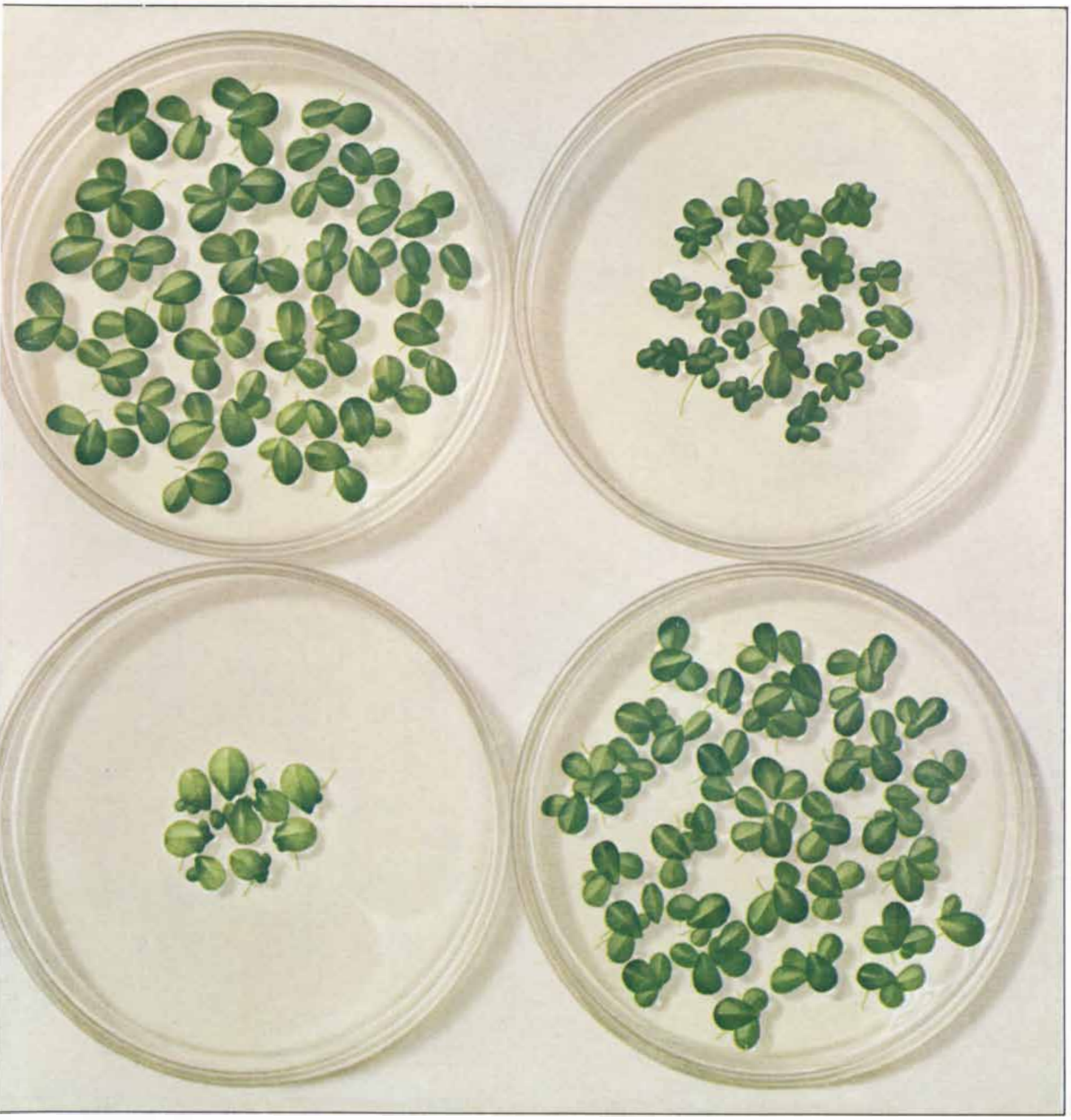
SCIENTIFIC AMERICAN



PLANT HORMONE EXPERIMENT

SEVENTY-FIVE CENTS

July 1968

Sometimes a fabrics man needs a bank that's willing to change the pattern.

The business world, like the rest of the world, is a jet-paced world these days.

Today is rarely like yesterday.

The ground rules change, sometimes dramatically.

And sometimes overnight.

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Because we know it won't be the same as it was last year. Or even last week.

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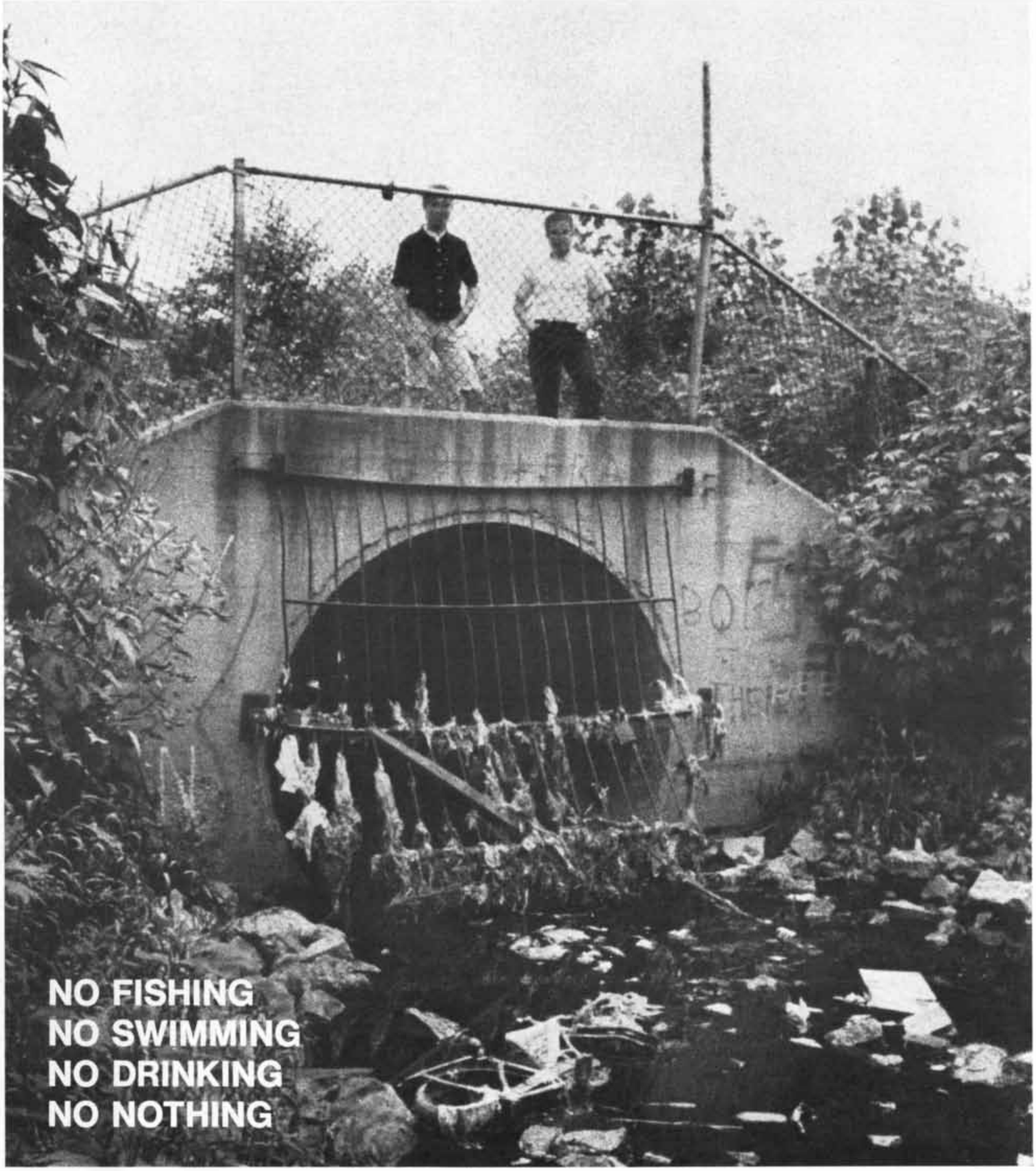

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ARTICLES

DEPARTMENTS

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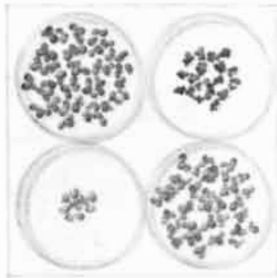

THE COVER

The painting on the cover shows the effect of minute changes in the hormone dosage on the growth of four nine-day-old cultures of duckweed, a small free-floating aquatic plant that normally multiplies by budding. All four specimens were grown on sterile nutrient solutions in Petri dishes. Originally each dish contained three little plantlets and its contents weighed nine milligrams. The contents of the dish at top left were untreated; after nine days they weighed 130 milligrams. The contents of the dish at top right were treated with .1 part per million of dormin, a natural growth-inhibiting hormone; after nine days they weighed 40 milligrams. The contents of the dish at bottom left were treated with one part per million of dormin; after nine days they weighed 20 milligrams. The contents of the dish at bottom right were treated with .1 part per million of dormin plus .1 part per million of benzyladenine, an artificial growth-promoting substance; after nine days their weight and appearance were normal. Such experiments suggest that in nature too plant growth is controlled by a balance between promotive and inhibitory hormones (see "The Control of Plant Growth," page 75).

THE ILLUSTRATIONS

Cover painting by Thomas Prentiss

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RECENT FINDINGS

RESEARCH LABORATORIES

Ford

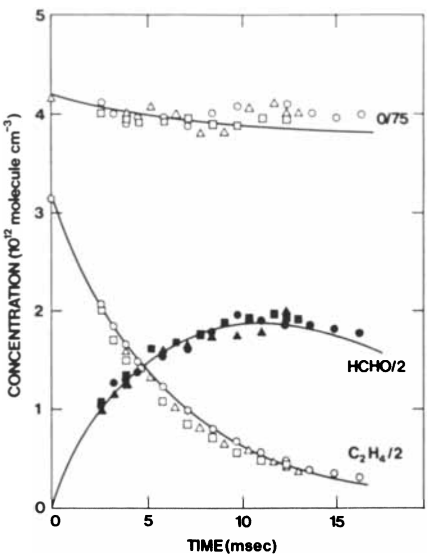
The Discharge-Flow Technique Applied to the Dynamics of Atom-Molecule and Atom-Radical Reactions

A variety of important gas phase reactions such as combustion and atmospheric photochemistry proceed by complex reaction sequences involving atoms and free radicals. Knowledge of the chemical behavior of these highly reactive species is rather incomplete and is generally deduced from an analysis of the relation between the composition of the initial reactants and the final reaction products.

The discharge-flow technique is being successfully applied by Ford scientists to study directly the dynamics of atom-molecule and atom-radical reactions that are of importance in these systems. In this method, atom species (such as hydrogen or oxygen atoms) are produced in a microwave discharge and flow through a tube where they are mixed with a stream of reactant introduced through a multi-holed inlet. This reaction mixture is sampled downstream through a pinhole into a time-of-flight mass spectrometer which provides a simultaneous measurement of concentrations for a variety of species. Since the flow pattern is linear, the distance between the point of mixing and the mass spectrometer pinhole divided by the flow velocity gives the reaction time. Typically, a one centimeter reaction distance corresponds to one millisecond reaction time. The point of mixing can be varied continuously so that a detailed profile of concentration versus reaction time is obtained. An important advance that has been made in these studies is an improved sampling and measuring technique for mixtures of atoms, radicals and molecules.

One system recently studied is the reaction between ethylene, C_2H_4, and atomic oxygen. A typical plot of the kinetic behavior for ethylene, atomic oxygen, and formaldehyde, HCHO, in this system is shown in the figure. Similar reaction profiles were also simultaneously obtained for other reaction products such as atomic and molecular hydrogen and carbon dioxide.

An important new discovery in this research is the demonstration that formaldehyde is a major intermediate species in this system. From an analysis of these data, it has been shown that formaldehyde is formed from the reaction of atomic oxygen with the methyl radical, CH_3, (the methyl radical being formed in the primary reaction $O + C_2H_4$). This reaction, $O + CH_3$, is of fundamental importance to the understanding of the high temperature oxidation of hydrocarbons, but it has evaded explanation. Of the five different mechanisms that have been proposed for this reaction during the past few years, the one yielding formaldehyde and a hydrogen atom is clearly delineated.

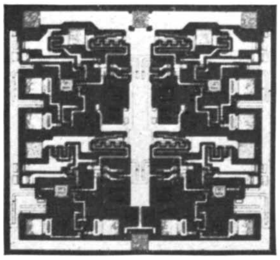


Production of formaldehyde (HCHO) as an intermediate step in the reaction of atomic oxygen and ethylene.

Studies of this type are also important to understanding the formation of photochemical smog. Hopefully, a clearer insight into the mechanism of smog formation may indicate a solution to this problem.

PROBING DEEPER FOR BETTER IDEAS

Ford



Today one company is being called the "production house of the industry" by engineers who specify integrated circuits.

LETTERS

Sirs:

In Victor F. Weisskopf's brilliant article "The Three Spectroscopies" in the May *Scientific American,* I note the presence of the recently popular term "quark" as the name of a hypothetical entity postulated to explain certain facts in the behavior of excited particles. The story current about the origin of the term "quark" has a number of interesting quirks.

The term is said to have originated with the phrase in James Joyce's *Finnegans Wake:* "Three quarks for Muster Mark!" (page 383 of the Viking Press edition). The reason for the deformation of "cheers" into "quarks" is that the line is the first verse of a derisive song sung by gulls as they wheel about the ship of Tristan and Isolde. "Muster Mark" is poor old King Mark, the archetypal *senex amans* and natural cuckold, who is, as the gulls sing, an "old buzzard whooping about for uns shirt in the dark" and also looking for "uns speckled trousers" while the young lovers have fled to sea. At this point in the book the younger generation has taken over lovemaking and creative activity from the old; as Joyce says, "All the birds of the sea they trolled out rightbold when they smacked the big kuss of Trustan with Usolde."

By the oddest chance in the world, the word "quark" turns out to be an allusive reference to one of the secrets of the universe! In Goethe's *Faust* Mephistopheles satirically describes the creation and sustention of the universe by God; he ends his description by marveling how God controls all the movements of the physical universe no matter how material or messy; he says, "He [God] sticks his nose into every mess" ("In jeden Quark begräbt er seine Nase"). "Quark" is a German slang term for a complicated messy business, given a scientific slant by Mephistopheles, and thus ultimately describing just such a subtly complicated mess as Professor Weisskopf elucidates so carefully.

Joyce read Goethe carefully, although not always approvingly; there is an excellent chance that Joyce borrowed "quark" from Goethe. That there are *three* quarks is Joyce's addition, however. Joyce always believed in the value of coincidence, and in his own powers as a prophet. (On page 353 of the *Wake,* published in 1939, he reproduces the sound and effect of a nuclear explosion, the result of the "abnihilisation of the etym.") I think it is interesting to see Goethe's bird coming home to roost 150 years after *Faust* and 30 years after the composition of *Finnegans Wake.*

EDMUND L. EPSTEIN

Carbondale, Ill.

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Sirs:

On first reading "The Sexual Life of a Mosquito," by Jack Colvard Jones [SCIENTIFIC AMERICAN, April], my impression was that the statement "the entire copulatory act takes from 14 to 20 seconds" implied a commendably efficient performance.

More careful reading reveals no such implication. The author is undoubtedly aware of the "scaling laws" as they apply to a wide variety of mechanisms and functions. As an example of these laws, similar machines may be defined as having dimensions proportional to some characteristic dimension, and as being made of materials with the same properties. In other words, the machines are scale models of one another.

If, then, they are operated at the same characteristic velocity (tip speed, piston speed, etc.), they will have much the same performance. That is, the pressure stresses and vibration stresses will be the same; internal fluid velocities, volumetric efficiencies, etc., will be nearly coincident. D'Arcy Thompson, in his beautifully written book *On Growth and Form,* discusses the application of these principles in the animal kingdom.

The relationship pertinent to this discussion is that the time required for a defined function (one revolution of the impeller, or one cycle of the four-stroke internal-combustion engine, or such) is directly proportional to the linear size of similar mechanisms. Thus by measuring the drawing on page 110 the male mosquito seems to be about $1.75 \times 1/10$, or .175 inch long. Now, suppose this insect were 72 inches in "characteristic dimension." The scale factor would be 72/.175, or about 400.

Under these "natural circumstances" the copulatory act should take 400 times longer than the 14 to 20 seconds mentioned above. That corresponds to a time range of about 1½ to 2¼ hours! From my limited knowledge it would seem that the mosquito is a pretty slow worker, whether timed from the crossing of the bar or the pulling of the sheets.

C. E. HOLVENSTOT

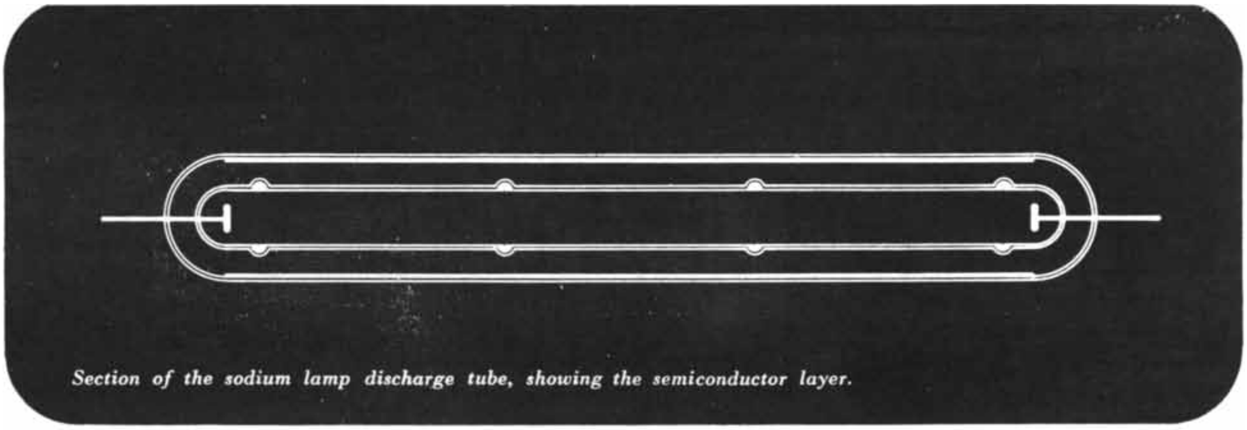
Flanders, N.J.

P.S. Further scaling of such statements as that the male mosquito satisfies five or six females, and fools another 24 or 25 within a 30-minute period (page 113), may be of interest. For a six-footer the comparable time would be 200 hours, or about 8½ days.

C. E. H.

Sirs:

In reply to C. E. Holvenstot's interesting letter, one must compare the sexual prowess of the adult *Aedes aegypti* male mosquito with that of his peers in the world of real mosquitoes, and not to some imaginary 72-inch monster, in order to determine with fairness whether he is a "pretty slow worker." When the *aegypti* male is compared with *Deinocerites cancer* males, which copulate for up to two hours, and usually for 40 to 50 minutes (Provost and Haeger, 1967), or with *Opifex fuscus* males, which copulate for 10 to 20 minutes (Haeger and Provost, 1965), or with *Culiseta inornata* males (shortest copulation time measured by Rees and Onishi, in 1951, was three hours and 27 minutes; longest time was six hours and 40 minutes), then *aegypti* males seem like pretty fast workers. On the other hand, many other species of *Aedes,* as well as *Culex* and *Pso-*



Section of the sodium lamp discharge tube, showing the semiconductor layer.

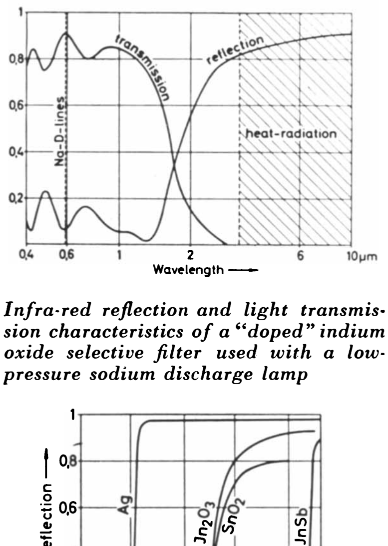
Semiconductors cast new light on an old problem

The ordinary electric lamp still gives only a poor performance in term of its energy conversion efficiency. As every physics student knows, the ordinary gas filled tungsten filament lamp only converts about 3% of its electrical energy consumption into visible light, the remainder mainly being dissipated as infra-red radiation. Even the low pressure sodium lamp only achieves something like 21% efficiency, which compares very badly with, say, the common electric motor's 90 to 95%. Many attempts have been made over the years to improve lamp efficiency, at first with improved tungsten emitter materials and more recently with a variety of reflective or absorbent radiation filters. Calculations show that if a low pressure sodium lamp, for example, could be provided with a selective radiation filter which reflected nearly all the infra-red radiation back to the source, while remaining nearly transparent to yellow sodium light, the electrical energy consumption could be almost reduced to half of its value for constant light output.

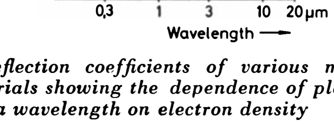
Unfortunately, selective radiation layers based on thin metal films do absorb part of the visible light. Therefore, when two Philips scientists (Drs. Groth and Kauer of Philips Zentrallaboratorium GmbH, Aachen, Germany) re-examined the problem of sodium lamp efficiency some years ago, they decided to investigate the properties of the new semiconductor materials for this purpose.

It is well known that the high infra-red reflection of metal films is related to their good electrical conductivity. Electron density in a normal metal is, however, so high that the plasma wavelength - which separates the region of transmission from that of high reflection - lies in the near ultraviolet. For the sodium lamp, the plasma wavelength should be at 1 to 2 μm, to separate the sodium lines from the heat radiation of the lamp. The Philips workers calculated that this state could be achieved with a free electron density in the order of 10^{20} cm^{-3}.

Although ordinary germanium and silicon semiconductor materials can be made to exhibit concentrations up to 10^{19} cm^{-3}, their corresponding plasma wavelength is still too long - about 10 μm. Further experiments revealed however, that suitably "doped" tin and indium oxide films can have a free electron concentration up to 6.10^{20}cm^{-3} and could therefore, at least in theory, have the desired selective filter characteristics.



Infra-red reflection and light transmission characteristics of a "doped" indium oxide selective filter used with a low-pressure sodium discharge lamp



Reflection coefficients of various materials showing the dependence of plasma wavelength on electron density

Experimental work proceeded with layers of tin and indium oxide deposited on the inner surface of the sodium lamp glass envelope. The film structure had to be carefully chosen so that electron "relaxation time" is as long as possible, giving maximum infra-red reflection properties.

Tests at Philips laboratories on a normal 200 W discharge lamp show an increase in light output from 110 lumens/W to 175 lm/W, using an indium oxide layer 0.3 μm thick, chosen so as to have maximum transmission in interference for the sodium D-lines. Such a layer has an infra-red reflection coefficient of 90%, while transmitting 91% of the sodium light (compared with 92% for the uncoated glass envelope). Overall efficiency of the sodium lamp was increased from 21% to approximately 33% - the highest efficiency ever recorded for a light source.

The selective radiation layer principle means far more than just better sodium discharge lamps. Doped tin- and indium-oxide layers could be produced by modern methods at a reasonable cost for all kinds of applications. Consider, for example, the possibilities of window glass, coated to reflect infra-red or heat radiation, yet still transmitting visible light with negligible losses.

Philips scientists believe that certain advanced semiconductor materials may prove as useful in future for their optical properties as for their electrical properties, proving once again the value of combining experience in such apparently un-connected fields of scientific research.

rophora, mosquitoes are also very rapid copulators (Lum, 1961).

I should like to point out to Holvenstot that there is an Indian antelope (the "nilgai") that is said by Hediger (1965) to copulate in "a fraction of a second," and that another antelope is reported as copulating in two to four seconds. Also according to Hediger, big whales and dolphins have been observed to copulate for five to 20 seconds. Holvenstot should use his calculations on these large animals, after the appropriate miniaturization (say down to the size of an *aegypti* male, whose length is only five millimeters) and see what figures he comes up with. Without any miniaturization the male *aegypti* mosquito seems to be as fast as a whale.

JACK COLVARD JONES

University of Maryland
College Park, Md.

Sirs:

For many years the British patent office, unlike the American one, regularly granted patents on perpetual motion devices. I recall seeing one, issued late in the 19th century or early in the 20th, that disclosed essentially the Fludd system ["Perpetual Motion Machines," by Stanley W. Angrist; SCIENTIFIC AMERICAN, January]. But that inventor was cagey. He had added a Prony brake to the waterwheel to make sure it didn't "run away"!

ROBERT KEITH SHARP

Kennewick, Wash.

ERRATA

In the article "Pollen," by Patrick Echlin (SCIENTIFIC AMERICAN, April), it should have been mentioned that the scanning electron micrographs that appeared in conjunction with the article were made possible by the cooperation of the Cambridge Instrument Company Limited.

On page 65 of the article "The Lunar Orbiter Missions to the Moon," by Ellis Levin, Donald D. Viele and Lowell B. Eldrenkamp (SCIENTIFIC AMERICAN, May), the vertical scale of the graph at the bottom should be labeled "kilometers" rather than "miles."

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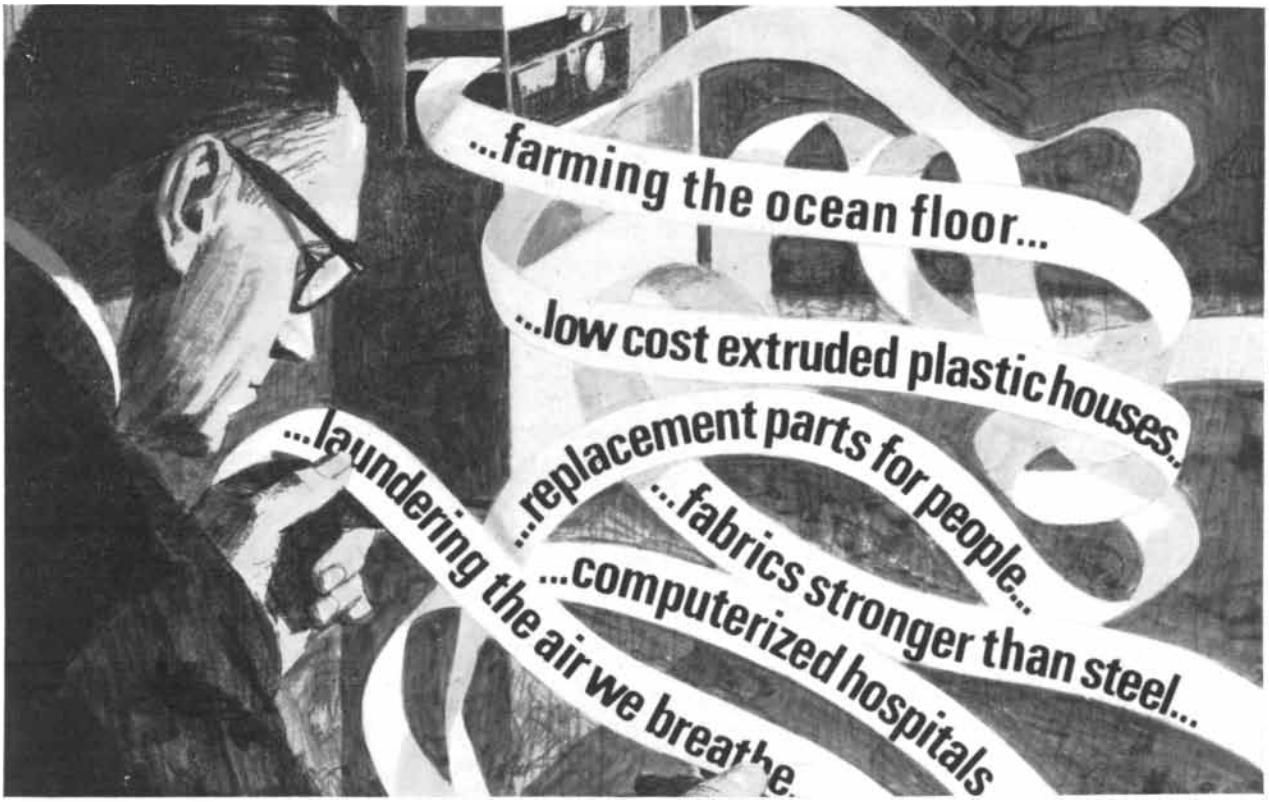

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1918: "A Reuters dispatch from Petrograd states that the Commissariat of Commerce has issued a summary of what Russia has lost by the peace treaty of Brest-Litovsk. The losses specified are: 73 per cent of the total iron production, 39 per cent of the total coal production, 268 sugar refineries, 918 cloth factories, 574 breweries, 173 tobacco factories, 1,685 spirit distilleries, 244 chemical factories, 615 paper factories, 1,073 machine factories, 21,530 kilometers of railways (one-third of all the railways of Russia), 56,000,000, or 32 per cent, of the whole population and 780,000 square kilometers of territory."

"If there are any people in the enemy countries who believe that the U-boat is going to starve our Allies and prevent American troops from crossing the Atlantic, we commend to their attention the fact that in a single day—July 4th—there were launched from our American shipyards 92 ships, having a total deadweight tonnage of 450,000. The magnitude of this effort will be appreciated when we bear in mind that the launchings represent about one-third more than was the production of seaborne tonnage in the fiscal year 1915 to 1916, and that it exceeds by more than 52,000 tons the launchings for the year 1901, which was the record year in American shipbuilding before the present war."

"In a recent communication to *La Société suisse de Chimie*, A. Stettbacher dealt with the subject of explosives that are chemically or theoretically possible. To obtain the maximum production of heat from a combustible substance, it must undergo direct combustion with an exact quantity of oxygen. In the case of explosives this condition is realized with 'oxyliquite,' a mixture containing liquid oxygen that develops 2,000 calories on combustion, as compared with 1,580 calories from nitroglycerin. The ozonides of ethylene and benzene develop less heat than oxyliquite, but their disruptive power is far greater—probably the greatest known. The highly unstable trichlorate of glycerol contains relatively more oxygen and greater exothermic energy than any other explosive, and its heat of explosion should be about 3,000 calories. Theoretically the most powerful of all would be a stoichiometrical mixture of liquid hydrogen and liquid ozone, one kilogram of which would liberate 4,500 calories. Although there is no strict comparison, it is worthy of note that in the disintegration of radium the energy set free exceeds the latter figure by more than 200,000 times."

"Again the project of crossing the Atlantic in an airplane is being discussed in earnest and is receiving the fullest approval of Allied and American officials. Indeed, so certain are the authorities that such a flight can be made that the suggestion of forwarding our large military planes via the air route to Europe has been made by no less an authority than Major General William Brancker of the British Royal Air Force. According to General Brancker, the enterprise could be carried out with motors of 740 horsepower, capable of 40 hours' flight. The motors should be capable of developing a speed of 85 miles an hour. If the transatlantic flight is attempted in September, as is now being discussed, there seems to be no reasonable ground for doubting the possibility of the feat. The airplane is no longer the fragile, baulky, unreliable and slow craft that it was in 1914."

SCIENTIFIC AMERICAN

JULY, 1868: "The *San Francisco Bulletin* says:—'One of the prominent executive officers of the Central Pacific Railroad has declared within the last 10 days that this road will be finished to Salt Lake, and passengers will be transported over its entire length by July 4, 1869. It is pretty certain now that there will be very little difference of time in the completion of the two roads. The prediction amounts to this: That on July 4, 1869, passengers will be able to travel by continuous rail across the continent from San Francisco to New York."

"Hitherto the velocipede has been considered a mere toy for the amusement of children, but at the present moment this vehicle has produced a fashionable mania in Paris among both sexes, and it is very likely to come over to us. The Paris velocipede is sometimes constructed of two large wheels, one following the other, and connected so as to provide a comfortable seat for the rider, who adroitly balances himself and at the same time guides and propels the machine with his feet. Generally, however, three large, nicely balanced wheels are used, and with a powerful crank and easily working levers the machine is propelled along with the greatest apparent ease and at high speed."

