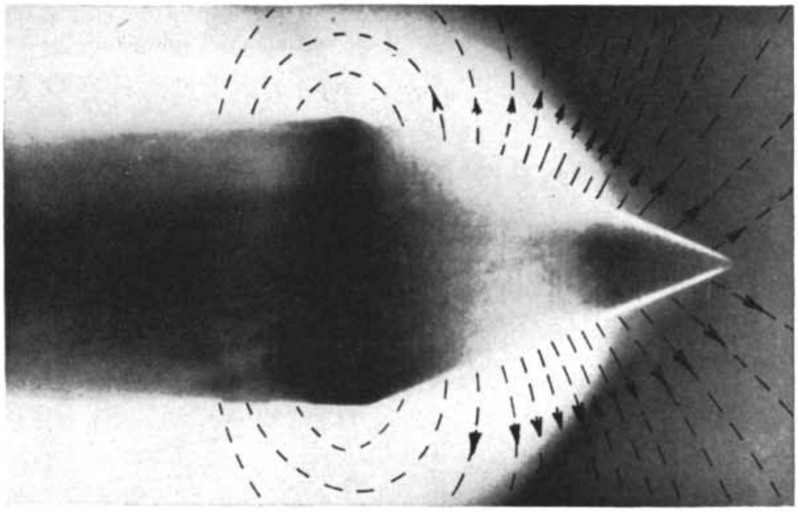
The color of the heme compounds arises, as we have seen, from their highly conjugated structure. The four pyrroles form a ring with alternating single and double bonds, and this type of structure can retain unpaired electrons for an appreciable time without reacting. In other words, a tetrapyrrole can form comparatively stable free radicals. Whereas free radicals usually react rapidly and indiscriminately with whatever substances happen to be at hand, the tetrapyrrole radical, by virtue of its structure, may be able to react in a controlled and selective way to perform its oxidation job.

PROGRESS REPORT FROM AVCO RESEARCH LABORATORY

NEW LIGHT ON MHD*



NO MAGNETIC FIELD. This shock tube photograph, taken by emitted light only, shows the typical shock wave configuration formed by high-velocity gas flowing around a pointed cone.



WITH MAGNETIC FIELD. Here is shown the magnetohydrodynamic displacement of the shock wave. The magnetic field is caused by electric current flowing through a coil of wire within the cone. This experiment qualitatively demonstrates the interaction of a high-temperature gas with a magnetic field. This effect would be expected to produce drag and reduce heat transfer to the body.

The Avco Research Laboratory was founded a little more than three years ago for the purpose of examining high-temperature gas problems associated with ICBM re-entry. The success of this research led to the birth of a new corporate enterprise, Avco's Research and Advanced Development Division.

The Research Laboratory, now established as a separate Avco division, has expanded to embrace all aspects of physical gas dynamics. We are currently gravid with several embryonic projects which we anticipate will likewise grow into new corporate enterprises. Our work in the physics, aerodynamics and chemistry of high-temperature gases is growing in the following areas:

Magnetohydrodynamics—
Flight and industrial power-generation applications

Space flight—
Manned satellites
Electromagnetic propulsion

These developments have created a number of openings for physicists, aerodynamicists and physical chemists. If your background qualifies you to work in any of these areas, we would be pleased to hear from you.

Arthur Kantrowitz

Dr. Arthur Kantrowitz, Director
Avco Research Laboratory

P. S. A listing of laboratory research reports indicative of the scope and depth of our activities is available. Address your request: *Attention: Librarian, Avco Research Laboratory, 2385 Revere Beach Parkway, Everett, Massachusetts.*

***Magnetohydrodynamics,** the study of the dynamics of electrically conducting fluids interacting with magnetic fields.

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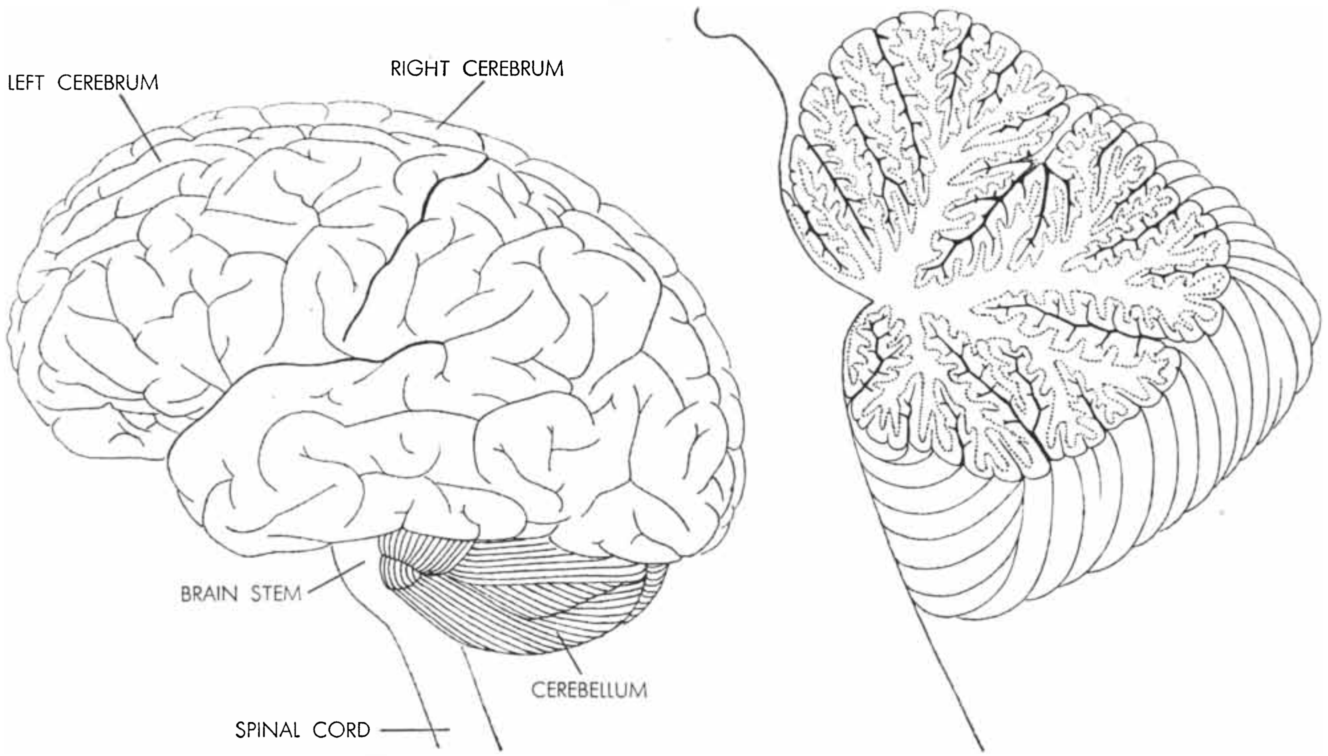
THE CEREBELLUM

Until recently the function of this part of the brain was unknown. Mapping of its electrical circuits now indicates it may be a monitor of communication between brain and body

by Ray S. Snider

In the back of our skulls, perched upon the brain stem under the overarching mantle of the great hemispheres of the cerebrum, is a baseball-sized, bean-shaped lump of gray and white brain tissue. This is the cerebellum, the "lesser brain." In contrast to the cerebrum, where men have sought and found the centers of so many vital mental activities, the cerebellum remains a region of subtle and tantalizing mystery, its function hidden from investigators. Indeed, the cerebellum was once regarded as a "silent area" of the brain. Today we know the brain has no such areas. The cerebellum discloses an intense activity of a highly distinctive kind to the sensitive instruments of modern brain physiology. Its elusive signals have begun to tell us that, while the cerebellum itself directs no body functions, it operates as monitor and coordinator of the brain's other centers and as mediator between them and the body.

The first men who ventured to dissect the brain were struck by what they saw when they came upon the cerebellum. Its surface is even more intricately wrinkled and creased than the cerebrum. The cerebellum constitutes only 10 per cent of the brain's total mass, yet it has 75 per cent as much surface area as either of the much larger cerebral hemispheres. It represents nature's supreme effort to pack a maximum of cortex—the brain "skin" which embeds the nerve circuitry—into a minimum of cranial space. The folds of the outer surface elaborate into subfolds deep within the organ; only 15 per cent of the cerebellar cortex can be seen without dissection. If the cerebellum is split along the mid-



CEREBELLUM lies on the brain stem, under and behind the cerebrum (*left*). The cross section of the cerebellum (*right*) shows its tree-like pattern of folds and fissures, which led anatomists of the medieval period to give it the name of *arbor vitae* ("tree of life").

line, the folding makes a pattern like a tree in full leaf. Medieval anatomists called this the *arbor vitae* ("tree of life"), and declared it to be the seat of the soul.

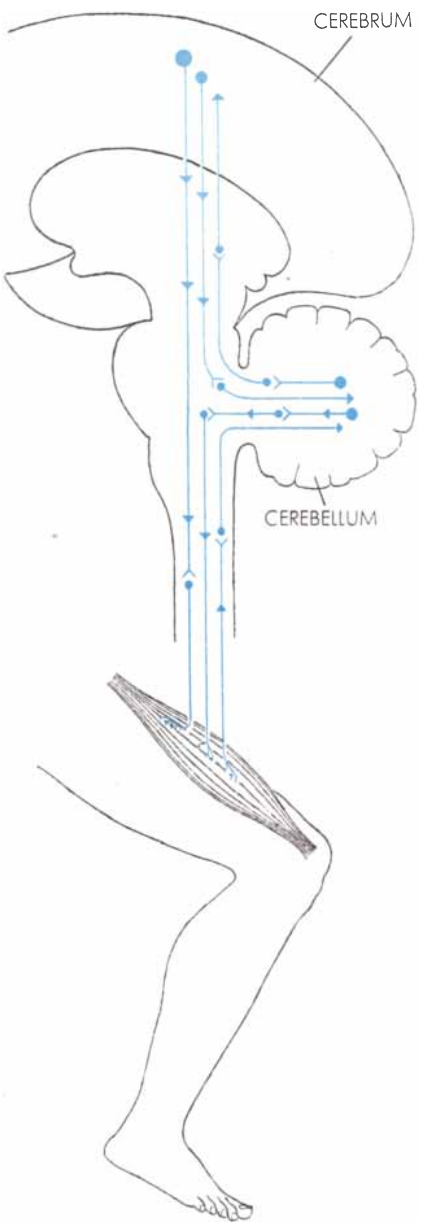
Speculation about the role of the cerebellum continued in the same imaginative vein until quite recent times. Franz Joseph Gall, the 18th-century founder of phrenology, noted the large size of the cerebellum in bulls and stallions and concluded that it must be the organ of the procreative instinct. Gall would have done better to relate the large size of the cerebellum in these animals not to sexual vigor but simply to their large body size. Elephants and whales have the largest cerebellum of all. Perhaps the most original notion was that of Luigi Rolando, the distinguished anatomist for whom the "fissure of Rolando" in the cerebrum is named. In 1828 he ventured prematurely into biophysics and declared that the cerebellum secreted nervous energy to excite and govern voluntary movement. The energy, he thought, was generated deep in the folds of the cerebellum by the alternate layers of white and gray matter, acting like the plates of a battery. As late as 1894 Frederick Courmont, a pioneer French psychiatrist, located "psychic sensibility" in the cerebellum. He made the mistake of not distinguishing between patients with cerebral and those with cerebellar lesions.

The 17th-century anatomist Sir Thomas Willis came closer to the mark when he "fancied" that the cerebellum was an organ "for the execution of involuntary or autonomatic actions and movements." In the 19th century the great French physiologist François Magendie conceived of it as a center for some sort of muscular sense. However, it was Luigi Luciani, an Italian physiologist, who performed the first controlled experiments on the cerebellum at the turn of the century and laid the foundation for our present concepts of cerebellar function. Luciani surgically removed all or part of the cerebellum from cats, dogs and monkeys and then observed their behavior. The gross function of his animals remained unimpaired, but they suffered loss of muscle tone and disturbance of coordination and equilibrium in gait and posture. Since Luciani's time physicians have taken "drunken gait" as a standard symptom of injury to the cerebellum in man. (Indeed, people with such an injury have occasionally been arrested for drunkenness. Studies of the effects of alcohol on the cerebellum, however, do not justify the implication that it is any more a haven for highballs than other parts of the brain.)

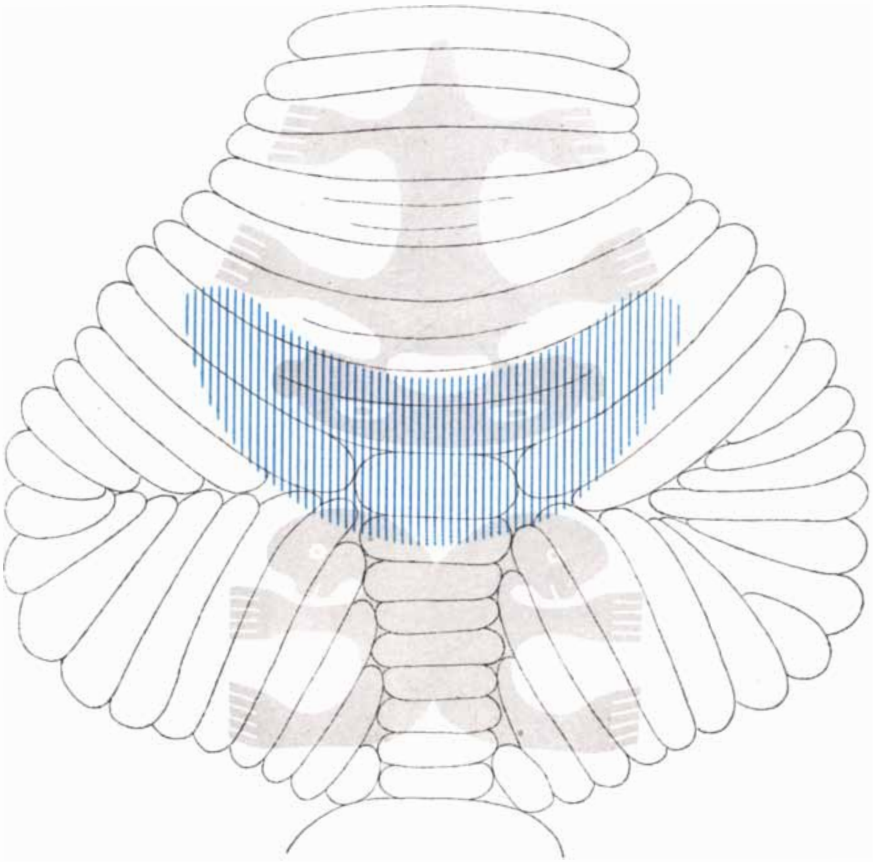
Following up the clue furnished by Luciani's careful work, other investigators soon traced out some of the major circuits connecting the cerebellum to the rest of the nervous system. They found that the cerebellum is linked with the motor centers of the brain and receives impulses from them similar to those sent out to the muscles. At the same time, they discovered, the cerebellum receives impulses from the end organs of the peripheral nervous system, the so-called proprioceptive endings, in the contracting muscles. The cerebellum "compares" these two sets of impulses and sends modified impulses back to the motor centers in the brain and, indirectly, out to the muscles. This checking of response against command and the modification of command in terms of response smooths and coordinates the action of the muscles. When action involves two opposing sets of muscles, as in the bending of the arm at the elbow, the cerebellum integrates the data for both, coordinating the contraction of the flexor muscles on the front of the arm with the relaxation of the extensor muscles on the back. This function of the cerebellum was recognized as early as 1898 by the great British physiologist Charles Sherrington, who called it "the head ganglion of the proprioceptive system."

For a time many of Sherrington's contemporaries mistook his eloquence to mean that this was the only function served by the cerebellum. Further investigation, however, demonstrated that the cerebellum plays a similar role in maintaining the equilibrium of the body. In this case the initial impulses arise in the semicircular canals of the inner ear. The cerebellum integrates these signals with the proprioceptive data from the opposing group of muscles that maintain the body's posture. As the product of this integration it sends out impulses to both lower and higher nervous centers directing the intricate performance of the many muscles that are in action even when the body is merely standing still.

Thus in the first 40 years of this century the cerebellum was established as a center governing the musculature, coordinating both consciously and unconsciously directed action. In engineering parlance, it is the control box in the feedback circuitry of the nervous system. Such a control box does not originate the input of commands to the system, but is informed of them by the command center; for example, by the setting of a dial. From the sensing instruments at the output end of the system it receives the feedback of data on the output. Comparing output with input, it informs the command centers of the corrections to be made or generates correcting command signals itself. Confident as we are that this is the function of the cerebellum, we are a long way



NERVE CIRCUITS connecting cerebrum, cerebellum and muscle are outlined. The main circuit (*left*), through which the cerebrum commands the muscle, is supplemented by feedback circuits to the cerebellum (*right*). Through these feedback circuits the cerebellum monitors main circuit, comparing command impulse from cerebrum with response (sensory) impulse from muscle.



"HOMUNCULI" or projection areas show localization of function in the cerebellum. They show some correspondence to similar projection areas of the cerebrum. Stimuli from the sense organs of touch and from the "proprioceptive endings" that monitor muscle behavior are projected both on the upside-down figure at top and on the partially split figure at bottom. Another projection area, which differs from these in not resembling the body shape, is indicated by the colored lines (*center*). Here auditory and visual stimuli are received.

from a complete understanding of how it carries out this function.

To be sure, microscopic studies demonstrate that the cerebellum is admirably designed to function as a control box for the musculature. The cerebellum does its work in its gray matter, the deeply wrinkled cortex. The cell structure of the cortex shows it to be a switching panel capable of establishing rich and rapid interconnection between the thousands of nerve circuits that tie it to the brain and body. Its .01-inch cross section separates discernibly into three layers: an outer "molecular" layer, an inner layer of "granule" cells, and, in between these layers, a single thickness of the all-important Purkinje cells, named after the Czech physiologist Johannes Evangelista Purkinje.

The illustration on the opposite page, showing a fold of the cerebellum in cross section, suggests the efficiency with which an incoming message is distributed in the cortex. As the message courses into the fold through the central white matter, it is picked up by one after another of the little granule cells that are tightly packed together in the innermost layer of the surrounding cortex. Each of these cells has four to six short fibers to convey incoming messages into the cell body—these are its "dendrites" or receiving apparatus. In addition, each granule cell has a sending apparatus or "axon": a long, thin fiber that reaches out through the Purkinje cell layer into the outer molecular layer. There these axons make contact with the dendrites of the Purkinje cells, which also branch out into the molecular layer. The Purkinje dendrites form an ornate network of tiny fibers, and each granule-cell axon contacts hundreds of them. The nerve messages gathered by these dendrites are borne to the Purkinje cell bodies.

The Purkinje cell is the key unit of the cerebellum; it is here that the incoming impulse becomes an outgoing impulse. Each Purkinje cell sends its message out of the cerebellum through a long, threadlike axon that passes out of the cortical fold through the white matter in its interior.