"In France the capitalists are rather slow in coming forward with any more money for the Suez Canal Company. The result is that the legislative body has taken the matter up and passed a bill that allows the managers to get up a lottery in aid of the enterprise. The lottery custom was put down in 1836, but it has been again permitted—'just this once.' Berryer, Thiers and a great number of others abstained from voting or stayed away, and some of the minority said some dreadful things about the immorality of lotteries. And yet they have, in their time, built churches, hospitals, etc.; they helped Queen Elizabeth to beat the Spanish Armada, and they may help M. de Lesseps to complete his cosmopolite canal."

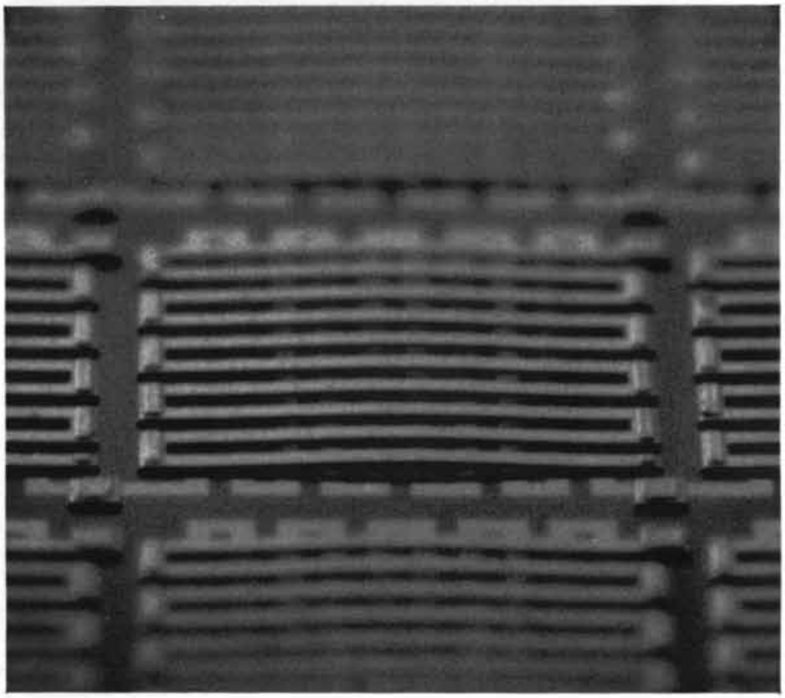
"Alfred Nobel's nitroglycerin manufactory at Stockholm was recently blown up. Fifteen persons were killed and several seriously injured. The destruction of property in the neighborhood was also extensive. This occurrence, if any further evidence was required in addition to what was lately given by successive violent and fatal explosions, shows the extremely dangerous nature of nitroglycerin, and will do much toward weakening the statements lately made by Mr. Nobel in leading European papers with regard to the comparative safety of this compound."

"At a recent meeting of the Society of Friends many of the most influential members expressed their wish that the denomination might more actively and generally cooperate with the efforts of the Peace Society; and in lamenting the increase of military armaments of late years, one of the speakers dwelt particularly upon the condition of France, where nearly 800,000 men are compelled to lead the demoralizing life of soldiers, being withdrawn from useful civil industry and taught only to slaughter and destroy their race. Another member, from Maine, stated that $1,250,000,000 is annually expended upon military armaments by Christian nations, while hundreds of thousands of their citizens are suffering from misery, ignorance, poverty and starvation."

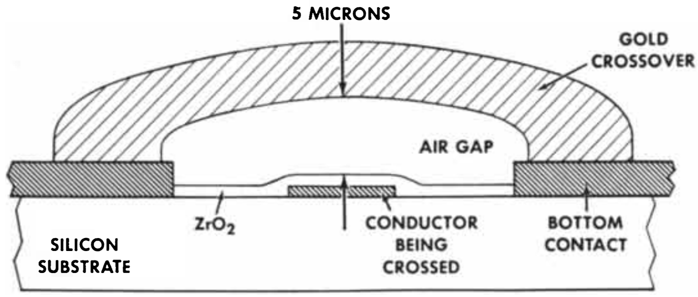
Report from

BELL LABORATORIES

Microbridges for electrons



Part of an experimental test pattern. This pattern, with 13,700 microbridge crossovers on a silicon substrate, has been fabricated without a short circuit. Each of the crossovers is less than 1/16 in. long. The combination of air and solid insulation can withstand 200 volts.



Cutaway view showing formation of the new microstructure: First, layers of titanium and platinum are deposited over the substrate to form both the conductors to be crossed and the bottom contacts. A layer of zirconium is then put down. Next copper, a spacer for formation of the crossover, is evaporated overall. Windows are etched through the copper so the crossover can reach the lower-level contact. The crossover is then applied in position by gold-plating the copper spacer; the spacer is then etched away. The zirconium layer is oxidized to act as protective insulation. Any pinholes present do not become short circuits.

As integrated circuits become more complex, designers are faced with something akin to the old puzzle: "without crossing any lines or lifting your pencil from the paper, connect so-and-so-many points." In a puzzle, it's just for fun, but with circuits it has been a design requirement.

Until now, most conductors have been crossed in virtually the same plane, separated only by extremely thin insulators. Such crossovers are undesirable because of the danger of leakage through pinhole imperfections in the insulator. As integration technology evolves, hundreds of crossovers may be needed on a single substrate. A short in any one means rejection of the entire substrate. For such integrated circuits to compete economically, the integrity and manufacturing yield of crossovers must approach perfection.

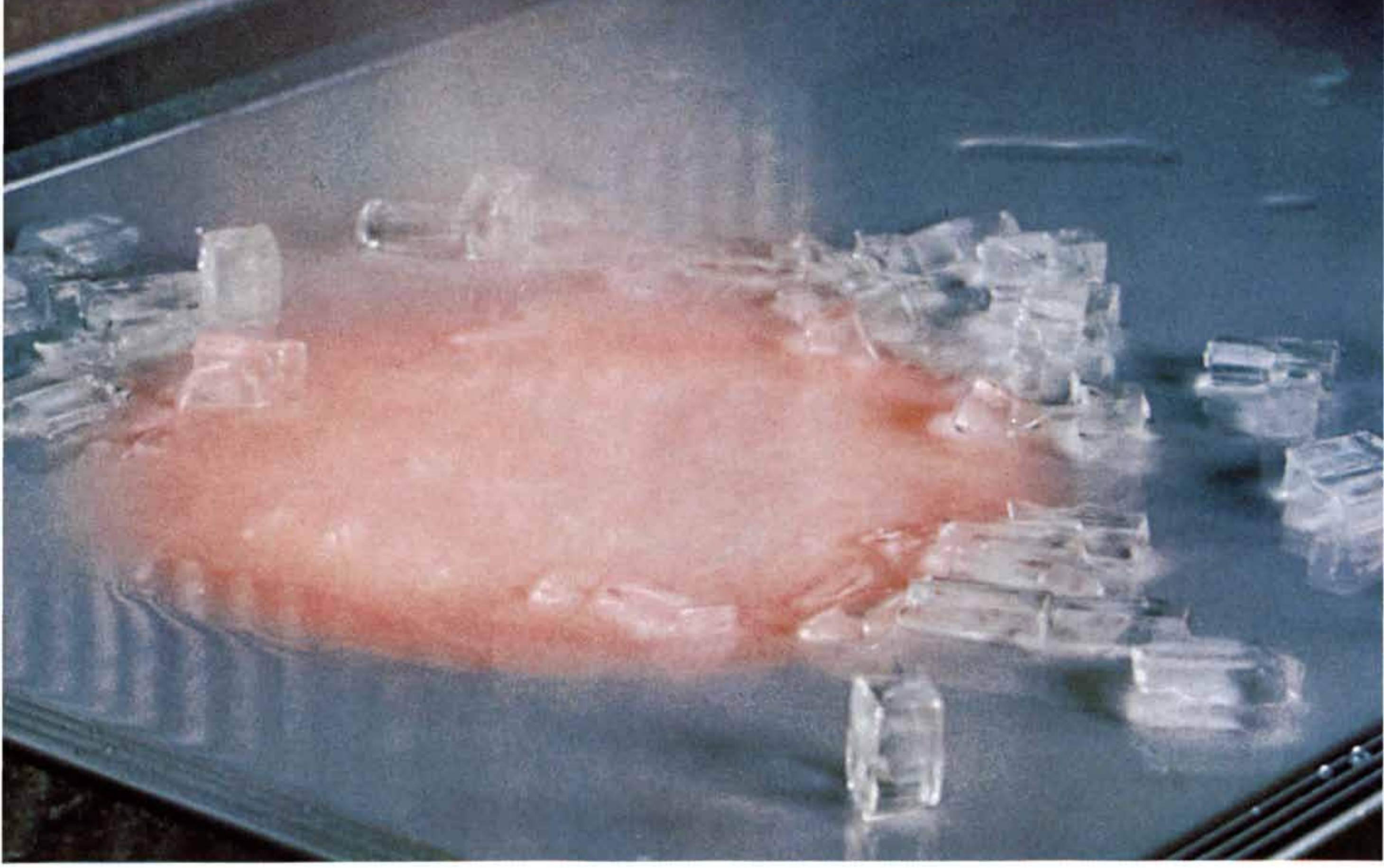
Obviously, the designer would like to "lift his pencil". . . make the crossing conductor rise above the one beneath it.

Recently, Martin P. Lepselter of Bell Telephone Laboratories has done just that. He has invented a process for making "microbridges"... integrated-circuit leads which cross others through the air, without touching (photo, left).

This new technique solves the insulation problem; because of the air gap, pinholes in the insulator do not cause leakage. It also reduces capacitance between the conductors. Finally, by separating the various materials, it eliminates stresses due to unequal thermal expansion.

The key to the technique (drawing, left) is a layer of a material like copper that can be selectively etched away, leaving an air gap between the conductors. Thus the combination of air gap and insulating layer provides a degree of insulation protection not previously available. Insulated circuits with microbridge crossovers will be used in a wide variety of communications equipment in the Bell System.

Bell Telephone Laboratories
Research and Development Unit of the Bell System



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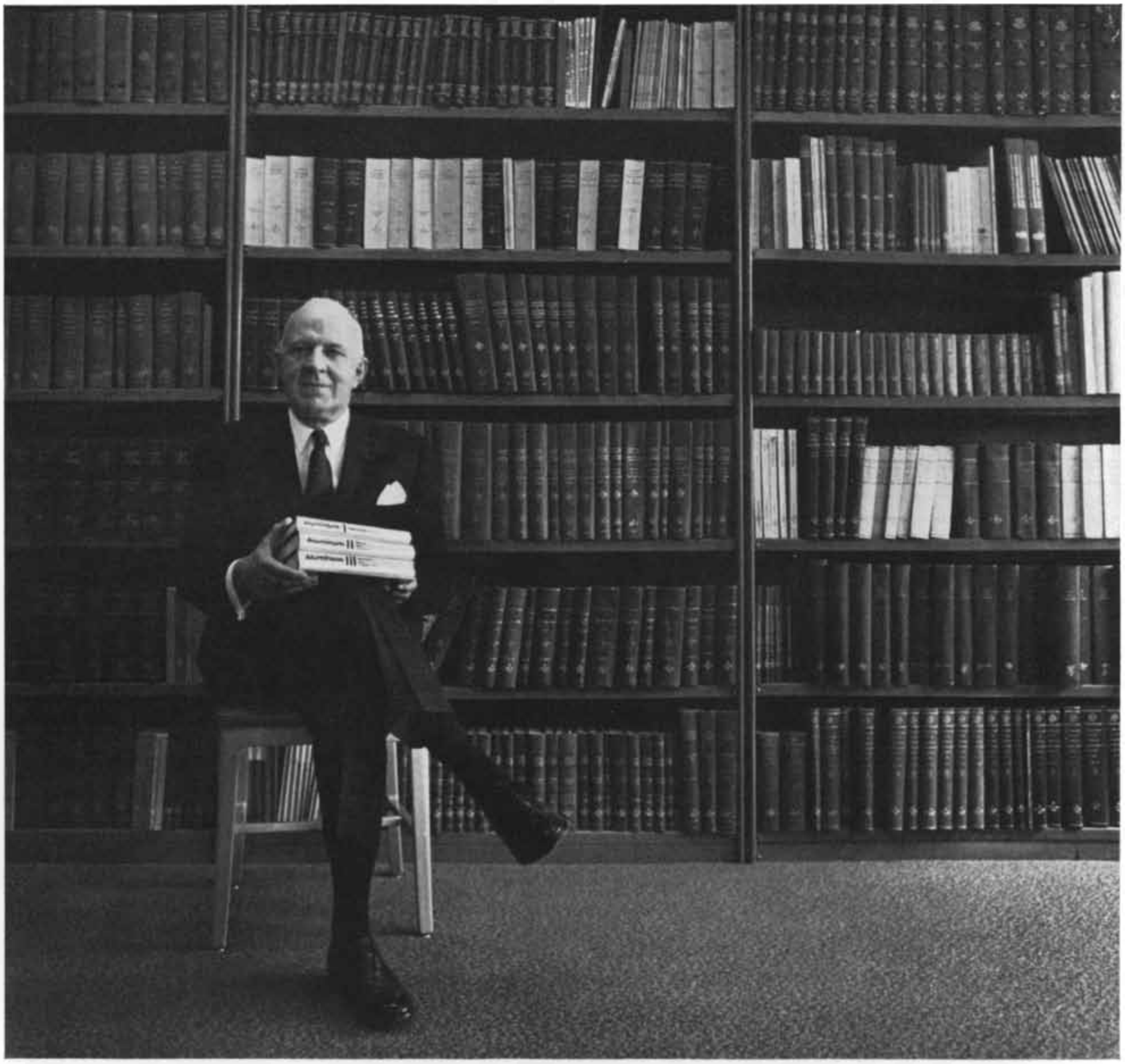

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THE AUTHORS

BERNARD LOWN ("Intensive Heart Care") is associate professor of cardiology at the School of Public Health of Harvard University. He is also senior associate in medicine at Peter Bent Brigham Hospital in Boston and director of the hospital's Samuel A. Levine Cardiac Unit. Lown was graduated from the University of Maine in 1942 and from the Johns Hopkins University School of Medicine in 1945. He took postgraduate training at the Yale University Medical School, Jewish Hospital in Brooklyn, Montefiore Hospital in New York and the Harvard Medical School. Among various activities related to his professional interests he is founder and chairman of Physicians for Social Responsibility.

IRWIN I. SHAPIRO ("Radar Observations of the Planets") is professor of geophysics and physics at the Massachusetts Institute of Technology and a member of the staff of M.I.T.'s Lincoln Laboratory. After being graduated from Cornell University in 1950 he began graduate work at Harvard University, where he obtained a master's degree in 1951 and a Ph.D. in physics four years later. In 1954 he joined the Lincoln Laboratory. In addition to the subject on which he writes his interests include nuclear physics, statistical mechanics and the dynamics of satellites.

FARRINGTON DANIELS, JR., JAN C. VAN DER LEUN and BRIAN E. JOHNSON ("Sunburn") have worked together at the New York Hospital–Cornell Medical Center. Daniels is associate professor of medicine and head of the dermatology division at the center. Van der Leun, who was visiting assistant professor of physics in medicine at the center last year, is in the dermatology department at the State University of Utrecht. Johnson is assistant professor of physiology in medicine in the dermatology division of the Cornell University Medical College. Daniels is a graduate of the University of Wisconsin, where his field was zoology. He received an M.D. degree from the Harvard Medical School in 1943 and a master's degree from the Harvard School of Public Health in 1952. During the Korean war he worked as an environmental physiologist with the U.S. Army Quartermaster Research and Development Center. His work there with men under arctic and desert conditions aroused his interest in the skin as an important component of environmental response and led him into dermatology at the University of Oregon Medical School, the University of Illinois College of Medicine and Cornell. Van der Leun has a Ph.D. in biophysics from the State University of Utrecht. Johnson has undergraduate and Ph.D. degrees from the University of London.

SIR LAWRENCE BRAGG ("X-Ray Crystallography") is retired director of the Royal Institution; he held the directorship from 1954 to 1966, and from 1953 until he retired he was also Fullerian Professor of Chemistry at the Royal Institution. Born in Australia, he took a degree in mathematics at the University of Adelaide in 1908 and a degree in physics at the University of Cambridge in 1911. In 1915, at the age of 25, he shared with his father, W. H. Bragg, a Nobel prize awarded for their work on the analysis of crystal structure by X rays. During World War I Sir Lawrence organized for the British Army the technique called sound ranging, which involved the detection of enemy guns by sound. In 1919 he succeeded Lord Rutherford as professor of physics at the University of Manchester. In 1938, after a year as director of the National Physical Laboratory, he succeeded Lord Rutherford as Cavendish Professor of Physics at the University of Cambridge. He has been a Fellow of the Royal Society since 1921.

JOHANNES VAN OVERBEEK ("The Control of Plant Growth") is director of the Institute of Life Science and of the department of biology at Texas A&M University. Born in Holland, he was graduated from the University of Leiden in 1928 and obtained a Ph.D. from the State University of Utrecht in 1933. He then spent nine years in research and teaching at the California Institute of Technology. From 1943 to 1947 he headed the work in plant physiology at the Institute of Tropical Agriculture in Puerto Rico. For the next 20 years, until he took up his present work, he was chief plant physiologist at the agricultural research laboratory of the Shell Development Company at Modesto, Calif. Van Overbeek is also a farmer; he owns a commercial vineyard in California and in that capacity he is a member of the Farm Bureau, the Allied Grape Growers and the United Vintners.

STUART PIGGOTT ("The Beginnings of Wheeled Transport") is Abercromby Professor of Prehistoric Archaeology at the University of Edinburgh. From 1929 to 1934, following his graduation from the University of Oxford, he was on the staff of the Royal Commission on Ancient Monuments in Wales. He then spent four years as assistant director of excavations at Avebury in southern England. During World War II he served with the British Army in India as an interpreter of aerial photographs. He writes of his interest in "antiquarian thought in Britain from the 16th century" and adds: "I also (anonymously) write on modern food and drink."

H. WILLIAM FLOOD and BERNARD S. LEE ("Fluidization") are respectively a chemical engineer at Arthur D. Little, Inc., and manager of gasification research at the Institute of Gas Technology in Chicago. Flood was graduated from the School of Mines and Metallurgy at the University of Missouri in 1943. His work has entailed evaluating the technical and economic feasibility of many projects involving metals, inorganic chemicals and minerals. Lee, who was graduated from the Polytechnic Institute of Brooklyn in 1956 and received a Ph.D. there in 1960, was with Arthur D. Little, Inc., for five years before joining the Institute of Gas Technology in 1965.

THEODORE H. SAVORY ("Hidden Lives") is vice-principal of Stafford House, a tutorial college at Kensington in England. Although he describes himself as having spent most of his adult years leading "the uneventful life of a British public school master," he is an authority on arachnids, the group of organisms that includes spiders, daddy longlegs and scorpions. "Years of grubbing about in woods for the spiders that were the first objects of my search," he writes, "caused me to realize how many and various are the small animals that share the safety of the same surroundings; it is from this experience that my interest in these so-called cryptozoa has grown." After being graduated from the University of Cambridge in 1918, Savory spent 31 years teaching science at Malvern College and seven years as senior biology master at the Haberdashers' School in Hampstead. His article is his fourth in SCIENTIFIC AMERICAN.

ANDRÉ LWOFF, who in this issue reviews *The Double Helix*, by James D. Watson, is head of the Department of Microbial Physiology at the Pasteur Institute in Paris. In 1965 he shared (with Jacques Monod and François Jacob) the Nobel prize in physiology and medicine.

Is your 16-year old son a better driver than you are?

	YES	NO
1. Do you use safety belts every time you drive?	☐	☐
2. Do you check your rearview mirrors every few seconds?	☐	☐
3. Do you signal when you're going to change lanes?	☐	☐
4. Do you stay a car's length behind the car in front for every ten miles per hour of speed?	☐	☐
5. Do you always stay within the posted speed limits?	☐	☐
6. Do you always reduce your speed when the pavement is wet?	☐	☐
7. Do you stop for a rest when you feel yourself getting tired?	☐	☐
8. Do you drive defensively, always assuming the other fellow might do something wrong?	☐	☐
9. Do you always lower your headlights for oncoming cars?	☐	☐
10. Do you always check your tires before setting out on a long trip?	☐	☐

Did you answer "no" to any of the questions above? If you did, your 16-year old may have better driving habits than you do. (Don't be mad. Be happy.)

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Intensive Heart Care

In hospitals equipped with coronary care units the mortality rate from heart attacks has been reduced by about a third. Widespread application of the new therapies could save 60,000 lives a year

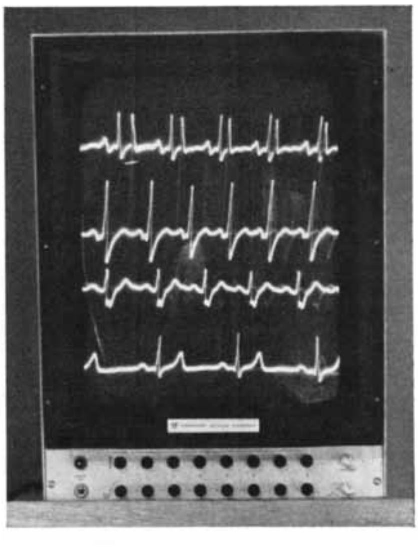
by Bernard Lown

The development of coronary care units promises a profound change in the treatment of patients with coronary artery disease. These units, although small and unpretentious facilities within a hospital, seldom exceeding eight beds, constitute a major therapeutic innovation in dealing with the inordinate mortality from heart attacks. In the past two decades there have been significant advances in the care of patients with cardiovascular ailments. Yet death from coronary disease has increased annually and has consistently exacted a higher toll than any other single disease. Each year more than 1.5 million Americans suffer coronary attacks, and of these about 600,000 die. Every minute around the clock someone in the U.S. is fatally stricken. A quarter of those who die are under the age of 65 and still in the prime of creative life [*see illustrations on page 127*]. A person who suffers a heart attack and who is taken to a hospital that lacks a coronary care unit has no better chance for survival today than a person so stricken 30 years ago.

A characteristic of coronary artery disease is sudden death, frequently occurring without premonitory symptoms or special inciting circumstances. More than 80 percent of sudden heart deaths occur within 24 hours of the initial attack. It would seem that with such a formidable illness one would find extensive pathologic changes in the heart to account for the catastrophic event. Other lethal illnesses are almost always associated with marked destruction of the diseased organ. In many victims of a coronary, however, the heart muscle appears anatomically intact or only minimally injured. The sudden death characteristic of a heart attack has been compared to the halting of the pendulum of a clock: the clock stops ticking even though its internal machinery is still in good working order.

What is the mechanism of such sudden death? It has long been recognized that the heart may arrest either because of power failure or because of electrical failure. The first is due to a chronic increase in work imposed on the heart muscle that finally results in overloading and inadequate pumping of blood. The second is due either to asystole or to ventricular fibrillation. Asystole, or standstill of the heart, is caused by a breakdown in the pacemakers that generate the electric "spark" initiating heart-muscle contraction. In contrast, ventricular fibrillation is due to excessive electrical activity conducted through the heart in a random, uneven and uncoordinated manner, leading quickly to death. The heart, so to speak, electrocutes itself. The large majority of sudden coronary deaths are thought to be due to ventricular fibrillation.

Ventricular fibrillation is a reversible disorder in heart rhythm. This was first demonstrated at the turn of the century by Jean-Louis Prevost and Frédéric Battelli, two Swiss physiologists who were able to restore a normal heart mechanism by applying strong electric currents directly to the heart of dogs through the opened chest. Scant attention was paid to their work. More than 30 years elapsed before electrical defibrillation became generally known as a result of the studies of William B. Kouwenhoven, a professor of electrical engineering at Johns Hopkins University, who developed a practi-



FOUR DAMAGED HEARTS are monitored on a large television-like screen. The traces are the electrocardiograms (ECG's) of four patients in the coronary care unit at Peter Bent Brigham Hospital, next to Harvard School of Medicine in Boston. The unit is known as the S. A. Levine Cardiac Center.

CORONARY CARE UNIT at Peter Bent Brigham Hospital is typical of several hundred such installations in U.S. hospitals. Four rooms for patients are clustered around a station from which specially trained nurses can keep a constant check not only on patients but also on oscilloscope screens that display the ECG of each patient. The screen at the upper left and another partly visible at the upper right display the ECG's of four patients. Simultaneously the ECG's are printed out on paper tape (*lower left*) or recorded on magnetic tape so that they can be reviewed later by cardiologists. The Brigham unit is under the direction of the author.

cal instrument for delivering an alternating-current discharge to the heart.

A decade ago Paul M. Zoll of the Harvard Medical School pointed out that it was not necessary to open the chest, that the electric shock was equally effective when administered across the intact thoracic cage. In 1960 my group in the Department of Nutrition at the Harvard School of Public Health developed a new method that delivered a single electric pulse from a capacitor, which was safer and more effective than alternating current for defibrillating the heart. It was also suitable for treating many other disturbances of the heartbeat.

In spite of the availability of effective methods for defibrillating the heart, resuscitation was only rarely successful. The problem was the brief interval of time available for instituting countermeasures. Once ventricular fibrillation begins, pumping of blood ceases entirely and serious brain damage follows within three minutes. When ventricular fibrillation occurs in the coronary patient, heart-muscle injury is increased and within less than three minutes may become so extensive as to be irreversible. Defibrillation was therefore seldom attempted, because only rarely and fortuitously was there a proper conjunction of afflicted patient, trained personnel and the necessary electrical equipment. For this reason most successful resuscitations were carried out when ventricular fibrillation began in patients undergoing some kind of operation. Indeed, the Cleveland heart surgeon Claude S. Beck popularized the phrase "Hearts too good to die" to describe hearts that had been successfully resuscitated following fibrillation.

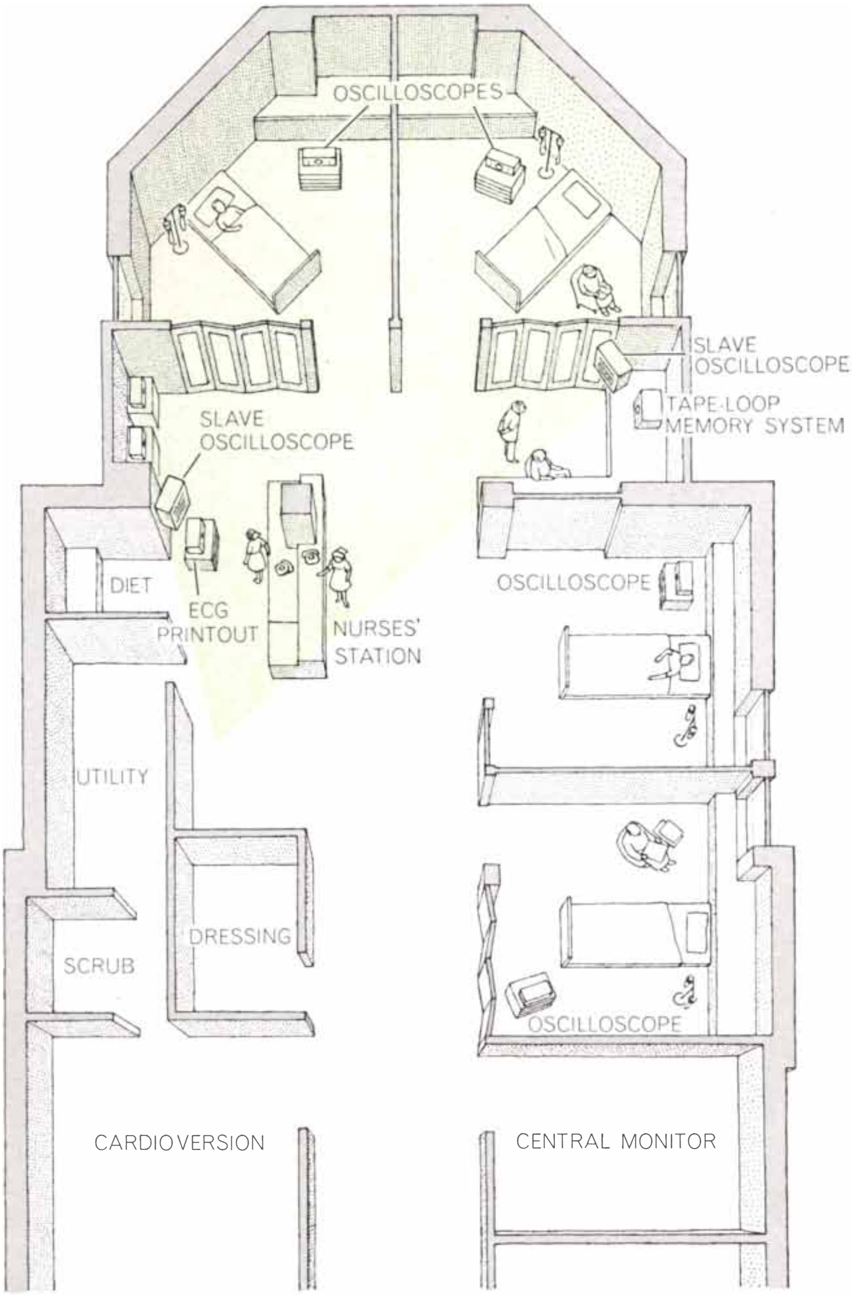
Resuscitation of ordinary heart attack victims outside the operating room awaited the rediscovery of an old method by Kouwenhoven, the same engineer who 30 years earlier had introduced electric defibrillation, and his colleagues. He and his group demonstrated that a person whose heart has stopped can be kept alive simply by rhythmically compressing the lower part of the breastbone. This maneuver propels enough blood to maintain the viability of such vital organs as the brain and the heart. This, of course, provides the necessary few minutes for getting physicians and other personnel, as well as equipment, to the patient's bedside. In the case of the victim of a heart attack, however, even with external cardiac massage the lapse of time is often too great for a high percentage of success.

These findings pointed to a need for revising the care of patients with a coronary heart attack. At this very time electronic techniques of monitoring heart rhythm reached a high state of perfection. In effect the logic of coronary care units was the culmination of these developments. As is true in other spheres of scientific work, a multiplicity of advances results in a qualitatively new approach that then springs forth nearly simultaneously in different places encouraged by a common social need. Coronary care units were pioneered at almost the same time by Hughes W. Day in Kansas City, Kansas, Lawrence E. Meltzer and J. Roderick Kitchell in Philadelphia, Kenneth W. G. Brown in Toronto, Desmond G. Julian in Melbourne and a number of others.

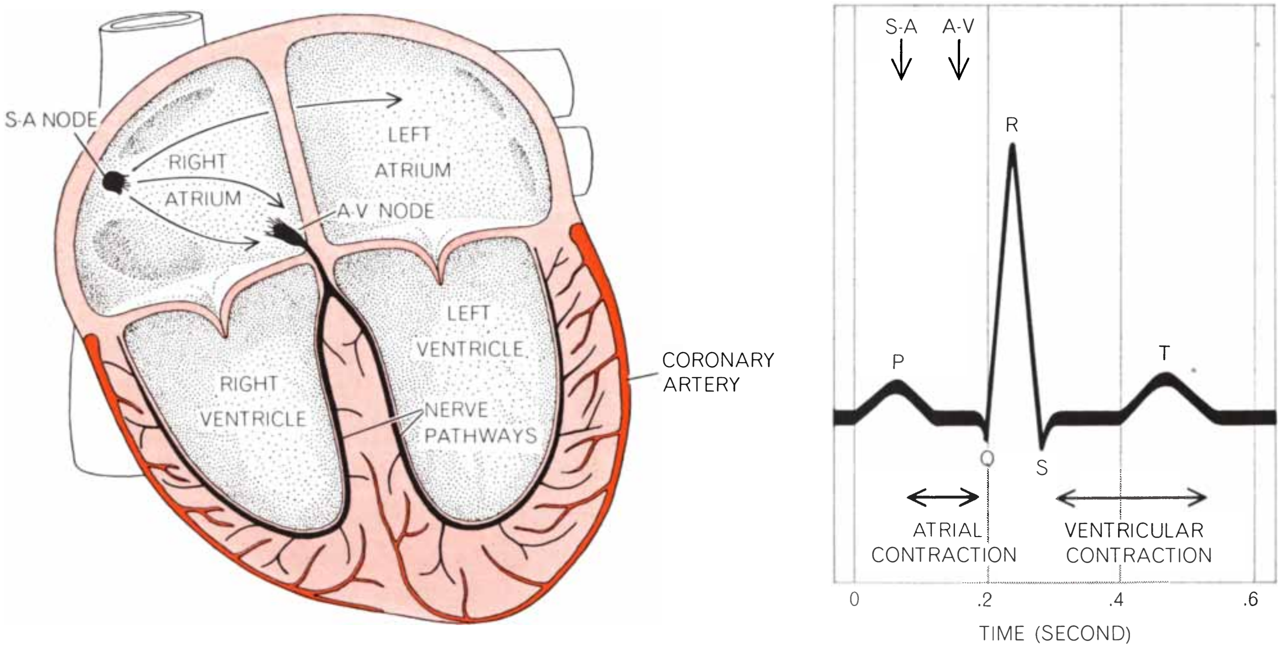
The reason for organizing a coronary care unit flows from the very nature of the coronary episode. When a coronary artery is narrowed by atherosclerosis (that is, the deposition of cholesterol and other fats in the vessel wall), it may reach such a degree of constriction that the blood supply becomes inadequate to sustain nourishment of a portion of myocardium, the heart muscle. The death of myocardium produced by myocardial infarction, the clinical term for the common heart attack, is usually not sufficient to compromise the heart and induce stoppage and death. More frequently what happens is that the damaged heart begins to beat erratically, resulting in ventricular fibrillation. For the patient with myocardial infarction who develops ventricular fibrillation, even seconds are crucial. If such a patient is treated within one minute, he has a 90 percent or better chance for survival. If there is a delay of three minutes, survival is less than 10 percent. It is therefore mandatory to recognize the electrical catastrophe at the instant it occurs.