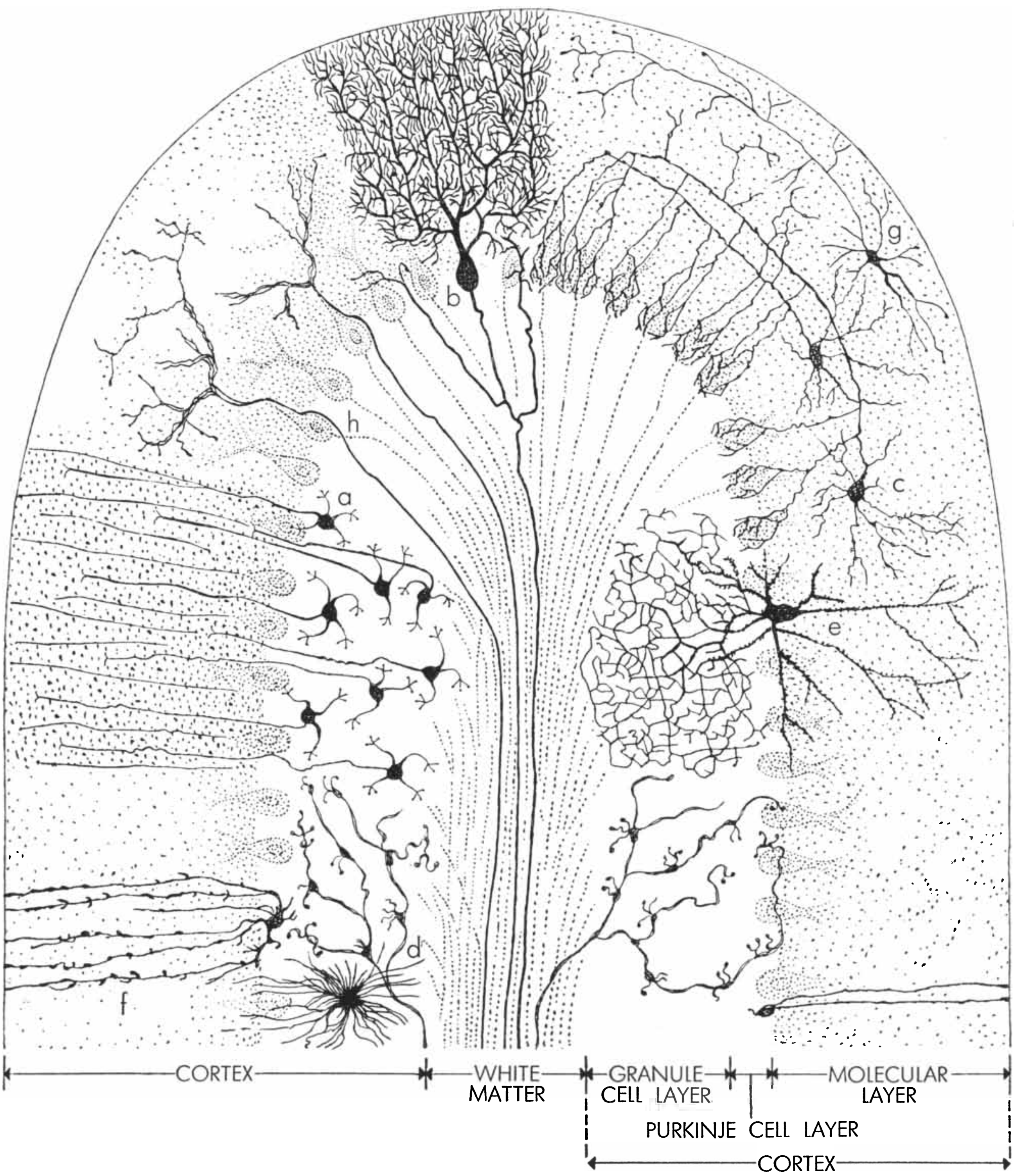
This, essentially, is the cerebellar nerve circuit. Note that the nerve impulse from each granule-cell axon reaches not one, but many Purkinje cells. This spread-out is amplified, moreover, by the basket cells of the molecular layer which pick up impulses from the granule cells and convey them directly to the Purkinje cell bodies via long axons, which embrace each of six to 12 Purkinje cells in a basket of fibers.

The information carried by a single impulse thus spreads widely in the cortex of the cerebellum. The impulse first excites a large number of granule cells. Each of these in turn relays the signal directly to hundreds of Purkinje cells and, via the basket cells, ultimately to thousands of them. The Purkinje cells now fire a huge volley of outgoing impulses, the original impulse many times multiplied, back into the white matter and thence to the brain stem.

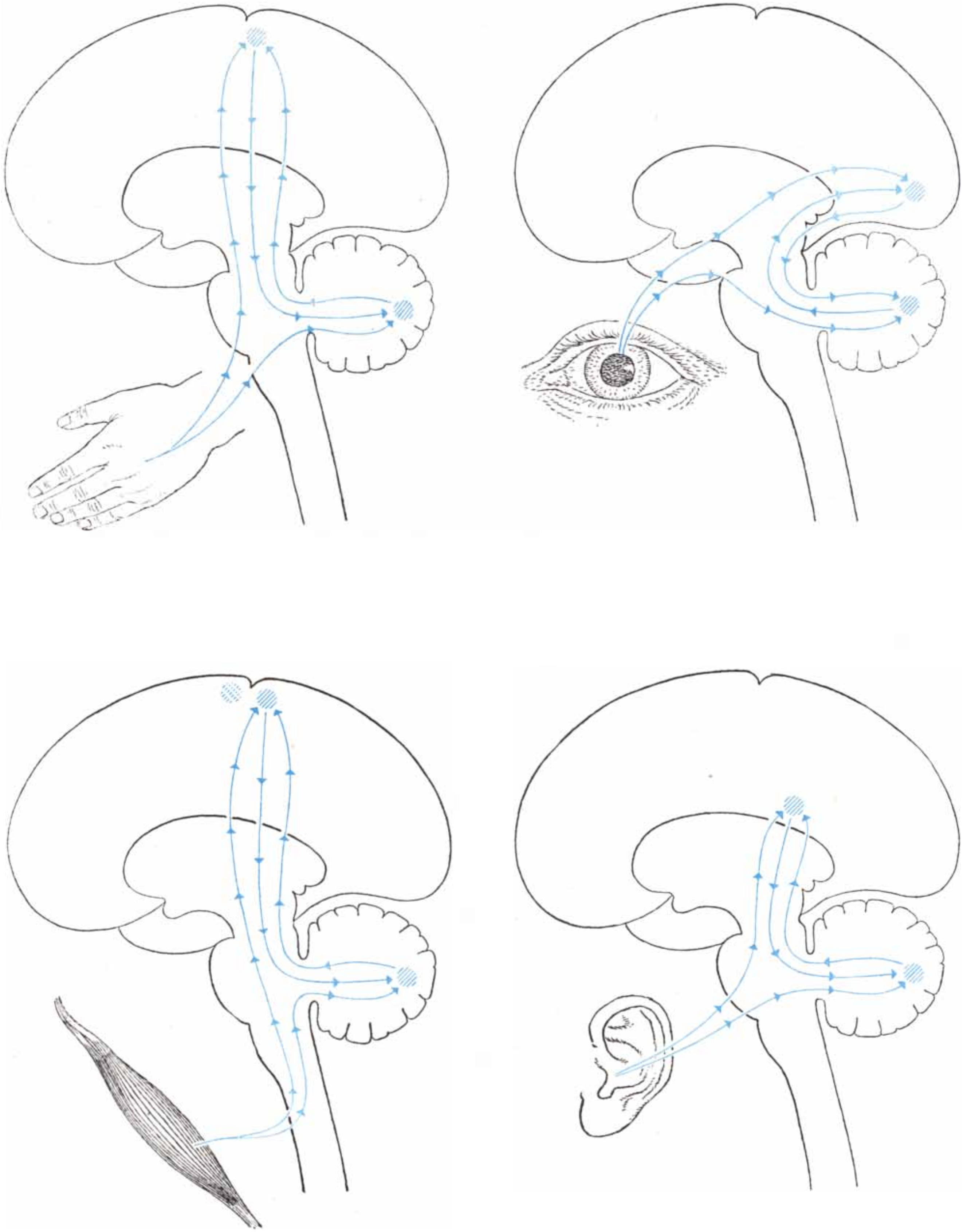
Close study of the circuitry within the cortex suggests that there are feedback circuits within feedback circuits. This is notably the case with the so-called "climbing fibers," whose function is not yet clearly established, although the Spanish physiologist Santiago Ramon y Cajal observed them over 50 years ago. These tiny axonal fibers ascend into the cortex from the white matter, climbing up the dendritic network of the Purkinje cells, branching wherever the dendrites branch—very much like a parasitic vine on a tree. It is possible that these fibers carry feedback impulses to excite or inhibit the Purkinje cells in some way.

As in the cerebrum, the various functions of the cerebellum are localized in distinctly defined areas of its cortex. Detection and plotting of the electrical activity of the cortex has made it possible to map these areas. The control of the body's equilibrium, for example, is localized in the extreme front and rear surfaces of the cerebellum. The proprioceptive areas appear as actual maps of the body on the cortex: two distorted "homunculi," one face-on and the other in double profile back-to-back as shown in the illustration on this page.

For a long time it was thought that the plotting of these areas had completed the map of the cerebellar cortex, in line with the notion that the cerebellum was restricted to the management



CROSS SECTION OF A CEREBELLAR FOLD is diagrammed to show the network of cells which transmits nerve impulses through it. Nerve impulses enter the fold through the white matter (*broken lines in center*). These impulses are drawn into the cortex, or gray matter, by the granule cells (*a*). Each granule cell receives an impulse through its short dendrites. It transmits the impulse into the outer, or "molecular," layer of the fold through its long, T-shaped axon. In the molecular layer the impulse passes from these axons into the many-branched dendrites of the Purkinje cells (*b*). The impulse then leaves the cerebellar fold through the axon of the Purkinje cell, embedded in the white matter at center. The process by which impulses pass from granule cells to Purkinje cells is abetted by basket cells (*c*). Each basket cell picks up impulses from a granule-cell axon, then transmits them through a long fiber to "baskets" of fibrils which surround the cell bodies of several Purkinje cells. Other auxiliary cells are the "mossy terminals" (*d*) and Golgi Type-II cells (*e*) which help diffuse incoming and outgoing impulses respectively. Cell-types *f* and *g* are of unknown function; *h* is a climbing fiber whose axon adheres to the Purkinje cell dendrites and may serve to "switch" them on and off.



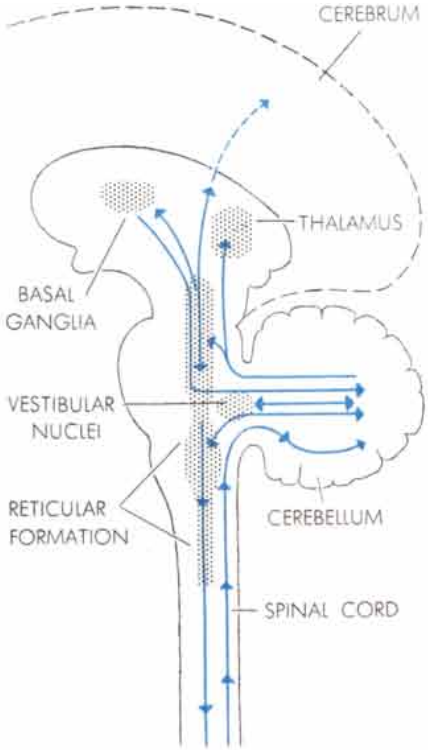
REVERBERATING CIRCUITS link the cerebellum (the fissured organ at right-center of each picture) to the sensory nerves which connect tactile, visual, proprioceptive and auditory sense organs to the cerebrum. While part of the messages from these organs goes to the cerebrum, part detours through the cerebellum, then "reverberates" through the cerebrum to the cerebellum. It is thought that these circuits serve a feedback function. Proprioceptive impulses from muscles (*lower left*) may reach more than one cerebral center.

of the body's equilibrium and muscular activity. However, at the Johns Hopkins University in 1942 Averill Stowell and I undertook an investigation which has established that the cerebellum is equally involved in the coordination of the sensations of touch, hearing and sight.

We worked with animals and, by touching hairs, shining a sharply focused light on the retina or sounding a distinct sound at the ear, we were able to pick up the resulting nerve signals with probes applied to the cerebellar cortex. Interestingly enough, the tactile area coincides with the two proprioceptive areas, while the auditory and visual senses register in a separate overlapping area that lies between them. This arrangement reflects the close association of these two pairs of sensations in behavior: when an animal feels a touch on the leg, for example, its response is to flex the leg; when it hears a sound, it turns to look. In the cerebrum the visual and auditory centers occupy separate areas, and their cellular complexity is many times greater.

Our investigation showed also that the tactile, visual and auditory centers of the cerebellum are linked to the corresponding centers in the cerebral cortex by the same sort of feedback loop that connects the proprioceptive areas. By stimulating the appropriate areas in the cerebellum directly with electrodes we found we could project the stimulus to the matching areas of the cerebrum, and *vice versa*, and thus lay out the feedback circuits shown in the illustration on the opposite page. Our studies developed further feedback pathways to the thalamus, the basal ganglia and the reticular formation of the lower brain stem [*see illustration on next page*]. This array of feedback loops should stimulate the cerebral servomechanism of any student of cybernetics. In sum, the cerebellar circuitry is an accessory control system imposed upon the basic ascending (sensory) and descending (motor) circuits of the nervous system.

The big question remains: How does the cerebellum play its role? We know that removal of the cerebellum produces severe disturbances in muscular coordination of the animal. On the other hand, it is necessary to remove large areas of the cerebellar cortex in order to produce enduring loss of muscular coordination. How does the nervous system so smoothly absorb so great an insult? Does it mean that the cerebellum acts in such close harmony with some as yet unidentified center that this second center takes over its functions? Or



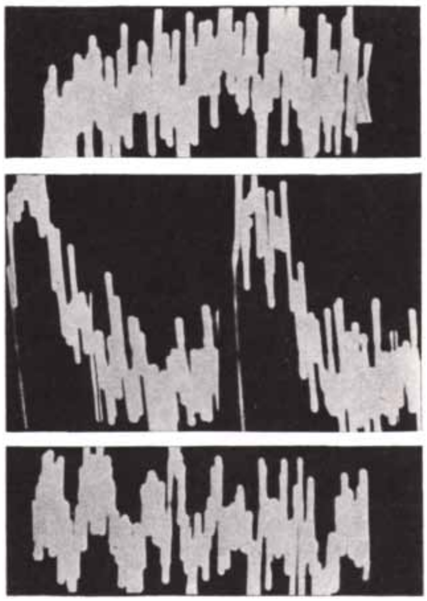
BRAIN STEM is diagrammed to show the circuits linking its organs to the cerebellum. Each one of these organs is involved in cerebellar feedback "reverberating circuits."

does it mean that the cerebellum has little functional significance? The category of puzzles becomes larger when one considers the cerebellar sensory areas. Few, if any, measurable sensory losses occur when these areas are destroyed.

The electrical characteristics of the cerebellar cortex furnish the principal clues for future investigation. The cerebellum generates electrical waves at the highest frequency in the nervous system. They range from 200 to 400 per second—10 times faster than those of the cerebral cortex. The amplitude of cerebellar discharges, on the other hand, seldom exceeds 200 microvolts; this is a fraction of the operating level of the cerebrum, which runs 10 or more times higher. The cerebellum imposes its peculiar high-frequency, low-amplitude characteristics upon all the impulses that pass through it. Often it seems to "smother" the frequency-amplitude characteristics of impulses originating elsewhere in the nervous system. The characteristic electrical signature of the cerebellum helped us considerably to detect and map the sites at which impulses from its cortex arrive in the cerebrum.

But what purpose is served by this peculiar electrical activity? Modulation of signals is so common and so useful in radio technology that one is tempted to see the cerebellum as the great "modulator" of nervous function. The imposition of high-frequency rhythms on low-frequency impulses would enable appropriate centers to discriminate between impulses modulated by the cerebellum and those not so modulated. This is interesting speculation, but it may not be the mechanism at all. The cerebellum might equally well act as a "band-pass" filter; that is, its fast activity may allow some wave patterns to go through, while blocking or altering others. Another line of speculation argues that wave frequencies have little to do with the case, and holds that the important thing is the total energy added by the cerebellum to the outgoing impulses. Whether these speculations (or any added by the reader) may help to solve the riddles of the cerebellum, only time and more experimentation can tell.

In the meantime we may have to contend with the possibility that the cerebellum is involved in still more diverse aspects of the nervous system. It becomes increasingly evident that if "integration" is a major function of this organ, trips into the realm of mental disease may cross its boundaries more frequently than the guards in sanatariums suspect.



ELECTRICAL ACTIVITY of the cerebellum is traced by an oscilloscope. "Resting" signal (*top and bottom*) has amplitude of 50 to 100 microvolts and frequency of 300 cycles per second. This activity is imposed on larger-amplitude, lower-frequency impulses which originate elsewhere (*middle*).

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POISONOUS TIDES

The explosive multiplication of certain marine microorganisms can kill fish by the millions. The investigation of these outbreaks is now elucidating some fundamental questions of oceanic ecology

by S. H. Hutner and John J. A. McLaughlin

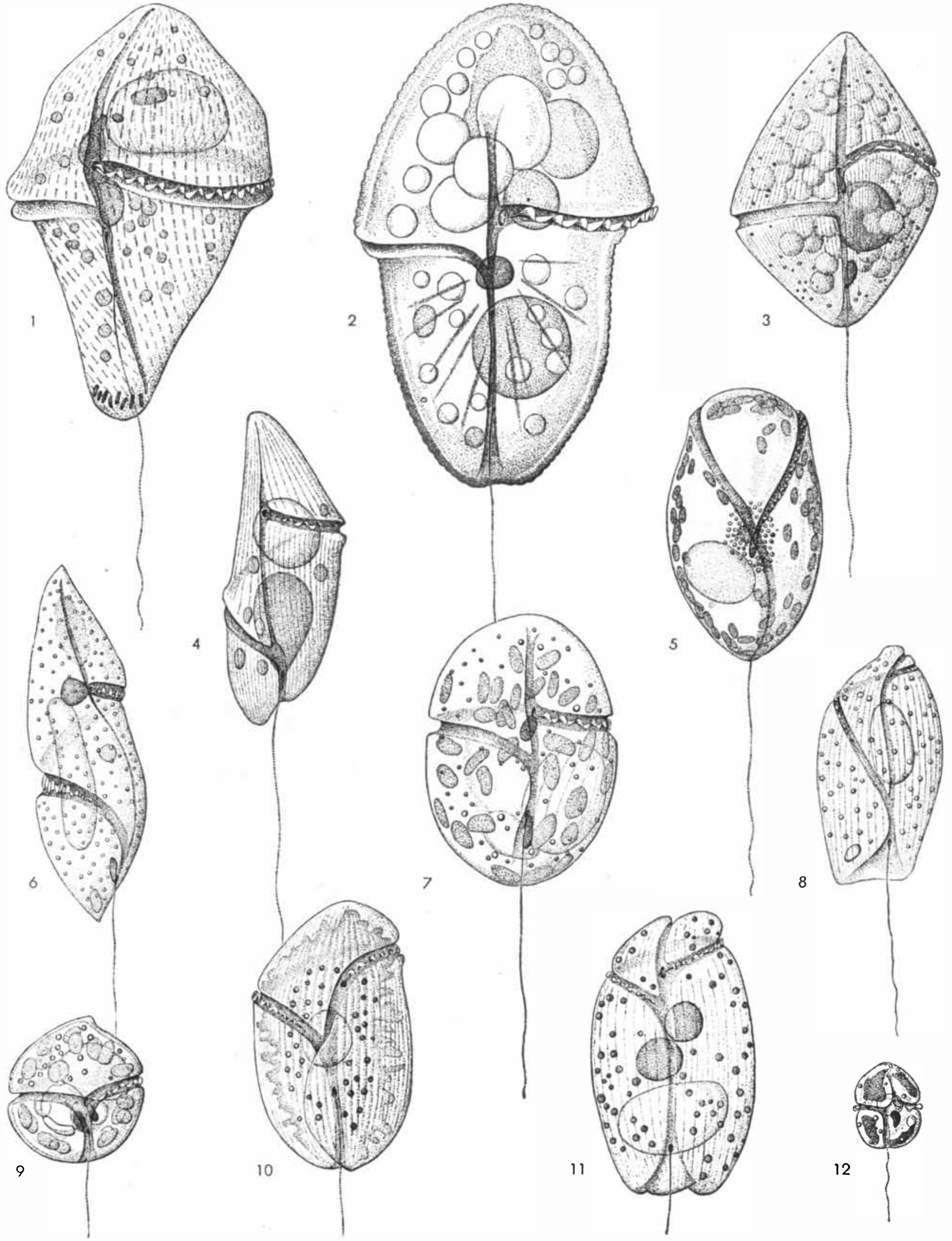
Toward the end of 1946 the ocean waters along the west coast of Florida took on a turbid yellow hue. The cause of this curious sea-change was the explosive multiplication of a particular species of one-celled marine microorganism. Dead and dying fish soon gave evidence that these creatures were poisonous. By June the microorganisms had multiplied so abundantly that the water became thick and viscous. Turtles, barnacles, oysters, shrimp and crabs were killed. Stinking windrows of fish piled up for 60 miles along the beaches. Spray from the surf was so irritating to human beings that schools and hotels near the shore had to close.