These considerations have led to the segregation of patients with myocardial infarction in a specialized area in the hospital—the coronary care unit. The typical unit consists of a suite of two to 12 private rooms clustered around a nurses' station that allows the patients and a variety of instruments to be directly observed. At each bedside is an oscilloscope screen that displays a continuous electrocardiographic (ECG) tracing. The ECG patterns of all the patients in the unit are simultaneously displayed on large multichannel oscilloscopes that are strategically placed so as to be readily visible from any direction. These tracings are also recorded on tape-loop systems so that in case of a change in heart rhythm they can be reviewed by the attending physicians. Each bedside monitor is equipped with automatic devices to alert the staff should any heart-rate condition, preset for each patient, be exceeded. An undesirable shift will activate visible and audible alarms. In many coronary care units the pulse rate of each patient is heard in the background as a steady beeping, which the nurses learn to ignore unless one of the beeps changes in frequency or stops.

Neither monitors nor the most complicated electronic gear makes a coronary care unit. The fundamental ingredient is a properly indoctrinated nursing staff. The reason for this is obvious. The nurse



S. A. LEVINE CARDIAC CENTER, opened in 1965, has rooms for four patients. Photograph on the opposite page shows the area shaded in color. The room labels are largely self-explanatory. The central monitor room contains equipment for continuous magnetic tape recording of ECG records. The "cardioversion" room contains devices for administering electric shocks to restore normal rhythm in hearts that have developed dangerous arrhythmias. The Levine Center has now served more than 500 victims of critical heart attacks.

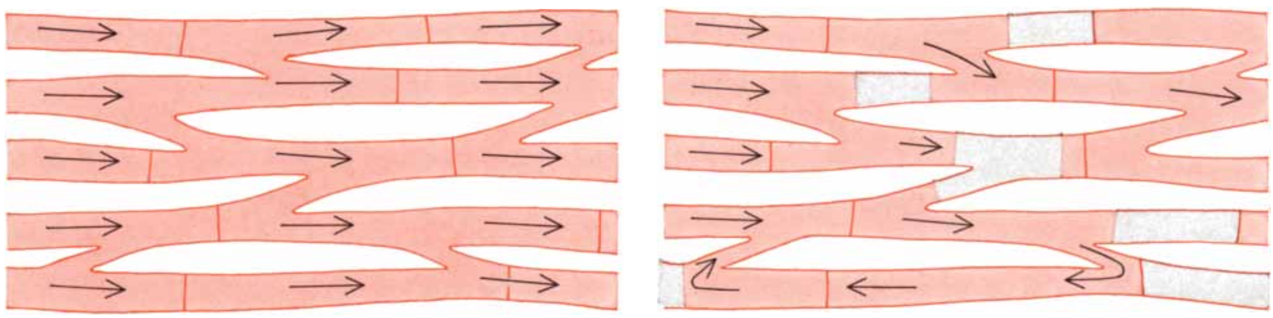


ELECTRICAL ACTIVITY OF NORMAL HEART begins with a nerve impulse generated by a bundle of fibers known as the pacemaker, located in the sinoatrial (*S-A*) node. The impulse spreads across the atria (*arrows*) in slightly more than .1 second, causing them to contract and speed the flow of blood into the ventricles below. The atrial portion of the heart impulse corresponds to the *P* wave in the ECG trace (*right*). The impulse continues on to stimulate the atrioventricular (*A-V*) node and the ventricles, producing the *Q-R-S* portion of the trace, which has a duration of .08 second. The final rise in the trace, the *T* wave, is produced by repolarization, or recovery, of the ventricular muscles. The valves between the atria and the ventricles are shown closed in this diagram.

is usually the only trained medical professional at the bedside during important clinical events. The time for effective action is brief and does not usually allow delay for the arrival of a physician. The nurse is trained in the recognition of arrhythmias and is delegated the authority for enacting the entire repertory of lifesaving techniques. In fact, many well-functioning coronary care units have been successful because of the elite spirit and competence of the nursing staff.

Initially the focus within the coronary care unit was on resuscitation. This was based on the supposition that the occurrence of potentially fatal derangements in heart rhythm were unpredictable and unpreventable. Distressingly, a high percentage of resuscitated patients eventually died. Even brief spells of ventricular fibrillation were poorly tolerated by the already compromised heart. In experimental studies we have found that regardless of the method employed for blocking a major coronary artery in a dog, if death occurs within the first few days after such closure it is from ventricular fibrillation. Although ventricular fibrillation develops suddenly, it is invariably preceded by other abnormalities in the heartbeat. These arrhythmias are almost continuously present for about 72 hours, during which time the heart can be stilled at any moment by an electrical catastrophe.

In the experimental animal, immediately after coronary occlusion there are recurring bursts of irregular heartbeat. The most frequent abnormality is the ventricular premature beat, also referred to as a ventricular extrasystole. Normal-

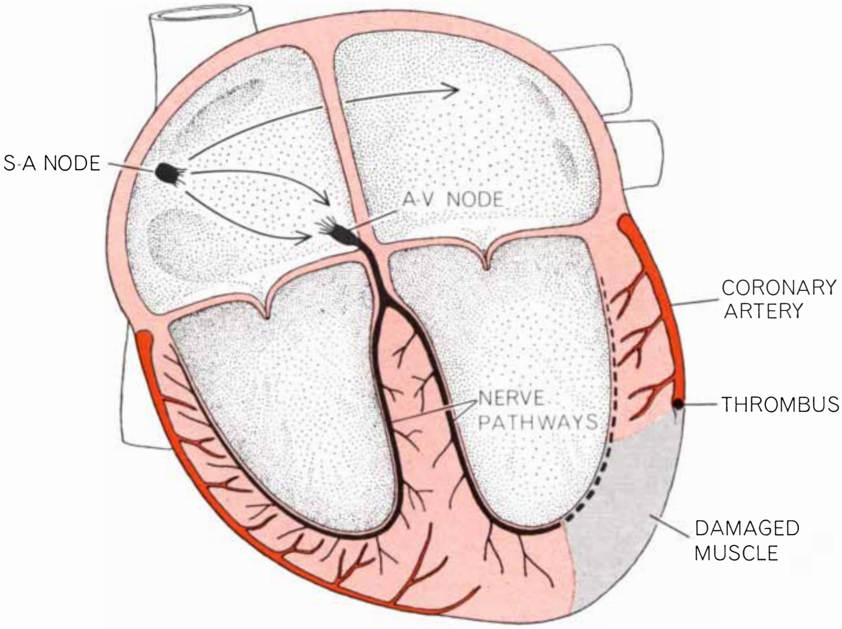


ELECTRIC IMPULSES IN HEART flow unobstructed through the muscle fibers in normal cardiac tissue, as depicted schematically at the left. In a heart attack the flow of blood to a portion of the heart muscle is blocked by an obstruction in one of the coronary arteries. Deprived of nourishment, some of the muscle fibers begin to die. Accordingly when an electric impulse reaches such necrotic fibers (*gray areas at right*), it is deflected from its course and may even start recirculating to create a continuing excitation. Such erratic electrical behavior constitutes the arrhythmia known as ventricular fibrillation (*see bottom illustration on opposite page*).

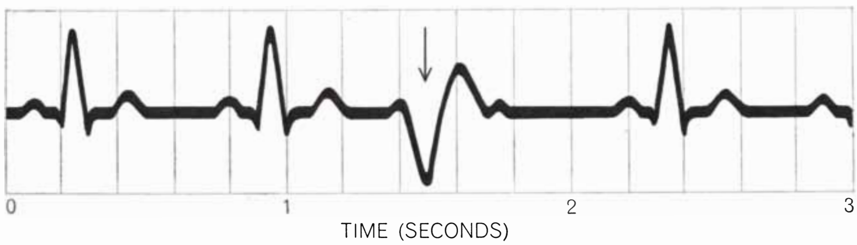
ly the electric impulse that activates the heart emerges from a conglomeration of nerve elements in the right atrium, the upper chamber receiving blood from all parts of the body [*see top illustration on opposite page*]. This aggregate of nerve fibers is the pacemaker of the heart, called the sinoatrial node. It emits an impulse from 60 to 100 times per minute. The electric impulse leaves the sinoatrial node and travels smoothly over a conduction system that rapidly and uniformly activates the ventricles, the pumping chambers of the heart. When, however, the electric spark originates outside the sinoatrial node directly from the ventricular muscle, the resulting beat is called a ventricular extrasystole. Such extrasystoles commonly occur in normal people and are without consequence. In the presence of myocardial infarction, however, they can result in ventricular tachycardia (a train of rapidly recurring ventricular extrasystoles) or in ventricular fibrillation.

How, then, does the ventricular extrasystole trigger ventricular tachycardia or ventricular fibrillation? Each time the heart beats there is a brief interval in the cardiac cycle that is susceptible to ventricular fibrillation. This is true in the normal as well as the diseased heart. The interval is referred to as the ventricular vulnerable period. It is located early in the heart cycle during inscription of the *T* wave of the electrocardiogram, which marks the recovery of the excitable state [*see top illustration on next page*]. The vulnerable period is extremely short, lasting anywhere from .02 to .04 second. In the normal heart large energies are required to activate the vulnerable period and precipitate ventricular fibrillation. In the presence of myocardial infarction, however, the threshold of the vulnerable period is significantly reduced, so that if a sequence of several extrasystoles—or if even a single extrasystole—falls during the vulnerable period it may suffice to disorganize the heart electrically.

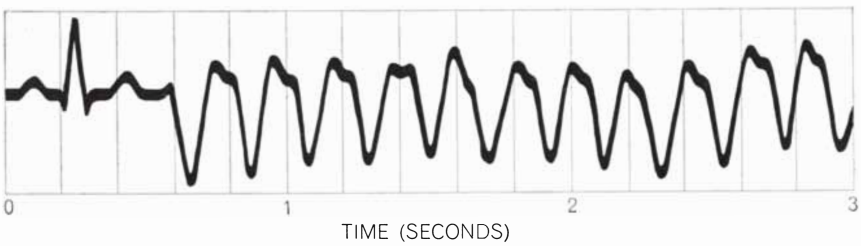
When dogs with coronary artery occlusions are continuously monitored, it becomes evident that ventricular fibrillation occurs only when extrasystoles are triggered during the vulnerable period. Thus ventricular fibrillation or death, while sudden, is not unannounced. It follows that if ventricular extrasystoles are controlled, electrical death should be preventable. This hypothesis was tested in dogs. When they were given continuously by vein an arrhythmia-suppressing drug for three days after coronary occlu-



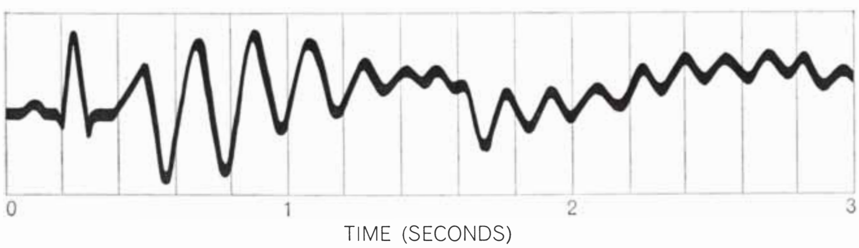
ELECTRICAL ACTIVITY OF DAMAGED HEART is erratic because nerve impulses can no longer flow smoothly from the atrioventricular node through the pathways that feed impulses to the ventricular muscles. The normal route (*broken line*) is blocked by necrotic tissue. Most heart-attack patients develop one or more of the arrhythmias shown below.



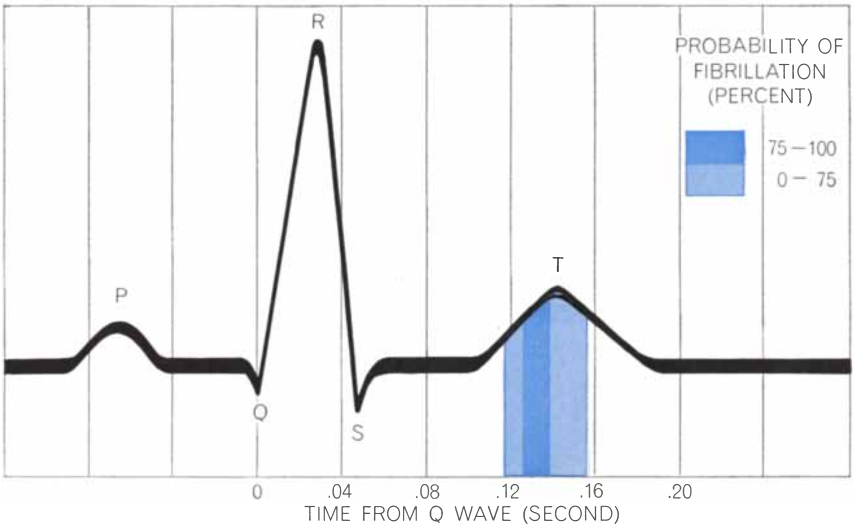
FIRST SIGN OF ARRHYTHMIA in the heartbeat, following a coronary heart attack, usually takes the form of a premature ventricular beat (*arrow*), also known as an extrasystole.



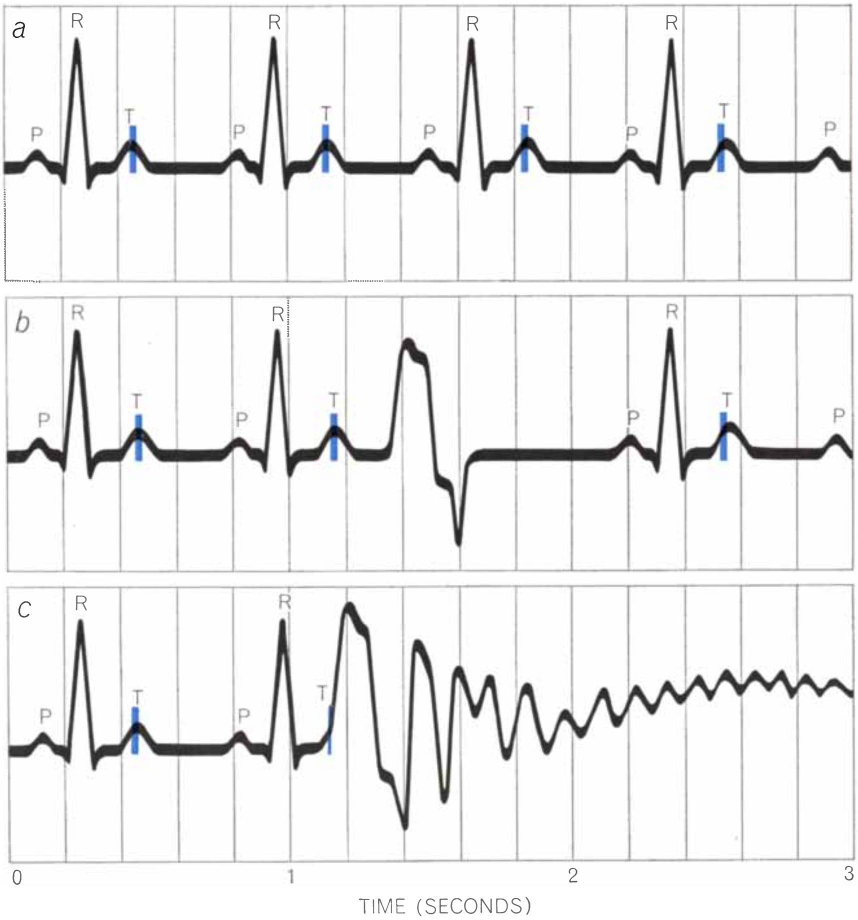
MORE SERIOUS ARRHYTHMIA is tachycardia, or fast heartbeat, in which ventricular impulses occur at two or three times the normal rate. If not halted, they can cause death.



FATAL ARRHYTHMIA known as fibrillation can develop from tachycardia or when premature beats fall within a critical part of the *T* wave, as illustrated on the next page.



VULNERABLE PERIOD in the heart's electrical cycle occurs in the *T* wave. It has long been known that an electric shock can restore normal rhythm in a heart that is fibrillating. The author's studies on dogs showed that a shock was also effective in halting tachycardia. But he also found that a shock administered during the *T* wave would cause fibrillation and death. Colored bands show how vulnerability varies in *T* wave of a dog's ECG. He then designed an instrument, called a cardioverter, that avoids the *T* wave in administering a shock.



THEORY OF HOW FIBRILLATION OCCURS following a heart attack is based on recognition of the vulnerable period in the *T* wave, identified in these diagrams. Diagram *a* shows the vulnerable period in the ECG record of four normal heartbeats. Occasionally an extrasystole will occur even in a normal heart (*b*), where it replaces a normal beat. In a damaged heart extrasystoles are more frequent and often occur in bursts. These bursts make the heart more vulnerable to fibrillation when an extrasystole occurs in a *T* wave (*c*).

sion, none died from ventricular fibrillation.

We were now ready to confront the problem in man. In the first three days after a heart attack, as we learned in the experimental animal, there is a profusion of irregularities in heart rhythm. A majority of these are seemingly trivial. The most common disorder is the ventricular extrasystole, which occurs in 70 percent of patients. When the coronary care unit was opened in February, 1965, at the Peter Bent Brigham Hospital (it was named the S. A. Levine Cardiac Center after Harvard's distinguished cardiologist Samuel A. Levine), therapy was oriented to prevent the need for resuscitation. The directive given to physicians and staff was to treat minor rhythm disturbances; the objective was to prevent entirely the occurrence of ventricular fibrillation.

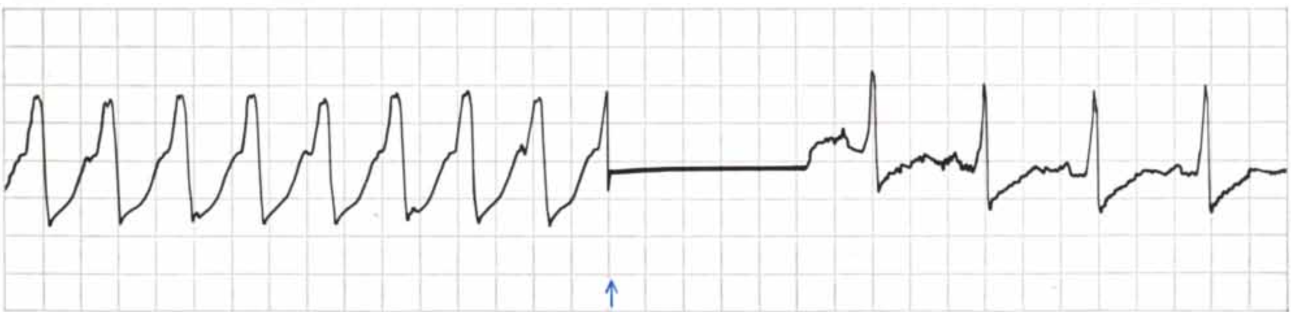
The drug we selected for suppressing ventricular extrasystoles was lidocaine, commonly employed by dentists as a local anesthetic. It was administered by vein continuously for 48 hours or longer until ventricular extrasystoles were no longer present. Previous experience had shown that about 15 percent of hospitalized heart attack patients develop ventricular fibrillation. In the first year of operation, during which time we treated 130 patients in the S. A. Levine Cardiac Center, there was not a single episode of ventricular fibrillation. As of this writing we have observed 520 patients; the incidence of ventricular fibrillation has been held to less than 1 percent.

The general principles we espoused have now been widely adopted. Mortality in coronary care units has been reduced from about 30 percent to 20 percent. If the same level of care could be extended to the approximately 200,000 patients who die annually from heart attacks in hospitals, at least 60,000 could be saved. The life expectancy of this group thereafter would be that of heart attack survivors generally: a mortality rate of about 4 percent annually.

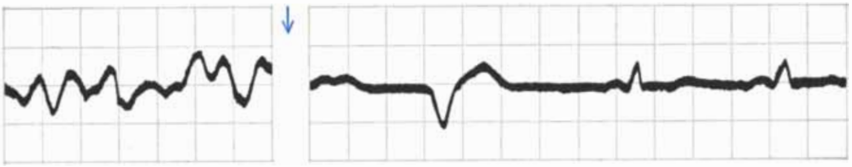
It is unlikely that further material reduction in coronary mortality will be achieved in the hospitalized patient. The majority of deaths now occurring within coronary care units are due to power failure—the result of massive and seemingly irreversible cardiac injury. Looking to the immediate future, ventricular-assistance devices and special surgical interventions may enable a number to survive. It seems unlikely, however, that treatment that depends for success on highly technical, complex and time-consuming procedures is going to have a significant impact on coronary mortality. Even if these approaches were practicable, they still would not confront the major problem of death from coronary disease, since the majority of those who die are never brought to a hospital.

A number of studies now document the thesis that coronary deaths occur predominantly outside the hospital. Lewis Kuller and his co-workers at the Johns Hopkins School of Medicine analyzed all coronary deaths occurring in Baltimore in one year (1964 to 1965); they found that only 34 percent of those stricken survived long enough to be hospitalized. Similarly, Cedric R. Bainton and Donald R. Peterson of the U.S. Public Health Service, who examined a smaller series in the Seattle area, reported that of 122 coronary fatalities among

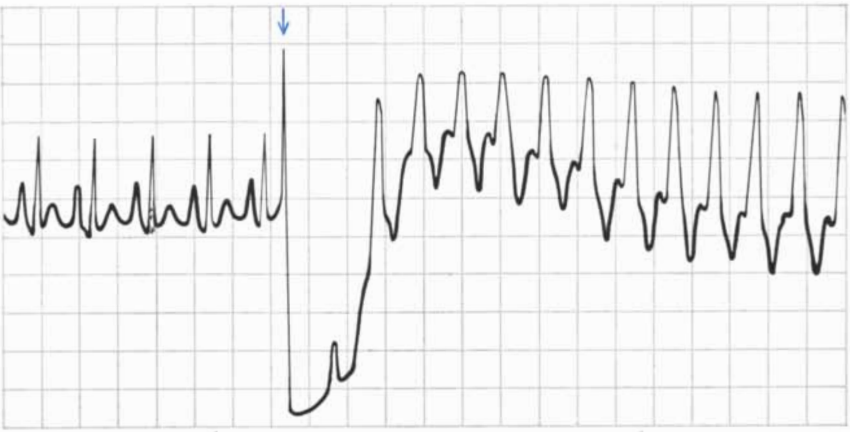
THREE KINDS OF ARRHYTHMIA are exhibited in ECG's recorded from three heart-attack patients who were treated at the S. A. Levine Cardiac Center. In the first patient (*top*) the arrhythmia takes the form of extrasystoles (*arrows*) that occur quite close to the critical *T* wave. In the second patient (*middle*) the extrasystoles come in clusters (*arrows*) and fall dangerously close to the *T* wave. In the third patient (*bottom*), who suffered an acute coronary infarction, the ECG records the onset (*arrow*) of tachycardia.



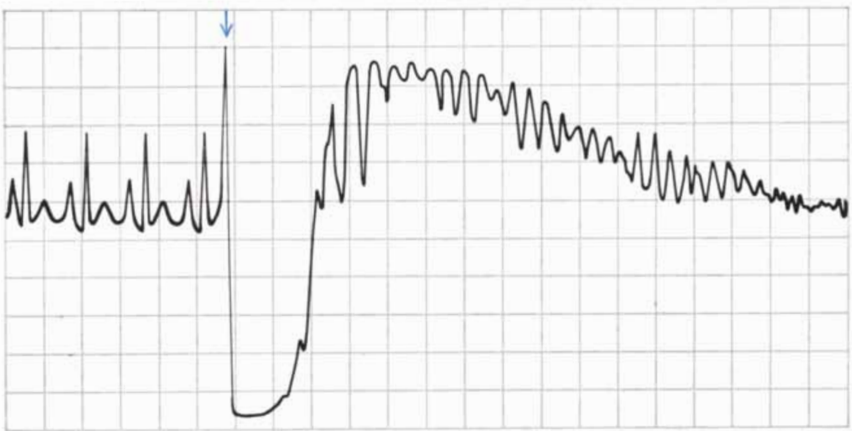
RESTORATION OF NORMAL RHYTHM in a patient with tachycardia was achieved by means of a cardioverter, which delivered an electric shock (*arrow*) across the chest wall. The horizontal line after the shock is a blocking current that protects the cardiograph.



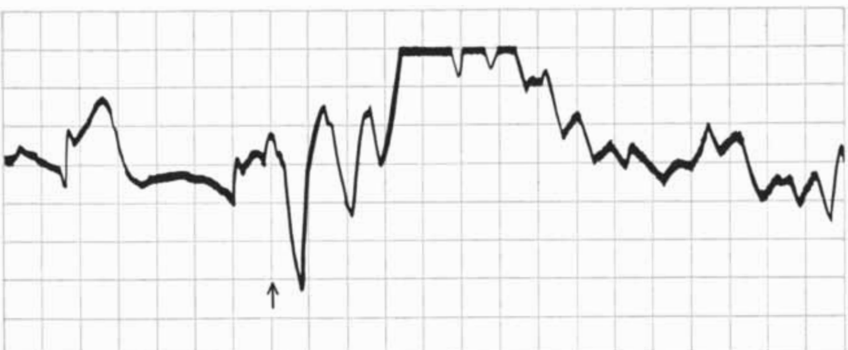
RESTORATION OF NORMAL RHYTHM in a fibrillating heart was achieved by a direct-current shock (*arrow*) across the chest wall. A single extrasystole followed the shock.



ELECTRIC DISCHARGE GIVEN TO DOG with an artificially induced coronary occlusion produced tachycardia. The mild discharge (*arrow*) was given at the peak of the *T* wave.



HEAVIER DISCHARGE subsequently given the same dog sent its heart into fibrillation. Again the shock (*arrow*) was given in the vulnerable period close to the peak of the *T* wave.



EXTRASYSTOLE IN VULNERABLE PERIOD (*arrow*) triggered fibrillation in a patient with a coronary occlusion. If given promptly, an electric shock can restore normal rhythm.

people under 50 years of age, 63 percent died within an hour. Only 23 percent lived long enough to be medically attended, however briefly, during their final illness. The younger the individual afflicted with coronary disease, the more precipitate appears to be the terminal event. These and similar reports suggest that only about a third of coronary deaths occur within the confines of a hospital.

What is the cause of these early deaths? Existing evidence suggests that it is the result of a derangement in heart rhythm. The incidence of ventricular fibrillation is directly related to the time of the coronary episode, being highest at the very inception and then receding almost exponentially with the passage of time. It therefore appears that if death is to be reduced, the problem must be dealt with outside the hospital.

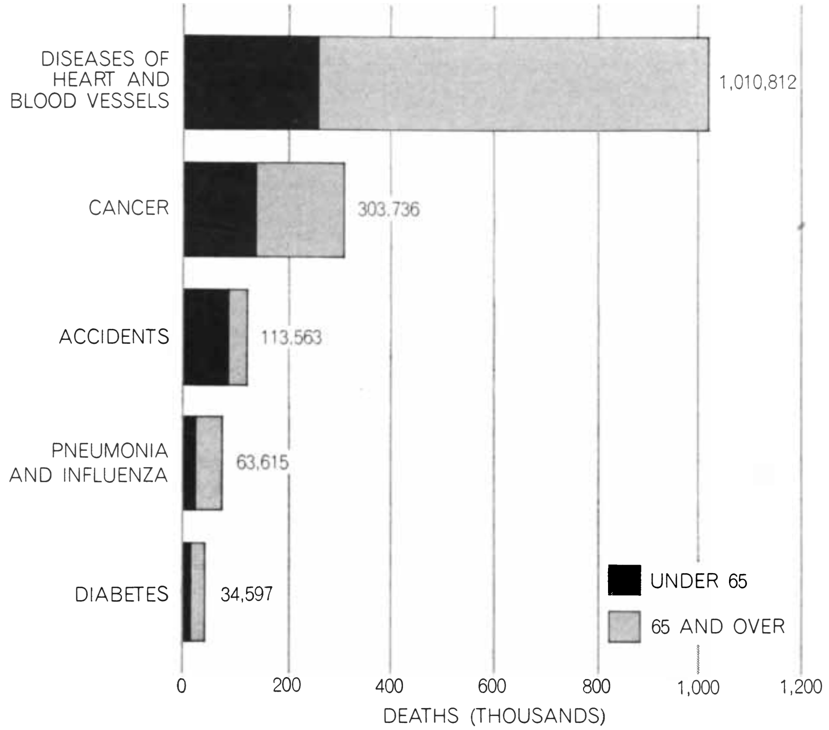
The coronary care unit experience has provided the broad answer to the problem of sudden coronary death. What remains is its implementation outside the hospital. This is a formidable challenge, because the prospective victim of electrical derangement in the heartbeat exhibits no clinical telltale marks of the impending catastrophe. Certainly, since death is most frequent at the very onset of the coronary attack, the patient should be brought under electrocardiographic monitoring and transported to a coronary care unit as quickly as possible.

One approach is to equip and staff special ambulances as mobile coronary care units expressly for heart attack patients. This idea was initiated by J. F. Pantridge and J. S. Geddes of the Royal Victoria Hospital in Belfast. Such ambulance teams, called "flying squads," have now been introduced in many major Russian cities. (Western cardiologists have been advised by their Russian colleagues that when visiting Moscow a flying squad can be summoned by dialing "03.") It is doubtful that flying squads can deal adequately with the problem, since these special ambulances are usually summoned by a physician after he has examined the patient. If a physician is in attendance, he can institute the very therapeutic measures so successfully employed in the coronary care unit. Once the heartbeat has been stabilized, a regular ambulance can safely transport the patient.

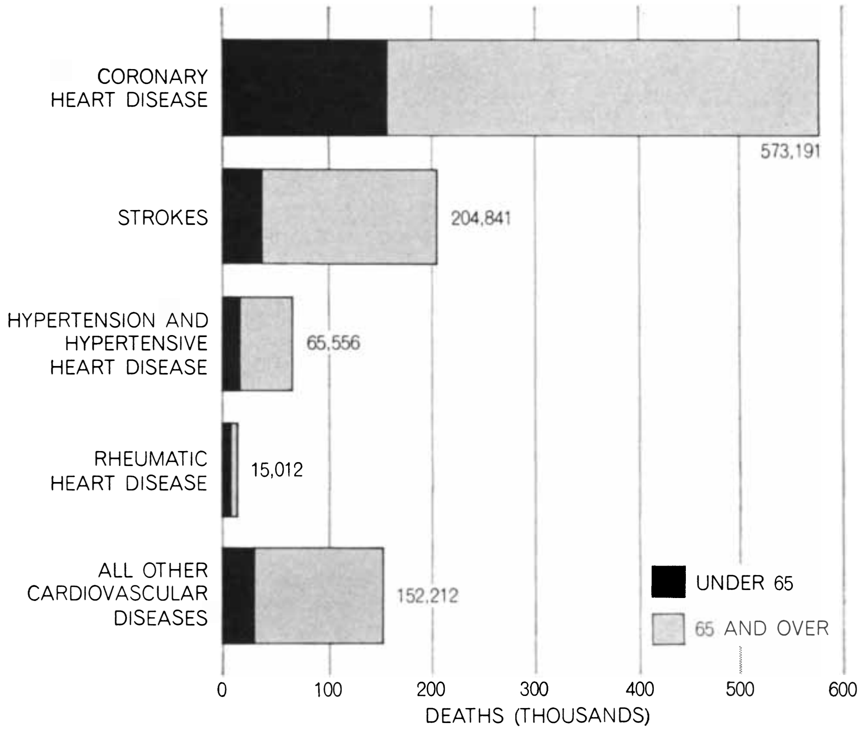
The problem really lies in the many delays between the first onset of symptoms and their ultimate interpretation by a physician as a coronary episode. It is my view that attention should be given to the concept of precoronary care. This involves educating the community as to the nature of the coronary episode and encouraging the precoronary patient to go to a hospital even with relatively minor symptoms. It requires the development within hospitals of a precoronary area where monitoring of coronary suspects can be carried out. Such a policy would bring patients under electrocardiographic surveillance early in the course of their disease. It may be argued that such a practice represents a major effort for a small yield of significant results. The very essence of preventive medicine, however, is to apply prophylactic measures to the many in order to protect the few who may become afflicted. It is also imperative to educate physicians so that they will expedite the transfer of patients to hospitals once a diagnosis has been made. Whenever possible the physician should institute antiarrhythmic measures before the patient is transported.

Another important effort is to begin monitoring a selected group of patients with coronary artery disease. If we should discover that in ambulatory individuals minor arrhythmias precede major derangements in the heartbeat, as is true in the hospitalized coronary patient, then monitoring on a large scale will have to be initiated. The information could be telemetered to special computers that are able to interpret the signals almost instantly and are programmed to alert both physician and patient of changes in heart rhythm. An additional strategy in precoronary care is to institute antiarrhythmic measures in certain high-risk patients who already exhibit minor disorders in the heartbeat.

The spirit of the time is the critical touchstone of progress, since it defines the possible. As we have seen, it is now possible to reduce sudden coronary deaths. In sheer magnitude of wasted human life, this cause of death is one of the most important medical problems in the highly developed countries. Yet this area of study has been woefully neglected. It is clear that the coronary care unit is only a first step. These units have already resulted in a reduction of hospital mortality from myocardial infarction. From the long-range point of view, however, the sharpening focus on the problem of sudden death and the placing of this problem on the agenda of current research may be the most important contribution of the many small coronary care units that have sprung up during the past five years.



LEADING CAUSE OF DEATH IN U.S. is the failure of some part of the cardiovascular system, usually the heart itself. Almost exactly one-quarter of the one million who died in 1966 from diseases of the heart and blood vessels were under 65 years of age. The number of people under 65 who died from cardiovascular diseases slightly exceeds the number under 65 years who were killed by cancer, accidents, and pneumonia and influenza combined.



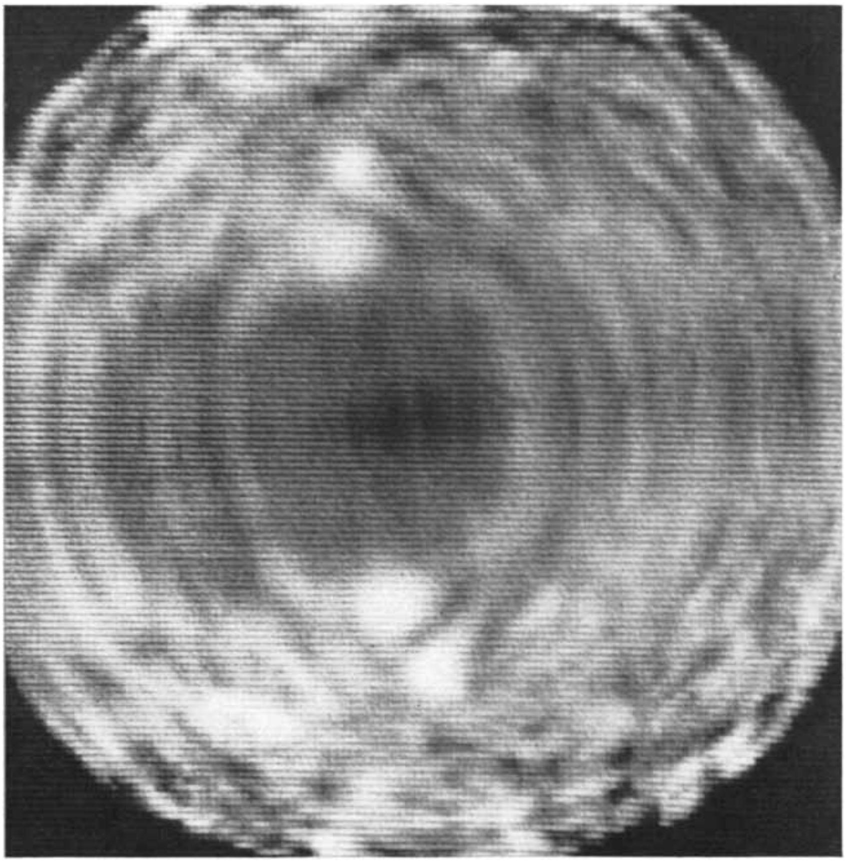
CORONARY HEART DISEASE, the clinical term for heart attack, regularly accounts for more than half of the victims of all cardiovascular diseases. About 28 percent of those dying from coronary heart disease in 1966 were younger than 65. Only rheumatic heart disease, a relatively minor cause of death, has a higher percentage of victims in the under-65 age group. In contrast, the great majority (82 percent) of stroke victims are over 65.

Radar Observations of the Planets

Echoes of high-frequency waves aimed at the planets from the earth provide a new test of the general theory of relativity and precise determinations of the anomalous spin rates of Mercury and Venus

by Irwin I. Shapiro

Just a decade ago planetary radar astronomy was only a glint in the eyes of a few electrical engineers and physicists. Yet by 1961 the first echoes of radar signals reflected from Venus had been detected. Radar contacts with Mercury and Mars soon followed. Although radar astronomy is still a very young science, it has already produced results whose scientific importance has far exceeded the most enthusiastic predictions. With this new technique one can, for example, investigate the spin and orbital motions of planets, their surface characteristics and the properties of the medium through which the radar signals pass. The data obtained and the theories developed are already far too extensive to be discussed adequately in a single article. I shall therefore concentrate primarily on a few of the more significant results: a new test of Einstein's general theory of relativity and, most surprising of all, discoveries concerning the rotation of Mercury and Venus.



RADAR PICTURE OF VENUS was made by Raymond F. Jurgens of Cornell University with the 1,000-foot radio telescope at Arecibo in Puerto Rico. In radar mapping the power of an echo from a given area of the target is determined as a function of the time the echo is received and the shift of the echo's frequency from that of the transmitted signal. A twofold ambiguity in plotting each point (*see text*) gives the planet a symmetrical appearance. This picture was obtained from the data shown in more direct form at the bottom of page 36.

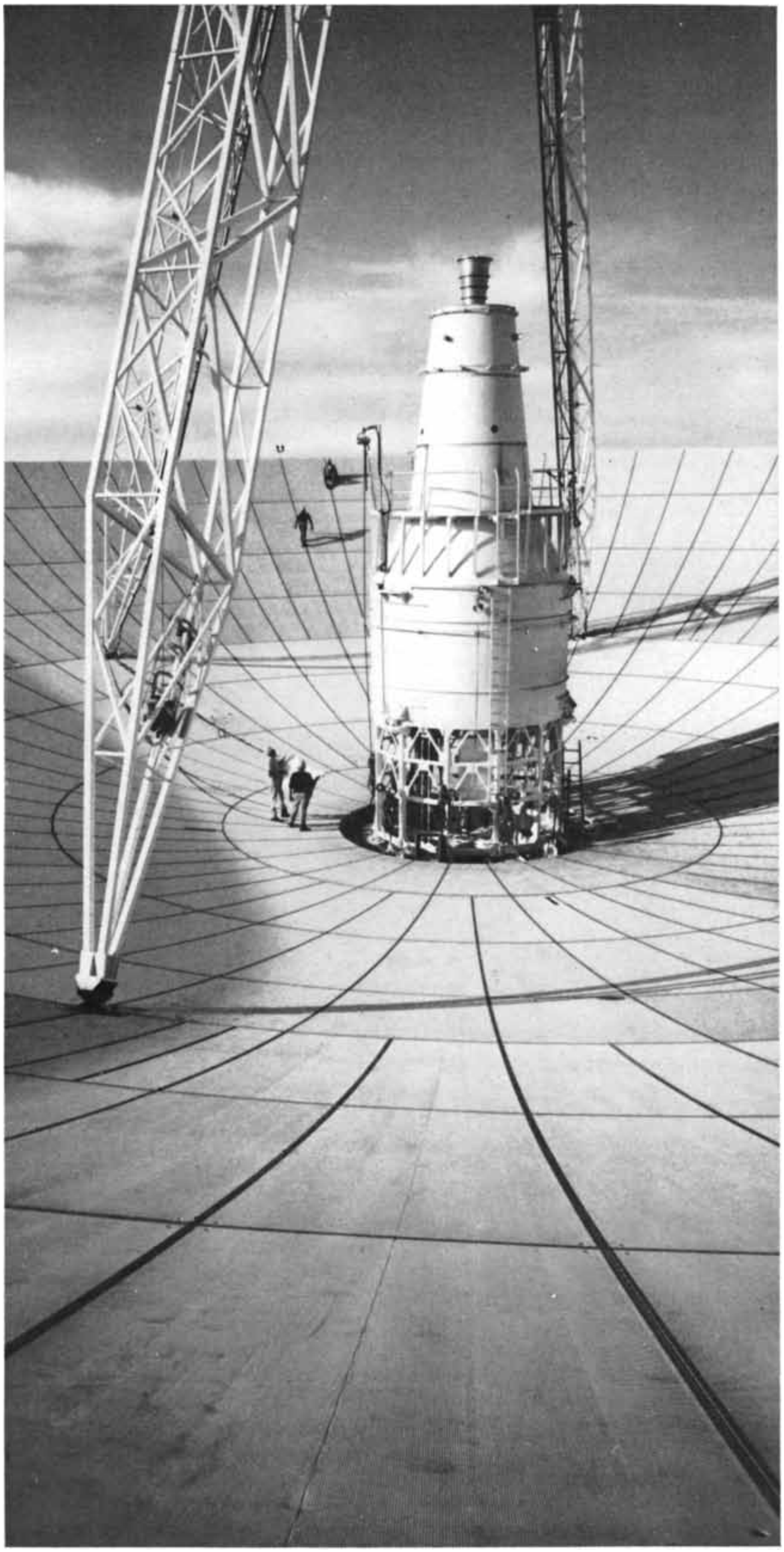
The basic experimental problem is to aim a carefully controlled radio signal at a distant planet, detect the echo and analyze it for the information it carries. For this to be done the energy in the echo must be sufficiently large. Since the energy density of both the transmitted and the reflected waves decreases with the inverse square of the radar-target distance, the energy of the echo received at the radar antenna varies inversely with the fourth power of that distance [*see top illustration on page 30*]. Hence there are enormous differences in the relative difficulty of detecting various objects in the solar system. The step up from the detection of echoes from the moon to the detection of echoes from Venus (at its closest approach to the earth) required about a 10-million-fold improvement in the sensitivity of radar systems. Yet only 15 years was required for this advance.

The primary instruments now being used for planetary radar astronomy are the Lincoln Laboratory's Haystack facility in Tyngsboro, Mass., operated at a frequency of 7,840 megacycles per second; Cornell University's 1,000-foot telescope at Arecibo in Puerto Rico (40 and 430 megacycles), and the Jet Propulsion Laboratory's radars at Goldstone, Calif. (2,388 megacycles). These three sites are continually jockeying for the lead in overall system sensitivity, having far outdistanced the competing facilities at Jodrell Bank in England and at the Crimean Tracking Station in the U.S.S.R., which have apparently given up the radar race.

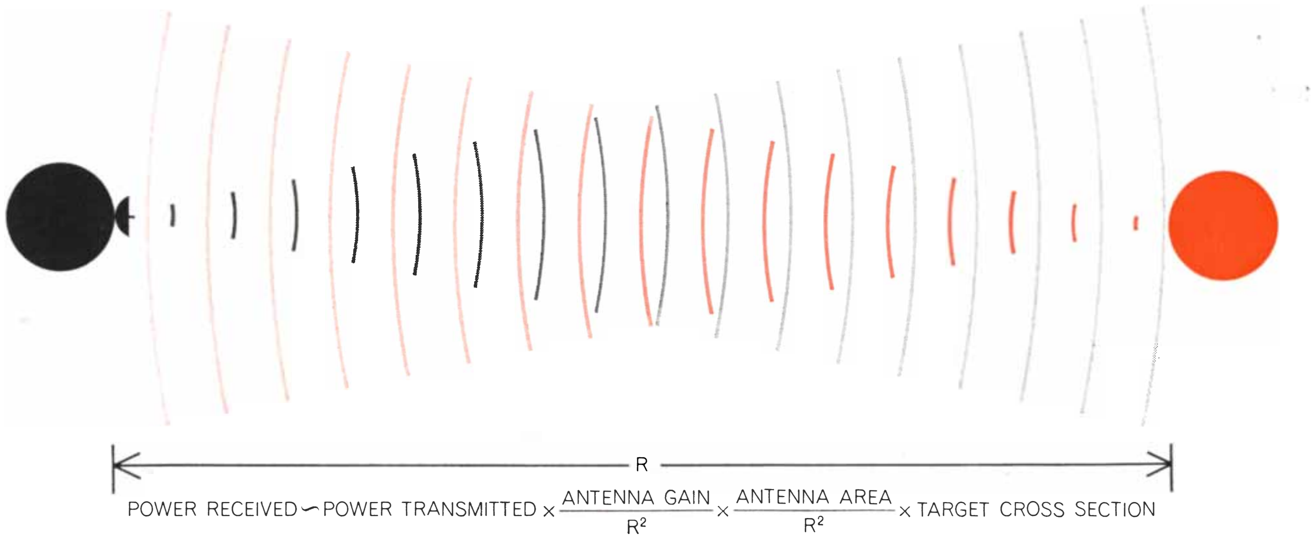
Just how sensitive are these contending radars? As an illustration, consider the Haystack facility, which can transmit continuously up to 400 kilowatts of power and routinely detects echoes almost 27 orders of magnitude weaker. Such echoes—about 10^{-21} watt—represent far less power than would be expended by a housefly crawling up a wall at the rate of one millionth of a meter per year. These minuscule signals are extracted from the much more powerful radio noise (originating partly in the receiver) by computer processing. Because the received signals are accumulated for many hours, the quantum aspects of detection can be safely ignored.

Considering the centuries of precise optical observations of the planets, one might wonder how a few years of radar measurements could make an important contribution to the study of planetary orbits. The significance of the radar data flows from two facts. First, radar adds two new types of measurement: the echo time delay, which is related to the round-trip distance through the travel time of light, and the Doppler shift of the echo from the planet, which yields the velocity of the reflecting surface along the line of sight. Second, many of the radar measurements are of unprecedented accuracy; precision exceeding one part in 100 million is now achieved routinely in interplanetary time-delay observations.

Why should anyone want to add yet another significant digit to the expressions for the orbital positions of the planets? One reason is that in planning planetary spacecraft missions knowledge of the distance to the objective is vital. Such distances were traditionally expressed in terms of the astronomical unit (in essence the average distance between the earth and the sun). Before 1961 the relation between this unit and the kilometer was known to only about one part in 1,000. Since no planet comes closer to the earth than 40 million kilometers, .1 percent errors can be serious! The first measurements of interplanetary time delays and Doppler shifts made by Gordon H. Pettengill and others at the Lincoln Laboratory and by Richard M. Goldstein, Duane Muhleman and others at the Jet Propulsion Laboratory contributed significantly to the success of the *Mariner II* mission to Venus in 1962. Recently Michael E. Ash, William B. Smith and I, using Lincoln and Arecibo radar data, have established the light-time equivalent of the astronomical unit



210-FOOT ALUMINUM ANTENNA operated by the Jet Propulsion Laboratory at Goldstone, Calif., is now being used for planetary radar astronomy. Its size and almost perfectly paraboloidal surface make it a sensitive instrument for aiming radio signals at planets and detecting the echoes. The "feed cone" protruding through the center contains both the transmitter and the receiver when it is used for radar observations. Signals are reflected between cone and antenna by a subreflector above them (*not visible in photograph*).



RADAR EQUATION shows how the received echo power is related inversely to the fourth power of the range (*R*). The planet (*right*) intersects a very small segment of the total spherical wave front emanating from the radar transmitter and reflects only a fraction of that power; the receiver, in turn, can collect only a small fraction of the signal (*colored wave front*) returned by the target.

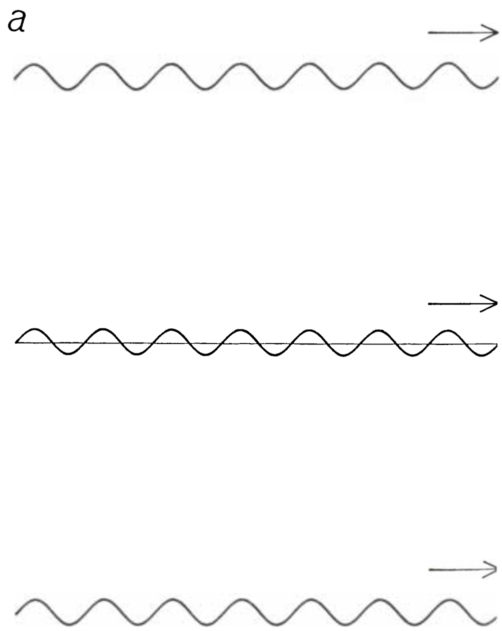
to about one part in 100 million. (The kilometer equivalent remains less accurate because the speed of light is still known only to one part in a million.)

In addition to the practical value of precise interplanetary distances there is an important potential theoretical gain: The more accurately one knows the positions of planets, the more decisively one can test the physical laws that attempt to account for them. These laws are embodied, for example, in Einstein's general theory of relativity, which had been subjected to only three experimental tests when, in 1964, improvements in radar sensitivity led me to point out that a fourth test was technically feasible. According to general relativity, a light wave or radio wave passing the sun is not only deflected (the basis of one of the three classical tests of the general theory) but also slowed. (This effect is just the opposite of what one might have expected, since matter speeds up on approaching a massive body. In both cases, however, the trajectory is bent toward the attracting center.) Can such a slowing be measured by radar? Suppose we continually beam radar signals at a planet. Only when it is on the opposite side of the sun from the earth at "superior conjunction" will the signals pass close to the sun and so be significantly affected by solar gravity [*see top illustration on page 33*]. The maximum increase in delay, when the signal just grazes the sun, was predicted to be some 200 microseconds, about one part in 10 million of the total echo time delay.

The experimental problem, then, is to search for this very small difference. One should, of course, first know what delays to expect in the absence of a relativistic effect. That is, one must determine the orbits of the earth and the target planets far more accurately than was previously possible. This intermediate goal is accomplished by making a large number of accurate radar time-delay and Doppler-shift measurements and using them to determine the orbits and such necessary quantities as the masses and radii of the target planets. All calculations are carried out within a consistent (relativistic) theoretical framework. By following this procedure we can now predict planetary positions to within about 10 microseconds in terms of the travel time of light, or to within roughly 1.5 kilometers one way.

So far I have made the tacit and false assumption that the radar signal is unaffected by the medium between the earth and the target planet. The most important influence is the plasma of the solar corona, which also tends to decrease the speed of propagation of the radar signal. Fortunately this slowing can be distinguished from the corresponding effect of relativity: The plasma influence is inversely proportional to the square of the radar frequency, whereas the relativity effect should not vary with frequency. These facts present us with several experimental options, the most convenient of which is to make the measurements with waves of a frequency high enough to reduce the plasma effect to a negligible level.

A major question remains: How is it possible to measure the round-trip radar delay to within 10 microseconds considering that a planet is a huge target and that the radar beam is wider still? A key point in the answer lies in the planet's reflecting radar waves in a quasi-specular manner, that is, reflecting them much as a polished ball bearing reflects light. Most of the echo power therefore stems from reflections near the subradar point: the point where the surface of the planet



DELAY-DOPPLER MAPPING depends on the delay and frequency of the echo from each reflecting area (*a*). The signal (*black waves*) is reflected first from the subradar point (*on line from radar to center of tar-*

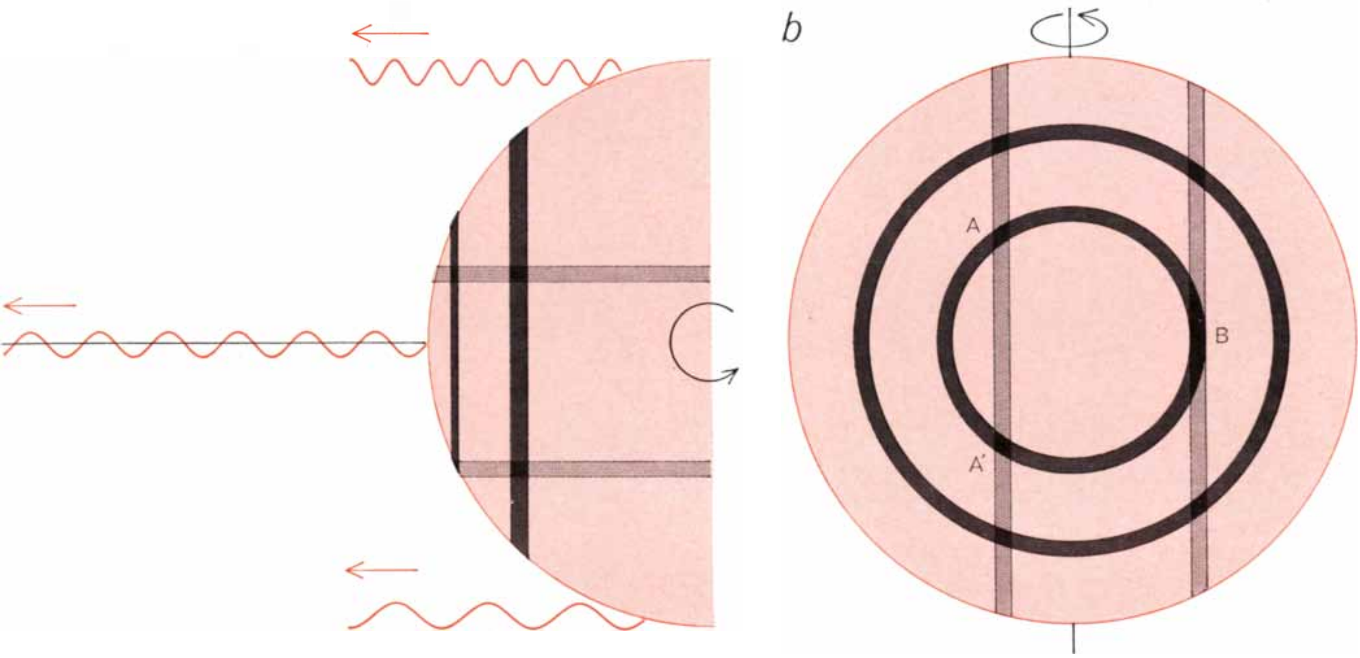
intersects the line from the radar site to the planet's center. Further refinement in establishing the time delay specifically to the subradar point is achieved through delay-Doppler mapping, a major tool of the radar astronomer that was first suggested by Paul E. Green, Jr., of the Lincoln Laboratory in 1959. This technique is based on the planet's being so large compared with the wavelength of the radar signal that one can consider its surface to be composed of separate elements, each reflecting independently of the others. Every surface element is therefore considered to reflect an incident wave front at a particular time delay and to impart to that reflection a particular Doppler shift.

If the transmission consists of short pulses, then the echo received at any instant will correspond to reflections from a set of points equidistant from the earth. These points define contours of equal time delay, which correspond to rings on the planet that are perpendicular to the line from the radar to the planet's center. Similarly, there are contours of equal Doppler shift. As viewed from the radar the target planet appears to have a certain rotation, the result of the relative orbital motion of the earth and the planet and of the planet's intrinsic spin. This apparent rotation causes each reflecting element to impart a characteristic Doppler shift to the single-frequency radar signal: A surface element moving toward the earth will return an echo with a frequency higher than the frequency of the transmitted signal; an element moving away from the earth will return an echo with a lower frequency. Points on the surface that impart the same Doppler shift to the incident signal define an arc on the surface in a plane parallel to the plane containing the radar site and the target's apparent rotation axis [*see illustration below*].

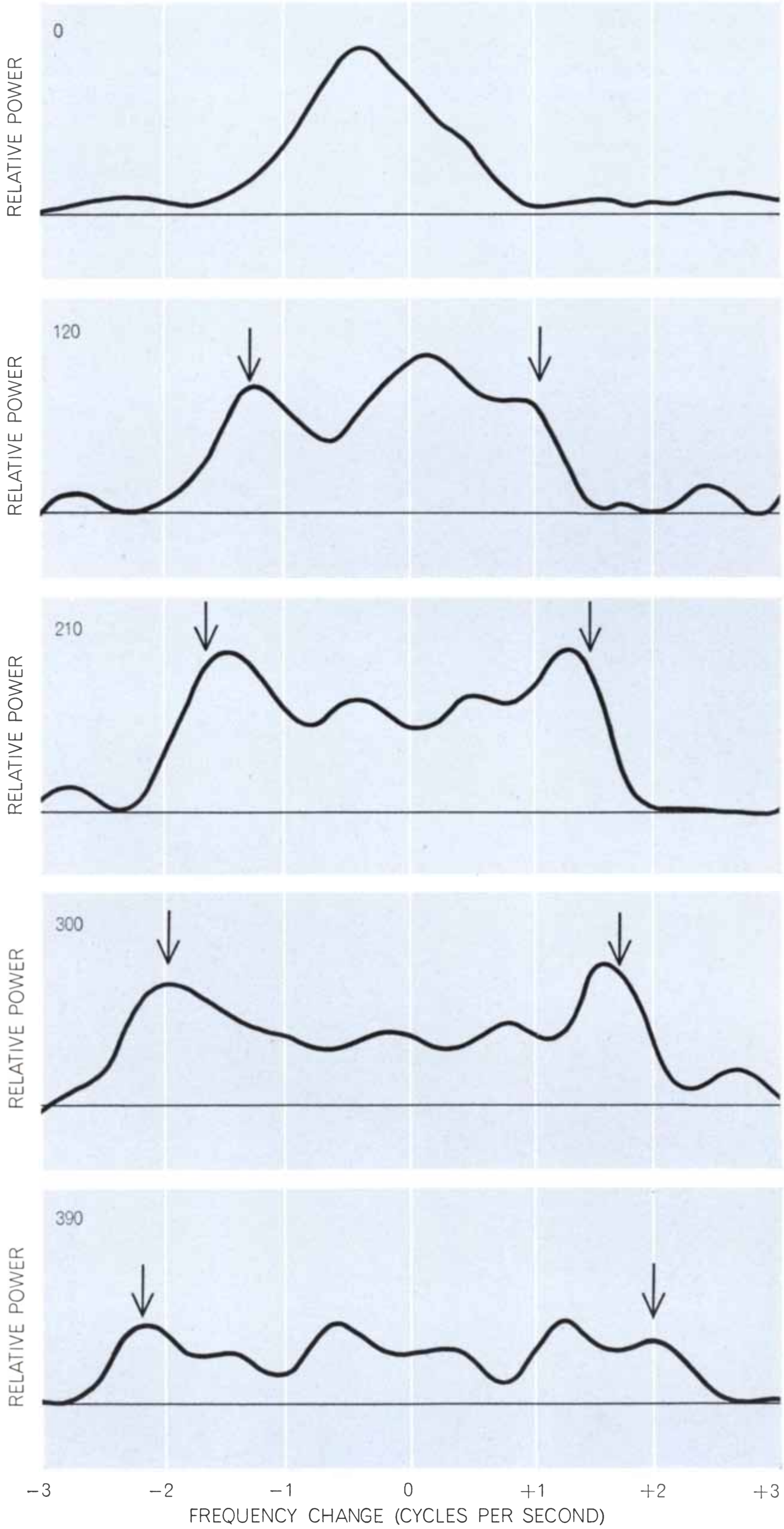
A combination of the contours of equal time delays and equal Doppler shifts yields a delay-Doppler map of the planetary surface, a map in which the echo power of elements on the surface is plotted against delay and frequency [*see illustration on next page*]. Such maps have an unusual property: Since the same Doppler shift is imparted to the signal by two different points on the surface, there is a twofold ambiguity for all points not lying on the apparent equator. Along this equator a Doppler contour intersects just a single segment of a delay ring. Since the Doppler and delay contours are parallel at that point, the area of intersection is greatly enlarged.

How do we use the delay-Doppler mapping principle to pinpoint the time delay and the Doppler shift that correspond to reflections from the subradar point? First we prepare a two-dimensional "template" from observations made when the target planet is nearest the earth and the echo signal is consequently strongest. This is an electronic record of the expected form of the echo: its power as a function of the delay and Doppler coordinates in relation to the subradar point. Now, in any given situation—when the planet is far away, for example—the template, correctly adjusted, shows the expected echo power with respect to the subradar point. What will be unknown are the actual values for the delay and Doppler shift corresponding to the reflection from that point. These values are obtained by cross-correlating the actual echo with the template; the values for which the cross correlation is maximum constitute the best estimates of the delay and Doppler shift undergone by the signal reflected from the subradar point.

This procedure, first suggested by Robert Price of the Lincoln Laboratory, has been applied since 1966 to planetary echoes observed at Haystack. From such measurements made near the superior conjunction of Venus in that year and during the first three superior conjunctions of Mercury in 1967, Pettengill, Ash, Melvin L. Stone, Smith, Richard P. Ingalls, Richard A. Brockelman and I concluded that the sun's gravity does decrease the speed of propagation of electromagnetic waves by about the amount



***get*) and later from areas nearer the limb. An echo from the limb approaching the earth (*top*) is Doppler-shifted to a higher frequency than the echo from the subradar point, an echo from the receding limb (*bottom*) to a lower frequency (*colored waves*). Areas of equal delay lie in planes (*dark gray*) perpendicular to the line of sight; areas of equal Doppler shift lie in planes (*light gray*) parallel to the axis of apparent rotation and the line of sight. On the face of the target (*b*) these planes establish delay (*rings*) and Doppler (*strips*) contours. There is a twofold ambiguity in mapping (*A, A'*) except at the apparent equator, where the intersection area is enlarged (*B*).**



SPECTRA of echoes from Mercury provide a crude delay-Doppler map of the surface. The echo power is plotted, for returns from each of five delay contours up to 390 microseconds from the subradar point, as a function of the frequency shift in relation to the echo from the subradar point. The arrows show the positions of the edges of the spectra (the enlarged areas of intersection of contours at the apparent equator) that correspond to a rotation period for Mercury of 59 days. The spectra were obtained at the Arecibo observatory.

predicted by general relativity; the experimental uncertainty was about 20 percent [*see bottom illustration on opposite page*]. It should be possible to increase the accuracy significantly with the aid of space probes or of radio beacons placed on the surface of planets.

The same delay and Doppler measurements can also be used to improve the accuracy of the third classical test of general relativity—the measurement of the advance of the perihelion of Mercury's orbit—and to show whether the sun is oblate and whether gravitational forces change with time. Such deductions, which depend primarily on the gradual accumulation of small effects, will become increasingly precise as measurements are collected over a long period. For example, within the next five years a change in the gravitational constant of less than one part in 10 billion per year should be discernible!