FISH KILLED by one of the worst poisonous tides on record dot the water off the west coast of Florida in August, 1947. They are part of a patch about five miles in diameter.

Poisonous tides, which may color square miles of ocean yellow, red or olive-green, bedevil fishermen and shore-dwellers in many parts of the world. Shellfish contaminated by such tides have killed at least 69 people since 1793. The poisonous microorganisms that cause them are an ever-present menace to the shellfish-canning industry, and they are implicated in the recurrent epidemics of fish poisoning which have affected some 40,000 people in the Pacific regions during the past five years.

Investigation of these catastrophic outbreaks has now begun to uncover the meteorological and oceanographic conditions which trigger them. Biologists are identifying the microorganisms and learning to culture them in the laboratory. These studies, it may be hoped, will lead eventually to techniques that will prevent or suppress the poisonous tides. They may also find the answer to one of the fundamental questions of marine biology: why organisms multiply prolifically in some parts of the ocean and not in others.

The natural history of poisonous ocean water, as compiled by the U. S. Navy Hydrographic Office, has an orthodox literary tradition, with references in Homer, the Bible, Tacitus and Darwin's *Voyage of the Beagle*. The seventh chapter of Exodus describes an outbreak in the Nile: "And all the waters that were in the river were turned to blood, and the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river. . . ." Just how far down the estuary of the river this outbreak occurred the Bible does not say. No such catastrophe, either



DINOFLAGELLATES, one-celled creatures with both plant and animal characteristics, may produce poisonous tides when they multiply. Twelve of the hundreds of known species are shown here, magnified about 600 (1-5), 1,100 (6-9) and 1,300 (10-12) times. Only No. 12 is definitely known to be poisonous. Several of the others may be, but have not been studied in the laboratory.

in the Nile or in the adjacent Mediterranean, has been reported in recent times. Biblical scholars and oceanographers are among the few who might welcome one.

Darwin saw red water 50 miles off the southern coast of Chile. He observed that the water was colored by some organism other than the red-pigmented alga *Trichodesmium,* whose nontoxic "blooms" are common in the tropics and give the Red Sea its name.

Serious investigation into the problem began in the 1940s after a series of outbreaks which contaminated shellfish off Monterey, Calif. The blame was soon fixed on *Gonyaulax catanella,* one of the dinoflagellates, an order of one-celled organisms found in most parts of the ocean. Subsequent research indicates that dinoflagellates are responsible for most or all poisonous tides.

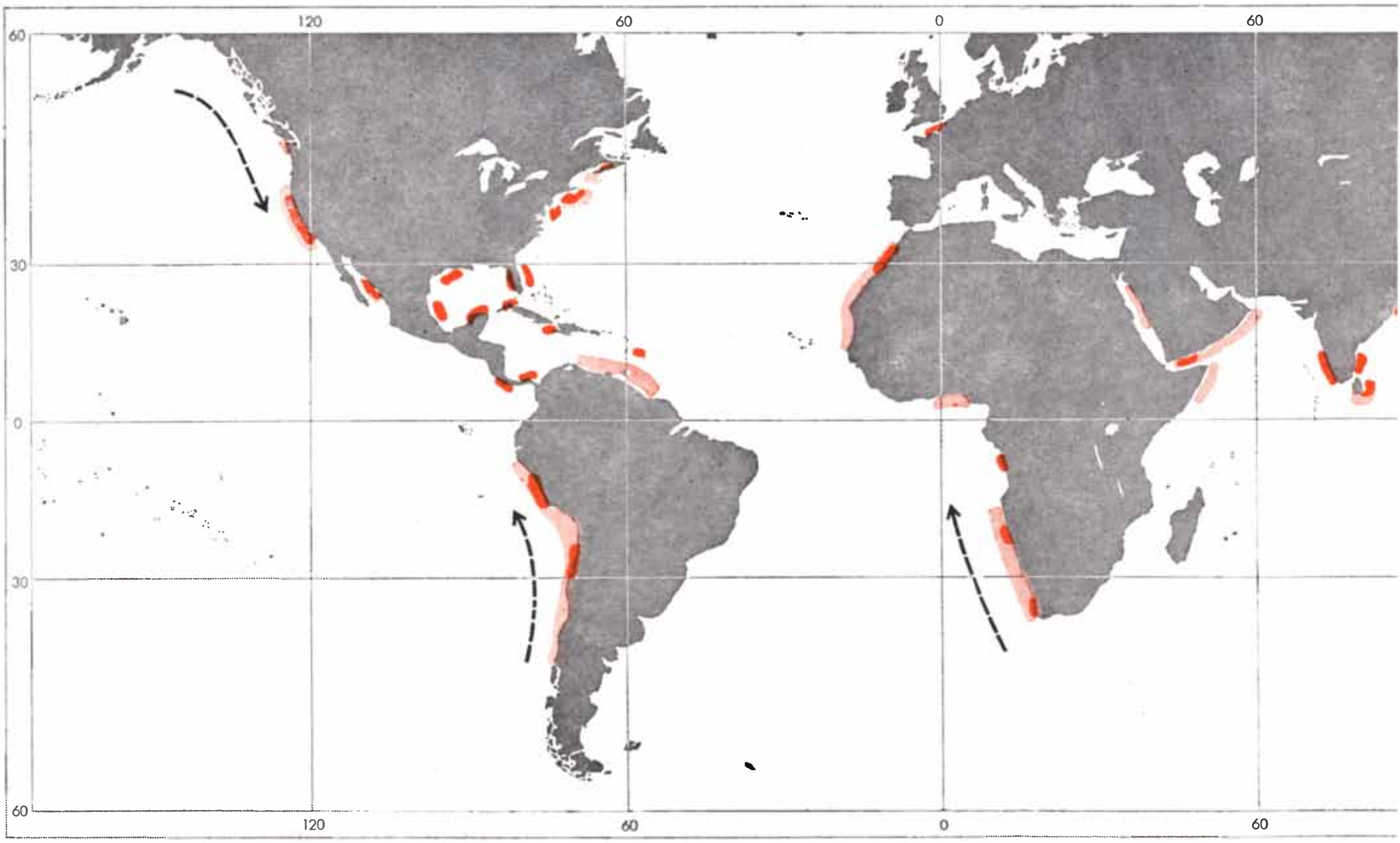
These fragile and beautiful little creatures [*see illustration on preceding page*] get their name from the whiplike flagella with which they lash the water to keep themselves whirling in the upper sunlit layers of the ocean. Biologically the dinoflagellates bridge the gap between plants and animals. Some species contain chlorophyll and live by photosynthesis. Some are predatory and feed on smaller organisms, including their own photosynthetic kin. A few pursue either way of life, as the opportunity occurs. The dinoflagellates are a main foundation stone of the ocean's food pyramid, consumed in countless numbers by shellfish, small crustaceans and other marine animals.

So far as we now know these creatures are the culprits in all poisonous tides. Other microorganisms, the Red Sea algae for example, can bloom; and not all dinoflagellates are toxic. The armored dinoflagellates, which have skeletons of silica-impregnated cellulose, have never been implicated in poisonings. The naked dinoflagellates, on the other hand, seem to be poisonous as often as not.

When a poisonous species blooms, it may kill all the fish in the area. But even when their multiplication is restrained in the dynamic equilibrium of the ocean's economy, the poisonous dinoflagellates remain an invisible menace. The shellfish that consume them are protected by some capacity to segregate the poison in one of their organs. On occasion, this segregated and concentrated poison makes shellfish dangerous to human beings. It happens also that the shellfish which survive a bloom may remain poisonous long after the waters are restored to normal.

The peculiar nature of the dinoflagellate poison is suggested by this description of a victim's experience: "She awoke quite conscious but helplessly paralyzed—arms, legs and trunk. She could not move in her bed or stand when lifted to the floor. She was scarcely able to speak for numbness about the face and mouth; was violently sick but unable to vomit; had a severe headache and backache and extreme dizziness." Her condition improved the following morning, but she still could not leave her bed a day later.

At the Haskins Laboratories in New York we have been investigating the effects of dinoflagellate toxins (under a grant from the U. S. Public Health Service Institute of Neurological Diseases and Blindness). The paralyzing action of these toxins indicates that they are nerve poisons. Thus they join the evil, distinguished company of atropine, curare and the tetanus and botulinus toxins. Though no dinoflagellate toxins have yet been isolated in pure form, they

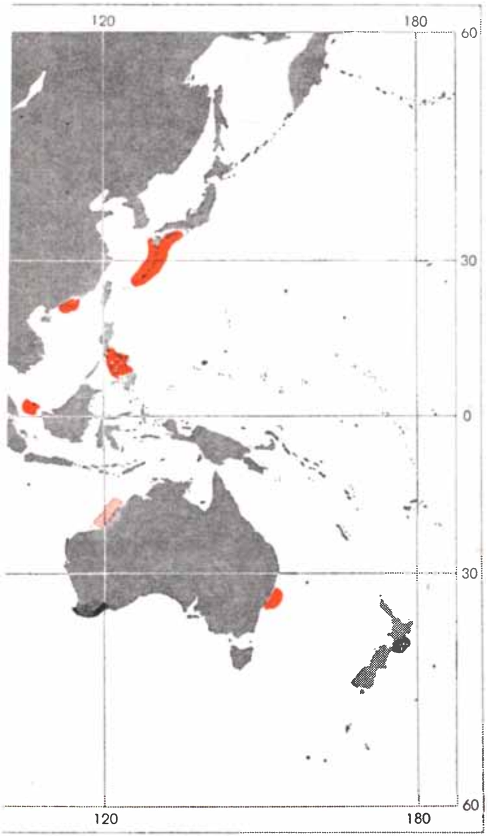


DISTRIBUTION OF POISONOUS TIDES (*heavy color*) **gives clues to their causes. In many regions cool currents** (*broken arrows*)**, tidal turbulence or winds produce upwellings of nutrient-laden cold waters** (*light color*)**. In other regions tides are**

seem to be just as deadly as botulinum, which weight for weight is the most poisonous substance known. They resemble botulinum also in the way they work. Both poisons appear to block nerve impulses by preventing the production of acetylcholine, the substance which acts on the "end plate" of a muscle fiber to make the fiber contract [see "Messengers of the Nervous System," by Amedeo S. Marrazzi; SCIENTIFIC AMERICAN, February, 1957].

No antidote to either toxin has yet been found. A nerve poison such as curare, which makes the end plate less sensitive to acetylcholine, can be neutralized by injecting substances which prevent acetylcholine from breaking down. The increased concentration of acetylcholine then overcomes the reduced sensitivity of the end plate. But the botulinus and dinoflagellate toxins cannot be offset in this way, because they prevent the production of acetylcholine in the first place.

Even poisons have their uses. As the great French physiologist Claude Bernard long ago pointed out, they can serve as powerful tools for investigating normal functions. Several nerve poisons have already deepened our knowledge of the physiology of the nervous system. Dinoflagellate poisons may well prove equally useful.



due to runoff from heavy rains on land and to other causes which are still unknown.

Curiously the capacity to manufacture poison does not seem to serve a useful function in the life of the dinoflagellates themselves. There is no clear evidence that it gives them a selective advantage, any more than it does the tetanus and botulinus bacilli. English investigators have isolated two dinoflagellates which are almost identical in appearance: one is poisonous, the other is harmless. Similar toxic-nontoxic pairs have been isolated on this side of the Atlantic. Such findings suggest the toxicity of dinoflagellates may be quite unconnected with their capacity to bloom. On the other hand, it can be argued that some poisonous blooms may generate their explosiveness by a biological chain reaction: the poison kills fish, decaying fish increase the supply of nutrients in the water, the increase in nutrients yields a larger number of dinoflagellates, they make more poison . . . and so on.

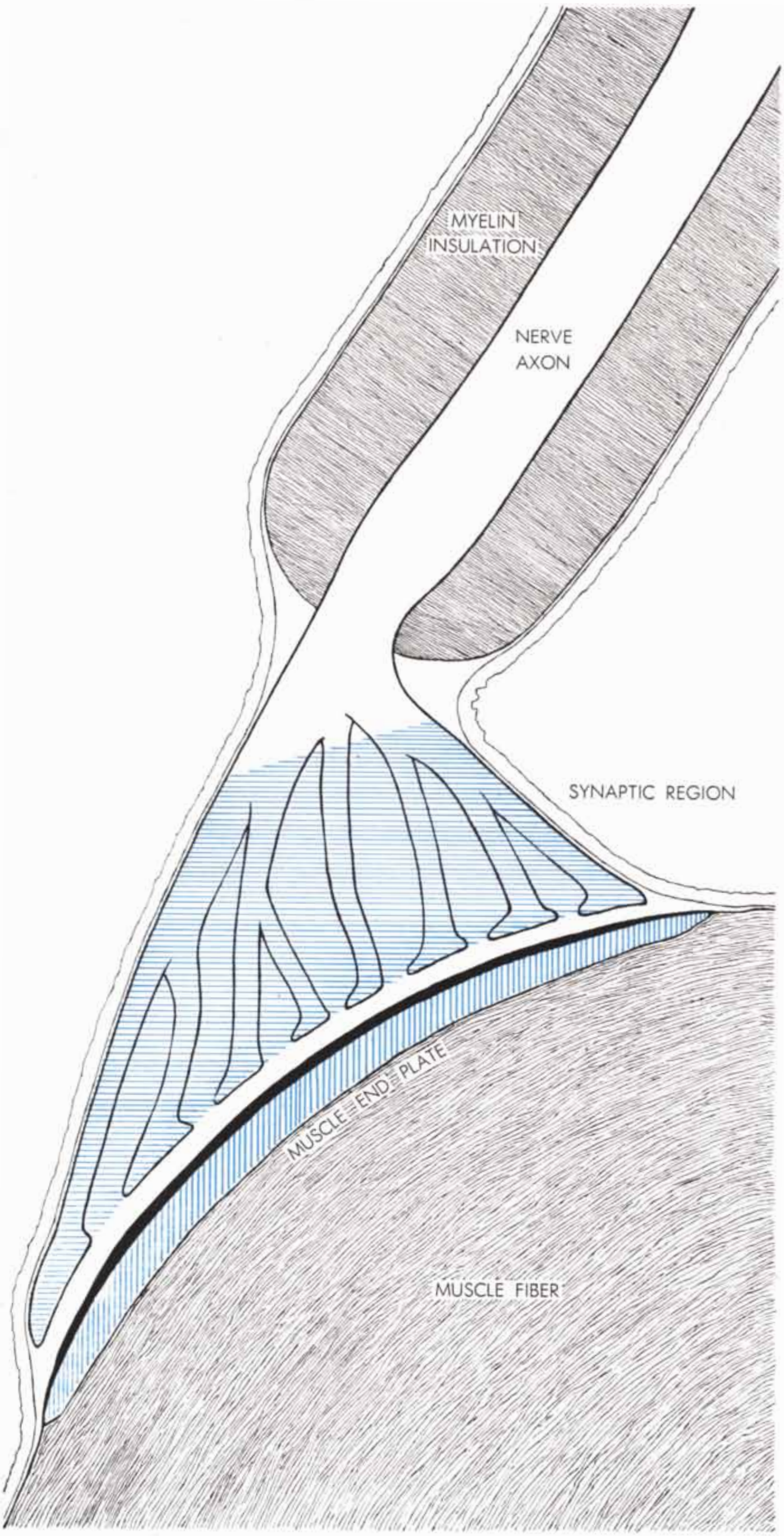
But what starts the bloom in the first place? A survey of the world map of dinoflagellate outbreaks [*left*] suggests a number of oceanographic factors. In many coastal waters they seem to be associated with the surfacing of concentrations of nutrients, by the upwelling of ocean currents or by tidal turbulence (as in the Bay of Fundy). In other areas (such as the Florida coast) blooms seem to be set off by heavy rains on land. The runoff from these rains washes down phosphates from sewage or phosphate rock and lowers the salinity of the water. (In the laboratory many dinoflagellates do best in somewhat diluted sea water.) Quantities of vitamin B-12, which is essential to dinoflagellate metabolism, may also be washed into the ocean from the soil and from salt marshes where it is manufactured by bacteria and blue-green algae.

The prospect for restraining blooms by removing essential nutrients from the water seems poor. Vitamin B-12, for example, could conceivably be cut down by dumping carboys of B-12-destroying bacteria in the water, but truly enormous quantities of bacteria would be required to make any impression on several hundred square miles of ocean. Around the Gulf Coast scientists of the U. S. Fish and Wildlife Service have poisoned flagellate-breeding lagoons with copper sulfate, the standard inhibitor of algae in reservoirs. But dinoflagellates also abound in open water where poisons rapidly become diluted. A more promising attack seems to be the encouragement of natural predators, the technique which has so often been successful with insect pests. Dinoflagellate blooms are often succeeded by blooms of creatures that prey on them, most conspicuously the ciliate protozoa and, in warm waters, the luminous, predatory dinoflagellate *Noctiluca*. But we still know next to nothing about how to cultivate these microscopic creatures.

The picture of dinoflagellates in their natural habitat will soon be highlighted by study of these creatures in the laboratory. By comparison with most microorganisms that are cultured in glassware, however, the dinoflagellates are delicate wildflowers. Not only are they extremely fragile, but each species also requires just the right combination of temperature, salinity and light. Moreover, they are choosy in their nutritional preferences. Differences as small as one part per million in the concentrations of trace elements such as iron, zinc, magnesium, cobalt or copper can determine whether a particular species will reproduce or not. The ecological requirements of some species can scarcely be reproduced in the laboratory. Certain dinoflagellates, for example, are adapted to live in beach sand under the battering of surf; in fact, different species are adapted to different types of sand. Out of the hundreds of known species only 18 have thus far been successfully cultured.

The laboratory experience makes it clear that each species is adapted to its own narrow niche in the life of the ocean. When conditions are just right for a particular species, it blooms. In the process it probably secretes substances (distinct from its toxin) to inhibit the growth of related species which might otherwise flourish almost as well under the same conditions. What these substances are we do not yet know. Once they are isolated and analyzed, however, it will be surprising if many of them do not turn out to be valuable additions to the pharmacopeia of antibiotics, enzymes and other biologically active substances.

One of the most interesting results from controlled culture of dinoflagellates concerns vitamin B-12. This compound, which alleviates pernicious anemia in human beings and steps up the growth of pigs and chickens, turns out to be an especially critical factor in the metabolism of dinoflagellates and probably many other marine microorganisms. The large and complex B-12



NERVE-MUSCLE CONNECTION shows the actions of different nerve poisons. Botulinus and dinoflagellate toxins (*horizontal hatching*) prevent the synaptic region from producing acetylcholine, which acts on the end plate to make muscle contract. Curare (*vertical hatching*) blocks the nerve impulse by making the end plate less sensitive to acetylcholine.