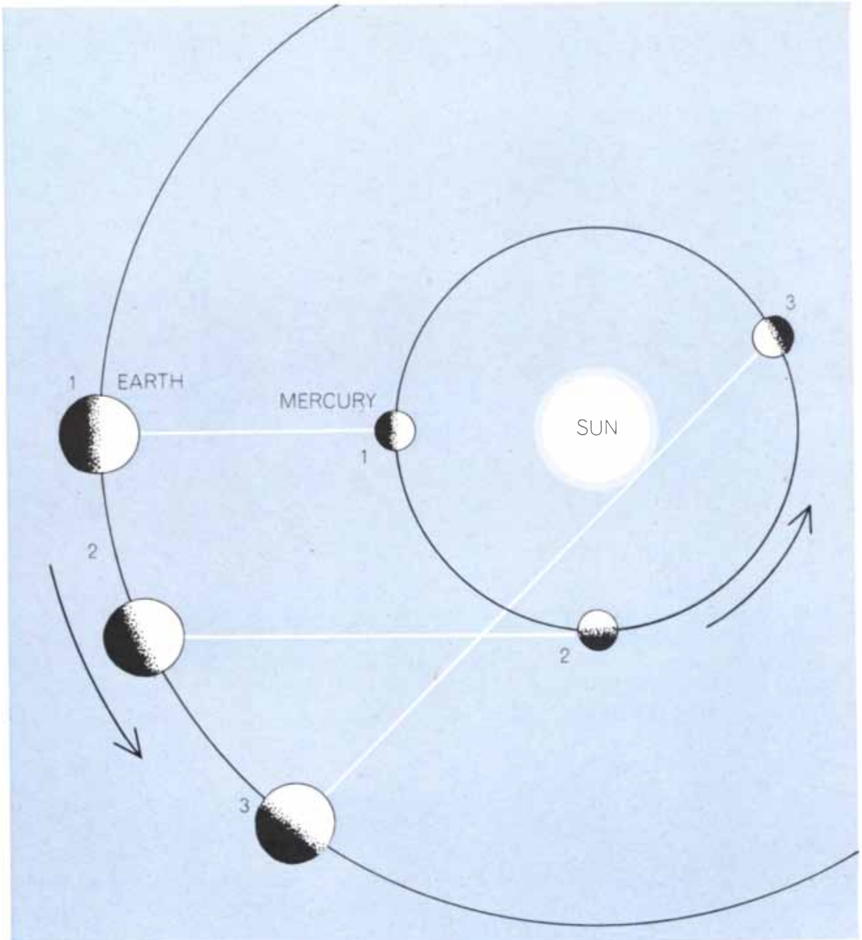
The most striking discoveries made with planetary radar observations concern the rotation rates of Mercury and Venus. It may seem strange that these rates have not been well known from telescopic observations. Astronomers had indeed thought they knew the spin of Mercury, but thoughts change. Venus, on the other hand, is hidden behind the veil of its atmosphere, and optical observations of its surface have been impossible.

Early in the 19th century the German observer J. H. Schröter noted mountains rising to 20 kilometers on Mercury and made many drawings of the appearance of the planet's surface. From these the mathematician Friedrich Wilhelm Bessel deduced a rotation period of just over one day. Although some astronomers remained skeptical, many found it aesthetically appealing to think that Mercury, like Mars, had a day about as long as the earth's. Not until the late 1880's was this "fact" discredited: Giovanni Schiaparelli's extended series of observations then convinced almost everyone that Mercury was rotating much more slowly. He himself concluded that Mercury's spin was actually synchronous with its orbital motion, the planet making one rotation on its axis for each revolution about the sun. From that time until the spring of 1965 all observations—and there were literally hundreds—were interpreted as being consistent with the 88-day synchronous spin period. (One noted astronomer, in affirming this conclusion, even scoffed indignantly at earlier observers who had accepted the 24-hour period, "as if God would adhere to the aesthetic views of Man.") He went on, however, to point out the aesthetically pleasing similarity between Mercury's synchronism with the sun and the moon's with the earth!) Although partial rationalizations can be given, it is nonetheless unsettling to contemplate this persistence of self-deception.

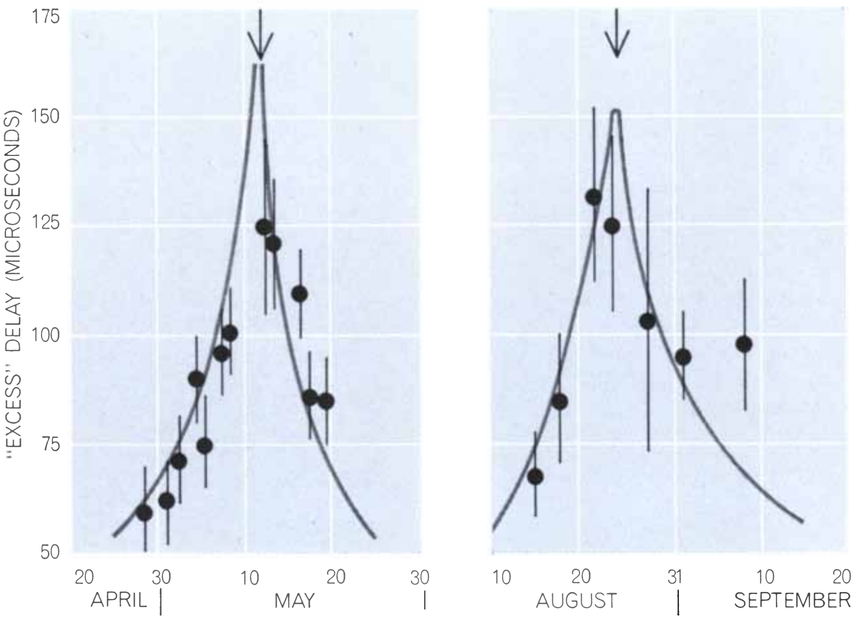
Then, in the spring of 1965, Pettengill and Rolf B. Dyce used radar observations made at Arecibo to show rather conclusively that Mercury's spin period is nearly 59 days. The basis of this radar determination was again delay-Doppler mapping: the faster the apparent rotation of the planet, the greater the difference in frequency between reflections from the two sides of each time-delay ring [*see illustration on opposite page*]. By making a large number of such measurements at different orbital positions, the various ambiguities were resolved and the speed of the planet's rotation was established.

How is this result for Mercury's spin to be interpreted? Does it represent a stable, final spin state or a stage in evolution toward a synchronous spin? Stanton J. Peale and Thomas Gold of Cornell suggested that because of the large eccentricity of Mercury's orbit the present spin state could be stabilized by the average torque exerted by the sun on the tidal bulge it raises on Mercury. Shortly thereafter Giuseppe Colombo of the Smithsonian Astrophysical Observatory noted that 59 days is almost exactly two-thirds of Mercury's orbital period of 88 days. He proposed that Mercury's spin might be locked to its orbital motion in a 3/2 spin-orbit resonance, with the planet rotating precisely one and a half times during each revolution about the sun. Colombo and I then developed a mathematical model, taking account of the tidal effects and also of the torque exerted by the sun on any permanent axial asymmetry in Mercury's mass distribution, and found that the resonance lock was possible and indeed would be stable. Peter Goldreich and Peale confirmed this, showing that the probability of capture into the 3/2 state might be about one chance in five. That is not a large probability, yet no one could be mortally offended that our one sample (Mercury) corresponded to an event with a probability of .2.

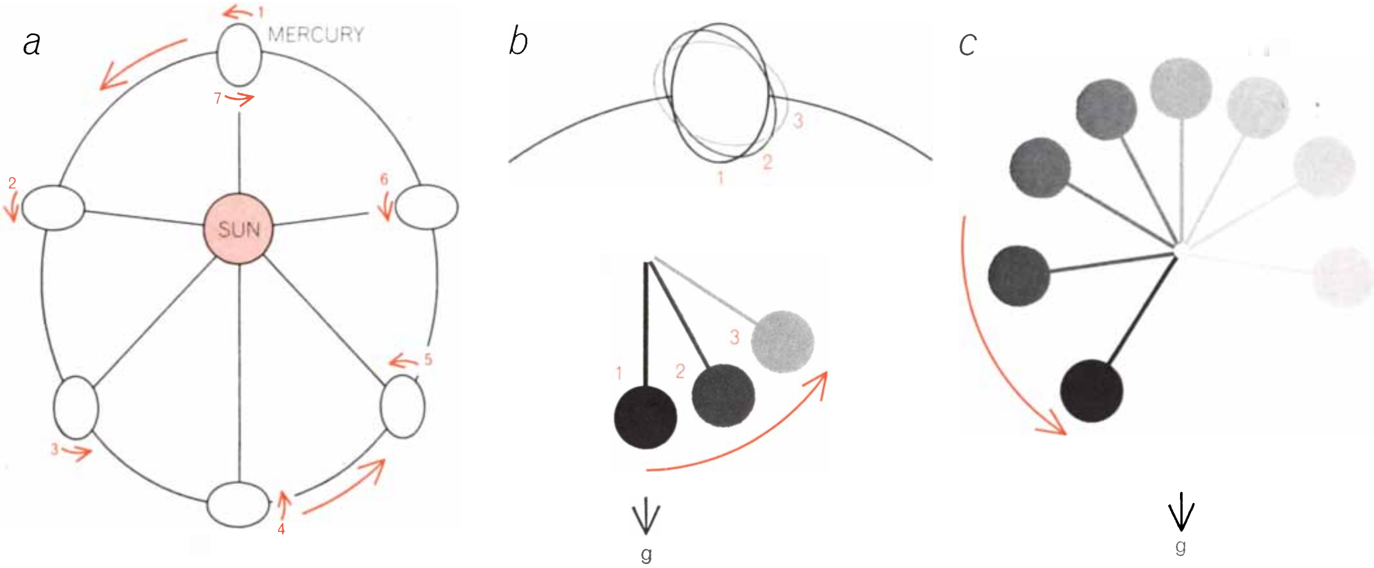
The story does not end here, however. The probability calculation was based on Mercury's having maintained its present orbital eccentricity during the process of capture into the spin-orbit resonance, but in fact the pull of other planets tends to change the eccentricity



SUN'S EFFECT on radar travel time between the earth and Mercury is very small at inferior conjunction (*1*) and elongation (*2*), but near superior conjunction (*3*), as the general theory of relativity predicts, radar signals will be slowed down appreciably as they pass the sun.



EFFECT OF SOLAR GRAVITY on earth-Mercury delays near two 1967 superior conjunctions (*arrows*) was about as predicted by general relativity. From delays computed on the basis of radar determinations of orbits, the "excess" delay caused by the sun was predicted (*gray curves*). Then actual delays were measured and "excess" delays determined (*black*).



SPIN CAPTURE of Mercury by the sun can be understood by analogy with the motion of a pendulum. In the 3/2 spin-orbit resonance state Mercury will rotate one and a half times during each revolution around the sun (*a*). If it rotated slightly "too fast," its positions at successive perihelia (close approaches to the sun) would be like successive positions of a swinging pendulum (*b*). Coming to a halt at 3, the pendulum swings back under the influence of gravity (*g*); similarly, Mercury's orientation at perihelion swings back through the action of the solar torque exerted on Mercury's egg-shaped equator. However, Mercury probably once rotated much faster than the 3/2 rate, its orientations at perihelia corresponding to a rotating pendulum (*c*). Mercury's rotation rate was undoubtedly slowed by

and thus affects the capture process. Charles Counselman of the Massachusetts Institute of Technology therefore introduced the available material on past variations in eccentricity and found that the probability of capture was reduced to about .02. That a single sample should correspond to an event with this low a probability is quite offensive to one's sensibilities. What could be wrong?

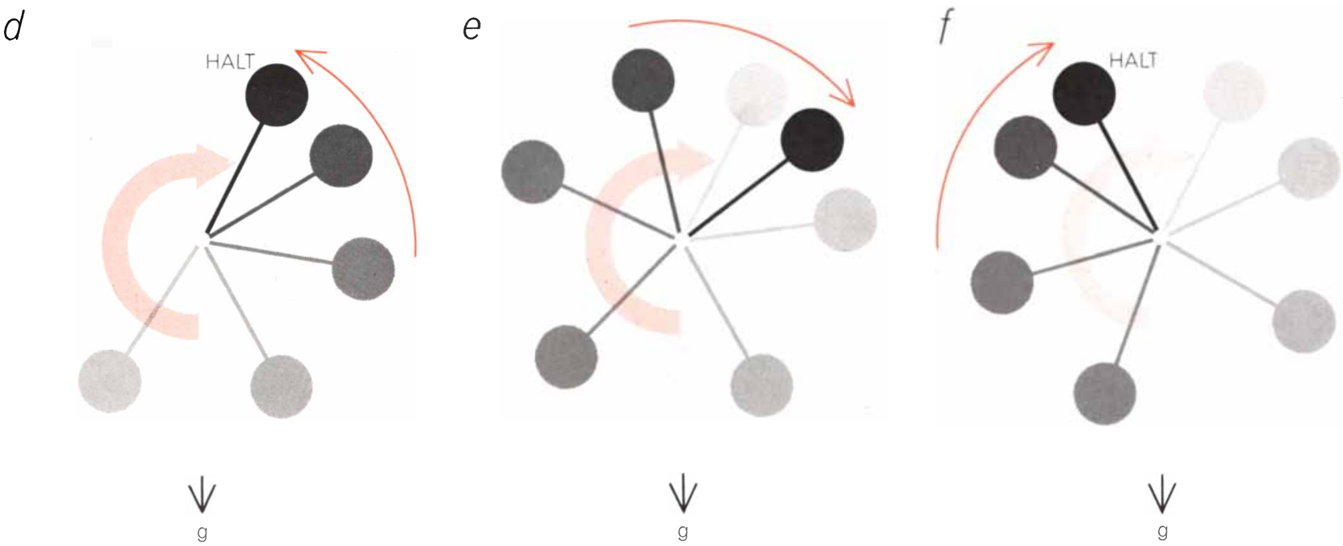
The value for the capture probability is clearly no better than the assumptions on which it is based. Two important assumptions may contain serious flaws. First, values of Mercury's orbital eccentricity have only been calculated reliably back a million years; perhaps deeper in the past the eccentricity was larger, a condition that would enhance the probability of capture. Second, Mercury may not be a rigid solid, as has been assumed; if its outer portion is coupled to an inner core by a viscous medium of some kind, the drag forces introduced could significantly raise the probability of capture. Both possibilities are now being investigated.

Finally, we must entertain the possibility that Mercury's spin may not be in the 3/2 resonance after all. The radar result established the spin period only approximately, as 59 ± 3 days. Some astronomers, studying old drawings and photographs, have pinned it down more closely, however, to within .01 day of the exact resonance value of 58.65 days. (Astronomers have tended to observe Mercury once a year, when conditions are most favorable. In that period Mercury completes about four orbits. It did not occur to the earlier observers that Mercury could meanwhile have rotated not four times but, say, six.) This optical confirmation is heartening, but past experience suggests that we should await more evidence before concluding that Mercury's spin is adhering to our current aesthetic values.

The Venus story is equally fascinating. Because of its veil—now thought to resemble smog more closely than clouds—the surface of Venus has never been seen from the earth. Before the first radar observations estimates of Venus' rotation period were therefore based on the Doppler shifts of spectroscopic lines from constituents of the planet's atmosphere and on the motion of features in the atmosphere. Even the sense of the rotation—direct (in the same direction as Venus' orbital motion) or retrograde—could not be determined. The evidence seemed to favor a slow rotation; most astronomers thought the spin was direct and synchronous, as Mercury's was then thought to be. The first Venus radar measurements in 1961 established only that the rotation was slow. Later more detailed analyses of these data by Smith and independently by Roland L. Carpenter of the Jet Propulsion Laboratory suggested that the direction might be retrograde. By the time Venus was again near the earth (in 1962) the sensitivity of the Goldstone facility had improved enough for Carpenter and Goldstein to prove that the rotation is indeed retrograde. On Venus (at least above its atmosphere) the sun rises in the west and sets in the east.

The retrograde spin is demonstrated when bandwidth data, obtained by the delay-Doppler technique, are plotted against time. The curve always dips near inferior conjunction, showing that the total angular velocity is least when the earth-Venus distance is smallest. Now, the apparent rotation caused by the relative orbital motions of the earth and Venus is inversely proportional to the distance between the planets. The dip in the curve therefore implies that the two contributions to the total angular velocity are opposing each other. Since the apparent rotation is in a direct sense (because Venus moves around the sun faster than the earth does), the intrinsic spin of Venus must be retrograde.

Since 1962 the spin period has been determined with increasing precision from bandwidth data and from following the motion of distinguishable surface features that appear on radar maps. My most recent calculations yielded a period of 243.1 ± .2 days. This number is significant because, as Goldstein noted in 1962, a retrograde rotation with a period of 243.16 days implies that Venus presents the same face to the earth at every close approach. The experimental results suggest strongly, therefore, that the rotation of Venus is being controlled not by the sun but by the earth!



tidal friction as an analogous pendulum (*d*) is brought to a halt by an opposing torque (*broad arrow*). Further evolution can proceed by one of two paths. If the opposing torque maintains its strength, the pendulum will continue to accelerate, with the rotation now in the opposite direction (*e*); this possibility corresponds to Mercury's penetrating the resonance "barrier." If the opposing torque has a velocity-dependent component, and hence has a magnitude that depends on the direction of rotation, the pendulum may halt again (*f*), oscillate and finally come to rest. This possibility corresponds to Mercury's being trapped in the spin-orbit resonance (*a*). The outcome also depends on the initial conditions of the rotational state, which makes the capture process a probabilistic affair.

How can the retrograde motion and the control apparently exerted by the earth be explained? One might assume that Venus' primordial spin was retrograde, but data from other planets suggest that this possibility is unlikely; the initial rotation of Venus was probably rapid and direct. Solar tidal forces could have been strong enough to slow the rotation to a synchronous value, but for Venus such a state should be quite stable, and it is hard to imagine torques strong enough to break the resonance lock. One rather fanciful possibility is that Venus once collided with an asteroid with a diameter of about 200 kilometers, a cataclysm that could have reversed the planet's rotation, converting a synchronous spin into a retrograde one near the present value.

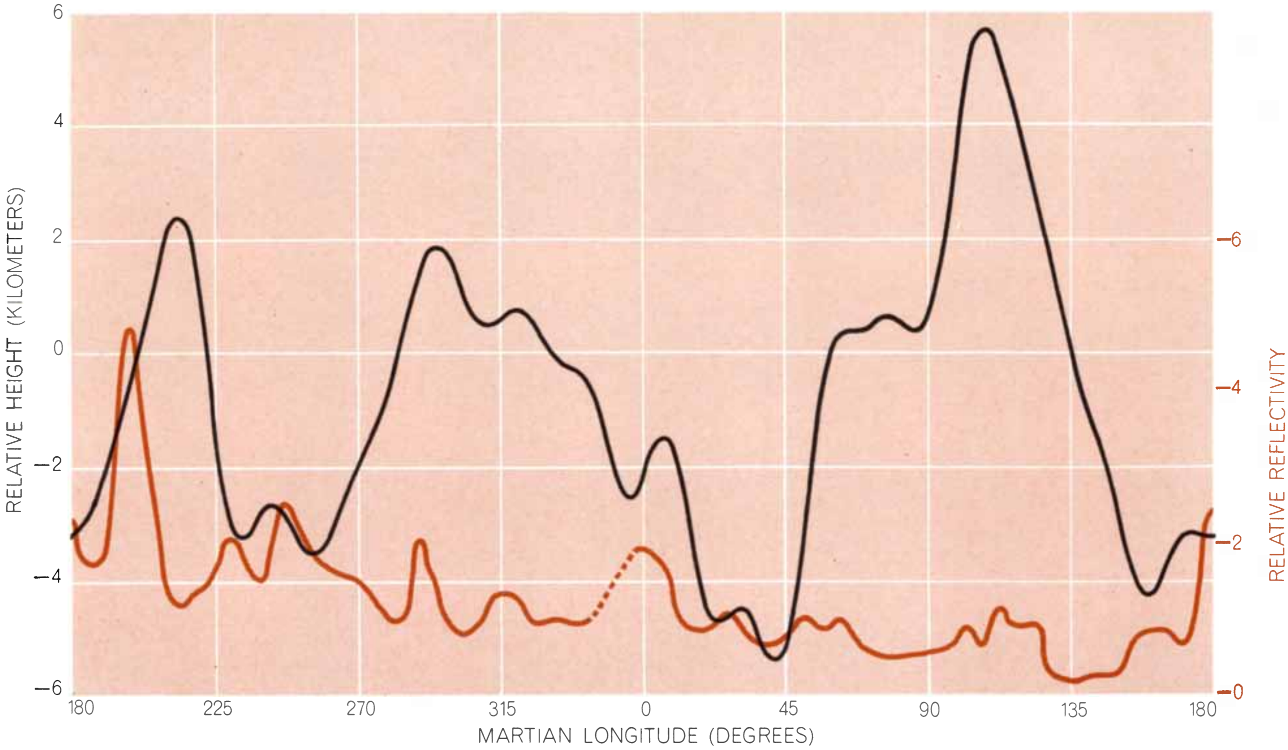
Given that Venus' spin was somehow established at a rate near resonance with the relative orbital motion of the earth and Venus, it is conceivable that the earth could acquire a controlling influence over that spin through the gravitational torque exerted on a permanent axial asymmetry in Venus' distribution of mass. The probability is vanishingly small, however, unless—as Ettore Bellomo, Colombo and I suggested—a viscous tidal force is operative. Goldreich and Peale went considerably further and assumed that Venus had a liquid core, suitably coupled to its mantle. They showed from this model that the probability of spin capture by the earth could be raised to a respectable level—perhaps to about .1. In spite of all this theoretical activity our understanding of the axial rotation of Venus is still far from complete. Yet one cannot help but be impressed at the thought that sensible inferences about a liquid core in Venus can be made from earth-based radar observations.

Radar reflections from a planet can, as one might expect, disclose properties of the planet's surface and sometimes of its atmosphere as well. Simply from the fraction of incident signal power that is reflected (more precisely, the radar cross section, which takes into account the size of the target, its surface roughness and its reflectivity), one can infer the approximate dielectric constant of the surface material in the vicinity of the subradar point and thereby obtain an important clue as to its composition. The average values of the radar cross section for Mars, Mercury and the moon are all about the same (approximately 7 percent of the geometric cross section) and seem not to vary much as the radar frequency is changed. There is, however, substantial variation over the surface, apparently greatest for Mars. For example, at Arecibo's 430-megacycle frequency the effective dielectric constant was observed to vary from about 2 to 4.5 around the 22nd parallel of north latitude. Such values suggest a material much like some of the earth's rock and soil and eliminate the possibility of appreciable expanses of water.

The cross-section values for Venus are generally higher and show less change with aspect but a marked change with frequency: the cross section was discovered to drop off sharply at high frequencies, a change that is attributed largely to the attenuation of short radar waves in Venus' atmosphere. The dielectric constant of 4.5, determined in 1961 at longer wavelengths, seemed clearly incompatible with large bodies of water, as has been verified by later ground-based and space-probe data.

Planetary topography can be studied with radar by monitoring the time delay of the echo from the subradar point as the planet rotates and thus recording fluctuations in altitude. For a rapidly spinning planet such as Mars the variations in delay caused by changing topography are readily differentiated from those caused by relative orbital motions because the periodicities of the two effects are so different—one day as compared with two years. Measurements made by Pettengill at Haystack in 1967 along the 21st parallel of north latitude on Mars disclosed height variations of about 12 kilometers, the most striking aspect of which was the regular, wavelike nature of the fluctuations [*see top illustration on next page*]. An unexpected finding was the lack of a strong correlation between elevation and either optical or radar brightness.

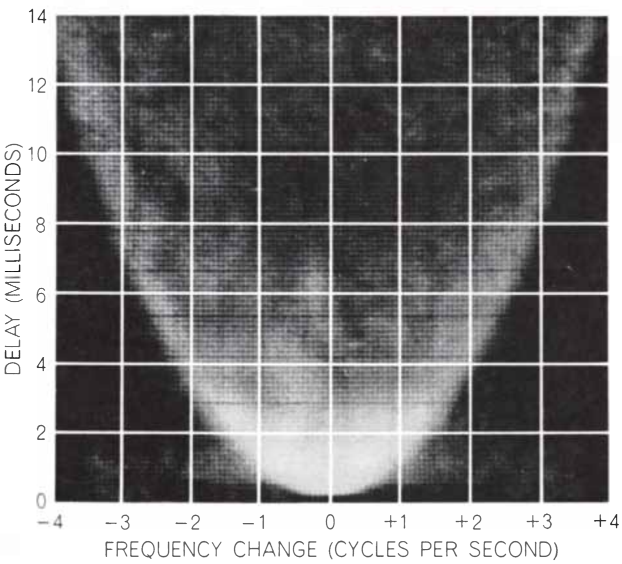
The determination of corresponding height variations on Mercury and Venus is greatly complicated by the similarity of their spin and orbital periods, which

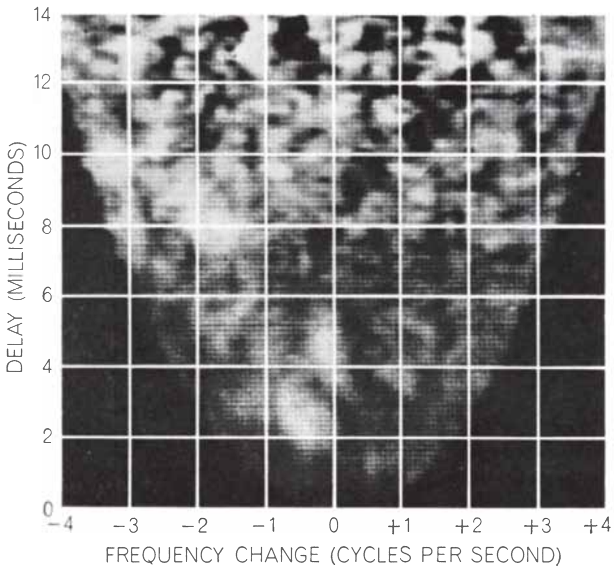


TOPOGRAPHY AND REFLECTIVITY of Mars along the 21st parallel of north latitude are based on measurements made as the planet rotated 360 degrees with respect to the earth. The altitude (*black*) does not seem to be strongly correlated with the radar reflectivity (*color*). Some of the fine structure shown is probably attributable to measurement error and may not be significant.

inhibits the separation of topographic and orbital effects. Nonetheless, the separation is possible, and preliminary analyses indicate that the height variations are far less pronounced than they are on Mars.

Using the delay-Doppler technique, one can in principle construct a picture of a planet from the signal power reflected from each surface element (or, more precisely, from each delay-Doppler "resolution cell"). Such a radar picture, which is a plot of power as a function of delay and frequency, is analogous to an optical photograph, which is a plot of intensity as a function of latitude and longitude. The major difficulty in making radar pictures is a practical one: insufficient signal strength requires integration of the power over a comparatively large area, making the delay-Doppler cell



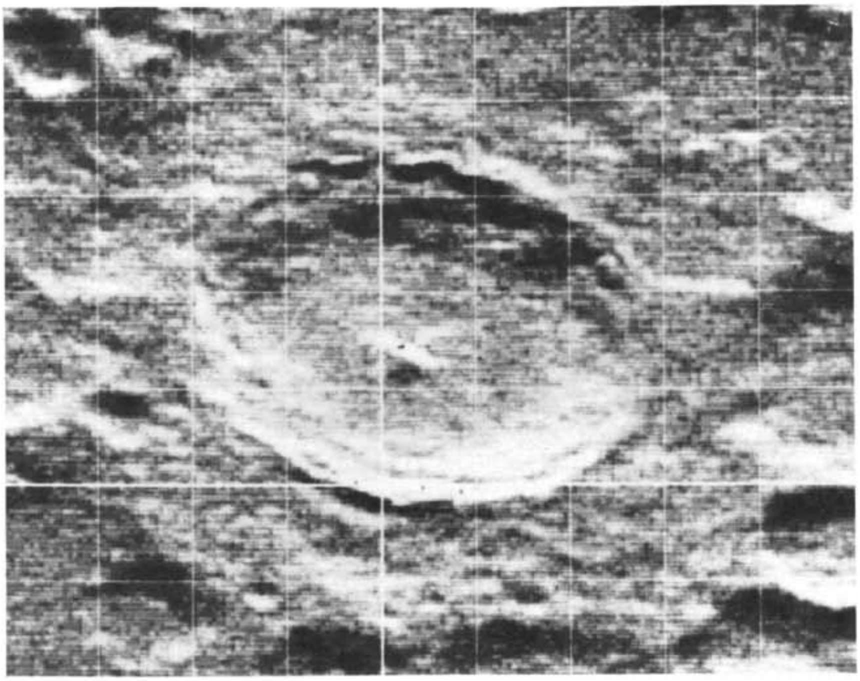


PRODUCTION of the radar picture of Venus (*see page 28*) began with the delay-Doppler map (*left*) based on August 6, 1967, observations, in which brightness is proportional to the logarithm of the power received at a given delay and frequency. The very bright area surrounds the subradar point. Its brightness is reduced and surface features are revealed when the theoretical values for a smooth, spherical surface are subtracted, leaving a representation of anomalous reflecting areas (*right*). This information is mapped into the usual surface coordinate system to prepare the final picture, which covers an area of Venus about 100 degrees in diameter.

large and sacrificing the inherently high resolution of the technique.

At present only radar pictures of the moon can be produced with high quality. These are comparable to the best earth-based optical photographs but are naturally far inferior to the Lunar Orbiter or Surveyor results. Radar pictures of the surface of planets that are not readily accessible to optical observation would of course be most valuable. Relatively crude (100- to 200-kilometer resolution) radar pictures of Venus have been prepared recently by Tor Hagfors and Alan Rogers at Haystack and by Raymond F. Jurgens at Arecibo [*see illustration on page 28*]. The echoes from Mercury are quite weak for mapping, but there are indications that the planet may turn out to have unusual surface characteristics. To achieve the goal of mapping more of the surface of these inner planets with substantial resolution, better radar systems are required.

Another approach to taking radio-wavelength pictures of planetary surfaces is to use two terminals, a large one on the earth and a second in a spacecraft orbiting the target planet. With one acting as transmitter, the other can receive both the direct rays and those reflected by the planet, thus enabling a hologram to be constructed. An attempt at applying this technique to the moon was made recently by G. L. Tyler, Von R. Eshleman and their colleagues at Stanford University using the Lunar Orbiter. The results are promising but much work must still be done to perfect the analysis.



PICTURE OF MOON made with radar at the Lincoln Laboratory by Gordon H. Pettengill and others is comparable in resolution (one or two kilometers) to a ground-based optical photograph. The major feature is the crater Tycho in the moon's southern hemisphere.

Quite surprisingly earth-based radar observations have also played a crucial role in determining the surface temperature and pressure on Venus. Last October Russian workers reported that their spacecraft *Venus 4* had radioed such information from the surface. The data indicated that the temperature there was about 550 degrees Kelvin (280 degrees centigrade) and the pressure approximately 20 atmospheres. The following day *Mariner V* passed by Venus. From an analysis of the changes in Doppler shift of the signals transmitted from the U.S. probe it was possible to infer temperatures in the higher regions of the atmosphere as a function of the distance from the *Mariner*-earth ray path to the center of Venus. On the basis of a single radar measurement made by *Venus 4* of its altitude, the Russian values of temperature were related to the height above the surface. Combining the measurements from the two spacecraft led to a determination of the radius of Venus. There was only one difficulty: the radius deduced from the probe data was about 25 kilometers higher than the one Ash, Smith and I had found in 1966 from an analysis of the radar time-delay data. This year several independent studies were made of the accumulated radar data from Arecibo, Goldstone and Haystack. All confirmed the previous radar value of the radius.

Assuming that the *Mariner V* measurements and the radar radius are correct, one can extrapolate to find a surface temperature of about 700 degrees K. and a pressure of about 100 atmospheres. These values have the virtue of being able to account, through absorption, for the low radar cross section observed at high frequencies by Smith, John V. Evans and others at the Lincoln Laboratory. Consistency is then also achieved with earth-based measurements of the frequency dependence of Venus' radio-brightness temperature. The surface atmospheric properties inferred from *Venus 4* can explain neither without the aid of rather arbitrary assumptions. One is almost forced to conclude that the altitude measurement made aboard *Venus 4* was in error and that the spacecraft stopped transmitting its steady stream of remarkable data about 25 kilometers above the surface. Thus the seemingly innocuous determination of the radius of Venus from radar data will play a pivotal role in the planning of further space-probe investigations of the lower atmosphere and surface of our sister planet.

The most recent triumph of radar astronomy was the first direct contact with a minor planet, Icarus, achieved at Haystack and Goldstone in mid-June during Icarus' close approach to the earth.

What can be predicted for the future of radar astronomy? The past growth in radar capability can only be termed explosive. Since World War II overall system sensitivity has improved on the average by a factor of almost four each year. Although sustaining this growth rate permanently might prove a bit difficult, the pace could be maintained easily for at least another decade using only present technology and without spending a significant fraction of the gross national product. In fact, a radar telescope has already been designed that would be nearly 1,000 times more sensitive than Haystack. The estimated costs for the new facility are less than for a single Mariner spacecraft. This increased sensitivity would bring many more objects in the solar system—such as the Galilean satellites of Jupiter and the two tiny moons of Mars—under radar surveillance. The solar system abounds with mysteries, and new experimental information seems to solve fewer than it creates. There is little danger that future radar observations of the planets will reverse this trend.