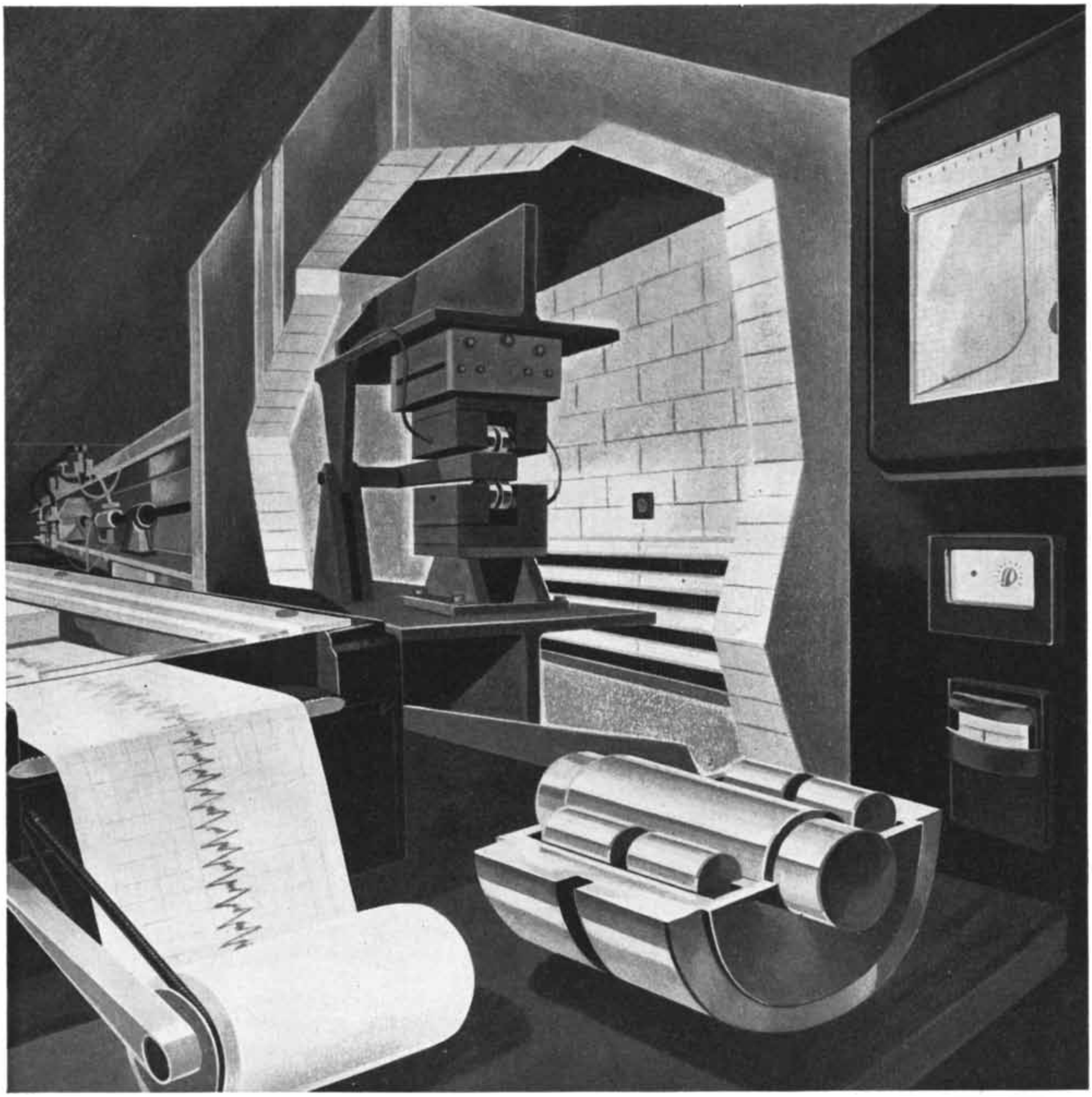
molecule is built around an atom of cobalt, much as chlorophyll is built around magnesium and hemoglobin around iron [see "A Universal Molecule of Living Matter," page 77]. All three compounds are brightly colored: B-12 is a beautiful purple. Like hemoglobin, it can exist in many forms. By hitching different rings or chains of atoms to its basic structure it can be converted into pseudo-B-12s with similar but not identical properties. Some of these imitations occur in nature, and many others can be built in the laboratory. All these pseudo-B-12s are worthless to human beings, but many species of dinoflagellates appear to thrive as well on them as on the genuine vitamin.

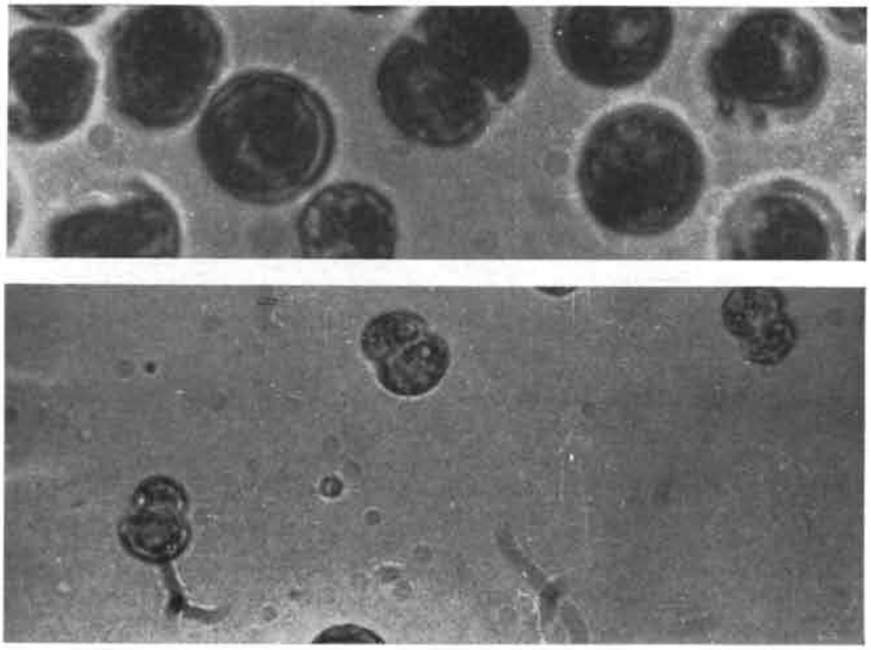
The importance of these cobalt-containing compounds to marine microorganisms suggests that their absence in some oceanic regions may account for a lack of productivity which cannot be explained by shortages of other, more easily measured nutrients. We know that there are "cobalt deserts" on land where livestock die for lack of this element in the soil. Perhaps some deserts in the sea have the same deficiency.

A technique for measuring precisely the amount of B-12 present in ocean water would obviously be useful to marine ecologists. At present, however, there is no simple way to make such measurement. In fresh water the alga *Euglena* is a sensitive indicator. The rate at which this microorganism multiplies in a solution provides a quite accurate estimate of the amount of vitamin present. Unfortunately *Euglena* tolerates salt poorly. An international race is now on to discover an organism which can measure B-12 in the ocean.

Some of the complexities of dinoflagellate ecology are suggested by the epidemiology of fish poisoning suffered by people in the Pacific region. Many U. S. servicemen in that theater during World War II were numbered among its casualties; more recently it has assumed the status of an indigenous public health menace. The whole problem is enmeshed in a tangle of fish, coral, symbiotic algae and South Sea taboos which we are just beginning to unravel.

Many species of fish implicated in these poisonings are reef dwellers and feed on the coral polyps whose skeletons build the limy structures of the reefs. It has long been known that some species of coral are crammed with zooxanthellae, symbiotic algae whose role in the coral's economy is still obscure. The very simple and generalized structure of these microscopic symbionts makes them hard





SYMBIOTIC ALGAE from jellyfish tissues are shown magnified about 3,000 times. Normally they are simple, motionless cells (*top*), but when they are cultured in artificial media they change into smaller, mobile dinoflagellates (*bottom*). While this species is not poisonous, similar symbionts of coral polyps may be. Fish which feed on coral would then be poisonous.

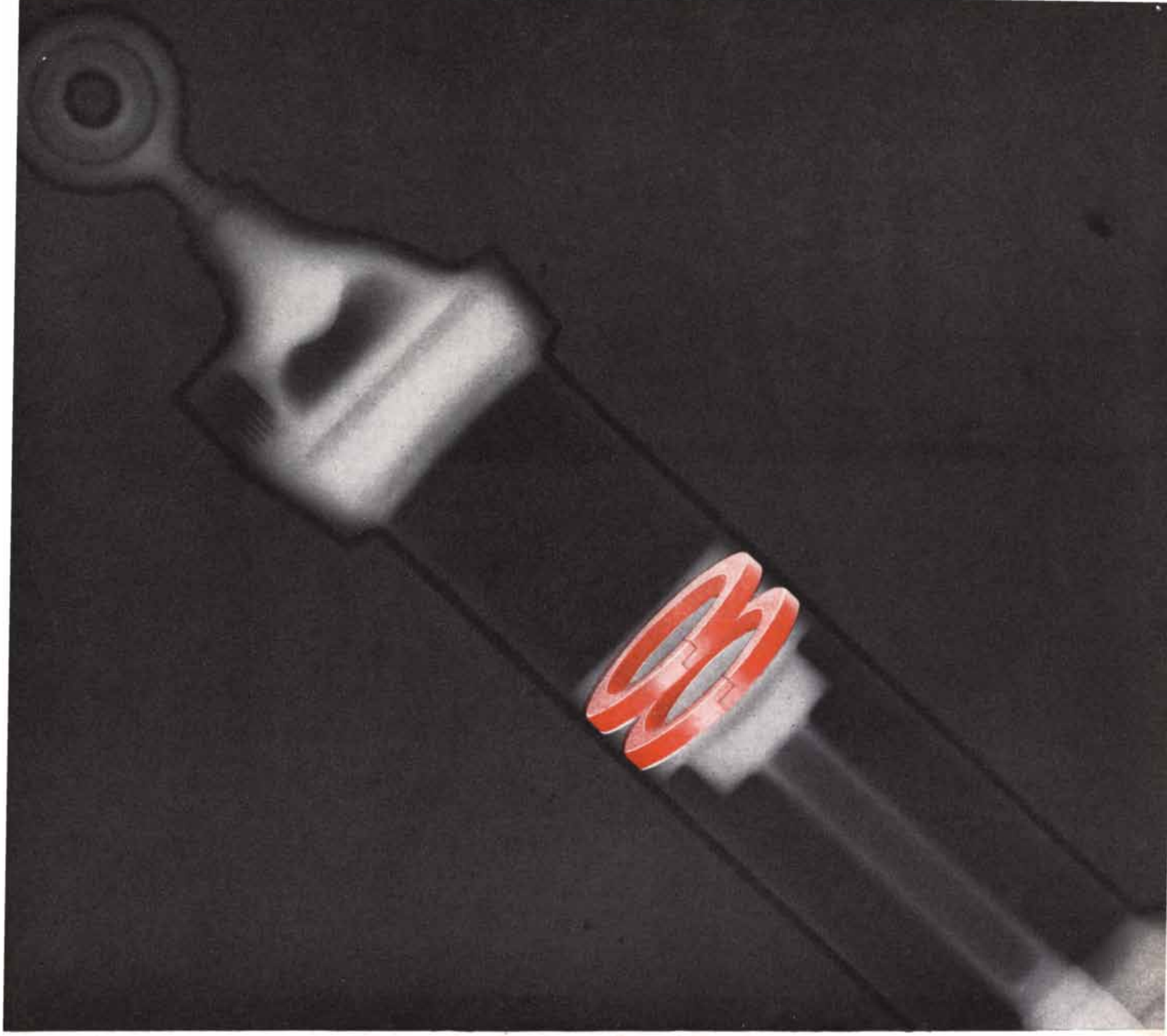
to classify, but several investigators have suggested that they might be dinoflagellates in disguise.

Recently Paul A. Zahl and one of us (McLaughlin), working at the Haskins Laboratories, were able to isolate some zooxanthellae from a jellyfish, some sea anemones and corals. After trying hundreds of permutations of nutrient media we hit on several which suited the microorganisms. A few days after being placed in these media the hitherto simple and immobile cells changed their shape, grew flagellae and began to swim about [*see illustrations above*]. We were able to identify them as the dinoflagellate *Gymnodinium adriaticum*. While this particular symbiont dinoflagellate is not poisonous, other symbiotic zooxanthellae may be, and fish which feed on coral containing them would presumably become poisonous in turn.

Another possibility is that free-living rather than symbiotic dinoflagellates are to blame. Certain winds may favor the upwelling of fertile cold waters around coral reefs, as they are known to do along many continental coasts. These upwellings might set off poisonous blooms in the endemic dinoflagellate population. The coral animals and shellfish which feed on dinoflagellates would then pass their poison up the food chain to fish and predators which feed on fish. South Sea islanders have elaborate tabus governing how and when reef-fish may be eaten. A comparison of these tabus with hydrographic data might yield interesting results.

The sinister role played by poisonous dinoflagellates can too easily obscure the usefulness of their harmless relatives. One of the main aims of laboratory work with marine microorganisms is to learn how to produce desirable species in quantity for feeding to commercial fish and shellfish. The Japanese are already raising young oysters in great concrete tanks containing decaying eel-grass, bacteria and brown flagellates (predatory microorganisms allied to the dinoflagellates). The bacteria feed on the eel-grass, the flagellates on the bacteria, and the oyster spat on the flagellates. As the oysters grow bigger they are transferred to beds in shallow water off the coast, where this intensive feeding is continued. Researches along similar lines are reaching the pilot-plant stage in Great Britain and the U. S.

Dinoflagellates and the other marine microorganisms which use chlorophyll to bind the sun's energy into protoplasm have been called the grass of the sea. They are the pasture on which all other marine life ultimately depends. As we learn more about the conditions under which they flourish, we should some day be able, not only to prevent poisonous tides, but to set off nutritious tides, cultivating the sea as we now do the land and producing more food for our hungry planet.



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

MATHEMATICAL GAMES

A third collection of "brain-teasers"

by Martin Gardner

In the 18 months since this department was inaugurated, it has presented two collections of mathematical "brain-teasers." Here is the third. None of these problems requires advanced mathematics for its solution, although the reader will find it easier to compute the survival chances of the three duelists in the final problem if he is familiar with the theory of probability. The answers will be given next month.

1.

Two identical bolts are placed together so that their helical grooves intermesh [*illustration at the bottom of this page*]. If you move the bolts around each other as you would twiddle your thumbs, holding each bolt firmly by the head so that it does not rotate, will the heads (a) move inward, (b) move outward or (c) remain the same distance from each other? The problem should of course be solved without resorting to actual test.

2.

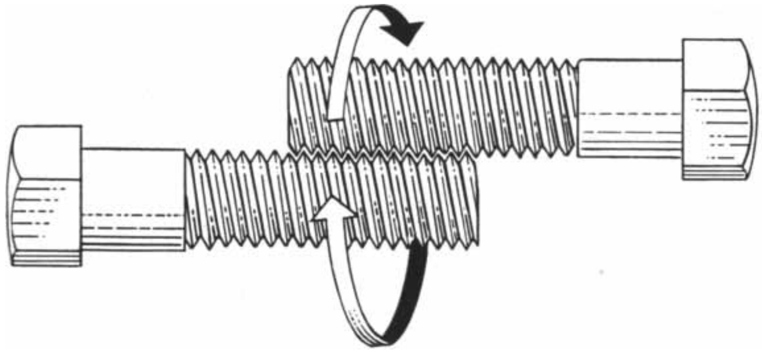
A group of airplanes is based on a small island. The tank of each plane holds just enough fuel to take it halfway around the world. Any desired amount of fuel can be transferred from the tank of one plane to the tank of another while the planes are in flight. The only source of fuel is on the island, and for the purposes of the problem it is assumed that there is no time lost in refueling either in the air or on the ground. What is the smallest number of planes that will insure the flight of one plane around the world on a great circle, assuming that the planes have the same constant ground speed and rate of fuel consumption and that all planes return safely to their island base?

3.

What is the radius of the largest circle that can be drawn entirely on the black squares of a chessboard with squares that are two inches on a side?

4.

Many old puzzle books explain how a cork can be carved to fit snugly into square, circular and triangular holes [*illustration at bottom of page 102*]. An interesting problem is to find the volume of the cork plug. Assume that it has a circular base with a radius of one unit, a height of two units, and a straight top edge of two units that is directly above and parallel to a diameter of the base. The surface is such that all vertical cross sections which are made perpendicular to the top edge are triangles. The plug's volume can of course be determined by calculus, but there is a simple and elegant way to find it with little more information than knowing that the volume



Puzzle 1

of a right circular cylinder is the area of its base times its altitude.

5.

An amusing parlor trick is performed as follows. Ask spectator A to jot down any three-digit number, and then to repeat the digits in the same order to make a six-digit number (*e.g.*, 394,394). With your back turned so that you cannot see the number, ask A to pass the sheet of paper to spectator B, who is requested to divide the number by 7.

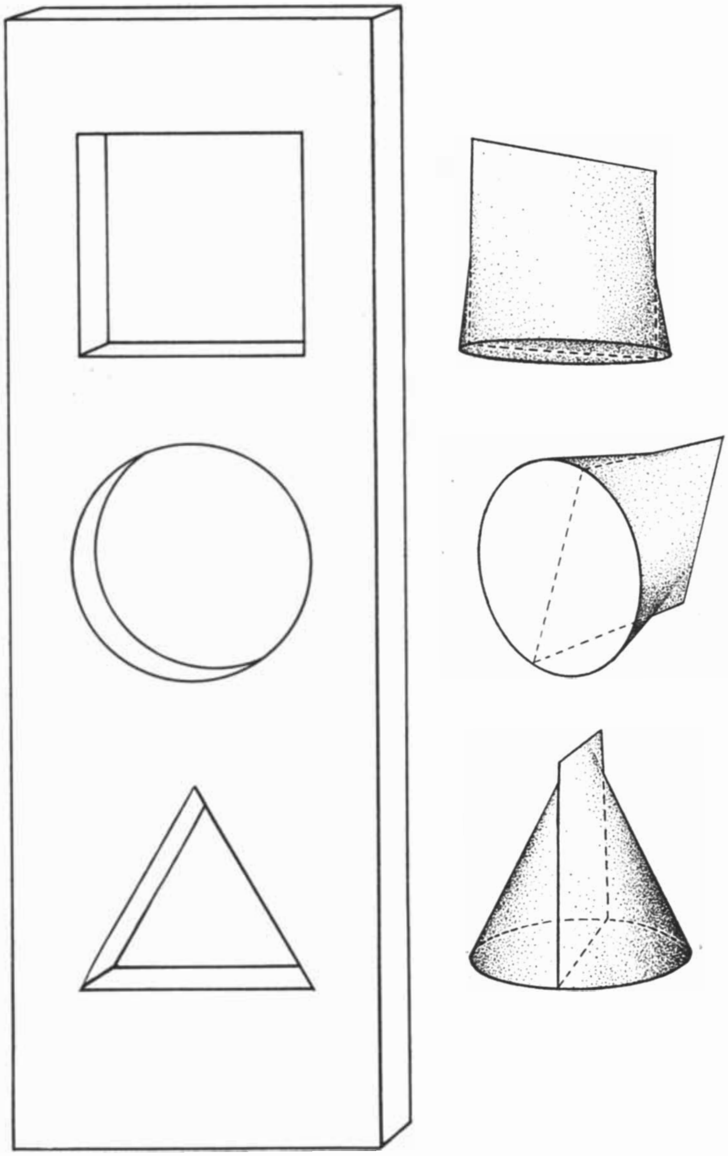
"Don't worry about the remainder," you tell him, "because there won't be any." B is surprised to discover that you are right (*e.g.*, 394,394 divided by 7 is 56,342). Without telling you the result, he passes it on to spectator C, who is told to divide it by 11. Once again you state that there will be no remainder, and this also proves correct (56,342 divided by 11 is 5,122).

With your back still turned, and no knowledge whatever of the figures obtained by these computations, you direct a fourth spectator, D, to divide the last result by 13. Again the division comes out even (5,122 divided by 13 is 394). This final result is written on a slip of paper which is folded and handed to you. Without opening it you pass it on to spectator A.

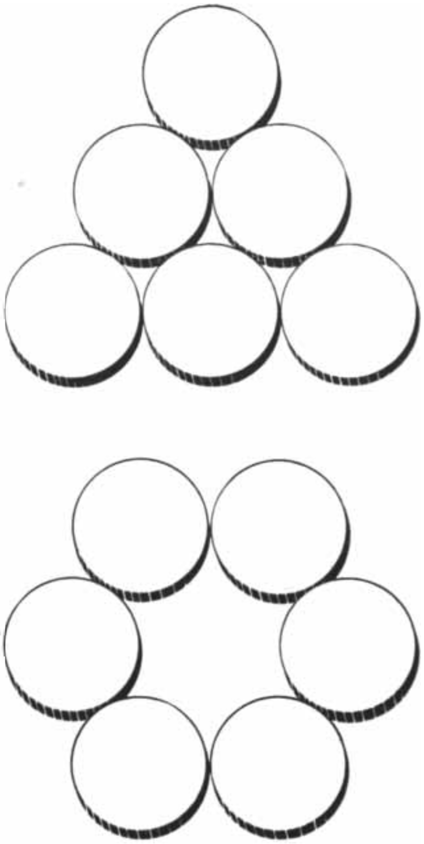
"Open this," you tell him, "and you will find your original three-digit number." Prove that the trick cannot fail to work regardless of the digits chosen by the first spectator.

6.