SUNBURN

What happens to human skin, its various types of cells and their molecular constituents when it receives an overdose of ultraviolet radiation?

by Farrington Daniels, Jr., Jan C. van der Leun and Brian E. Johnson

Sunburn is notoriously the unpleasant consequence of pleasant expectations. Typically the victim lies down for a happy time under a warm sun with a cool breeze playing over his exposed skin. His nose clears, his muscles relax, his tension is eased, and he may doze off. He (or, to be sure, she) comes to feel refreshed, reposed—and then uncomfortable. The skin may already be tender and feel slightly burned. During the next few hours it becomes redder and more painful and may swell or blister. In severe cases more deep-seated consequences may follow within 12 hours: fever, chills, nausea and perhaps prostration. The sufferer receives from his fellows the same kind of sympathy that is accorded to the victim of a hangover. As the burned layers of the epidermis peel off in the ensuing days and the skin becomes pale again, the victim may be left without even the satisfaction of a socially admired tan.

We live in an environment of solar radiation that is essential for the existence of life on our planet and at the same time is potentially lethal to living matter. The dangerous portion of the sun's radiation is at the short-wavelength end of the spectrum: from the X rays through the ultraviolet rays [*see illustration on page 43*]. Life on the earth is made possible by the attenuation of these rays in their journey through the earth's atmosphere, which filters out the shorter wavelengths. Oxygen in the outer part of the atmosphere absorbs these rays and forms ozone (O_3), which in turn acts as an effective filter blocking almost all the ultraviolet radiation at wavelengths up to 2,900 angstrom units. (The visible spectrum lies between 3,800 and 7,600 angstroms.) Hence the ultraviolet rays of shortest wavelength do not reach the earth's surface. A substantial amount of ultraviolet radiation between the wavelengths of 2,900 and 3,200 angstroms does penetrate to the surface. This minute portion of the solar spectrum is what produces sunburn.

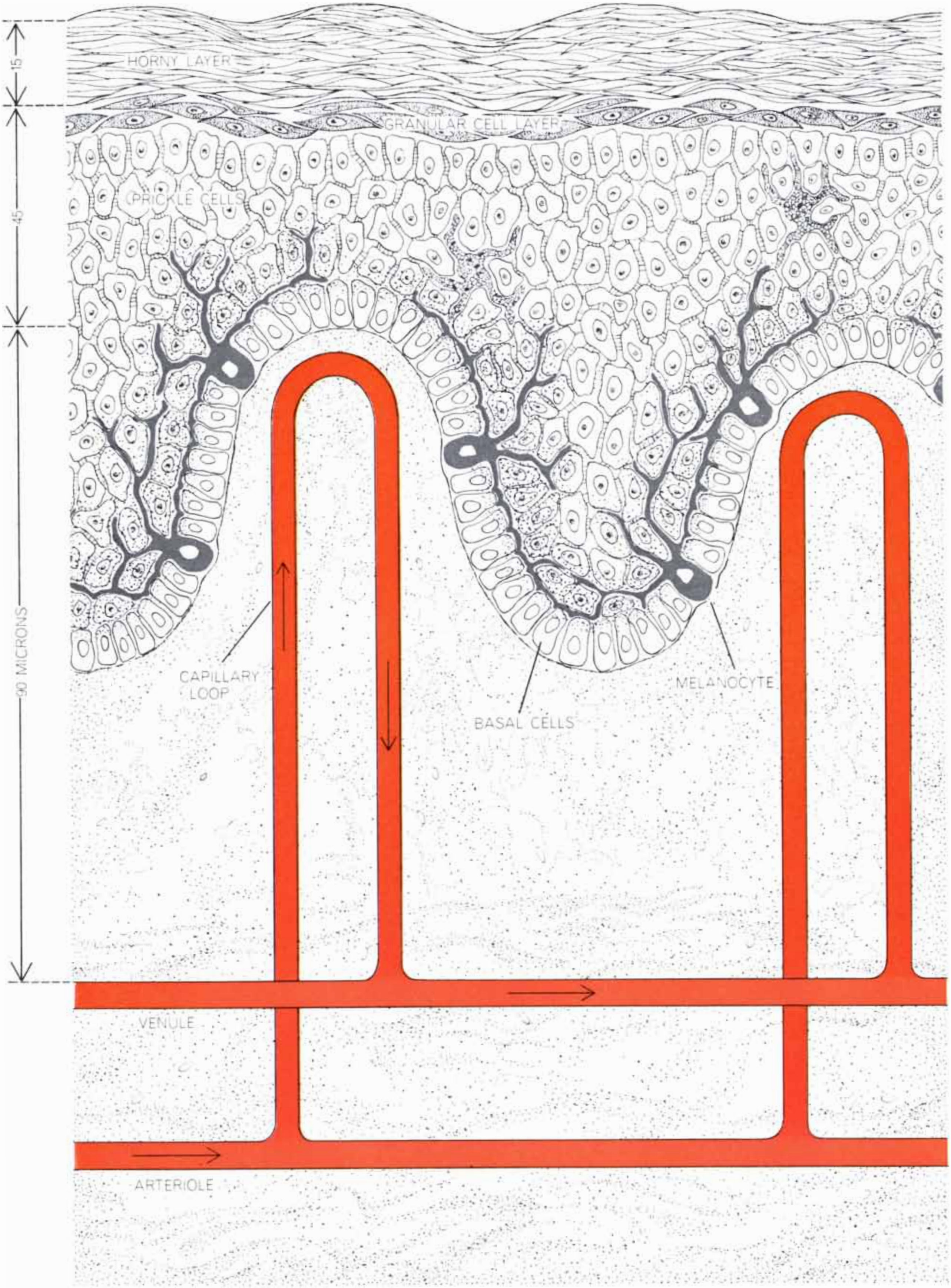
Obviously the sunburn hazard is greater at high altitudes (for example on mountain ski slopes), where the ultraviolet rays have traversed less of the atmosphere. On such slopes the radiation is also intensified by reflection from the snow. The amount of ultraviolet radiation reflected, like the amount of light, is high from snow and sand, low from vegetation and water. Sunburn is particularly common at the beach because of reflection from the sand and one's exposure to scattered ultraviolet rays from the entire hemisphere of the sky. Under these conditions untanned skin may be affected in as little as 10 to 20 minutes. Contrary to a common notion, two or three hours on the beach is by no means a short exposure. People are misled at the beach by the cooling effect of the breeze and the water. Not feeling an intense heating effect from the sun, they do not realize that they are nonetheless being burned by the invisible ultraviolet rays.

Why is it that basking in the early-morning or late-afternoon sun almost never produces sunburn, even on the brightest summer day? The answer is simply that, when the sun is low in the sky, its radiation must pass through a greater thickness of the atmosphere, and the atmosphere selectively scatters the shorter wavelengths. The longer wavelengths of light get through, which accounts for the yellow, orange and red tints of the sunrise and the sunset. The shorter waves at the blue end of the visible spectrum are largely blocked out, and of course the still shorter waves of ultraviolet radiation are scattered and attenuated even more.

This suggests that sun-worshipers, particularly those with a sensitive skin, would be wise to do their sunbathing when the sun is not too high. A simple "sunburn dial" can indicate the safe times of day and the duration of exposure needed to avoid painful burning and to start producing the tan that our society equates with health and leisure. In this instrument the shadow of a vertical needle shows the elevation of the sun, and circles drawn on the horizontal dial can be calibrated to prescribe the safe length of exposure for any given solar elevation. The "safe" exposure of course will depend on the individual's skin sensitivity; hence the dial should be calibrated to specify different exposures for skins of high, medium and low sensitivity.

The skin's main defense against ultraviolet radiation lies in the brown-to-black pigment known as melanin. The melanin polymer is synthesized by special cells called melanocytes; these cells are descended from nerve cells that migrate out of the central nervous system during embryonic development. (Their

STAINED SECTION of human skin shows one effect of sunburn. Orange staining indicates the presence of keratin, the horny material that is formed from aging epidermal cells and is abundant in the outer layer of the skin (*top*). Keratinization of skin cells appears to be accomplished in part by enzymes released from intracellular bodies called lysosomes. The action of ultraviolet radiation can rupture the lysosomes' thin membrane; the premature keratinization of one skin cell (*right center*) may have been caused by such radiation damage.

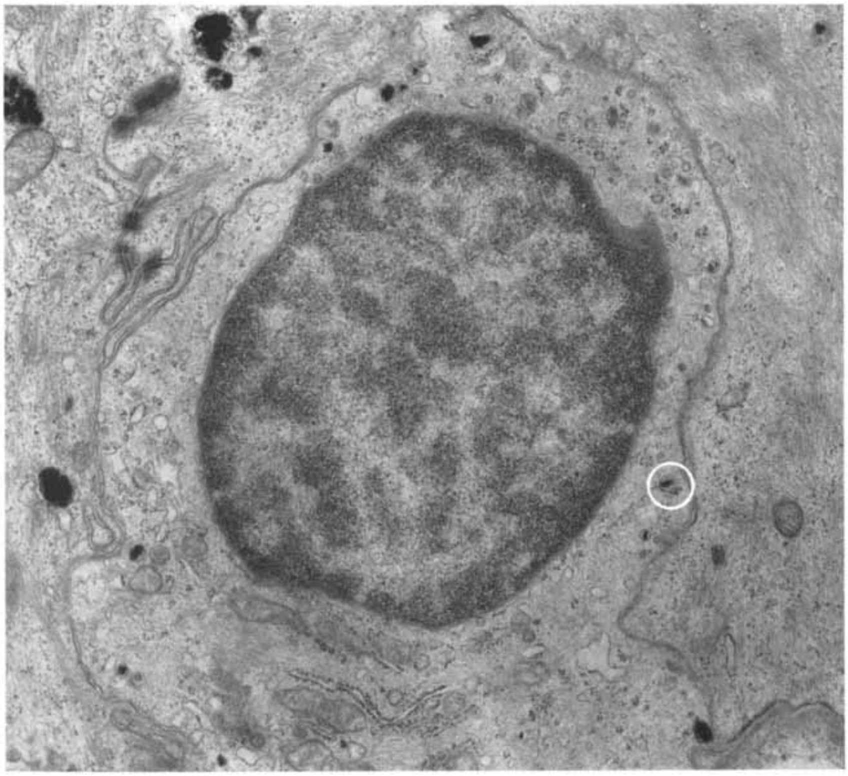


ZONES OF SKIN affected by the ultraviolet light wavelengths that produce sunburn are shown in a schematic cross section. The hill-and-dale boundary between the epidermis (*top*) and the dermis below allows capillary vessels to come to within 65 microns of the skin surface. Ultraviolet radiation causes enlargement of the vessels and produces the characteristic redness of sunburned skin.

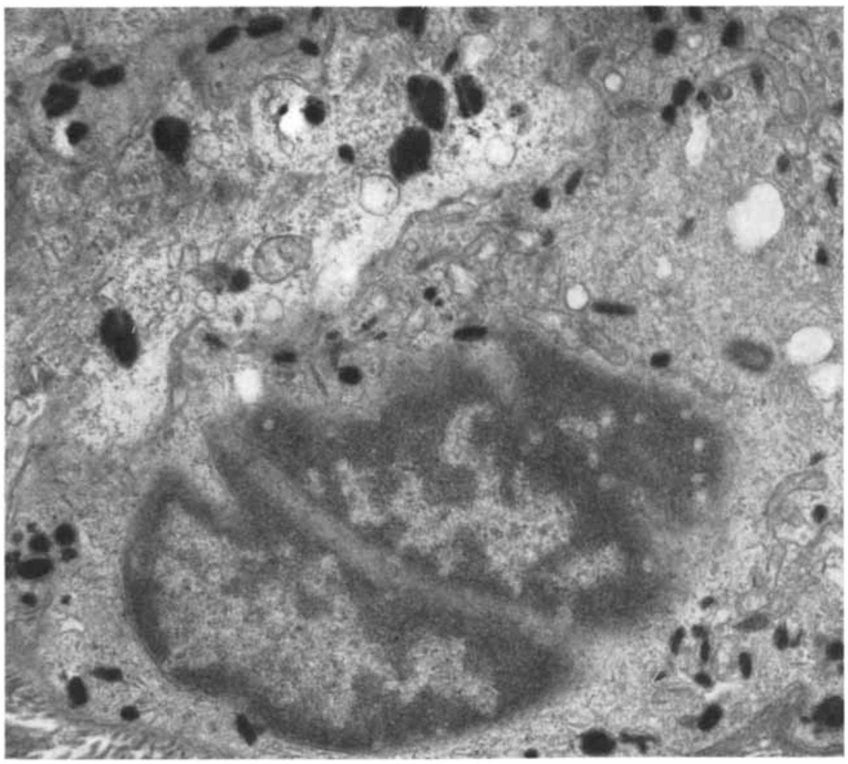
kinship to nerve cells is indicated by the fact that they have many dendrites, or threadlike extensions.) In the melanocytes melanin is produced by a series of oxidations of the amino acid tyrosine with the aid of the enzyme tyrosinase. In its final polymerized form the pigment, bound to protein molecules, is aggregated in granules that typically are between a tenth of a micron and two microns in diameter. The melanocytes inject these granules through their dendrites into the cells of the epidermis that manufacture the tough protein keratin. A considerable amount of the melanin moves into the horny outer layer of the skin as the keratin-producing cells move to the surface and flatten out to form this layer. The amount and dispersion of melanin in the epidermis determines the color of a person's skin.

Even in an untanned skin melanin serves to protect the genetic material of the cells in the epidermis by concentrating in a cap that screens the nucleus of each cell against ultraviolet radiation. In tanned or naturally dark skin the supply of melanin is greatly augmented. The tanning of the skin in response to ultraviolet irradiation involves more than one mechanism. First there is an immediate darkening of the skin as the result of the oxidation of pigment that is already present in a bleached form. (The degree and duration of this tanning without sunburn varies greatly among individuals.) Meanwhile the enzyme tyrosinase, which in fair skin is ordinarily inactive, somehow becomes activated. The mechanism of this activation is not entirely clear; it may be that the ultraviolet radiation inactivates an inhibitor of tyrosinase. The activation of tyrosinase initiates increased production of melanin by the melanocytes and the injection of this pigment into the keratin-producing cells. The process takes four or five days to develop, and the tan reaches its peak in about a week and a half, after which, without further exposure, it gradually fades over a period of months.

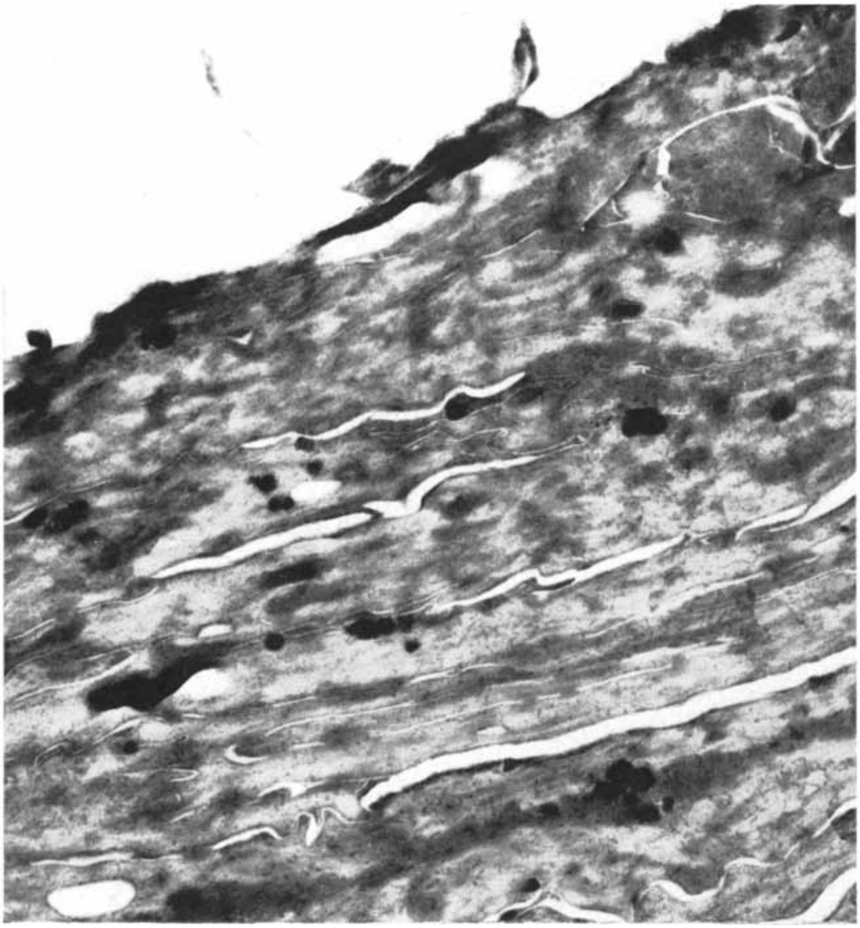
The melanin in a well-tanned or naturally dark skin is so effective a shield that it reduces the amount of ultraviolet radiation penetrating to the underlying dermis by 90 percent or more. Melanin is not, however, the only defense against sunburn. A tanned skin can suffer sunburn from intense exposure to ultraviolet radiation before the tan has faded, and it is well established that even dark-skinned Negroes can become sunburned on an initial visit to the beach. Conversely, an albino skin can develop some tolerance to ultraviolet radiation although it has no pigment. Clearly the hu-



TANNING PROCESS involves activation of epidermal cells known as melanocytes that produce a pigment, melanin, in the form of granules called melanosomes. In this electron micrograph a melanocyte from a subject not exposed to ultraviolet radiation is seen to be almost devoid of melanosomes (*example inside white circle*), although they are abundant in the Malpighian cells of the surrounding tissue. The skin section is enlarged 12,000 times.



DEVELOPED TAN, following 10 days of exposure to controlled ultraviolet radiation from an artificial source, is evidenced by a large increase in the number of melanosomes within a melanocyte from the same subject. The section is enlarged 16,000 times. Both micrographs are the work of George Szabó of the Harvard Medical School's Department of Dermatology.



HORNY LAYER of the skin is seen in transverse section following repeated exposures to radiation. Melanosomes in small clusters are visible inside the flattened and keratinized cells. The micrograph, which is also the work of Szabó, enlarges the structures 10,000 times.

man skin must contain other protections against this radiation. One of these is the horny layer at the skin surface. This layer scatters and absorbs radiation, and it becomes thicker after sunburn. Another possible protective agent is urocanic acid, a substance in the epidermis that is an effective absorber of ultraviolet rays. On exposure to the radiation the "trans" molecular form of this substance is changed to the alternate "cis" form, and the change is reversible. Thus urocanic acid may absorb the ultraviolet energy in a chemical reaction and then dissipate the energy harmlessly in a reversal of the reaction.

The large industry devoted to protection of the human epidermis against the sun attests to the human propensity for trusting to artificial rather than natural defenses. The antisunburn ointments and lotions fall into three general categories: (1) substances such as *p*-aminobenzoic acid, which absorb the wavelengths between 2,900 and 3,150 angstroms; (2) substances such as the benzophenones, which absorb all the ultraviolet wavelengths, and (3) opaque preparations containing zinc oxide or titanium oxide, which provide a total shield for very sensitive skins. Unfortunately most preparations do not adhere well or are uncomfortably greasy. It is difficult to find one that will serve for all purposes; a preparation that is satisfactory for a fishing trip may cause discomfort by interfering with sweating in a hot location such as a tropical beach. The best protection for anyone who must expose himself to the noonday sun is to build up the skin's tolerance by starting with small doses of sun and gradually increasing the exposure over a period of weeks. Most skins cannot take hours of sunshine at a first sitting, any more than a man can run two miles without training for it.

Let us now look in detail at the physiological and chemical effects of ultraviolet radiation on the skin. More than a century ago the English physician John Davy (brother of Sir Humphry Davy) investigated this subject with experiments conducted under the Mediterranean sun at noon in midsummer. The reddening of the skin giving the first sign of sunburn is caused by a dilatation of the venules that bring more blood near the skin surface. After a longer exposure to the sun the arterioles also become dilated, with a consequent increase in blood flow, a rise in the skin temperature and of course intensified erythema (redness).

Nowadays most studies of the effects are carried out not with natural sunlight but with ultraviolet lamps of one kind or another that make it possible to measure the doses precisely and to examine the skin's reactions to particular wavelengths. The lamps used for these experiments may be of the carbon-arc, the mercury-arc or the xenon type. In one notable respect the skin's response to exposure under these lamps is strikingly different from the response to natural sunlight. At low or moderate doses from a lamp the erythema that signals sunburn may be greatly delayed, sometimes as much as eight hours after the exposure. (A user of a sun lamp should therefore limit himself to a brief exposure. If he waits until he sees signs of redness, he may already have suffered a severe burn.) The emission spectra of artificial sources differ considerably from the spectrum of sunlight, both in wavelengths and in energy distribution. Since the skin's response to ultraviolet radiation varies with wavelength, the difference between a "natural" sunburn and one from an artificial source is not surprising. It is possible that the longer erythema-producing wavelengths in sunlight, together with a heating effect, are responsible for the early appearance of erythema on exposure to the sun.

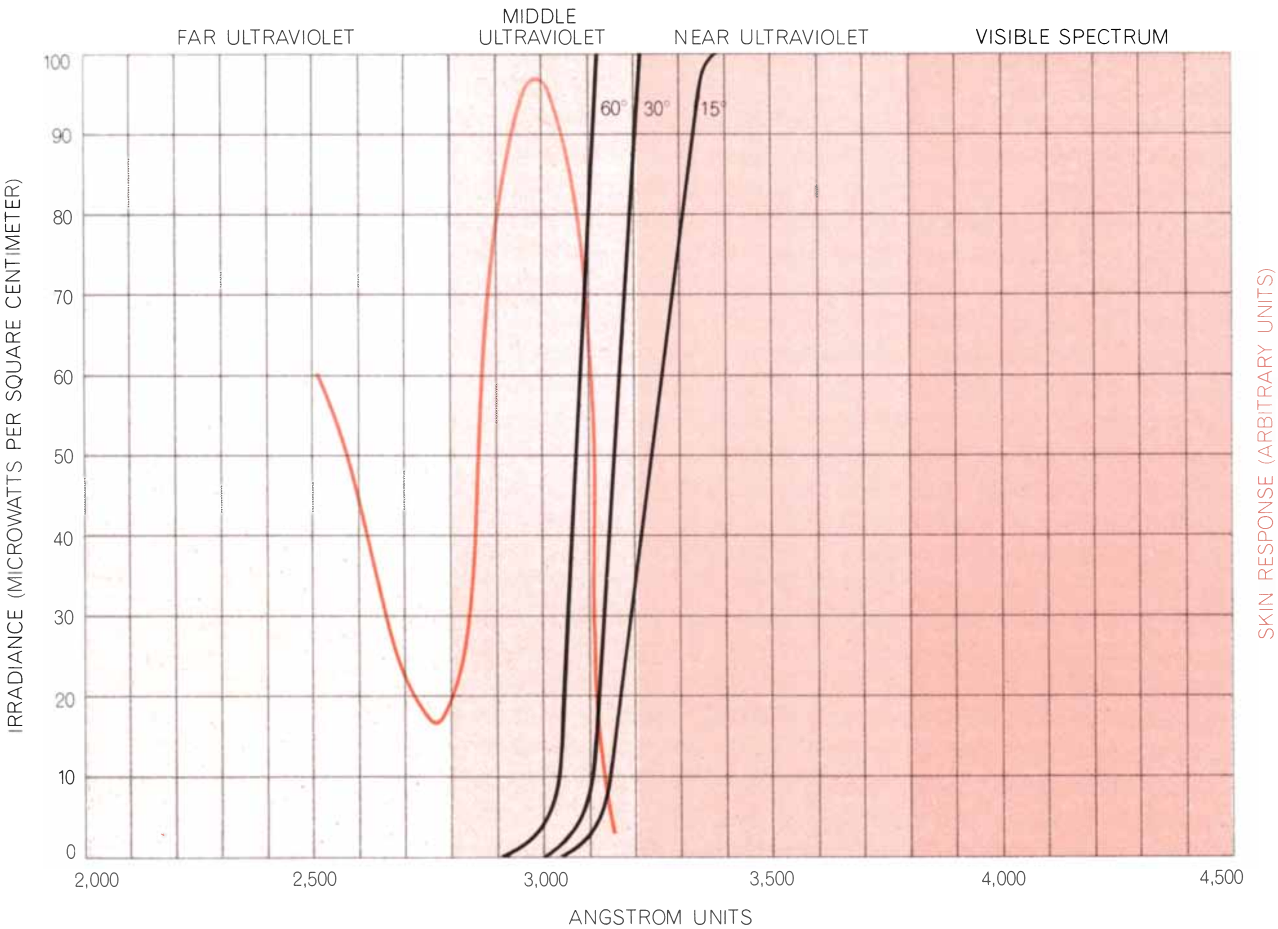
Where does ultraviolet radiation produce the primary injury—in the epidermis or in the dermis? This question has been debated for nearly a century and is still undecided. The Danish physician Niels Finsen, who received a Nobel prize in 1903 for his discovery that skin tuberculosis could be treated with ultraviolet radiation, suggested that the radiation acts on the dermis, because the erythema originates there. A generation later other investigators, principally Sir Thomas Lewis of Britain, swung opinion to the view that the primary target is the epidermis and that injury to this layer releases a substance that causes the dilation of the blood vessels in the dermis. One argument in favor of the epidermal theory is that the delay in the onset of erythema can be explained on the basis that time is needed for a substance to diffuse out of the epidermis and affect the blood vessels in the dermis. About 1960 the dermal theory began to swing back into favor. The observational evidence is so complicated, however, that some current hypotheses propose that both the epidermis and the dermis are attacked by ultraviolet radiation, some wavelengths of the radiation doing injury to the epidermis and others to the dermis.

The detailed evidence on ultraviolet effects is mainly biochemical. Intensive studies have been made of the effects of ultraviolet irradiation on tissues, cells and specific substances. The picture presented by the findings is ambiguous, to say the least. The complexity of the situation is suggested by the experimental information on enzymes and other proteins. It is well known that very high doses of ultraviolet radiation can break down protein molecules, and specifically that such dosage can inactivate enzymes by breaking their disulfide bonds. Studies of sunburned skin tissue, however, show no loss of enzymes.

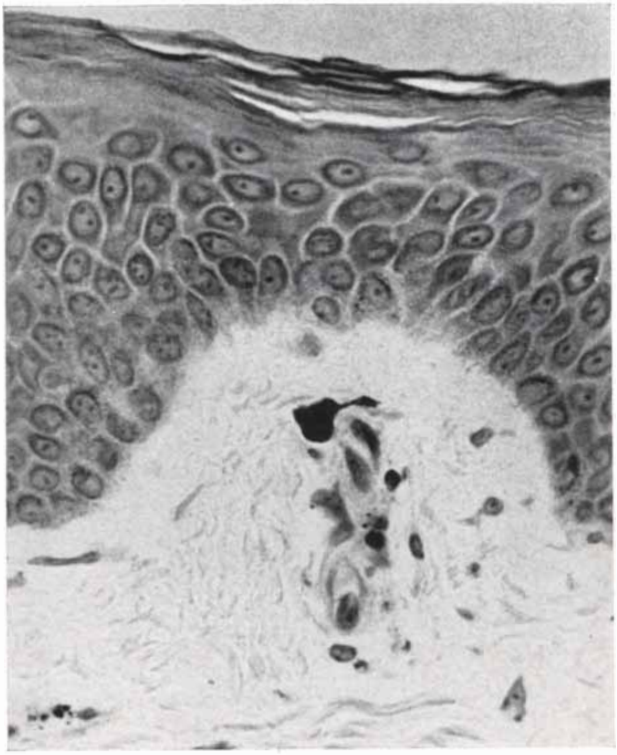
The significance of ultraviolet effects on other proteins in the skin tissues is likewise unclear. Certain changes have been found to take place in the proteins of the skin's horny layer, but no connection has been established between these changes and damage to the deeper tissues. Ultraviolet radiation also alters proteins, notably collagen, in the dermis.

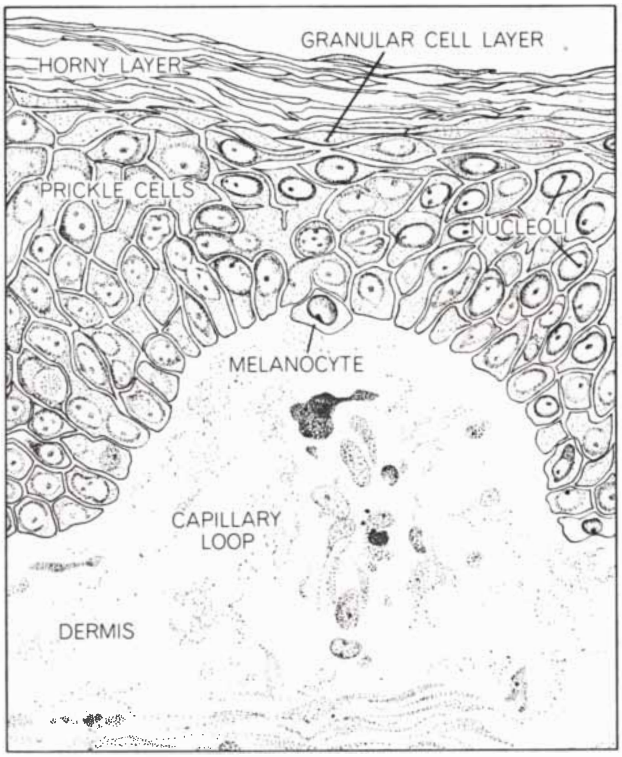
Does a sunburn dose of ultraviolet damage the genetic material—deoxyribonucleic acid—of the skin cells? On the basis of studies of the effects of ultraviolet radiation on the cells of microorganisms there is reason to believe this radiation may produce certain chemical changes in DNA, but no such change has yet been detected in the DNA of irradiated skin cells. As a general rule the sensitivity of cells to radiation damage is associated with cell division. In skin cells there is little evidence of such damage. The cells in the basal layer of the epidermis, the only ones capable of dividing, do appear to be affected by moderate doses of ultraviolet radiation. The radiation briefly inhibits the synthesis of DNA, but the cells quickly recover that ability.

It has long been assumed that DNA and proteins were the primary targets of ultraviolet damage, because the relationship between wavelength and the production of erythema was similar to the absorption spectra of these substances. In our work at the Cornell University Medical College we have asked: What other specific structures in the skin cells may be particularly vulnerable to ultraviolet damage? The radiation has been found to reduce the phospholipid content of skin and to alter its cholesterol. Since these substances are important contributors to the stability of cell membranes, research attention has been drawn to testing the effects of ultraviolet radiation on membranes, including the

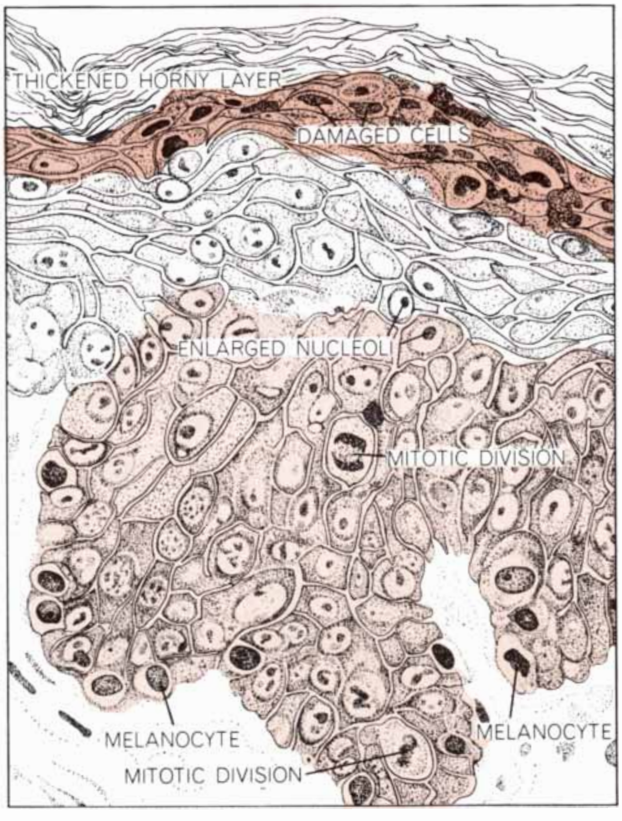


HUMAN SKIN IS AFFECTED by ultraviolet radiation at wavelengths from 2,500 to 3,150 angstrom units in length. One curve on the graph (*color*) shows that the effect varies with the wavelength. Almost all solar ultraviolet radiation below 2,900 angstroms and above 3,200 angstroms is filtered out by the atmosphere. The wavelengths that affect the skin most intensely lie in a narrow band on each side of 3,000 angstroms. Atmospheric scattering also weakens solar ultraviolet radiation: the black curves show the amount of energy at various wavelengths reaching the ground when the sun is respectively 60, 30 and 15 degrees above the horizon.





SKIN BEFORE SUNBURN is seen in transverse section (*left*). The drawing (*right*) duplicates the micrograph and identifies the major anatomical features. The white area that seems to intrude from below into the epidermal zone containing prickle cells is part of a capillary loop, surrounded by dermal tissue (*see illustration on page 40*). This feature is not duplicated in the section shown below.



SUNBURNED SKIN, 72 hours after exposure to radiation, shows signs of damage, as well as evidence that processes of replacement and repair are under way. The damaged prickle cells gathered near the surface of the skin will be shed by peeling. An increase in the ribonucleic acid content of many of the prickle cells, evidence of protein synthesis for repair processes, has caused darkening over an extensive area. The mitotic division of several cells in the basal area of the epidermis gives evidence of replacement activity.

envelopes around subcellular particles. Our studies have focused particularly on the cell organelles known as lysosomes.

The lysosomes are tiny intracellular bodies that act as the cell's digestive system and apparently are involved in the aging of the cell [see "The Lysosome," by Christian de Duve; SCIENTIFIC AMERICAN, May, 1963]. They are packed with hydrolytic enzymes. Many investigators believe lysosomes play an important role in converting the living cells of the epidermis into the horny material that is continuously being formed as the protective outer surface of the skin. Examination of the epidermal cells with the electron microscope has not yielded absolutely clear evidence of the presence of lysosomes in these cells, but biochemical analysis shows that lysosomes are indeed present: the epidermal cells contain the enzyme acid phosphatase, known to be an identifying component of lysosomes.

Now, a number of cell investigations have disclosed that the thin, single-layer membrane of the lysosome is particularly susceptible to damage by ultraviolet radiation—more susceptible, for example, than the membrane of the mitochondrion (another intracellular body) or the complex membrane of the cell as a whole. We have shown that a moderately high dose of ultraviolet rays of the sunburn wavelengths reduces the amount of acid phosphatase in the skin of mice, and similar exposure of human skin also yields evidence of the rupture of lysosomes by this radiation. Moreover, in skin that has been sunburned the epidermis has a scattering of cells that are shrunken and appear to be prematurely keratinized (hornified), which suggests that the sunburn dose may have released hydrolytic enzymes by rupturing lysosomes. It is possible that substances discharged from the lysosomes may also be responsible for characteristic symptoms of severe sunburn such as dilatation of the blood vessels and fever.

The sunburn reaction can be minimized by administering drugs, such as aspirin or hydrocortisone, that stabilize lysosomes against breakdown. Experiments with rat skin in vitro, however, have shown that even though cell breakdown may be prevented by hydrocortisone, after irradiation the basal skin cells lose their normal capacity for division. It may well be that in these experiments the radiation alters the DNA.

The skin is a site of continuous cell birth and death, controlled by a feedback regulatory system that normally matches the birth rate to the death rate. The cells of the epidermis differentiate into the dead material of the horny layer, which is continuously shed from the skin surface in the form of minute flakes. As the old cells die, cell division in the basal layer of the epidermis produces new cells, so that the epidermis's cell population, and apparently its thickness, is maintained at a constant level. The control system involves certain metabolites supplied to the living cells and the feedback of a specific inhibitor of cell mitosis (called the chalone-epinephrine complex of Bullough) from the upper levels of the epidermis.

Sunburn produces a form of damage to the epidermis that impairs these control mechanisms, with the result that cell division goes on unchecked for a time. In moderately sunburned skin this increase in mitosis reaches its peak at 72 hours, whereas if horny material is simply stripped from the surface (say with Scotch tape), the step-up of cell division for replacement reaches its peak at about 48 hours. Consequently in sunburned skin the entire epidermis becomes thickened; indeed, the thickness of the epidermis more than doubles within 48 hours after a mild sunburn. The abnormal thickness may last for six weeks.

The transient uncontrolled multiplication of cells that follows a single exposure of the skin to ultraviolet radiation is similar in many respects to that produced by exposure to a single dose of a chemical carcinogen. The mechanisms involved are perhaps the same in both cases. It is now well established that ultraviolet radiation can produce skin cancer. This has been shown experimentally in mice, and there is much clinical evidence of the same effect in man. Fair-skinned people are particularly prone to develop skin cancers; the cancers occur mainly in exposed areas of the head and the back of the hands, and the affected skin shows other evidence of radiation damage. These signs of damage—commonly found in ranchers, sailors and others who spend a great deal of time outdoors—include thinning of the skin, dark blotches of melanin, chronic redness of the skin and sometimes yellowing from an increase of elastic fibers in the dermis. When the cancers arise in the epidermal layers, they can usually be treated successfully if caught before they have become invasive. Ultraviolet exposure can also, however, generate the highly dangerous malignant melanomas, which arise from the pigment cells.

Skin cancer is a particularly important problem for persons of northern European descent (particularly Irish or Scottish) who work outdoors in the perpetual sunshine of the U.S. Southwest, South Africa or Australia. This is not to say that dark-skinned peoples are immune. In dark skin, however, epidermal tumors usually stem not from ultraviolet radiation but from chronic lesions such as burns or unhealed ulcers.

To round out the story of the hazards from sunlight we must note that under certain conditions the skin can suffer injury from wavelengths other than ultraviolet, including radiation in the visible region of the spectrum. In one way or another the skin may become photosensitized, so that substances in the epidermis absorb radiation that normally would be harmless, with a consequent formation of free radicals and peroxides that produce cell damage. The photosensitization can be produced by certain chemicals that come into contact with the skin and even by some taken orally, and this hazard is increasingly a matter of concern in this chemical age. Many chemicals commonly used in industry, in drugs and in cosmetics, perfumes and antibacterial soaps are capable of photosensitizing human skin. A classic example of compounds with this property is the group of plant substances known as furocoumarins, which sensitize the skin to wavelengths in the range from 3,200 to 3,800 angstroms. Herbs (such as *Ammi majus*) that contain these substances have been used in Egypt and India for thousands of years to treat vitiligo ("white spot" disease), and the substances had a flurry of popularity as suntan pills a few years ago.

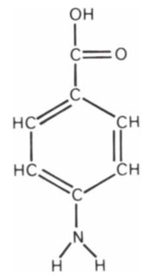
Exposure to sunlight can precipitate or exacerbate several well-known skin diseases, among them lupus erythematosus, a grave condition marked by patches of discoloration and scars. Some of the sunshine hazards are curiously complex. For example, the skin can be sensitized to light (specifically at the wavelength of 4,000 angstroms) by an abnormality in the metabolism of porphyrins, precursors of hemoglobin, that results in the concentration of porphyrins in the skin. A person with this condition may develop urticarial skin eruptions (like those characteristic of hives) shortly after exposure to the sun. For many such people the only remedy is to stay out of the sun, at least between 9:30 A.M. and 3:30 P.M., or clothe the skin completely with opaque covering.

We have deliberately left a discussion of the beneficial effects of sunshine for the conclusion of our article, because the constructive aspects of this radiation surely outweigh the destructive ones for both animal and plant life.

The best-known specific benefit of exposure of the skin to the sun is the production of vitamin D. This vitamin is essential for the absorption and metabolism of calcium, and a deficiency of the vitamin in growing children results in the bone disease called rickets. Ultraviolet radiation brings about the synthesis of a form of the vitamin (D-3) in the human epidermis through the conversion of 7-dehydrocholesterol. A certain daily dose of radiation at the wavelength of 2,970 angstroms, applied to 200 square centimeters (about 30 square inches) of skin, has been found to be sufficient to cure rickets, and this dose is only about 5 percent of the amount that would be required to produce a perceptible sunburn. Sunlight is not effective in supplying this dose when the sun is lower than 35 degrees above the horizon. Since in many parts of the world the sun remains below that height for several winter months, inhabitants of those regions need vitamin D in their food, and this of course is also true for children elsewhere who avoid the sun. The rickets problem was essentially eliminated in the U.S., for all but undernourished children, after the late Harry Steenbock of the University of Wisconsin discovered in the 1920's that vitamin D could be produced by irradiating milk and other foods with ultraviolet rays; within a few years poisoning by an excess of vitamin D became more of a medical problem than rickets. Some evolutionists have speculated that overproduction of vitamin D in the skin by sunshine may have been a factor in preventing the development of white races in the Tropics, but we have found no reports indicating that fair-skinned dwellers in the Tropics are particularly prone to form the calcium deposits that are characteristic of vitamin-D poisoning. Apparently the formation of vitamin D by the epidermis under ultraviolet exposure is self-limiting: as the exposure continues beyond a certain point the vitamin begins to break down, presumably because it is converted to other substances.

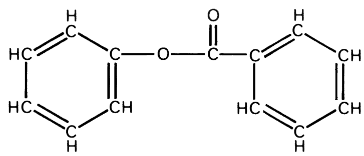
Basking in the sun confers many benefits besides the synthesis of vitamin D, some that are known and undoubtedly many others that have not yet been explored. The practice is common to many species of animals. In cold-blooded animals the sun's warmth can determine the body temperature; in warm-blooded animals it can supplement the heat of metabolism when that is necessary in a cold climate. In hairless man the sun's drying effect on the skin surface prevents bacterial and fungus infections. Unquestionably there are also health-giving systemic effects. Studies in northern Europe and the U.S.S.R. have shown that indoor workers and those in lands of weak sunshine improve in physical fitness when they are given moderate supplementary doses of ultraviolet radiation. Engineers in the U.S. are investigating this means of enhancing the healthfulness of working environments.

a



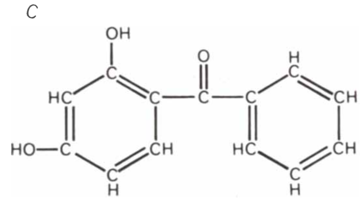
p-AMINOBENZOIC ACID

b

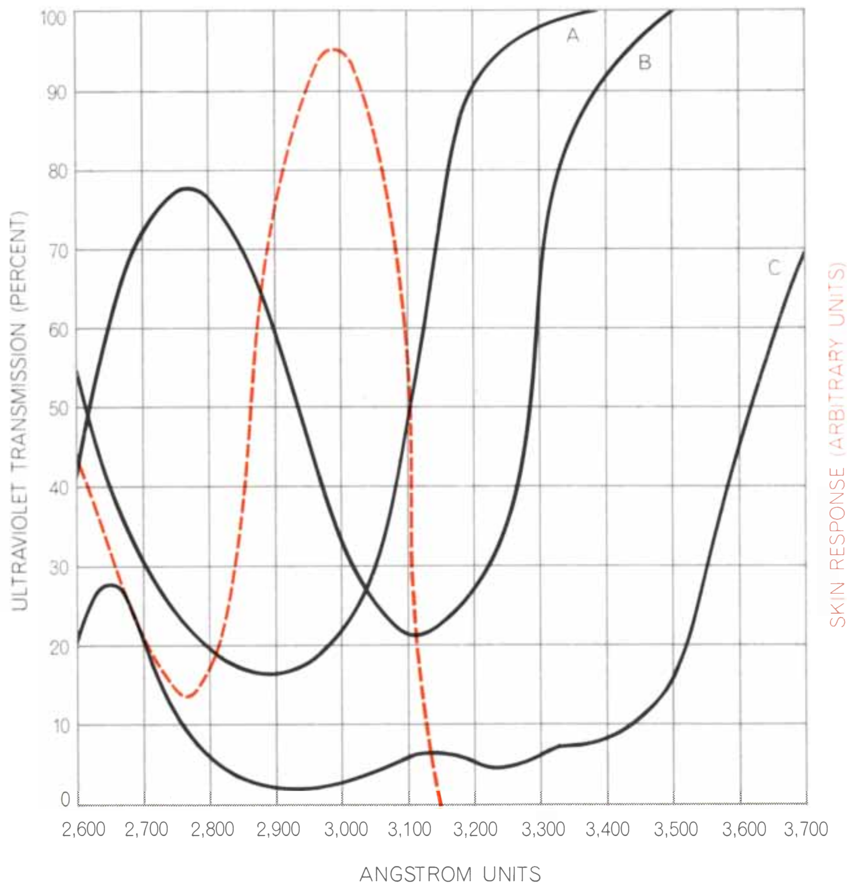


PHENYL SALICYLATE

c



2,4-DIHYDROXYBENZOPHENONE



SCREENING COMPOUNDS that absorb some or all ultraviolet wavelengths are the key ingredients in antisunburn lotions. Of the three compounds illustrated, two (*a*, *b*) selectively absorb part of the radiation that most intensely affects the skin. The third (*c*) almost completely absorbs the entire ultraviolet spectrum. For total protection opaque ointments such as zinc oxide can be applied.

In hope of doing each other some good

7,000 persons of influence

In hope of doing each other some good on a cold, rain-swept morning at Atlantic City in March, we in company with two other equally well known technology corporations entertained 7,000 of the most influential people in the country, all wearing convention badges of the Association for Supervision and Curriculum Development. This pallid appellation identifies professionals who tell teachers what to teach and how. The parents dutifully send the kids to school, trusting that these people will know why.

The three of us put on a big multi-media show for them. Not the least of the media was the art of the dance: competent teeny-bopping by youthful personnel from Atlantic City High School helped convey the message that the li'l red schoolhouse had been knocked down by a bulldozer and is not about to be rebuilt, not even in spirit.

To our guests this was hardly news. They understand our position. They can see that we, too, want to be influential in a large way but have only technology—in which we have placed all our faith—to win us a sense of participation.

A tour of the exhibits at the convention was reassuring. Photography, the technology in which we happen to specialize, need no longer plead hard. It is accepted. It shows the child the great and real world direct, not just the way the teacher sees the world. The machinery which this technology brings into the schoolhouse now gets less in the way also, having been recently shrunk physically. On exactly how to use the film image, our powerful friends have not yet endorsed any one line of sales talk. Standardization seems far off. Bless them.

Laser as a pen

Better not to ask why, but it seems likely that five years from now a substantial proportion of all oscillographs will be writing with lasers in some elegant fashion. Nevertheless, as of the moment these words are committed to paper the prophecy rests largely on a carbon of a letter to the editor of *Laser Focus* from Dr. Richard L. Hansler, a General Electric physicist. He expresses surprise to find himself successfully writing with a one-milliwatt He-Ne laser (632.8mμ) at speeds exceeding 20 inches/sec on KODAK LINAGRAPH Direct Print Paper, Type 1843, a product for which we claim sensitivity only from 360 to 620mμ. Does it with only a "long focal length lens" between the front of the laser and the paper emerging from a commercial oscillograph, which he uses just as a drive. Saw no need to employ a high-pressure mercury arc and fancy optics merely to keep track of a galvanometer deflection. Seems unimpressed by our talk of 70,000 inches/sec writing speed he could have had from the paper.

To be guided to a source of supply of KODAK LINAGRAPH *Paper write Eastman Kodak Company, Instrumentation Products, Rochester, N.Y. 14650.*

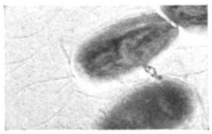
Activated sludge, a fascinating subject

We take water from Lake Ontario and put it back in the Genesee River after we are through with it. Right now we are building a $6.5 million plant further to improve the quality of the discharge. We are going to give the water back sparkling clear and fit for trout. Biggest voluntary project of private industry in support of the state's pure water program, says the Governor.

• If the factory were closed, the benefits of the light-sensitive materials made there forgotten, and the people sent far away, the quality of the water in the Genesee River would further improve. There is a better way.

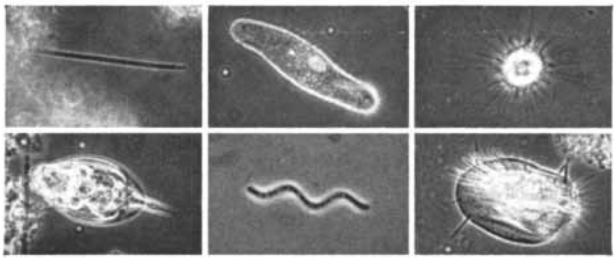
• Distillation purifies water the most. Some day nuclear energy may be cheap enough to distill half a billion gallons of water a day. But the heat evolved might change the climate. Too bold for now.

• Passing through artificial membranes also does a good job. Plant to do it might run a few hundred times the cost of any other purification plant on earth. Imprudent.



• Better at the job than any passive artificial membrane is the natural one that separates the outside world from the active and incredibly efficient and adaptable chemical plant inside a bacterium. Nobody knows how to build such a plant, nor is there any need to. Underfoot everywhere and awaiting the chance to flourish are abundant prototypes in whatever design is required to disassemble any compound presented, including phenol and other "germicides." Poison for one nurtures another.

• The public (including millions of healthy, satisfied owners of septic tanks) equates all bacteria with disease, failing to understand what a mess there would be if they were all wiped out forever.



Members of the team on a certain day

• Bacteria serve as food for organisms of more complex form, which are eaten in turn by other forms, and so up a chain. All are so small that one sees with the naked eye only brown broth, an abomination almost by definition. Yeasts and other fungal cells may also be present to compete with the bacteria for the nutrients we wish to get rid of. Except for certain bacteria at the bottom of the chain, all the organisms need oxygen. Supply that in abundance and life is lived in the tank at high pitch. Thus are wastes burned off biologically. Steps are taken to make sure the organisms remain behind when the cleansed water leaves.

• The chain of life that cleanses streams was working long before vertebrates and factories evolved. Engineers just make the process more efficient.

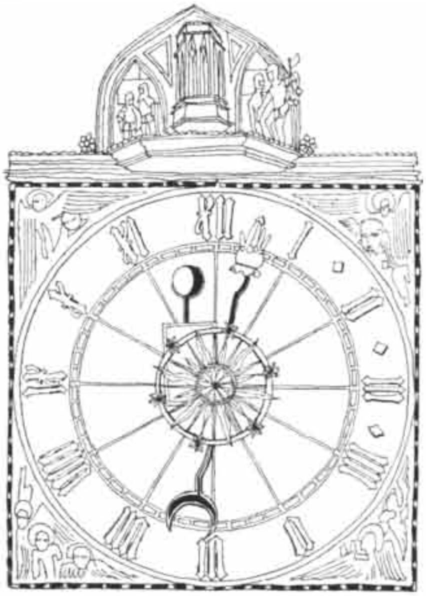
• Activated sludge systems like the one we are building are designed and operated by engineers who wish the biologists would get interested and clear up the mysteries of the day-to-day and hour-to-hour population changes in the tank. Predictability and clear, firm specifications are wanted.

• Biologists are well aware that many mysteries are there to be unraveled, but it's hard to establish a scientific position on a foundation of factory effluvia.

• Our management has committed us to share happily any technology we develop as the plant progresses.

EASTMAN KODAK COMPANY An equal-opportunity employer

SCIENCE AND



Fourth Step

The UN General Assembly took a fourth step—perhaps the most important so far—along the road to disarmament when it endorsed, by a vote of 95 to four, a treaty designed to halt the spread of nuclear weapons. The earlier steps were treaties controlling nuclear weapons tests, prohibiting nuclear weapons in space and barring nuclear weapons from Latin America. The latest step had its origin in 1960, before France or China had even an atomic bomb, in an Assembly resolution calling for a nonproliferation treaty. Last August the U.S. and U.S.S.R. finally proposed a draft text in Geneva. Early this year, after changes had been made to meet objections by nonnuclear countries, a text was approved by the committee and placed before the Assembly. The treaty must now be ratified (and presumably it will be) by the U.S., U.S.S.R., Great Britain and at least 40 other nations. China and France have indicated they will not sign.

Under the treaty nonnuclear signatories agree not to acquire or manufacture nuclear explosive devices or weapons. The nuclear powers agree not to transfer such devices or weapons to countries that do not have them, or to assist in their manufacture. The *quid pro quo* provisions, which were progressively strengthened at Geneva and in the Assembly debate to meet the objections of countries being asked to abjure nuclear weapons, include commitments by the nuclear powers to exchange information, equipment and materials that will facilitate peaceful development of nuclear energy and to work toward control of the nuclear arms race. The three powers are also pledged to a Security Council resolution binding them to assist a nonnuclear country that is threatened by a nuclear nation.

Missing Neutrinos

Surprising as it may seem, no more than two million neutrinos per centimeter per second reach the surface of the earth from nuclear reactions inside the sun. This is one of the main conclusions to come out of a pair of experiments carried out in the past year at the bottom of a gold mine in South Dakota. If the findings are confirmed by subsequent experiments, they may call for a number of revisions in current models of the sun's energy processes. A report of the experimental results and a discussion of their theoretical implications appear in two recent articles in *Physical Review Letters*.

The search for the solar neutrinos is being conducted by a team of experimenters headed by Raymond Davis, Jr., of the Brookhaven National Laboratory. Because the neutrino lacks both mass and electric charge and so cannot be detected directly, the detection system used by the Brookhaven team is indirect; it is based on the interaction of a neutrino with a chlorine nucleus to produce an unstable argon atom. The chlorine nuclei are contained in a 100,000-gallon tank of tetrachloroethylene (C_2Cl_4), an ordinary cleaning fluid. The electrons from the decaying argon atoms are detected by Geiger counters. In order to avoid contamination of the results by the products of high-energy cosmic ray interactions in the earth's atmosphere, this entire detection system is located nearly a mile underground in the Homestake gold mine at Lead, S.D.

In two separate experimental runs last year—one lasting 48 days and the other 110 days—the detection system failed to record a solar-neutrino flux rate higher than the background flux rate expected from nonsolar sources. From this finding the experimenters concluded that at most two million neutrinos per centimeter per second reach the earth from the sun. This is considerably lower than the calculated flux rate originally expected from theoretical estimates of the rate at which neutrinos are produced by the decay of boron-8 nuclei in the sun.

In discussing the experiments of the Brookhaven group, John N. Bahcall and Neta A. Bahcall of the California Institute of Technology and Giora Shaviv of Cornell University point to three important implications of the negative findings: (1) that the sun does not derive most of its radiated energy from the carbon-nitrogen-oxygen cycle; (2) that elements heavier than helium constitute less than 2 percent of the mass of the sun; (3) that the primordial helium content of the sun was about 22 percent. The low counting rate recorded in the experiments, they conclude, would appear to "cast serious doubt on the correctness of current ideas concerning the way nuclear fusion reactions produce the sun's luminosity."

Flicker from a Pulsar?

Astronomers at Kitt Peak National Observatory have provisionally identified a pulsating light source close to the radio position of *CP* 1919, the original pulsar discovered at the University of Cambridge early this year. *CP* 1919 emits strong radio pulses at the precisely timed interval of 1.33730113 seconds. Efforts at a number of observatories to find light pulses at this frequency were all negative. When the Kitt Peak workers analyzed their results, they found a small variation in light output at *twice* the radio interval, or 2.6746 seconds. Participants in the study were Stephen P. Maran, Clarence R. Lynds and Donald E. Trumbo.

Maran reported the Kitt Peak findings at a conference on pulsars held recently at the Goddard Institute for Space Studies in New York. He explained that individual photons from the suspected object were detected by a photomultiplier coupled to the observatory's 84-inch reflecting telescope. More or less by chance he and his co-workers decided to divide a two-pulse interval into 400 parts and to collect the number of photons detected in each part over a period of several hours. The experiment was conducted for three consecutive nights for a total observing time of 8.7 hours.

With the help of an accurate clock the recording cycle was kept in step with the pulsar's own highly regular cycle from night to night. The timing of the cycle took advantage of a late report by workers in Australia, led by V. Radhakrishnan, that the radio pulse interval was .0000216 second longer than the figure originally published by the Cambridge group.

The first experiment showed that the light intensity of the object presumed to be *CP* 1919 varied by about 4 percent on the 2.67-second cycle. In follow-up studies, however, the variation has fallen below 4 percent, which has made the Kitt Peak workers cautious in claiming that the variation is real. At this writing there has been no confirmation of the Kitt Peak findings. (A confirmation reported at the New York meeting was subsequently withdrawn.)

In the Kitt Peak experiment light was collected from a small patch of sky centered on the radio position of *CP* 1919 as determined at Cambridge. Although this patch shows a faint blue star on sky survey plates, there is no evidence that the star is actually *CP* 1919 or that it is the source of the variable light recorded at Kitt Peak. The pulsar mystery is still far from solution.

Nuclear Power in the U.S.S.R.

A recent report of nuclear power developments in the U.S.S.R., given to the International Atomic Energy Agency, shows that Russian technology has closely paralleled that in the West. Since the U.S.S.R. announced the world's first nuclear power station in 1954 it has experimented with a wide range of reactor types: ordinary water, heavy water, pressurized water, boiling water, gas-cooled and sodium-cooled. Moreover, Russian engineers have evidently been every bit as cost-conscious as engineers elsewhere.

In 1963 the Russians began operating a boiling-water reactor with an electric output of 100 megawatts. Whereas most U.S. reactors of this type feed wet steam into their turbines at 546 degrees Fahrenheit and a pressure of 1,000 pounds per square inch, the Russian reactor uses steam superheated by nuclear heat to some 900 degrees F. and a pressure of 1,325 p.s.i. The Russians report that they consider such reactors so reliable that they have been built inside large cities.

They have also developed pressurized-water reactors with typical ratings between 210 and 365 megawatts. "This type of reactor," according to I. D. Morokhov, First Deputy Chairman of the State Committee on the Utilization of Atomic Energy, "has been fully acknowledged as the basic source of heat for nuclear power stations for the period 1975–1977."

For the period beyond 1977, the Russians, like Americans, are working on fast breeder reactors that will create from 1.4 to 1.7 kilograms of plutonium for every kilogram of uranium 235 consumed. One such reactor now being designed, as it is described by Morokhov, would have a capacity of 1,000 megawatts. It would produce steam at a temperature of about 1,075 degrees F. and 3,600 p.s.i. Electricity produced by such a plant would cost around 40 kopecks per kilowatt hour.

Prostaglandins Synthesized

The synthesis of five of the 15 or so prostaglandins, a family of hormones that may play an important role in medicine, is reported in *The Journal of the American Chemical Society* by a group of chemists at Harvard University. The members of the group are Elias J. Corey, Niels H. Andersen, Robert M. Carlson, Joachim Paust, Edwin Vedejs, Isidoros Vlattas and Rudolph E. K. Winter. They believe adaptations of their approaches to the syntheses will make the other prostaglandins easily obtainable in the laboratory. Hitherto the hormones have been available only in very limited quantities, mainly from the testes of Icelandic sheep.

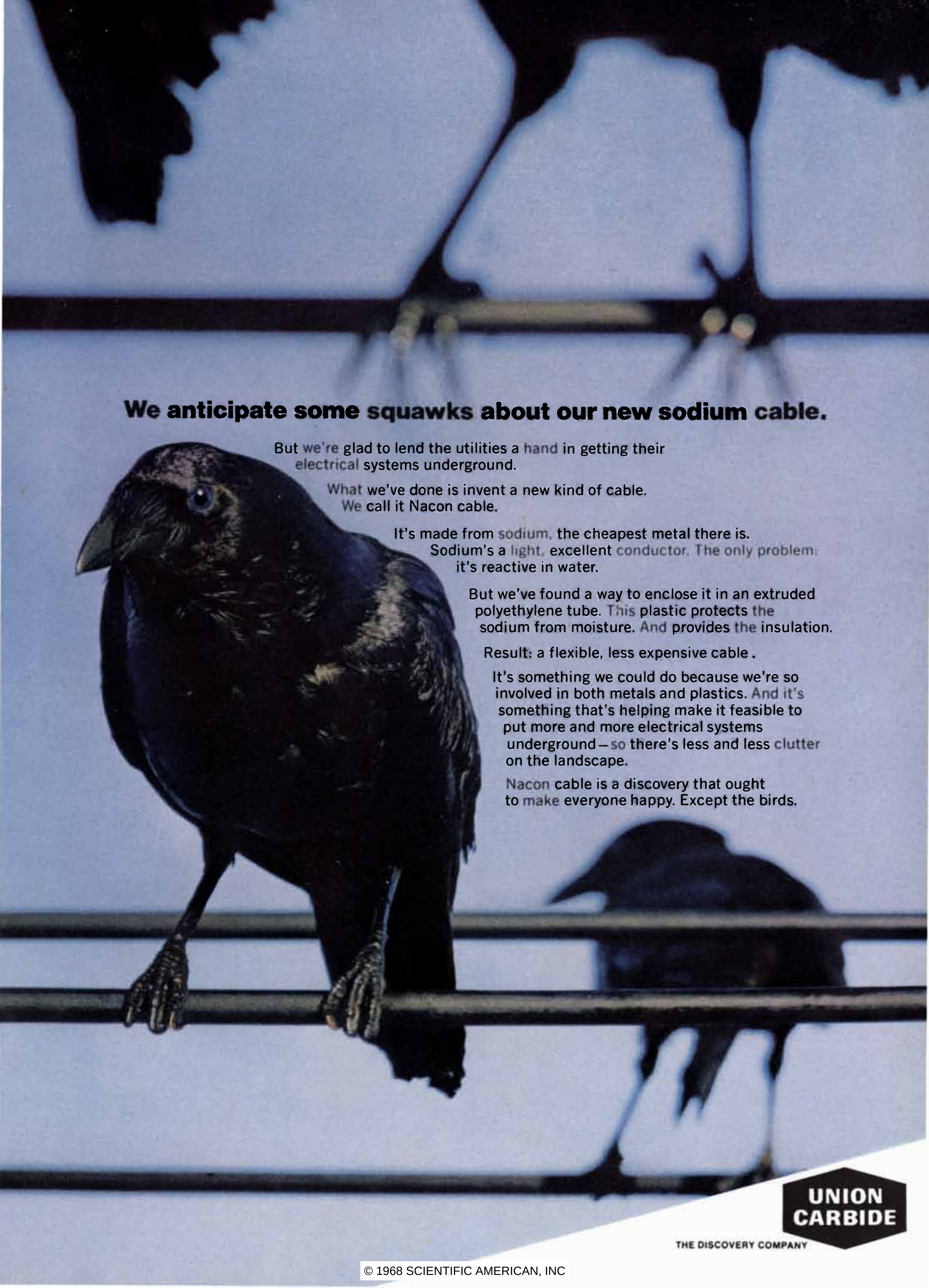
The prostaglandins are widely distributed in animal tissues. They are found in particularly high concentrations in seminal fluid, which accounts for the derivation of their name from the prostate gland. They have been found to affect blood pressure, the contraction of smooth muscle, the rate of the heartbeat, the mobilization of fatty acids and the firing rate of nerves. Corey and his colleagues write in their paper that the discovery of the "profound and diverse biological effects" of the prostaglandins "has opened a new chapter of hormone research."

Each prostaglandin is a fatty acid. Their molecular structures are similar; each hormone consists of a network of 20 carbon atoms, including a ring of five such atoms to which the others are attached. The molecules also have several reactive groups consisting of hydrogen and oxygen arranged in different ways. Synthesis of the molecules proved to be an intricate task, involving the development of a number of new chemical reactions. The success of the work assures a good supply of prostaglandins for the intensive studies still to be made of precisely what roles the hormones play in physiology.

Mammalian Gas

Mammals, including man, apparently manufacture nitrogen gas, a group of investigators at the Roswell Park Memorial Institute has discovered. Physiologists have assumed that the nitrogen ingested in food is either incorporated into the tissues or eliminated, largely in the form of such waste products as urea. Nitrogen is a key constituent of amino acids, the subunits of proteins, and protein metabolism is often investigated by the nitrogen-balance technique, in which the intake and elimination of nitrogen are monitored and a "positive nitrogen balance" is understood to represent nitrogen converted into body constituents. The trouble is that the test often shows nitrogen being "retained" in animals and men whose body weight fails to increase proportionately. A number of explanations for this anomaly have been advanced, but eight years ago Giovanni Costa concluded that none was satisfactory and that some of the nitrogen must be eliminated "through an unmeasured and hitherto unrecognized pathway." He suggested then that nitrogen gas might be an end product of protein metabolism, something that had been thought—but had never been shown—not to be the case.