Two missiles speed directly toward each other, one at 9,000 miles per hour



Puzzle 4



Puzzle 7

and the other at 21,000 miles per hour. They start 1,317 miles apart. Without using pencil and paper, calculate how far apart they are one minute before they collide.

7.

Six pennies are arranged on a flat surface as shown in the top illustration above. The problem is to move them into the formation depicted at bottom in the smallest number of moves. Each move consists in sliding a penny, without disturbing any of the other pennies, to a new position in which it touches two others. The coins must remain flat on the surface at all times.

8.

Prove that at a recent convention of biophysicists the number of scientists in attendance who shook hands an odd number of times is even. The same problem can be expressed graphically as follows. Put as many dots (biophysicists) as you wish on a sheet of paper. Draw as many lines (handshakes) as you wish from any dot to any other dot. A dot can "shake hands" as often as you please, or not at all. Prove that the number of dots with an odd number of lines joining them is even.

9.

Smith, Brown and Jones agree to fight a pistol duel under the following unusual conditions. After drawing lots to determine who fires first, second and third, they take their places at the corners of an equilateral triangle. It is agreed that they will fire single shots in turn and continue in the same cyclic order until two of them are dead. At each turn the man who is firing may aim wherever he pleases. All three duelists know that Smith always hits his target, Brown is 80 per cent accurate and Jones is 50 per cent accurate. Assuming that all three adopt the best strategy, and that no one is killed by a wild shot not intended for him, who has the best chance to survive? A more difficult question: What are the exact survival probabilities of the three men?

Last month a game with a single die was described in this department. The die is first rolled, then players alternate in giving it a quarter-turn, keeping a running total of points until a player wins by reaching an agreed-upon goal or forcing his opponent to go above it. A chart was promised [*see illustration below*] that would show the winning first rolls for the nine possible digital roots of the goal.

As the chart indicates, if the first player is permitted to choose the goal, he should pick a number with a digital root of 7. It is the only root that has three winning rolls, giving the first player a chance of 1/2 to win if he and his opponent play the best possible game.

DIGITAL ROOT OF GOAL	WINNING FIRST ROLLS OF DIE
1	1, 5
2	2, 3
3	3, 4
4	4
5	5
6	3, 6
7	2, 3, 4
8	4
9	NONE

The answer to last month's problem

THE AMATEUR SCIENTIST

An excursion into the problem of measuring irregular areas

Conducted by C. L. Stong

Despite their fascination with science, many amateur scientists shudder at the thought of having to use mathematics. When they encounter a problem which is essentially mathematical, they will sometimes go to great lengths to devise a solution which they firmly believe is nonmathematical. For example, amateurs have been known to invent remarkably ingenious methods, apparently involving no advanced mathematics, to determine the area of a flat surface with an irregular boundary.

F. W. Niedenfuhr of the Ohio State University writes to this department: "It may come to these people as something of a surprise to learn that they are skating dangerously close to the edge of integral calculus.

"Integral calculus is not nearly so formidable as it sounds. It is a study, at least in part, of the problem of measuring area. In view of the fun that can be got out of mathematics, and of the understanding of advanced work in science which it can afford, it is unfortunate that more amateurs do not devote some of their time to the subject. Experiments with problems of area can make an interesting starting point. I will give an example of a difficult problem later on, but first let us look into an easier case.

"Imagine that we have drawn a simple closed curve on a sheet of writing paper. (Simple means that the curve does not cross itself.) This curve marks out an area on our paper. How many ways can you think of to find this area?

"The problem is interesting to me because I like to watch the ways in which students at various stages of sophistication attempt to solve it. A third-year college student may begin by trying to write the equations of the curve. A mature mathematician will ask: 'How accurately do you want to know the area?' A graduate student in mathematics will sometimes protest that he is not sure he understands the problem, and that anyway it probably cannot be solved. An engineer may admit that he once knew how to find the area but has now forgotten, or he may produce a machine called a planimeter and proceed to measure the area for you. Usually he will not know why this machine works, but he is pretty sure that it does. But don't press the poor fellow—he has another job to do.

"I saw a very clever (and most significant) solution to this problem at a model-airplane meet some years ago. The contest rules required that the models have a fuselage whose cross-sectional area was not less than a certain minimum. This area was easy to check in the good old days when all the models had rectangular cross sections, but with the advent of more streamlined shapes the judges began to have trouble making sure that the rules were being followed. They finally decided to find the required area by first having an accurate drawing of it, and then cutting out the drawing and weighing it. Since the weight per unit area of the paper was known, the area of the cut-out drawing was easy to obtain. Now this solution to the area problem is a splendid example of applied integral calculus. It is a little surprising, then, that people who have actually studied calculus will laugh at the method, or dismiss it as impractical. Yet when an accurate balance or scale is at hand it is the quickest way to determine an area. (How many ways can you think of for improvising a balance to 'weigh areas'?)

"Another obvious way to find an area is to draw the figure on graph paper and count the number of little squares inside the simple closed curve. Then if we know the area of each square we find the total area by multiplying the area per square by the number of squares enclosed by the curve. Of course near the edges of the figure we will have to count partial squares, and some error will be introduced each time we estimate the size of such a square. But the total error will generally be small for two reasons. First, we will sometimes overestimate and sometimes underestimate the area of a partial square, and our errors from this source will tend to cancel out. Second, the human eye is an excellent judge of the relative sizes of small areas. This process is not so tedious as might be imagined, because on the interior of the figure we can count great blocks of squares at once, rather than each square individually. I find that making drawings on 8½×11-inch paper with quarter-inch squares printed on it provides excellent accuracy and is not too time-consuming.

"A variation on the system of counting squares is the Monte Carlo method. You might like to try this one experimentally. Draw the area on a piece of paper again, and put your finger down at random. One of four things will happen: (1) your finger will come down on the paper inside the unknown area, (2) it will come down outside the area, (3) it will come down on the boundary of the area, or (4) it will miss the paper entirely. Now on a separate tally sheet keep track of the results as follows: In the first case (your finger lands inside the area) write 'Yes' on the tally sheet. In the second case write 'No' on the sheet. In the third and fourth cases do not write on the sheet at all. After a large number of tallies have been made you can find the unknown area by multiplying the total area of the paper by the number of 'Yes' tallies divided by the number of 'No' tallies. The accuracy of the answer will depend on two things. First, the number of tallies must be large; second, you must put your finger down in a random manner each time. Obviously if you always put your finger down outside the given area, you would have no 'Yes' tallies, and the formula given above would indicate that the unknown area is zero.

"Pursued by hand, the Monte Carlo method will only lead to bruised thumbs and poor estimates of the area, but it does appear to be a useful method when automatic machines can be devised to make and record a large number of tallies. Machines have been constructed which integrate (calculate areas) by this method, but they are handicapped by the difficulty of providing random numbers which tell the machine how to 'put its finger down.' Any mechanical device to produce random numbers will be subject to wear, and this wear introduces a bias in favor of a particular number. For a time it was thought that the sequence of digits in *pi* (3.14159...) would be random, but this is not the case. There still is no completely satisfactory way to produce random numbers. In spite of this practical difficulty, the Monte Carlo method of integration holds great promise.

"There is still another way in which the original problem can be solved. Suppose our unknown area has been divided up into a large number of narrow strips by equally spaced vertical lines drawn on the paper [*Figure 1*]. By itself each strip differs little from a long, narrow rectangle. Suppose we have numbered each strip for identification purposes and measured its length. If the lengths of the strips are L_1, L_2, L_3 and so on, the following is an obvious formula for the area:

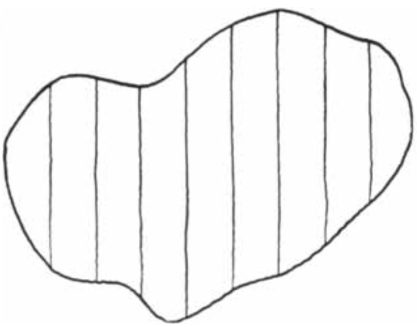


Figure 1

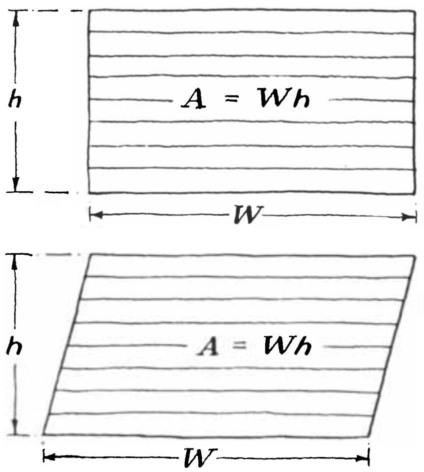


Figure 2

$$\text{Area} = (L_1 + L_2 + L_3 \ldots) \times B$$

"*B* is the width of the strips. Now the ends of each strip will not be rectangular but tapered or cut on the bias. If a strip is rather wide, you may have difficulty in deciding its length, and the accuracy of the final result will depend on how well you define the length of each strip. If the strips are narrow, however, it will be easy to decide the length. Imagine, for instance, that each strip is as narrow as the thickness of the paper. If the strips were literally cut apart, we could measure the length of a number of threads. This would be tedious but not difficult. Thus the accuracy of the formula increases as *B* becomes very small, and as the number of strips increases. The 'fundamental theorem' of integral calculus is based on this formula.

"The area given by the formula will not be changed if the strips are moved with respect to one another. This explains why the areas of the parallelogram and the rectangle in the accompanying illustration [*Figure 2*] are the same. The parallelogram is just the rectangle with its strips pushed over a little. The pushing process does not change either the length or width of a strip.

"Another process for finding areas is to divide the unknown area into a large number of triangles, find the area of each triangle, and add up the areas. We split the area by drawing rays, each of which has the same angular relationship to the others [*Figure 3*]. Now look at a typical element of this area [*Figure 4*]. Let *C* be the center of *AB*, and *R* be the distance from *O* to *C*. Imagine that we swing an arc of radius *R* (*OC*) between the lines *OA* and *OB*. If the angle *AOB* is very small, this arc will appear to be practically a straight line of length *W*. The area of the triangle is then one-half $R \times W$.

"If the angle *AOB* is denoted by the symbol $(d\varphi)$, you see that the two lengths *R* and *W* determine the angle. In fact, we may say by definition that $(d\varphi) = W/R$. You are familiar with measuring angles in degrees, but this new method of measuring angles is generally more useful in mathematics. The units of this measurement are called 'radians.' For instance, if in the above example $R = 3$ inches and $W = .3$ inch, then $(d\varphi)$ is an angle of .1 radian, which is equivalent to just under six degrees. Measurement of larger angles in radians may be done by drawing a circular sector [*Figure 5*]. Let *R* be the radius of the sector, and *L* be the length of the arc. The angle φ, expressed in radians, is $\varphi = L/R$. If we keep increasing the angle φ, the sector opens up into a

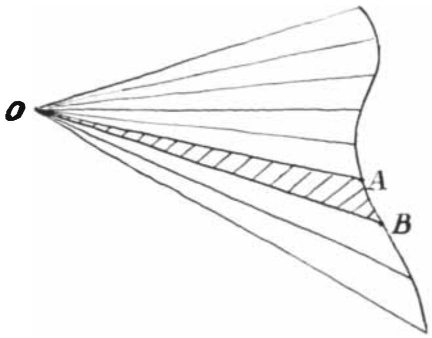


Figure 3

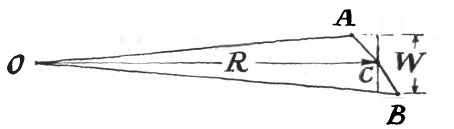


Figure 4

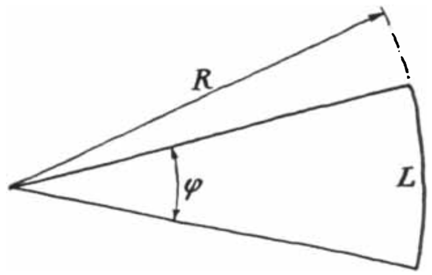


Figure 5

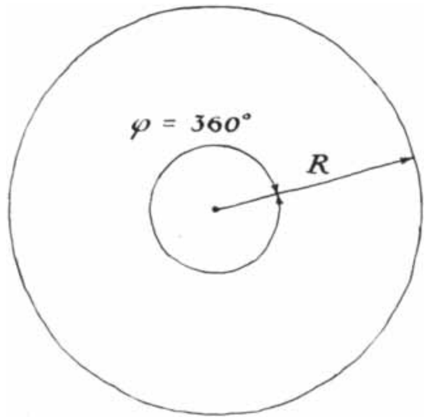
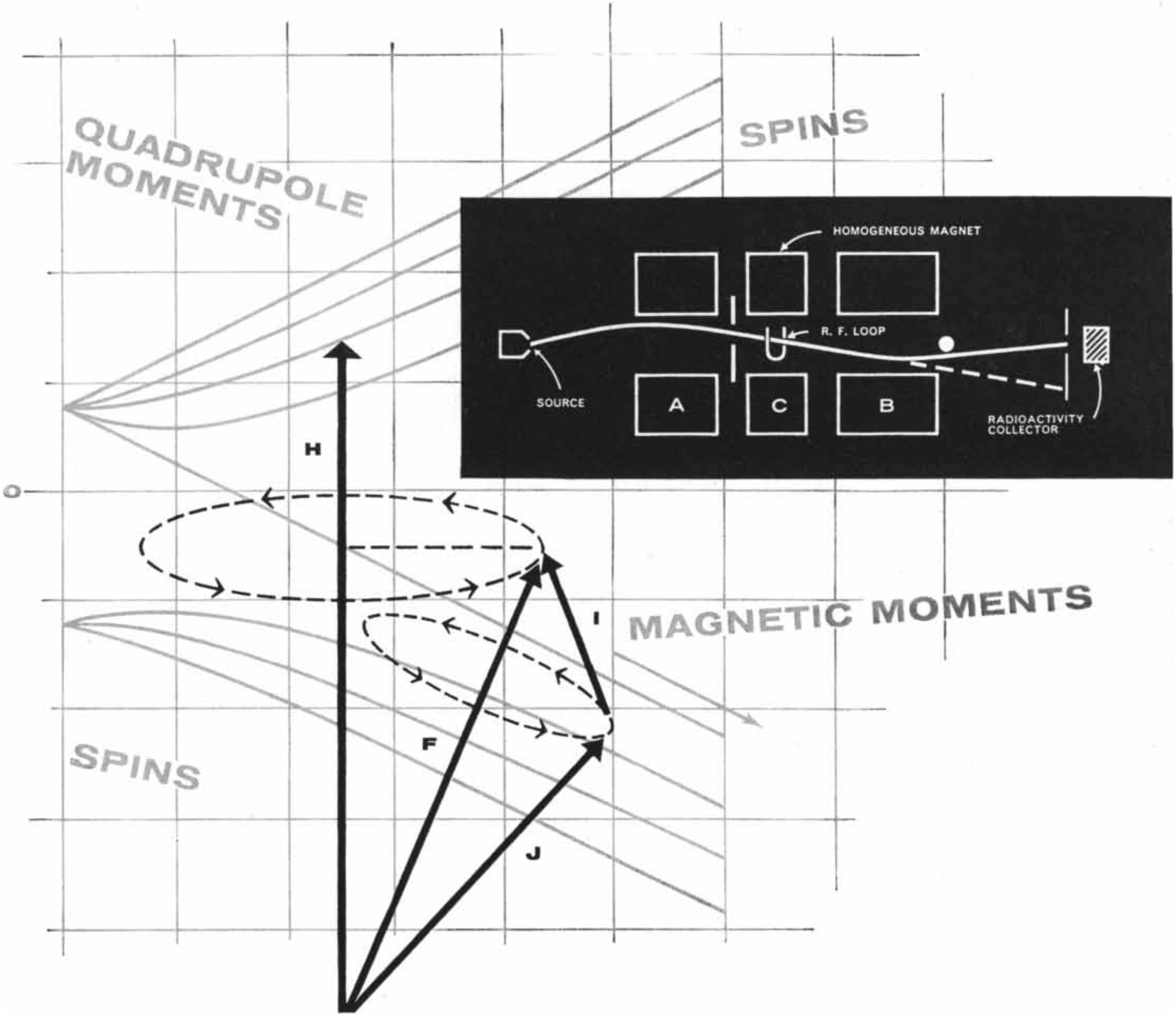


Figure 6

circle [*Figure 6*], and the angle φ becomes 360 degrees. How many radians is this? The 'arc length' *L* has become equal to the circumference of the circle, which is $2\pi R$. Then $\varphi = L/R = 2\pi R/R = 2\pi$. Thus 2π radians equals 360 degrees. The advantage of using the radian measure for angles lies in


QUADRUPOLE MOMENTS
SPINS
HOMOGENEOUS MAGNET
R. F. LOOP
SOURCE
A
C
B
RADIOACTIVITY COLLECTOR
O
H
I
MAGNETIC MOMENTS
F
SPINS
J

the fact that if we say 'angle equals arc length over radius,' we may also say 'arc length equals angle times radius.'

"Back to our little triangle. Since $(d\varphi) = W/R$, or $W = R(d\varphi)$, the area of the little triangle is $\frac{1}{2} RW = \frac{1}{2} R^2 (d\varphi)$. Let $R_1, R_2, R_3 \ldots$ be the radii of the small triangular 'slices' of the big area. Then, since each 'slice' has the same central angle $(d\varphi)$, the big area is given by the formula:

$$A = \tfrac{1}{2}(R_1^2 + R_2^2 + R_3^2 + \ldots)(d\varphi)$$

"This represents the sum of the areas of the little triangles. This formula too

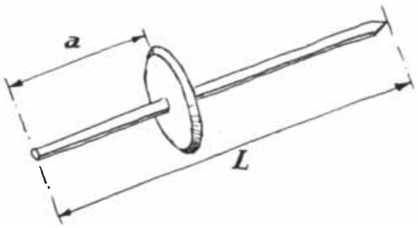


Figure 7

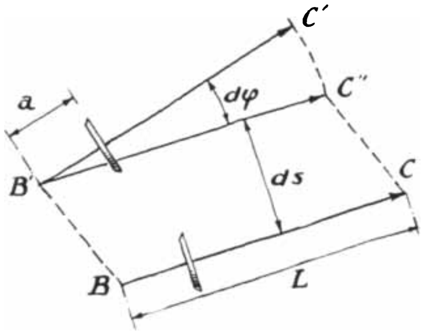


Figure 8

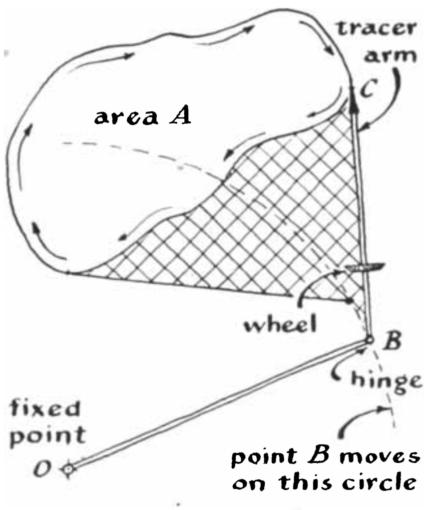


Figure 9

is very close to a calculus formula. Its accuracy will increase as $(d\varphi)$ decreases and the number of terms increases.

"You now have enough information to build a machine to measure areas (a planimeter). Imagine a straight bar which serves as the axle of a knife-edged wheel [*Figure 7*]. Now imagine that this bar moves a small amount parallel to the plane of the paper, while the wheel rolls and slides on the paper. Let the bar move from BC to $B'C'$ [*Figure 8*]. This motion could be accomplished by first moving the bar parallel to itself from BC to $B'C''$ and then rotating it about B' until it reaches $B'C'$. How far would the wheel roll during this motion? In moving from BC to $B'C''$, the wheel rolls (and slides sideways a little) a distance (ds), and in moving from $B'C''$ to $B'C'$ the wheel rolls a distance $a(d\varphi)$. [Here again $(d\varphi)$ is measured in radians, and is a small angle.] So the total distance the wheel rolls is (dp), where $(dp) = (ds) + a(d\varphi)$.

"What area did the bar sweep out? In moving from BC to $B'C''$ the area covered was $L(ds)$, and in moving from $B'C''$ to $B'C'$ the area covered was $\frac{1}{2} L^2(d\varphi)$, so if the total area swept out is called (dA):

$$(dA) = L(ds) + \tfrac{1}{2} L^2(d\varphi)$$

"Combining the last two equations:

$$\begin{aligned}(dA) &= L(dp) - La(d\varphi) + \tfrac{1}{2}L^2(d\varphi)\\ &= L(dp) + (\tfrac{1}{2}L^2 - La)(d\varphi)\end{aligned}$$

"Now you should know, if you have not already guessed, that in the notation of calculus if x is any quantity, the symbol (dx) stands for a little bit of x. For instance, if A is an area, (dA) is a very small 'slice' of that area. If p is a distance, (dp) is a short step along the way.

"Having mastered this much calculus, we may now play a trick on our little wheel and axle—or tracer arm, as it is properly called. We attach another bar to it at point B. This second bar is called a polar arm. The polar arm has one end hinged to the tracer arm at B, and one end fixed (but free to pivot) at point O [*Figure 9*].

"Now trace around the circumference of an area with the tracer point C. The area swept out by BC will be the area we are attempting to measure plus the area hatched in the illustration. But the hatched area will be covered twice, once with the wheel rolling forward and once with the wheel rolling backward, so it cancels out. If we consider the total area swept out by the tracer arm as being the sum of a large number of very small areas (dA), as described above, we may write:

$$\begin{aligned}A &= (dA)_1 + (dA)_2 + (dA)_3 + \ldots\\ &= L[(dp)_1 + (dp)_2 + \ldots] +\\ &\quad (\tfrac{1}{2}L^2 - La)[(d\varphi)_1 + (d\varphi)_2 + \ldots]\end{aligned}$$

"Now we must interpret each of these sums. The total distance (p) through which the wheel rolled is:

$$p = [(dp)_1 + (dp)_2 + \ldots]$$

"The total angle through which the tracer arm BC turned is:

$$\varphi = [(d\varphi)_1 + (d\varphi)_2 + \ldots]$$

"But since the polar arm forced the tracer arm to return to its exact starting point, the total angle turned is zero. Thus $A = Lp$ (p, again, is the distance the wheel rolled). This is easily obtained from scale markings on the rim of the wheel.

"The little instrument we have been discussing is called a polar planimeter [*Figure 10*]. There are several models on the market—all rather expensive for beginners, I fear. You can have more fun constructing your own. An accurate polar planimeter is a precision machine. If you are not quite up to fine mechanical work, there is another way out. Your pocket knife can be used as a satisfactory, if approximate, planimeter. Open both blades as shown in the accompanying drawing [*Figure 11*]. Make sure that blade B makes contact on the cutting edge, and that blade C makes contact at its point when the opened knife is held upright on a table. Determine the distance L.

"Now pick an area to be measured. The longest diameter of the area should be considerably shorter than L; say, no more than half as long. Locate the center of the area approximately. Draw a straight line (to be used as a reference line) outward from the center of area [*Figure 12*]. Now hold the knife so that point C is at the center of area, and B is on the reference line. Holding blade C, push the knife along the reference line until the point of C is on the boundary of the curve. Then, keeping the knife upright, guide point C completely around the area, tracing out the boundary line, and finally pull it back to the center. Meantime the supporting blade B will have been riding freely on the paper. When you return to the starting position, blade B will no longer be on the reference line, and the line of the knife, BC, will make an angle with the reference line. Call this angle φ (measured in radi-

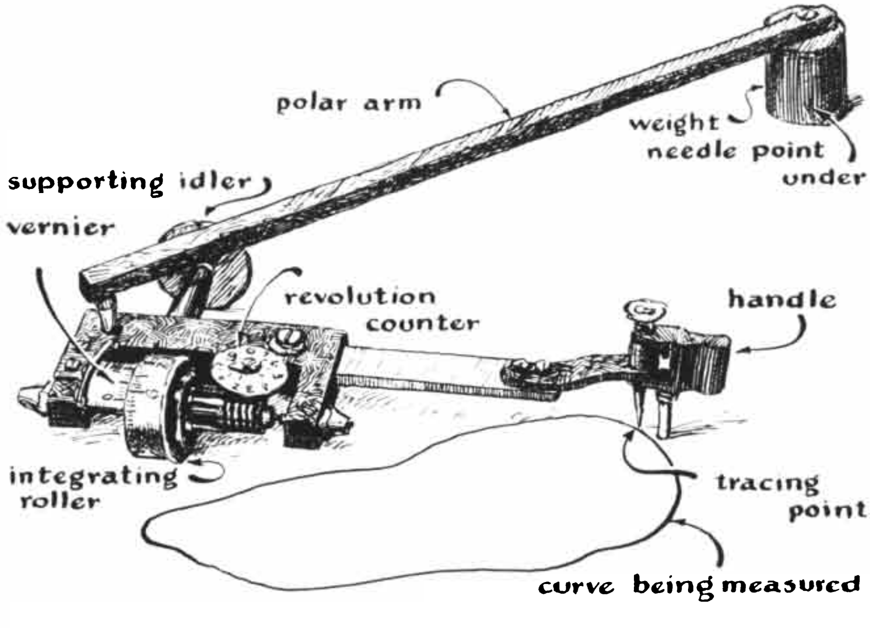


Figure 10

ans). The area you have traced around is then given approximately by the formula $A = L^2\varphi$. This is so easy to do that it is worthwhile trying it on a few known areas just to see how good your pocket knife really is.

"If it is inconvenient to measure the angle directly in radians, measure it in degrees, multiply by 2π and divide by 360, in accordance with the definition of a radian given above. This sliding type of planimeter is often called a hatchet planimeter.

"Now for the more difficult problem I promised earlier. It would seem natural, in view of all the foregoing, to seek the area of a curved surface by enclosing the surface in a polyhedron of many sides and then adding up the areas of the faces of the polyhedron. For example, the area of a cylinder can be obtained approximately by adding up the areas of the faces of an octagonal box in contact with the cylinder [*Figure 13*]. The result would be more accurate if instead of an octagonal box we used a box with many more sides. Just to show that this is not always such an easy process, consider the following. Cut the cylinder along a vertical line and unroll it into a flat sheet. The area of this sheet is the same as the area of the cylinder. Divide the flat sheet into rectangles and triangles as shown [*Figure 14*].

"Now roll up this sheet to form a cylinder again. Let each vertex of each of the triangles stay on the surface of the cylinder. By connecting these vertices with straight lines we form a polyhedron with a large number of triangular faces which is inscribed in the cylinder. The sides of the triangles are not on the surface of the cylinder, but run inside it from one surface point to another. It is tempting to assume that the area of the polyhedron more and more closely approximates the area of the cylinder as the number of triangles is increased, that is, as the grid of rectangles and triangles becomes finer and finer. This is in fact not true. If the grid is chosen properly, the polyhedron can be made to approach a kind of Japanese-lantern shape [*Figure 15*]. The area of such a polyhedron can be made very much *larger* than the area of the circumscribing cylinder. The reason for this is that the planes of the triangles slant in and out with respect to the surface of the cylinder. If the number of vertical divisions is very large as compared to the number of horizontal divisions, the triangles become almost per-

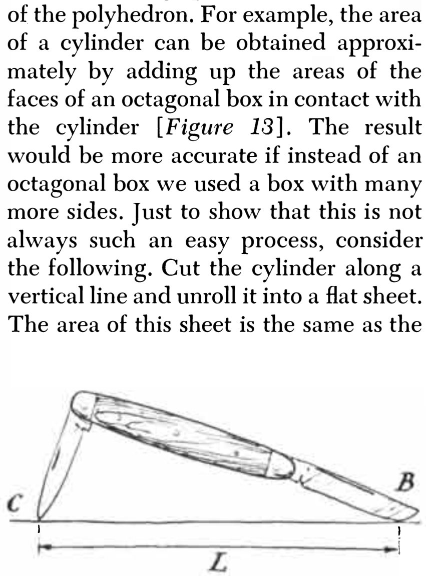


Figure 11

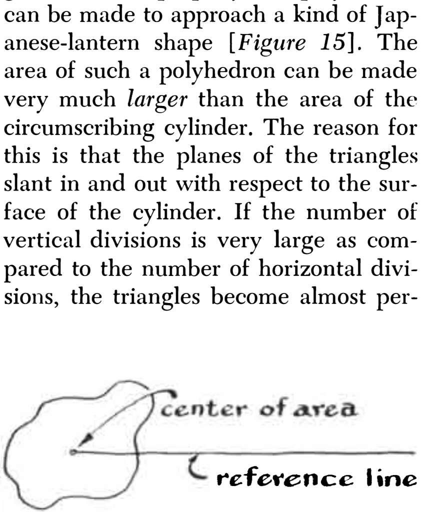
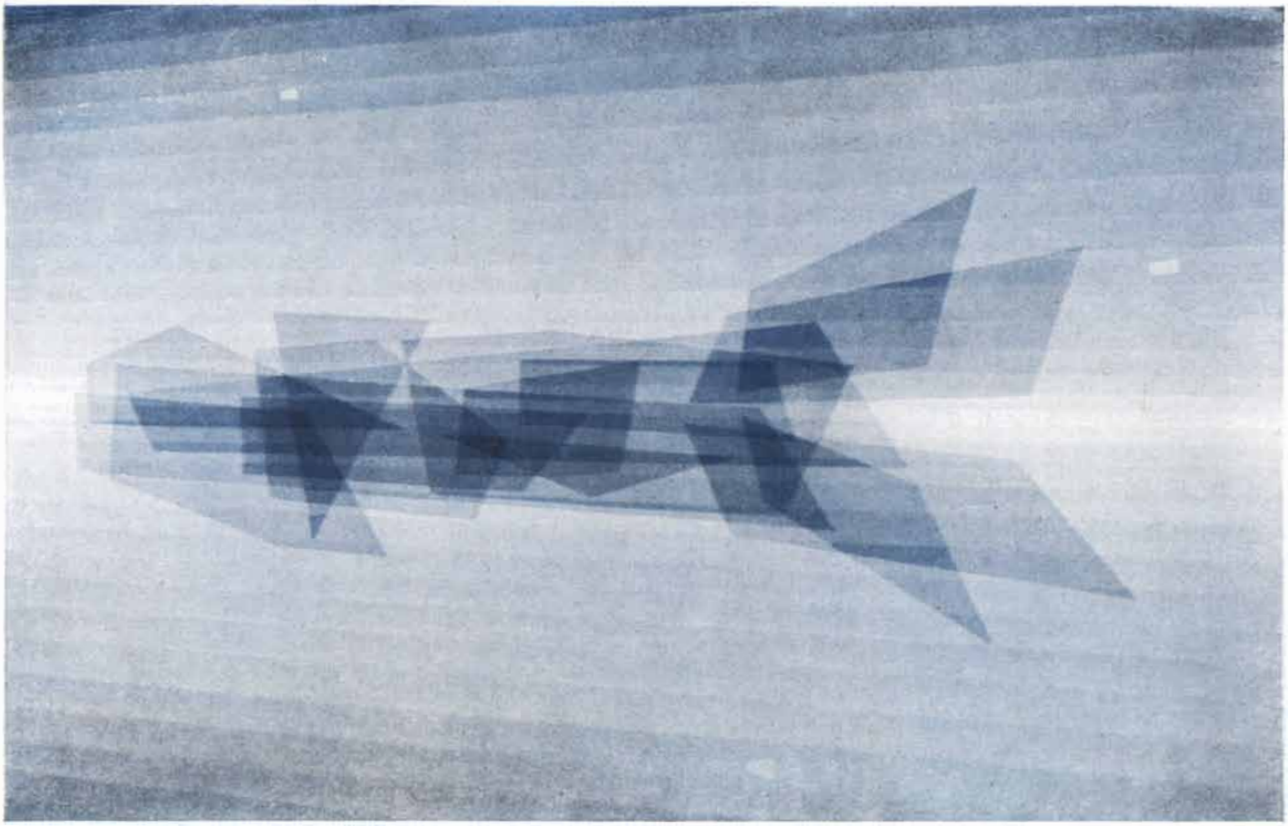


Figure 12



"ROCKETS", one of a series of paintings by Simpson-Middleman, a team of artists with the rare ability to translate scientific fact into creative imagery. Here, the rocket's blast and its guiding beam are thought of as a single stream of light through the center. Darks and lights of definite shape in a weak visual vector field are relied on to suggest the dynamics caused by the acts of the servo-mechanisms in making their adjustments. Painting courtesy John Heller Gallery, Inc.

man in space

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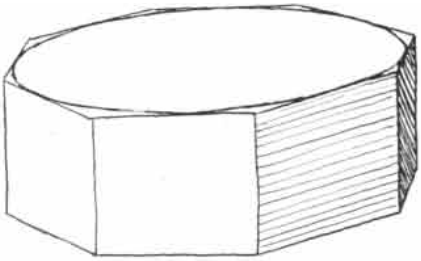


Figure 13

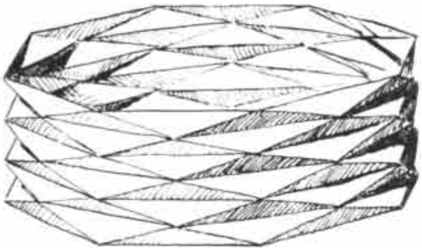


Figure 15

pendicular to the curved surface. Thus the area of these triangles bears no particular relation to the area of the cylinder.

Lewis J. Grant, Jr., secretary of the Chicago Rocket Society, calls attention to the fact that amateur science, like most other human activities, can be dangerous.

"I am glad," he writes, "that you helped popularize amateur rocketry in your issue of June, 1957. Moreover, I appreciate your warning to amateurs against experimenting with fuels other than the standard zinc dust and sulfur mixture. This mixture is by any standard the cheapest, safest and most effective propellant for small rockets. You also helped the cause of safety by pointing out the value of heavy earthen bunkers and of igniting rocket motors electrically from a distance. Despite your article, I still receive scores of inquiries from amateurs anxious to experiment with other fuels and other methods of firing. I reply with long letters full of dire warnings. I underscore the fact that in this hobby we are trying to build vehicles, not bombs. Amateurs are warned against tampering with gunpowder, nitrates, chlorates and so on. But sometimes I feel I am fighting an octopus. It is true that, of the thousands of test firings conducted by amateurs during the past 18 months, fewer than a dozen resulted in serious accidents. It is gratifying to learn from you that none have occurred in cases where your instructions were followed. Nonetheless, I should feel easier if you would devote a few paragraphs to the topic of safety.

"Only one other experiment described in your department thus far has made me feel uneasy. It appeared in the issue of July, 1956, and it described how to make an X-ray apparatus. There are plenty of readers of Scientific American who can build these little monster-makers but who have not reached the mental age at which they start worrying about side effects. For one thing, you might point out that lead aprons don't do much good if you turn your back to the machine, as I recently saw my doctor do. Some of your younger readers may be tempted to demonstrate their X-ray machine effects to their girl friends. This could mean a double ration of trouble. The whole U. S. is getting too much radiation today. Say a few words about homemade film badges and you may have another generation of readers. I am glad rockets are so much more popular now. At least the no-hands problem lasts only one generation.

"Don't censor ideas just because they are dangerous. This is a dangerous age. But please repeat your warnings. They may sink in the second time."

Grant's anxiety is well taken. Amateurs should not take chances when tinkering with potentially lethal apparatus. This admonition, incidentally, is not restricted to teenagers. The only person killed by an amateur rocket last year was a high-school science teacher. His device was fueled by gunpowder.

When the editor of this department was young, the hazards were posed not by rockets or X-rays but by the deadly wireless telegraph. A few impatient youngsters and careless oldsters tangled with the hot side of spark transmitters. But the vast majority took pains in learning to cope with nature, and among them are those who later built the electronics industry.

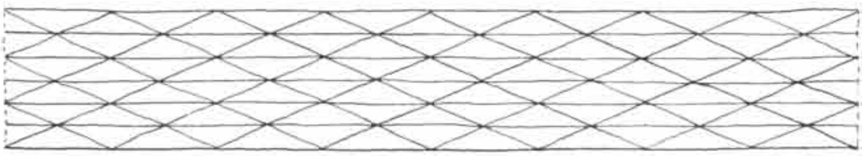
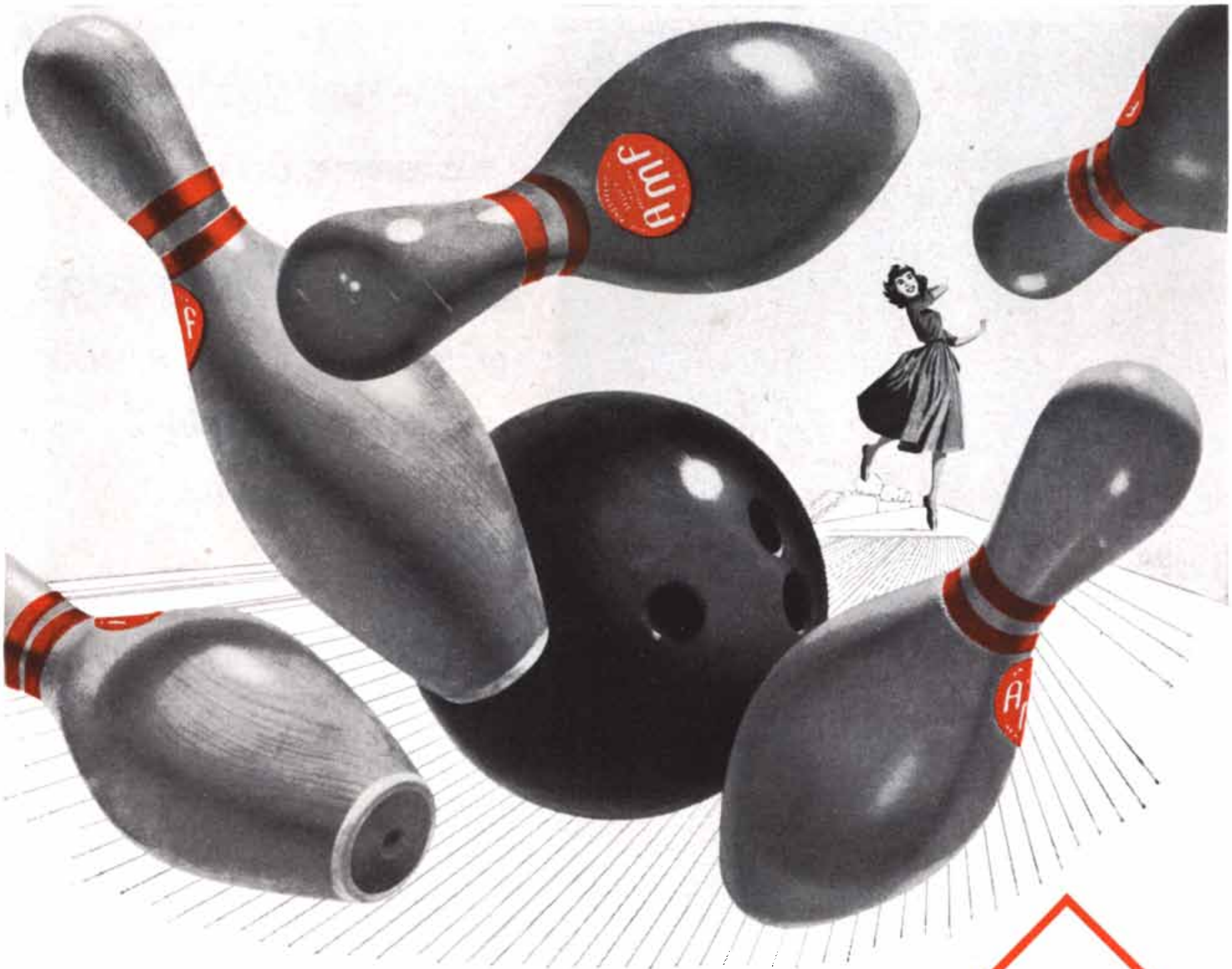
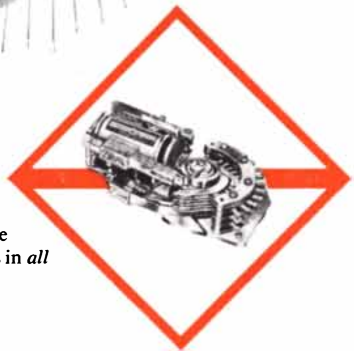


Figure 14



Pin boy in this alley: AMF Pinspotter



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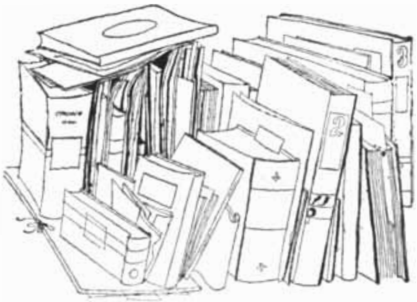

BOOKS

Charles Darwin in search of himself

by George Gaylord Simpson

The Autobiography of Charles Darwin, 1809-1882, with Original Omissions Restored, edited with appendix and notes by his granddaughter Nora Barlow. Wm. Collins Sons & Co. Ltd. (16 shillings).

There was one great outward adventure in Charles Darwin's life: the voyage of H.M.S. *Beagle*. From 1831 to 1836 that small surveying vessel circumnavigated the globe, enabling its young volunteer naturalist to observe and explore in South America, Australia and Africa, as well as on many islands of the Atlantic, Pacific and Indian oceans. The voyage is well documented, best of all in Darwin's *Journal*, of which two differing versions were soon published (1839, 1845). This is one of the great travel books of all time. It makes most recent books in that genre seem inane. A full narrative of the voyage was also published (1839) by Robert Fitzroy, in command of the *Beagle*, affording an enlightening contrast with Darwin's account. Much later one of Darwin's granddaughters, Nora Barlow, edited and annotated an edition (1933) of Darwin's original diary, on which his published *Journal* was based, and prepared a collection (1946) of letters and passages from Darwin's rough field notebooks written on the voyage.

Darwin's work on that voyage alone would have given him a permanent place in the history of science. Descriptions of his zoological and paleontological collections, prepared by others under his supervision, filled five large volumes (1839-1843). A general naturalist as a collector, Darwin then aspired to be a geologist as a research scientist. He had made two abortive starts toward professional training, one in medicine and the other in theology. His amateur knowledge of geology had been casually picked up by association with Professor Adam Sedgwick at the University of Cambridge and by study of Charles Lyell's great *Principles of Geology* during the voyage itself. Despite this scanty preparation, Darwin's three volumes of geological observations (1843-1846) are historical landmarks. Most striking was his theory of the formation of coral reefs, islands and atolls by the gradual lowering of land or rising of sea level. With slight modifications, that theory still stands, and it places Darwin among the great geologists.

It is, however, well known to every literate person that Darwin's towering position in the history of science—indeed, of mankind—is not derived directly from the voyage of the *Beagle* or from his geological studies. After the voyage, Darwin's life was about as barren of overt adventure as a life could be. While working on the *Beagle* reports, he settled temporarily in London from 1837 to 1842. During that period, in 1839, he married his cousin, Emma Wedgwood, granddaughter (as Darwin was grandson) of the originator of Wedgwood pottery. In 1842 Charles, Emma and their constantly increasing brood of children retired to a country house at Down. From then until his death 40 years later, Darwin rarely left Down and received few visitors except for the Darwin and Wedgwood families. Few monks have lived in greater seclusion from the world.

The retirement and seclusion were geographical and social, not intellectual or professional. Darwin's life at Down was in reality a period of high adventure such as he had never surpassed on the *Beagle* and such as few other men in history have equaled. The adventures ranged in space throughout the world and in time from the origin of the earth into our own future, but they occurred within the unbounded mind of a genius. The main results of these almost covert and no longer ostensible adventures appeared in a long series of volumes, from a monograph on the Cirripedia (barnacles) in 1851 to *The Formation of Vegetable Mould through the Action of Worms* in 1881. All are important but one is preeminent: *On the Origin of Species by Means of Natural Selection,* the first edition of which was published in 1859, and the sixth and last in 1872.

No other single human production has had so great an impact on science or on learning and thought in general as *The Origin of Species*. The reasons for that impact have often been stated, but a brief restatement may not be amiss. The reasons are two. First and most important, by the most painstaking marshaling of facts and inspired induction from them, in this book Darwin finally and definitively established the fact of organic evolution. Second, he proposed a theory (Darwinism, strictly speaking) as to how evolution has occurred. That theory, the heart of which was natural selection, made evolution plausible as a natural phenomenon (and incidentally a phenomenon congruent with concepts of the universe developed by physical scientists before and since Darwin). His theory was insufficient, as Darwin himself perceived, but most biologists still consider that it is essentially correct as far as it goes.

All that is significant in Darwin's works for the history and later development of science is set forth in full in his own publications. There is, however, a further, more personal, appeal in such a life. What sort of man was this who so revolutionized our view of nature and of ourselves? How did he progress toward his unexpected and remarkable achievements? Such questions are not answered by Darwin's scientific publications. Those are impersonal even beyond the scientist's usual avoidance of personal flavor. Moreover, they present final products with little mention of the mental processes by which they were reached. Darwin published few preliminary papers or progress reports. He waited until he felt that he had done everything humanly possible on a given subject, and then published the whole as a book. He worked 21 years on the origin of species before publishing a word about it. And then he felt that publication was premature, forced by the coincidence that Alfred Russel Wallace had independently reached some of the same conclusions.

Even Darwin's autobiographical book on the voyage of the *Beagle* is written with such reserve as to give inadequate clues to the development of his mind. His personality does shine through, but not the radical reorganization of his whole outlook that went on at that time. We know from later remarks that he was a rigidly orthodox believer in special creation when he left England and that he was already imbued with the idea of evolution when he returned. We know, too, that the turning point was in the Galápagos Islands. But this is not mentioned in the published *Journal of Researches . . . during the Voyage of H.M.S. Beagle*. Observing the high degree of endemicity (as biologists would now say) of the Galápagos species and their relationships to mainland forms, Darwin wrote: "Hence, both in space and time, we seem to be brought somewhat near to that great fact—that mystery of mysteries—the first appearance of new beings on this earth." In the light of much later events that remark is extremely significant, but in its own context it is not even a fair hint. And in summing up his observations of the Galápagos fauna Darwin still spoke in terms of "creative force."

In closer search of the man we naturally turn to the document known as his autobiography. This is hardly an autobiography in the usual sense, but a series of unpolished notes inspired by a request from "a German editor" and written because, Darwin says, "the attempt would amuse me, and might possibly interest my children or their children." The German editor, whoever he was, seems never to have received the notes. Most of the members of Darwin's family considered them strictly private. They were nevertheless published after Darwin's death and over the violent objections of several of the family, especially Henrietta Litchfield, one of Charles's daughters. Emma Darwin, Charles's widow, did acquiesce, but only after suggesting extensive deletions. The expurgated version was included by Charles's son Francis in *The Life and Letters of Charles Darwin* (1887). This book has several times been reprinted and has, of course, been taken into account by all of Darwin's many subsequent biographers.

Now at last, near the centenary of *The Origin of Species*, the full text of the autobiographical notes has been made public by Lady Barlow, one of Darwin's children's children whom he hoped to interest. One's first impulse is of course to turn to the passages deleted by his wife and children, which amount to about a sixth of the whole document. With quite unimportant exceptions, the deletions were of three sorts: intimate remarks about the family, critical or (at the time) tactless statements about others, and views on religion.

It is pleasing but not surprising to find that Charles wrote, but the family suppressed, statements of love and appreciation for Emma, his "greatest blessing," and for their children, who made him "most happy" and who never gave him "one minute's anxiety, except on the score of health."

It is more interesting and a little surprising to find how critical Darwin, so mild a man, could privately be of many friends and acquaintances. Even in the published journal and, still more, in the expurgated version of the autobiography, it was evident that Fitzroy and Darwin were not entirely congenial. The hitherto suppressed passages are almost brutally outspoken, specifying Fitzroy's "moroseness, . . . on one occasion bordering on insanity," calling him "utterly unreasonable," and adding to a statement that his character was "noble" the qualification that it was "tarnished by grave blemishes." Others fare no better. William Buckland (professor of mineralogy at Oxford) was "vulgar and coarse." Robert Brown (botanist, librarian to the Linnean Society) was "a complete miser." Richard Owen (the greatest 19th-century anatomist, outspoken critic of *The Origin of Species*) was "not only ambitious, very envious and arrogant, but untruthful and dishonest." (Here Darwin is quoting others, but with evident agreement.) Herbert Spencer was "extremely egotistical," and so it goes. Even Thomas Huxley, *fidus Achates*, although much appreciated by Darwin here in private as he was in public, is chided for scattering his talents and because "he attacked so many scientific men, although"—Darwin adds—"I believe he was right in each particular case." It is pleasant to note, however, that there is no hitherto suppressed criticism of many others whom Darwin might well have resented, notably Louis Agassiz, one of Darwin's bitterest scientific opponents, and Wallace, who unwittingly came so near to depriving Darwin of well-deserved priority for the theory of natural selection.

Even the expurgated autobiography made no secret of the considerable liberalization of Darwin's religious views. Before the voyage Darwin "did not . . . in the least doubt the strict and literal truth of every word in the Bible" and he persuaded himself that the creed of the Church of England "must be fully accepted." After the voyage (by about 1839) he "gradually came to disbelieve in Christianity as a divine revelation." Still later his belief in any sort of personal god was shaken, but he still felt "compelled to look to a First Cause" and considered himself a theist. There the previously published version of the autobiography left the matter. Emma Darwin was a Unitarian, liberal in religious matters although she firmly believed in revelation, prayer and salvation. She pleaded gently and touchingly with Charles (especially in two letters reproduced as a note in this new edition of the autobiography), but she did not object to the world's knowing him as a theist. She did persuade Francis to suppress much further discussion, in the course of which Charles called the Christian concept of salvation through faith "a damnable doctrine," argued cogently against all revealed religion, and roundly proclaimed himself at the end no theist but a thoroughgoing agnostic.

In one of the newly published passages Darwin proposes a naturalistic ethic which rests essentially on dealing with others so as to win their approbation and love, and hence to promote one's own happiness. He senses the contradiction in that his devoted labors were not calculated to win him the approbation of a majority of his fellow Victorians. Here he invokes as a further principle "the satisfaction of knowing that he has followed his innermost guide or conscience." This unfortunately leaves the problem unresolved. It is all very well for a Darwin to follow his "innermost guide," but we are not all Darwins. Some of us are Hitlers.

The unmutilated autobiography, as we now have it, takes us much nearer to the goal of knowing the man and understanding how his ideas developed—and yet it does not take us all the way. It gives the impression that Darwin himself was seeking that goal and that he did not reach it. When the sketch was written, Darwin was a great man, assured of one of the highest places in the history of science; of course he was well aware of that fact. Such unexpressed awareness of fame is not immodest. With true humility, Darwin was evidently trying in much of his autobiography to understand how he became so eminent. He did not find an answer really satisfactory to himself, or to present readers. His record in school was mediocre, and he was not inspired by brilliant companions. In another of the hitherto suppressed passages, he points out that none of his schoolmates "ever became in the least distinguished." The voyage of the *Beagle* reoriented his whole life and undoubtedly was crucial in his development, but many other highly able men (Fitzroy for one!) took such a voyage without becoming the "Newton of natural history," as Wallace justly styled Darwin.

Darwin also considers the argument that the subject of evolution "was in the air," "that men's minds were prepared for it." We may note that even if this was so, it would not explain why Darwin was the individual who plucked evolution out of the air or how he accomplished the feat. Darwin himself rejected the argument out of hand because, as he wrote, he "never happened to come across a single naturalist who seemed to doubt about the permanence of species," and he acknowledged no debt to his predecessors. These are extraordinary statements. They cannot be literally true, yet Darwin cannot be consciously lying, and he may therefore be judged unconsciously misleading, naive, forgetful, or all three. His own grandfather, Erasmus Darwin, whose work Charles knew very well, was a pioneer evolutionist. Darwin was also familiar with the work of Lamarck, and had certainly met at least a few naturalists who had flirted with the idea of evolution. He actually specifies one elsewhere in the autobiography: a Robert Edmund Grant, professor at the University of London. Of all this Darwin says that none of these forerunners had any effect on him. Then, in almost the next breath, he admits that hearing evolutionary views supported and praised rather early in life may have favored his upholding them later.

Lady Barlow has devoted an appendix to these contradictions, especially with respect to Charles's possible unacknowledged debt to his grandfather. In this excellent, brief (18 pages) essay she shows that the answer is really simple, and that it is significant for an understanding of Darwin's genius. To Darwin a hypothesis without adequate evidence was a mere "speculation." It had no value or any real status in science. Whatever it might be in the way of literature or philosophy, it was *nonexistent* as science. From this point of view it was not only fair but also necessary for Charles Darwin to ignore the "speculations" of Erasmus Darwin, of Lamarck, and indeed of all the pre-Darwinian speculative or philosophical evolutionists. That position can be accepted by hard-headed historians. To say that Erasmus Darwin or Buffon or Maupertuis anticipated Charles Darwin in the discovery of evolution is not much truer than the absurd claim that science-fiction writers invented the atomic bomb. On the other hand, data without a hypothesis are just as useless as a hypothesis without data. Darwin remarks elsewhere in the autobiography that "innumerable . . . facts were . . . in the minds of naturalists ready to take their proper place as soon as any theory which would receive them was [proposed]." Again that was not for Darwin an anticipation of his work, nor did it mean to him that the subject was in the air. The whole thing *started* when theory *and* data were brought together, and that is what Darwin did. Lady Barlow has neatly expressed this conclusion in a sentence that comes close to revelation of the elusive secret of Darwin's success: "The love of close observation of natural fact, and his need for a theory to explain everything he saw, form the closely woven tissue which constituted his genius."

That Charles Darwin himself became somewhat confused and contradictory in discussing his predecessors, especially Erasmus Darwin, suggests an emotional involvement. This seems to have been due, at least in part, to attacks on Charles, especially those by Samuel Butler, to which Lady Barlow devotes a long (53 pages) appendix in this edition of the autobiography. In a way, the Darwin-Butler controversy was like the Sherlock Holmes clue of the barking dog, the clue being that the dog did not bark. The mystery of this controversy is that it is not controversial, unless a controversy can be entirely one-sided.

In youth (he was 24 when *The Origin of Species* was published) Butler was an admirer of Darwin. He went out of his way to assure Darwin that *Erewhon*, Butler's utopian novel, was not meant to satirize Darwinism—in spite of the fact that it obviously does so. Although Butler disdained and disclaimed the scientific approach, he wrote four serious books (besides the satirical *Erewhon*) on the scientific topic of evolution. Like some later literary, as opposed to scientific, writers he felt increasing distaste for some aspects of natural selection, which he attacked with better rhetoric than logic. In his *Evolution, Old and New* (1879) his thesis was that Charles Darwin had derived his evolutionary views from Erasmus, and that where the two differed Erasmus was superior. Shortly thereafter a brief critical remark on Butler's book was inserted, at the last minute and without Darwin's knowledge, in a translation of a German article on Erasmus with a foreword by Charles. On grounds almost impossible to comprehend, Butler accused Darwin of bad faith in the matter, at first privately and then publicly and repeatedly throughout the rest of Darwin's life and even after his death.

Darwin's impulse was to reply publicly to this wholly unjust goading, but finally, after consultation with the family and with Huxley, he decided to ignore Butler. More than any possible reply, this silence infuriated Butler, who was deliberately trying to provoke a publicity-laden controversy with his more famous contemporary. The nature, virulence and continuity of Butler's attacks can be explained in no other way. The suppression of his normal reaction seems to have given Darwin considerable pain and to have increased his unnecessary insecurity concerning the intellectual origins of his views. As for Butler's status, it has been weighed well by Norman Douglas's *South Wind*, in a dialogue between Keith, the aging hedonist, and Denis, the romantic youth.

Keith says: "It was an age of giants—Darwin and the rest of them. Their facts were too much for [Butler]; they impinged on some obscure old prejudices of his. They drove him into a clever perversity of humor. . . ."

Denis asks: "Did he not prove that the Odyssey was written by a woman?"

To which Keith replies: "He did. Anything to escape from realities—that was his maxim. . . . He personifies the Revolt from Reason. . . . He understood the teachings of the giants. . . . But they irked him. To revenge himself he laid penny crackers under their pedestals. His whole intellectual fortune was spent in buying penny crackers. . . ."

In the privacy of his autobiographical essay Darwin put Butler's relationship to himself more succinctly: "Every Whale has its Louse."

The Darwin-Butler incident is insignificant in the whole sweep of Darwin's life, and Lady Barlow admits that her treatment of it "may appear overemphasized." Her book, however, is not in fact or intention a balanced treatment of Darwin's life but a compilation of materials for the really adequate biography that has never been but may yet be written. In this light, the inclusion of complete documentation on the Butler episode is fully justified.

A far more important and still mysterious aspect of Darwin's personal life is briefly treated by Lady Barlow in a note of four pages, consisting mostly of annotated references to discussions elsewhere. This subject is Darwin's ill health, beginning with the voyage and continuing to his death. The illness was never diagnosed and, as Darwin emphasized, it "annihilated" several years of his working life. However, he optimistically said that it saved him from "the distractions of society and amusement." Several later biographers have considered the invalidism as a blessing which enabled Darwin to work in undisturbed isolation. Some psychiatrists and psychoanalysts have considered the disease purely psychological. Although Lady Barlow cites these opinions with apparent agreement, this reviewer wants to enter a *caveat*.

As for the "blessing in disguise" theory, the illness *did not* permit Darwin to work undisturbed. Quite the contrary, it prevented him from working at all for months and years at a time. His character was such that he could and would have renounced time-wasting contacts and responsibilities, without needing illness as an excuse. From this point of view the disability really seems an unmitigated calamity. As for the psychoneurotic theory, this is an easy way out with any undiagnosed illness. But in Darwin's day many strictly organic diseases went undiagnosed. To mention only one, chronic brucellosis, unidentified but surely existent in Victorian times, is an infectious, long-continuing disease that frequently produces exactly Darwin's symptoms. Moreover, Darwin was undoubtedly exposed to this infection at about the time when his invalidism began, for he then visited areas where we now know that brucellosis has long been endemic. Any chronic illness has some neurotic involvements; doubtless it was so with Darwin, but surely we are not justified in concluding that his illness was primarily neurotic.

At the end of his search for himself in the autobiography Darwin sums up for the negative: "I have no great quickness of apprehension or wit. . . . I am . . . a poor critic. . . . My power to follow a long and purely abstract train of thought is very limited. . . . My memory is extensive, yet hazy. . . ." On rereading his brief for the affirmative, Darwin was evidently embarrassed and confused, for he inserted a long and completely irrelevant discussion of scientific hoaxes, as if to lay a false trail for the reader (who was, in fact, himself). Yet he does conclude with a statement of qualities that made for his success: "The love of science—unbounded patience in long reflecting over any subject—industry in observing and collecting facts—and a fair share of invention as well as of common sense." Still, his accomplishment remains for him "truly surprising." Darwin had no theory that would explain Darwin.

The mystery persists. The man is not really explained, his inner adventures are not fully revealed in his own autobiography, in the family biography by Francis Darwin, or in the many other biographical sketches and books. There will always be something hidden, as there is in every life, but a more complete and penetrating study of Darwin than any yet made is possible. When it is written, the author will be greatly indebted to Nora Barlow.

Short Reviews

Digging Up Jericho, by Kathleen M. Kenyon. Frederick A. Praeger ($5). Between the Sea of Galilee and the Dead Sea, in the trough of Jordan Valley, lies the site of the ancient city of Jericho. What gives life to the region, a vivid-green oasis surrounded by a flat, arid, dead-white plain, is a spring, Elisha's Fountain, which takes its source in an underground reservoir fed by rains up in the Judean hills. There is debate over whether Jericho is the oldest known settlement, but no one can deny that it is the lowest: 900 feet below sea level. The site of the ancient city today is a great oval mound, "a heap entombing dead towns," the Arabian name for which is *tell*. From the beginning of archaeological exploration in Palestine the Jericho *tell* attracted attention. The famous Old Testament story of the capture of the city by Israelites has conferred upon this historic place a unique and unending fascination. Modern excavations were begun in 1867 by a British party. This work was followed in 1908 by the diggings of an Austro-German expedition. Between 1930 and 1936 the site was explored by the archaeologist John Garstang of the University of Liverpool, and between 1952 and 1956 Miss Kenyon directed extensive excavations of different sections of the *tell*. In this engrossing and well-written book she recounts the discoveries of her group and attempts a reconstruction of life in the Neolithic community and its successors. Miss Kenyon's report is both scholarly and lively, scientifically objective and dramatic. She describes how the actual digging was done, the strenuous daily routine of the members of her party during the digging season, the vicissitudes, the haggling and bargaining with workers and local landlords, the sorting, classification and repair of the various finds, the anxious day when prizes are divided with the Jordanian Director of Antiquities (he, of course, has first choice), the harrowing task of packing and shipping objects (there is almost always breakage en route to museums). The first Jericho begins to tell its own story in deposits found at depths of about 70 feet. This was a Neolithic community which the author dates nine or ten thousand years ago. Massive defense walls were unearthed, along with a number of houses of excellent construction. Stone was used for foundations; brick set in thick layers of clay, for the walls. The floors are of clay; the majority have a surface of fine lime plaster, often colored red or cream and finished off "by burnishing to a high and beautiful polish." Storage vats, clay-lined bins, and drains were found in the houses. A great stone tower with an interior staircase, evidently part of the fortification, survives. Among other discoveries were exquisite polished-limestone dishes and bowls, various flint tools and weapons, miniature amulets, small figurines of possible religious significance and, most exciting of all, actual human skulls covered with plaster and skillfully "moulded in the form of features, with eyes inset with shells." There is reason to believe that the first Jericho was a sizable town, not a village, and that its people were both culturally and technically highly developed. Miss Kenyon carries the history of Jericho forward to its destruction by the Israelites, which occurred sometime between 1400 and 1260 B.C. The excavations furnish no information about the walls of Biblical Jericho nor why they fell down flat as described in the Book of Joshua. Perhaps, says Miss Kenyon, the cause was an earthquake, which the excavations have shown to have destroyed a number of the earlier walls, "but this is conjecture." The trumpet blasts and the shouting of the Children of Israel marching around the eight acres of the town might have terrified the inhabitants, but very likely had a less unsettling effect on the walls. On the other hand, the decline of the city after its greatness is fully in accord with Joshua's dread words: "Cursed be the man before the Lord, that riseth up and buildeth this city Jericho."

Observation and Interpretation, edited by S. Körner. Academic Press Inc. ($8). This volume presents a symposium of philosophers and physicists held in the University of Bristol in April, 1957. The contents, consisting of the papers read and tape-recordings of the discussions following them, are concerned for the most part with questions belonging to the philosophy of quantum mechanics. Scientific meetings rarely make a lively record, but this is an exception. The discussions especially are full of interest, and reveal a growing restiveness among physicists over the foundations of their subject. One of the highlights was the second session, at which David Bohm gave his proposed explanation of quantum theory in terms of hidden variables at a subquantum-mechanical level, and L. Rosenfeld attacked Bohm's position in a paper with the title "Misunderstandings about the Foundations of Quantum Theory." Bohm's views are substantially those set forth more fully in his book *Causality and Chance in Modern Physics*, reviewed here in January. Rosenfeld sticks to the orthodoxies of the so-called Copenhagen School. The tone of his argument is not without revivalist fervor, and he implies—as demonstrated again this year in his review of Bohm's book in *Nature*—that any physicist who challenges Niels Bohr's opinions is a fool, if not worse. Despite the vehemence of the assault, Bohm stood his ground; it is worth remarking that several of the participants joined with him, not perhaps so much because they accept his theory as because they enjoy poking at the established theology. Another incisive paper of the symposium is P. K. Feyerabend's "On the Quantum Theory of Measurement." This examines the inadequacies of the interpretations of Bohr, Werner Heisenberg and John von Neumann. In classical physics all processes which happen during measurement can be analyzed on the basis of the equations of motion only. This means that physical theory is simply a refined description of ordinary experience. But, says Feyerabend, when we enter quantum mechanics "we are apparently presented with a completely different picture"; for according to current opinion ordinary experience (and this now means classical physics) and physical theory (and this now means quantum mechanics) belong to completely different levels, and "it is impossible to give an account of the first in terms of the second." The quantum theory of measurement, in its most sophisticated form, requires, apart from the equations of motion, such "independent and unanalyzable processes as 'quantum jumps,' 'reduction of the wave-packet' and the like." Feyerabend regards these unanalyzable processes as confusing and unnecessary; he attempts to show that it is possible to give an account of measurement, adequate to the needs of modern

physics, which involves nothing beyond the equations of motion and "statements about the special properties of the systems involved." This symposium shows how hard it is to formulate the basic concepts of physics in clear, unambiguous terms, which is one of the reasons no two practitioners coincide in their statements about the foundations of the subject, even when they claim to agree. Another point which will strike the reader is that it is time philosophers and physicists got together to reduce some of the verbal swelling that afflicts physics today. One can, to be sure, squeeze the life out of a subject by too much formalism and linguistic analysis, but a little judicious squeezing of physics may be the thing to relieve its dropsy.

Birds of New Guinea, by Tom Iredale. Georgian House ($60). These two handsome volumes, a treat to the eye in all respects, form the best available general guide to the marvelously rich bird life of New Guinea. The text of Iredale's guide describes some 650 species and lists 1,500 subspecies. The illustrations, drawn by Lilian Medland, consist of 35 fine plates showing 347 birds in color. Information is given in some detail about the birds' appearance and habitat; nesting and other habits are treated more briefly, and, in some cases, omitted entirely. Among the birds discussed are the huge helmeted cassowary, which cannot fly; the frigate bird, which gets its food by bullying a weaker bird, forcing it to drop the fish it has caught (the frigate bird swoops down and snatches the fish before it reaches the water); the phalarope, the male of which species does all the work, even to the stay-at-home job of sitting on the eggs; the mound builder, which erects enormous heaps of decaying vegetation—sometimes 30 feet long and six feet high—in which the bird deposits its eggs for incubation; 27 species of birds of paradise, including the Magnificent Riflebird (with black metallic sheen), the Most Splendid Long Tail, Rothschild's Long Tail and Mrs. Reichenow's Bird of Paradise; the exquisite group known as the Little King and his friends, which includes the Lonely Little King (at first named *goodfellowi*), the Exquisite Little King and the Bare-Headed Little King. Put out by an Australian publisher, these volumes are available in the U. S. through the Import Book Company of Portland, Ore.

Introduction to the Theory of Sets, by Joseph Breuer. Prentice-Hall, Inc. ($4.25). An Introduction to the Foundations and Fundamental Concepts of Mathematics, by Howard Eves and Carroll V. Newsom. Rinehart & Company, Inc. ($6.75). Until a few years ago set theory and the foundations of mathematics were regarded as subjects suitable only for graduate students of mathematics. The minds of undergraduates were supposed too tender for such exertions. The new look in mathematical education rests on a different notion. Almost anyone, it is argued, can learn almost anything if it is well taught. The argument, and its implications, are unacceptable to many educators, but there can be no doubt that improvements and modifications in mathematics teaching are badly needed, and that high-school and college students are capable of digesting a good deal more than was once thought possible. Here are two books which skillfully introduce esoteric subjects to undergraduates. Breuer's text, translated from the German by Howard Fehr, fills a gap: there is no other English book on set theory designed for beginners. The approach is intuitive, based on concrete and familiar ideas; abstract theory based on an axiomatic system is not treated. The topics include finite, infinite and ordered sets, and point sets; there is a brief chapter, too sketchy to do more than tease the imagination—which is not a bad thing—on the paradoxes of set theory. Eves and Newsom cast a much wider net. Their purpose is to give a primarily historical account of the growth of ideas on the foundations of mathematics and the concepts basic to mathematical knowledge. Beginning with pre-Hellenistic mathematics, the authors survey the advance in method of Euclid's *Elements*, the rise of non-Euclidean geometry, the contribution of David Hilbert's *Grundlagen der Geometrie,* the concept of algebraic structure, the evolution of the modern postulational method, the real-number system, set theory, Boolean algebra, symbolic logic, the modern crises in the foundation of mathematics, various philosophies of mathematics. A good bibliography adds to the value of this attractive book. Both texts, it should be noted, will appeal to teachers and general readers as well as students.

Swifts in a Tower, by David Lack. Methuen and Co. Ltd. (21 shillings). No one writes more knowledgeably about birds than the British ornithologist David Lack. His *The Life of the Robin* is a classic of bird literature, and his other monographs, on Darwin's finches for example, are of high interest to the everyday reader and specialist alike. This study deals with a remarkable but little-known bird which is "preeminent in flight" and spends more of its life in the air than any other bird. There are some 70 species of swift in the world, nearly all looking alike, with slender wings, short legs, small bill, large mouth, and usually sooty color. The swift is known for its shrill scream and its high-speed flight. It is a small-bodied bird, about four inches from the tip of its beak to the base of its tail, and it weighs only about 1½ ounces; yet it has a wingspread of some 16 inches, which makes it an incomparable little flying machine. It is able to take its food and nesting material in the air, "to drink and to bathe without alighting, to mate in the air and to spend the night on the wing." It nests under eaves or in holes, usually high up, so that few have seen it under these conditions. The present account is based on a long study of a colony of swifts in the tower of Oxford Museum of Science, the very building in which Bishop Wilberforce had his ears pinned by T. H. Huxley in a memorable debate on the question of man's descent from the ape. Behind the ventilator holes in which the swifts nested, Lack and his party built ingenious glass-backed nesting boxes, in which the birds could be watched from only a few inches away. Ten years were spent in these observations, and we are now given the delightful fruits of these labors. Various chapters describe how the swifts build and fight for homes, their courtship, egg-laying and incubation, their feeding habits, flight and migration. There are excellent discussions of swifts at night, of their winter sleep, their death and its causes, the meaning of adaptation. Lack gave a briefer account of his work on the swifts in this magazine some time ago, and it is gratifying now to have the full story told in this lovely book.

Town-Building in History, by Frederick R. Hiorns. Criterion Books ($15). The author, a leading British architect, describes his book as an attempt to set out historically "the broad circumstances, causes, and methods by which towns came into being, were re-formed, or subjected to abuse" within a space of some 5,000 years. City-building is an ancient art. In its evolution since antiquity it showed a remarkable consistency and steady progress, "to be broken only when civilized control lapsed with the [post-18th-century] Machine Age." The overcrowding, confusion, decay, crudeness, ugliness and other evils of many modern cities degrade life, not only within their boundaries but also in adjacent

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CONVAIR IS A DIVISION OF GENERAL DYNAMICS CORPORATION areas. By studying the conditions, influences, ideas and methods which affected planned towns in the past, Hiorns believes that much can be learned toward the town-planning of the future. Fresh thought is needed and a re-evaluation of urban requirements in light of modern circumstances. Lewis Mumford describes this volume as "unique in the literature of cities, the only book in English that covers the whole field." Copiously illustrated.

GEORGIA BIRDS, by Thomas D. Burleigh. University of Oklahoma Press ($12.50). Georgia's relatively mild climate, varied physiography and lush vegetation combine to provide an ideal setting for many species of bird. Some 160 different species nest in the state and 300 others winter there or pass through. This well-designed book of 750 pages, generously stocked with photographs and with reproductions of original watercolor paintings by the well-known bird artist and ornithologist George Miksch Sutton, presents all that is known directly about the bird life of Georgia. A brief history of ornithology in Georgia by William W. Griffin, and a survey of the physiographic regions—beaches, swamps, forested highlands, valleys, piedmont plateau—by Robert A. Norris, are followed by a systematic description of each species and information on distribution, occurrence records, habits and recognition. The book has an excellent bibliography.

OEUVRES DE LAVOISIER: CORRESPONDANCE, Vol. II, edited by René Fric. Editions Albin Michel (2,750 francs). The second fascicule of the correspondence of Lavoisier, now being published by the Academy of Sciences of Paris as a supplement to the 19th-century edition of his writings, covers the years 1770 to 1775. As in the first volume, the letters and other documents exhibit the variety of Lavoisier's interests and activities. These include a continuation of his work in detecting the adulteration of tobacco; preparation of a mineralogical atlas of France; research on the problems of combustion; studies in astronomy, meteorology and optics; administrative labors. A photograph appears in this volume of Lavoisier's famous secret memorandum deposited with the secretary of the Academy, intending to establish Lavoisier's priority in discovering that sulfur and phosphorus become heavier when burned in combination with air; this contradicted the accepted belief that combustion involves a loss in weight. The editor has added many biographical notes about Lavoisier's scientific contemporaries.

MILTON AND SCIENCE, by Kester Svendsen. Harvard University Press ($5.50). *Paradise Lost* is not ordinarily thought of as a scientific treatise, yet, as this book shows, the great epic drew heavily upon the scientific knowledge of the 17th century. John Milton had read extensively in medieval and Renaissance encyclopedias of science; he was well acquainted with their content and that of other scientific books. His prose as well as his poetry abounds in scientific images. Astronomy, natural history, psychology and physiology were among the branches of learning which informed his art. The author has made an intensive examination of Milton's use of scientific sources; his essay will interest a variety of students.

ARCHAEOLOGICAL DISCOVERIES IN SOUTH ARABIA, by Richard LeBaron Bowen, Jr., Frank P. Albright *et al.* The Johns Hopkins Press ($10). Between 1950 and 1953 four archaeological expeditions were mounted to South Arabia, sponsored by the American Foundation for the Study of Man, and under the successive archaeological direction of W. F. and F. P. Albright. This volume, the first of a series reporting the material found, deals with sites in the Wadi Beihân (western Aden Protectorate) and at Marib (Yemen). Among the topics discussed are the wells, canals, cisterns, tanks, springs and other parts of the ancient irrigation system in Wadi Beihân, of the utmost importance to agriculture; ancient trade routes; burial monuments; bronze statues of infant riders mounted on lions, found at Timna'; excavations of walls, houses, mausoleums, temples; inscriptions related to the house called Yafash unearthed at Timna'; pottery and glass. Many maps, plans and photographs.

Notes

EFFECTS OF RADIATION ON MATERIALS, edited by J. J. Harwood, H. H. Hausner, J. G. Morse and W. G. Rauch. Reinhold Publishing Corp. ($10.50). Papers delivered at a Johns Hopkins University colloquium dealing with the changes that radiation produces in metals, ceramics, plastics and a wide variety of other materials.

BIOPHYSICAL CHEMISTRY, VOL. I, by John T. Edsall and Jeffries Wyman. Academic Press, Inc. ($14). This first volume of what promises to be a comprehensive and clearly written treatise covers thermodynamics, electrostatics and the biological significance of the properties of matter.

SELECTED WRITINGS OF JOHN HUGHLINGS JACKSON, edited by James Taylor. Basic Books, Inc. ($15). A two-volume selection of the writings of a 19th-century pioneer of neurology, known for his researches into the nature of epilepsy, chorea and hemiplegia.

FUNDAMENTALS OF GAS DYNAMICS, edited by Howard W. Emmons. Princeton University Press ($20). This volume in the High Speed Aerodynamics and Jet Propulsion series presents those aspects of the behavior and properties of gases in motion of most interest to aeronautical scientists.

A SHORT HISTORY OF ANATOMY AND PHYSIOLOGY FROM THE GREEKS TO HARVEY, by Charles Singer. Dover Publications, Inc. ($1.75). A corrected paperback edition of Singer's brief, scholarly monograph, originally published under the title *The Evolution of Anatomy*, and for many years out of print. Attractive, interesting, splendidly illustrated.

BRITISH BATTLESHIPS, by Oscar Parkes. Seeley Service and Co., Ltd. (six guineas). An exhaustively detailed history of British battleships from 1860 to 1950, describing design, construction and armament, the personalities of sea lords, builders, and politicians involved in naval affairs, the history of each ship in peace and war, "the behavior of the ships in battle and in heavy weather."

THE SCIENTIFIC PAPERS OF SIR GEOFFREY INGRAM TAYLOR, VOL. I: MECHANICS OF SOLIDS, edited by G. K. Batchelor. Cambridge University Press ($14.50). The first volume of the scientific papers of a pioneer investigator of the mechanics of solids and fluids. Subsequent volumes will contain papers on meteorology, oceanography and turbulent motion of fluids; high-speed flow and mechanics of explosions; and miscellaneous topics in fluid dynamics.

THE ORIGINS OF CULTURE, by Edward Burnett Tylor. Harper and Brothers ($3.50). A two-volume paperback reissue of a famous work first published in 1871, which was the first to achieve "a coherent and compelling monument of the cultural approach to primitive society," and which had a decisive influence on the course of anthropology.

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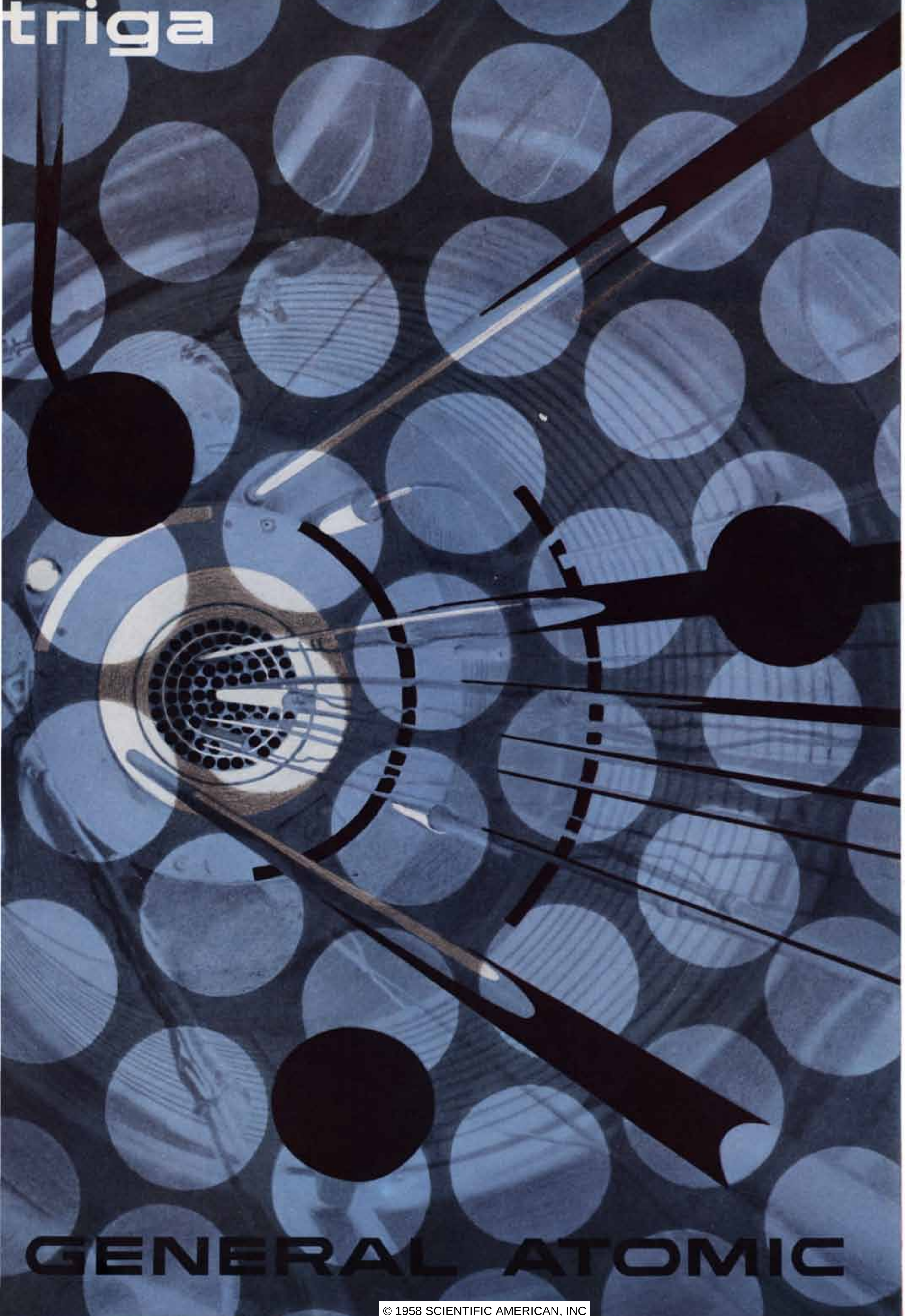
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