With Ludwig Ullrich, Ferenc Kantor and James F. Holland, Costa undertook a series of experiments, the results of which are reported in *Nature*. They sealed mice into an experimental chamber with food and water, an oxygen-producing electrolytic cell and a system for removing carbon dioxide. First the chamber was flushed with a helium-oxygen mixture for 12 hours, ensuring that the chamber was free of nitrogen gas and that the animals' tissues were almost completely free of dissolved nitrogen. Then the chamber was sealed. After another 12 hours and again after 24 hours the gas content of the chamber was analyzed with a mass spectrometer. In every case there was an unambiguous increase in the concentration of nitrogen, and a number of controls made it certain that the nitrogen could only have come from the animals. On the chance that bacteria harbored by the mice could have produced the gas, the experiment was repeated with germ-free strains of


We anticipate some squawks about our new sodium cable.
But we're glad to lend the utilities a hand in getting their electrical systems underground.
What we've done is invent a new kind of cable. We call it Nacon cable.
It's made from sodium, the cheapest metal there is. Sodium's a light, excellent conductor. The only problem: it's reactive in water.
But we've found a way to enclose it in an extruded polyethylene tube. This plastic protects the sodium from moisture. And provides the insulation.
Result: a flexible, less expensive cable.
It's something we could do because we're so involved in both metals and plastics. And it's something that's helping make it feasible to put more and more electrical systems underground—so there's less and less clutter on the landscape.
Nacon cable is a discovery that ought to make everyone happy. Except the birds.
UNION CARBIDE
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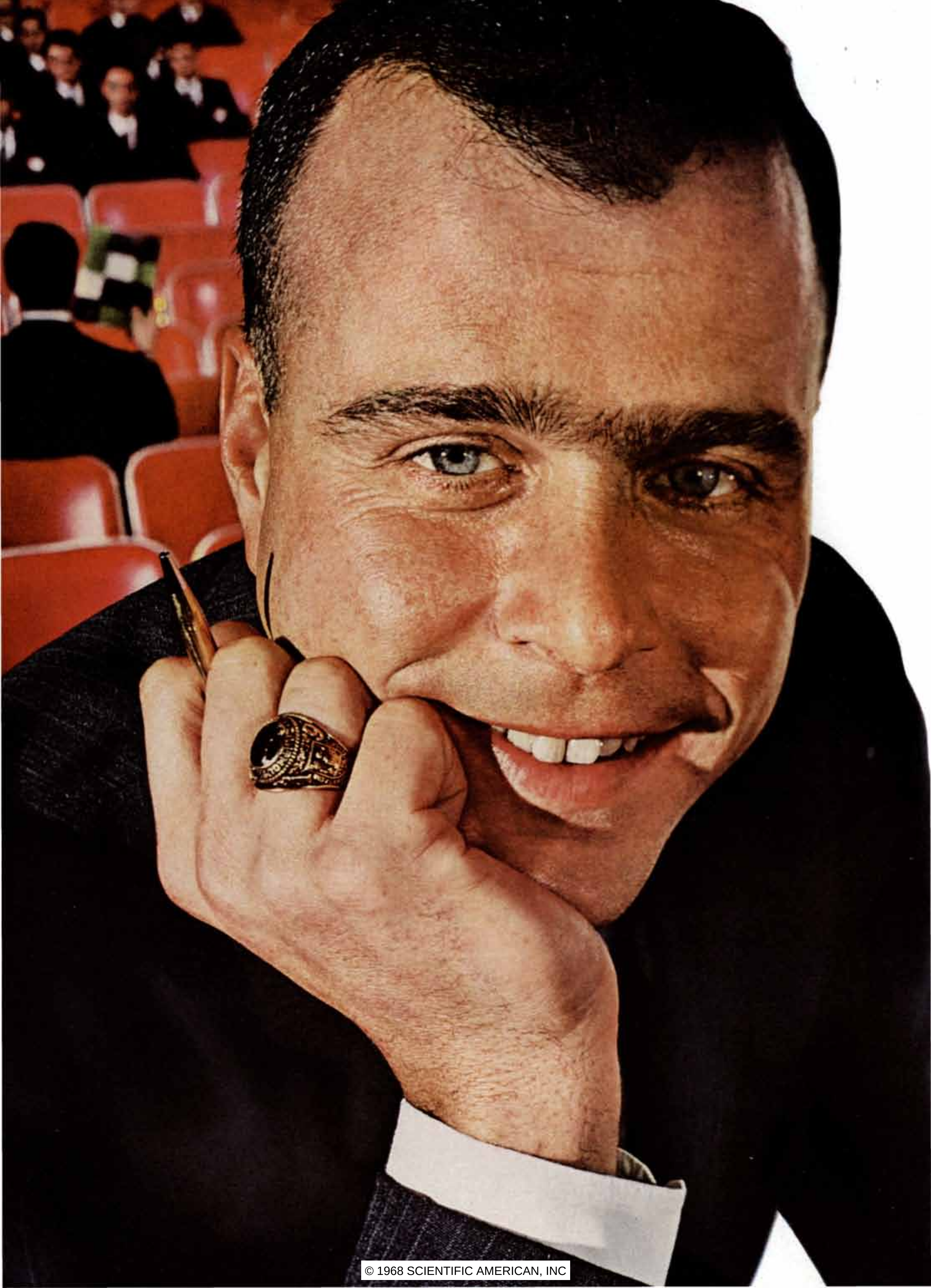

This man runs a "finishing" school that nobody ever finishes.

Technology in the data processing industry has developed at a remarkable pace. So fast, in fact, that computer salesmen must return to school regularly to keep up.

Bill Kramer runs one of these schools for IBM salesmen in Poughkeepsie, N.Y. Says Kramer, "A salesman never really finishes school because the industry just doesn't stand still long enough. He has to know hundreds of pieces of equipment, his own and his competitors', and scores of applications.

"Where computers were used mainly to handle routine things, like payroll, they are now doing such sophisticated jobs as helping to manufacture steel, and keeping track of airline reservations around the world.

"Fifteen years ago, there was only a handful of companies in the industry. Today, there are hundreds.

"In this kind of atmosphere—where many companies must innovate and improve all the time—it takes a lot of training and retraining to help a salesman do the best by his customers. And that's what my job's all about."

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From its very beginning less than two decades ago, the data processing industry and its customers have constantly come up with new ways to use computers. Bill Kramer is one of the many men and women in the industry who help bring these advances to more and more people every day.


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mice with similar results. In various experiments nitrogen was produced by the mice at rates ranging from 10 to 40 milligrams of nitrogen per kilogram of body weight every 24 hours. That is enough to balance the nitrogen equation, accounting for the previously anomalous nitrogen "retention."

Similar experiments were conducted with two human subjects, who were sealed into coffin-like fiber-glass boxes for up to 48 hours. The results were comparable, although less precise. The Roswell Park workers are now conducting a new set of experiments in which the production of nitrogen gas by mammals is measured more directly. Subjects are given food containing amino acids with a disproportionate amount of the heavy isotope of nitrogen, and the amount of heavy nitrogen in the atmosphere surrounding them is then determined.

Recessive Mendelism

How did it happen that the laws of heredity discovered by Gregor Mendel in 1865 went essentially unnoticed until 1900? Mendel read his paper, "Experiments in Plant Hybridization," to the Natural History Society of Brünn (Brno) in what is now Czechoslovakia in February and March of 1865. The lectures were published the following year in the *Transactions* of the society. It was only 34 years later that Hugo de Vries, Carl Correns and Erich Tschermak independently "rediscovered" Mendel's work and called attention to it. Was it simply that the work of the obscure Moravian monk was published in an obscure provincial journal? A number of scholars have pointed out that the journal was in fact rather widely distributed. Two British physicians, E. Posner and J. Skutil, undertook to trace as many original copies of the *Transactions* as possible, and their results are reported in *Medical History*.

The journal editor had ordered 40 reprints, according to a notation on the title page of the manuscript. Mendel sent one to the botanist Anton Kerner, who never even cut the pages, and one to the botanist Carl Wilhelm Nägeli, who did read it but denigrated Mendel's findings. Another reprint came into the hands of the Dutch biologist Martinus Willem Beijerinck, who at some point sent it to De Vries; it is still not clear whether De Vries saw the reprint before or after he undertook similar experiments and came to the same conclusions as Mendel.

Starting with a list of the 115 institutions and societies with which the Brünn society was exchanging publications in 1867, Posner and Skutil were able to track down 41 original copies of the *Transactions* volume containing Mendel's report. "Practically all prominent biologists of the mid-nineteenth century had access to Mendel's paper," they write, among them such cell biologists and botanists as Edouard van Beneden, Walther Flemming, Oskar Hertwig, Albrecht Kölliker and Eduard Strassburger, who, as H. J. Muller put it in 1943, were "preparing cytology for Mendelism." There is no indication that any of them read it.

A few workers did notice Mendel's paper before 1900. One H. K. H. Hoffmann saw it in the university library at Giessen in Germany and mentioned Mendel's experiments briefly in a book published in 1869. A Bremen physician, Wilhelm Olbers Focke, in a book on plant hybrids published in 1881, called Mendel's work "most instructive." It was a young Russian botanist, Ivan Fyodorovich Schmalhausen, who came on a copy in 1874 after his master's thesis on plant hybrids had gone to press, who best understood Mendel. He wrote in a footnote to his thesis: "The author's methods and his mathematical presentation deserve the closest attention and should be further pursued." Schmalhausen described Mendel's hypotheses on segregation and recombination of hereditary traits and he understood the importance of Mendel's mathematical approach, but unfortunately he did not take his own advice and pursue the matter. As for Mendel, he did little himself to make his results known. That had to await the independent repetition of his experiments by De Vries, Correns and Tschermak.

Perfect Columns

A structural column that is tapered can be twice as long as an untapered one of the same material without buckling under its own weight, according to calculations made by Joseph B. Keller of New York University and Frithiof I. Niordson of the Royal Technical University of Denmark. Their work is summarized in the annual report of the National Science Foundation, which assisted the work with a grant. The report makes the point that "today, when construction materials of almost all kinds are much more expensive than in earlier times, the question of economy looms large in the designer's mind, and it becomes worthwhile to consider the question of the shape of the structurally most efficient columns which can be made from a given amount of material."

Keller and Niordson found that the tallest tapered column (without load) can be 2.034 times taller than an untapered column having the same cross-sectional form and the same amount of material. With a load at the top the ratio decreases gradually to 1.075 when the load is infinite compared with the weight of the column. In the unloaded case the column would taper to a point at the top; in a tapered column designed to carry a load the ideal shape at the top would be round.

Nimble Dinosaurs

A Yale University investigator has cast doubt on the usual reconstructions of the Mesozoic scene of some 170 million years ago, in which carnivorous dinosaurs are shown running on their hind legs and preying on herbivorous dinosaurs that stand on all fours in postures that suggest sluggish locomotion. Robert T. Bakker challenges the assumption concerning the posture of the quadrupedal dinosaurs on anatomical grounds, denying that such museum favorites as *Brontosaurus, Stegosaurus, Ankylosaurus* and *Triceratops* ever assumed the stance of "a man cheating at push-ups," with hindquarters high but forelimbs sprawling outward like a lizard's.

Noting that the shoulder sockets of quadrupedal dinosaurs have the same downward orientation as those of four-footed mammals, whose forelimbs are held vertically rather than at an angle, Bakker suggests in *Discovery*, the periodical of Yale's Peabody Museum, that the ruling reptiles of Mesozoic times had postures "fully as erect and graceful as that of a mammal, both fore and aft." He considers this mammal-like posture to be badly at odds with the assumed clumsiness of the quadrupedal dinosaurs' locomotion. He holds that they were energetic and agile animals; the ceratopsians (horned dinosaurs), for example, could probably reach speeds of up to 30 miles per hour. Such speeds should have allowed them to charge their enemies the way the modern rhinoceros does.

Among several little-known aspects of dinosaur natural history reported by Bakker is evidence, in the form of fossil footprints, that the long-necked, long-tailed sauropods such as *Brontosaurus*, the largest of all dinosaurs, moved in herds. The young were concentrated in the center of the sauropod herd, evidently for protection against predators. Herd behavior is unknown among any living reptiles.

X-RAY CRYSTALLOGRAPHY

The new knowledge of the atomic structure of matter uncovered over the past half-century by the X-ray-diffraction technique has led to a fundamental revision of ideas in many sciences

by Sir Lawrence Bragg

Fifty-six years ago a new branch of science was born with the discovery by Max von Laue of Germany that a beam of X rays could be diffracted, or scattered, in an orderly way by the orderly array of atoms in a crystal. At first the main interest in von Laue's discovery was focused on its bearing on the controversy about the nature of X rays; it proved that they were waves and not particles. It soon became clear to some of us, however, that this effect opened up a new way of studying matter, that in fact man had been presented with a new form of microscope, several thousand times more powerful than any light microscope, that could in principle resolve the structure of matter right down to the atomic scale. The development of X-ray crystallography since 1912 has more than fulfilled our early expectations. It not only has revealed the way atoms are arranged in many diverse forms of matter but also has cast a flood of light on the nature of the forces between the atoms and on the large-scale properties of matter. In many cases this new knowledge has led to a fundamental revision of ideas in other branches of science. A culmination of sorts has been reached in the past few years with the successful structural analysis of several of the basic molecules of living matter—the proteins—each of which consists of thousands of atoms held together by an incredibly intricate network of chemical bonds.

The purpose of this article is to go back to the beginning and broadly summarize the course of X-ray crystallography over the past half-century or so. In so doing I shall try to answer two key questions: Why X rays? Why crystals?

X-ray crystallography is a strange branch of science. The result of an investigation lasting many years can be summed up in a "model." I have often been asked: "Why are you always showing and talking about models? Other kinds of scientists do not do this." The answer is that what the investigator has been seeking all along is simply a structural plan, a map if you will, that shows all the atoms in their relative positions in space. No other branch of science is so completely geographical; a list of spatial coordinates is all that is needed to tell the world what has been discovered.

The atomic structure of a crystal is deduced from the way it diffracts a beam of X rays in different directions. A crystal is built of countless small structural units, each consisting of the same arrangement of atoms; the units are repeated regularly like the pattern of a wallpaper, except that in a crystal the pattern extends in three dimensions in space. The directions of the diffracted beams depend on the repeat distances of the pattern. The strengths of the diffracted beams, on the other hand, depend on the arrangement of atoms in each unit. The wavelets scattered by the atoms interfere to give a strong resultant in some directions and a weak resultant in others. The goal of X-ray analysis is to find the atomic arrangement that accounts for the observed strengths of the many diffracted beams.

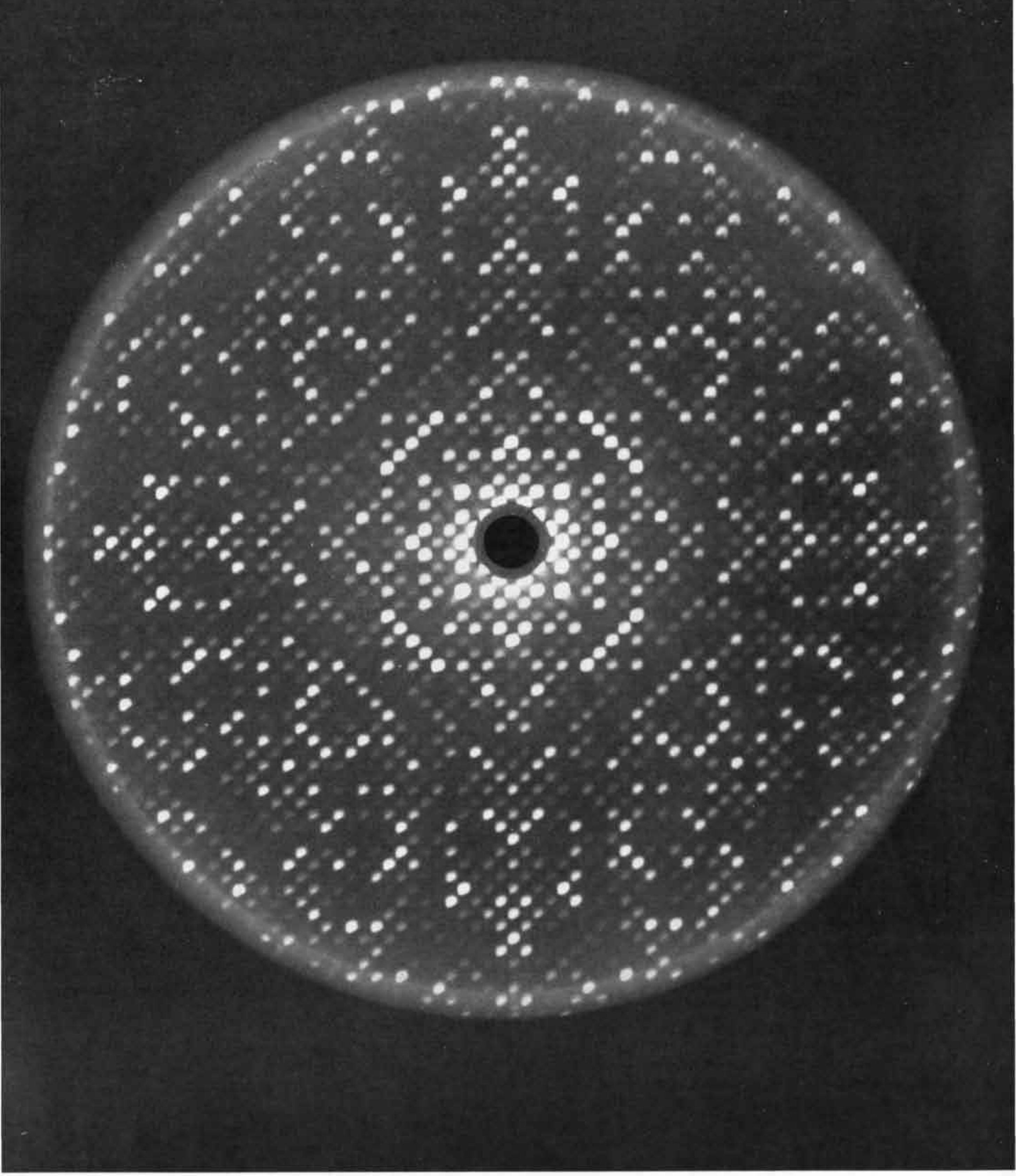
This brings us to the question of why X rays, of all the available forms of electromagnetic radiation, are indispensable for this method of investigation. In order for the interference of the diffracted beams to produce marked changes in the amount of scattering in different directions, the differences in the paths taken by reflected beams must be on the order of a wavelength. Only X rays have wavelengths short enough to satisfy this condition. For example, the distance between neighboring sodium and chlorine atoms in a crystal of sodium chloride (ordinary table salt) is 2.81 angstrom units (an angstrom is 10^{-10} meter), whereas the most commonly used wavelength in X-ray analysis is 1.54 angstroms.

Actually crystals came into the picture only because they are a convenient means to an end. The resultant scattering of X rays would be hopelessly confused and impossible to interpret if the scattering units were randomly distributed in all orientations. In a crystal the units are all similarly oriented and hence scatter the X rays in the same way; as a result a total scattering measurement made with a whole crystal leads directly to a determination of the amount scattered by an individual unit.

The Condition for Diffraction

The easiest way to approach the optical problem of X-ray diffraction is to consider the X-ray waves as being reflected by sheets of atoms in the crystal. When a beam of monochromatic (uniform wavelength) X rays strikes a crystal, the wavelets scattered by the atoms in each sheet combine to form a reflected wave. If the path difference for waves reflected by successive sheets is a whole number of wavelengths, the wave trains will combine to produce a strong reflected beam. In more formal geometric terms, if the spacing between the reflecting planes is d and the glancing angle of the incident X-ray beam is θ, the path difference for waves reflected by successive planes is $2d \sin \theta$ [*see upper illustration on page 60*]. Hence the condition for diffraction is $n\lambda = 2d \sin \theta$, where n is an integer and λ is the wavelength.

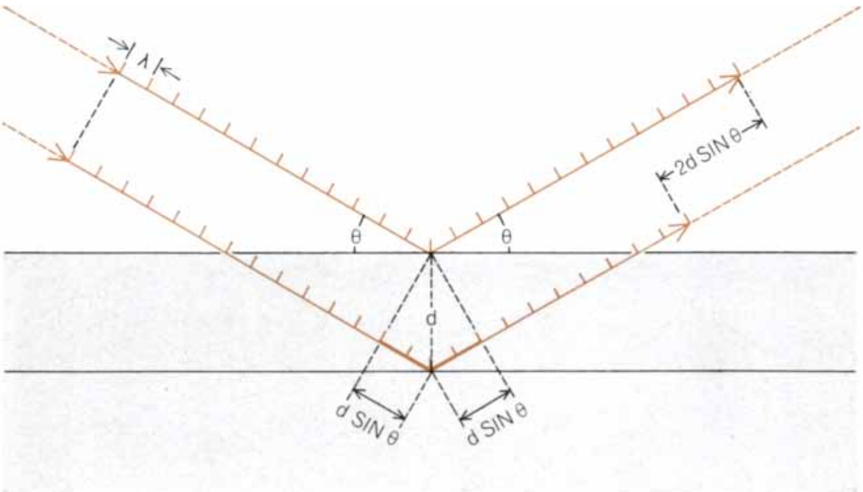
I first stated the diffraction condition in this form in my initial adventure into research in a paper presented to the Cambridge Philosophical Society in



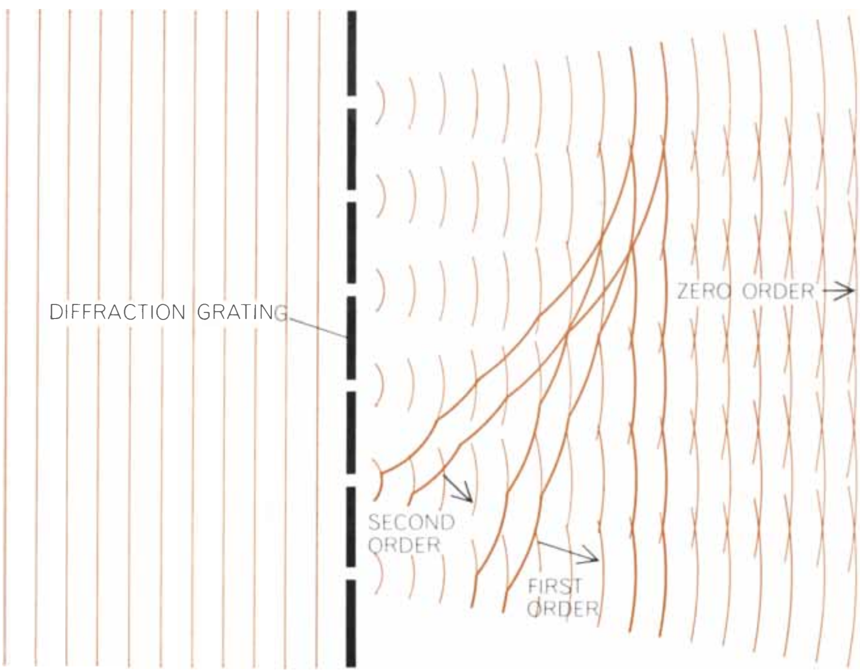
X-RAY PHOTOGRAPH of lysozyme, the second protein and first enzyme to have its molecular structure determined by X-ray analysis, symbolizes the recent achievements of the X-ray technique. The bright spots correspond to various orders of diffracted waves produced by irradiating the lysozyme crystal with a beam of monochromatic X rays. This particular type of X-ray photograph is called a precession photograph; it is produced by manipulating the crystal, the photographic plate and an intervening screen in such a way as to hold one of the three indices of the diffracted beams constant while recording the values of the other two indices in the form of a rectilinear pattern. The lysozyme molecule contains 1,950 atoms and measures approximately 40 angstrom units in its largest dimension.

1912, and it has come to be known as Bragg's law. It is, I have always felt, a cheaply earned honor, because the principle had been well known for some time in the optics of visible light.

The atoms of a given crystal can be arranged in sheets in a number of different ways; three possible arrangements of the sheets in a crystal of sodium chloride are indicated in the illustration on the opposite page. The equation for reflection can be satisfied for any set of planes whose spacing is greater than half the wavelength of the X rays used; this condition sets a limit on how many orders of diffracted waves can be obtained from a given crystal using an X-ray beam of a given wavelength.



BRAGG'S LAW, first formulated by the author in 1912, states the condition for diffraction of an incident beam of monochromatic X rays by the successive sheets of atoms in a crystal. In general terms the law states that if the path difference for waves reflected by successive sheets of atoms is a whole number of wavelengths, the wave trains will combine to produce a strong reflected beam. In more formal geometric terms, if the spacing between the reflecting planes of atoms is d and the glancing angle of the incident X-ray beam is θ, the path difference for waves reflected by successive planes is $2d \sin \theta$. In this diagram the extra path followed by the lower ray (*heavy colored line at bottom*) is four wavelengths long, which is exactly equal to the path difference of $2d \sin \theta$ between the two diffracted rays (*upper right*).



DIFFRACTION ORDERS are illustrated here for the comparatively simple case of a ruled optical diffraction grating. In this case the diffracted waves are defined by a single integer n in the equation $n\lambda = a \sin \theta$, where λ is the wavelength of the incident radiation and a is the spacing between the lines of the grating. In the case of a crystal, on the other hand, the pattern repeats in three dimensions, and so the order of the diffracted X-ray waves must be defined by three integers, which are represented generally by the letters h, k and l.

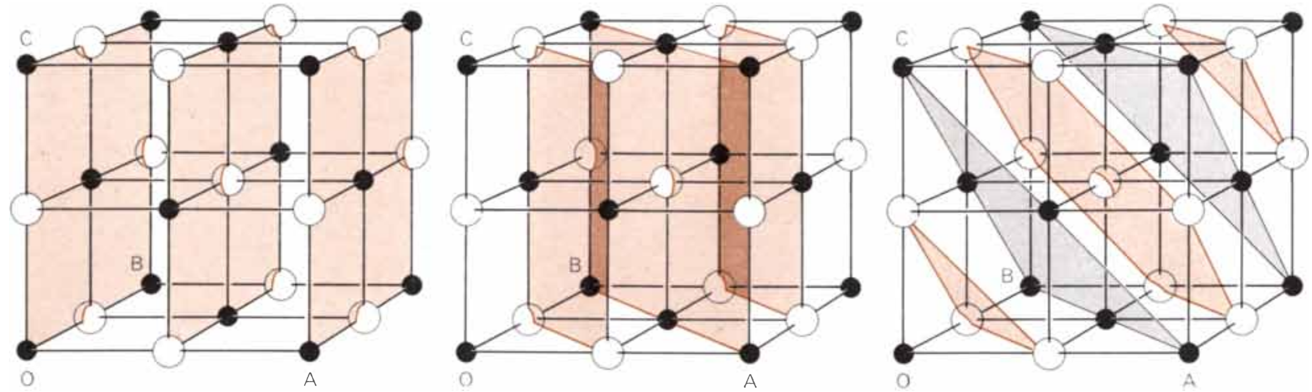
In the case of an optical diffraction grating with an interlinear spacing a, the orders of the diffracted waves are defined by a single integer n in the equation $n\lambda = a \sin \theta$; the diffracted waves are referred to as first-order waves, second-order waves and so forth [*see lower illustration at left*]. In the case of a crystal, on the other hand, the pattern repeats in three dimensions, and so the order of the diffracted waves must be defined by three integers, which are represented generally by the letters h, k and l.

In the structural diagrams of sodium chloride on the opposite page the axes of the structure are denoted by the letters OA, OB and OC, these being the intervals at which the pattern repeats. In the diagram at the left the first reflection to appear from the planes perpendicular to OA will be one for which there is a path difference of the two wavelengths between O and A, since there are two sheets of atoms in this distance. With respect to the spacing OA, then, this initial reflection is a second-order reflection; with respect to the spacings OB and OC, however, the same reflection is a zero-order reflection, since the reflecting planes are parallel to both OB and OC. Therefore this type of reflection, or diffraction, is assigned the order (200), indicating $h = 2$, $k = 0$ and $l = 0$. Similarly, the initial reflection to appear from the planes in the diagram at the center is (220), whereas for the diagram at the right it is (111). Higher orders of reflection would of course have higher integer values of h, k and l.

An Example of X-Ray Analysis

The structure of sodium chloride is a simple arrangement of cubic symmetry in which sodium and chlorine atoms occur alternately in three directions at right angles, like a chessboard in three dimensions. How was this structure derived?

The analysis will be gone into in some detail here, because it is generally representative, even though this particular case is so very simple. A glance at the structural diagrams of sodium chloride shows that the planes represented there are of two kinds. The reflections, or orders, designated (200), (400), (600) and so on, and those designated (220), (440), (660) and so on, arise from sheets of atoms that are identical, each containing equal numbers of sodium and chlorine



THREE POSSIBLE ARRANGEMENTS of the reflecting sheets of atoms in a sodium chloride crystal are indicated by the colored planes. The axes of this simple cubic crystal are denoted by the letters *OA*, *OB* and *OC*. In the diagram at left the first reflection to appear from the planes perpendicular to *OA* is assigned the order (200), since there is a path difference of two wavelengths between *O* and *A* while the reflecting planes are parallel to *OB* and *OC*. (In this case $h = 2$, $k = 0$ and $l = 0$.) Similarly, the initial reflection to appear from the planes in the diagram at center is designated (220), whereas for the diagram at right it is (111) with respect to chlorine planes. In general, orders with even indices arise from sheets that are identical and hence result in strong, in-phase reflections, whereas orders with odd indices arise from alternately occupied sheets and hence result in weak, out-of-phase reflections.

atoms. One would expect the sequence of successive orders to fall off regularly in intensity. As the diagram at the right on this page shows, however, the reflection (111) comes from a more complex set of planes, in that the sheets are alternately occupied by sodium and chlorine atoms. Since for (111) there is a path difference of one wavelength for the strongly reflecting chlorine planes, the waves reflected from the weaker sodium planes halfway between them will be opposite in phase. The order (111) will be weak, since the sodium contribution partially offsets the chlorine contribution. On the other hand, for (222) the contributions will be in phase and the order will be strong.

In this type of space lattice, as it is called, there are identical points at the face centers as well as at the corners of the cube; this implies that the indices must be either all odd or all even. These observations can be generalized by stating that orders with even indices, such as (200), (220) and (222), should form a strong sequence, whereas those with odd indices, such as (111), (113) and (333), should be comparatively weak.

This is the effect that is actually observed. The illustration on page 63 shows a very early set of measurements of sodium chloride and potassium chloride made with the ionization spectrometer, a device invented by my father, W. H. Bragg, in 1913. The abscissas measure the glancing angle, the ordinates the strength of the reflection. The two peaks seen on each order are the $K\alpha$ and $K\beta$ "lines" in the spectrum of the palladium anticathode, the $K\alpha$ line being the stronger of the two. The orders are reflected from crystal faces with crystallographic indices (100), (110) and (111). As the curves show, the order (111) for sodium chloride is anomalously small, whereas (222) fits into the same sequence with (200) and (220). For potassium chloride, on the other hand, the scattering powers of the potassium atoms and the chlorine atoms are so nearly the same that the order (111) is too weak to be observed. It was on the basis of such evidence that the structural arrangement of both of these alkaline halides was confirmed.

Although the preceding analysis is somewhat simplified, it is a typical example of the method used in the early determinations of crystal structure. A number of orders of diffracted waves were measured, either with the ionization spectrometer or on a photographic plate, and an attempt was then made to find an atomic arrangement that accounted for the relative intensities of the various orders.

The Significance of *F*(*hkl*)

The quantity *F*(*hkl*) is the cornerstone of X-ray analysis, and its determination is the final aim of all experimental methods. This quantity is a measure, for each order (*hkl*), of the intensity of the beam scattered by the whole unit of a pattern expressed in terms of the amount scattered by a single electron as a unit. For instance, the quantity *F*(000) is scattered in the forward direction through zero angle, so that there are no path differences to cause interference; *F*(000) is therefore the total number of electrons in the unit of pattern. For higher orders there is a reduction in intensity owing to interference.

It is important to note that *F*(*hkl*) is a dimensionless ratio, characteristic only of the crystal structure. It is independent of the wavelength of the X rays. If a smaller wavelength is used, the orders appear at lower angles and path differences are reduced, but phase differences remain the same. Thus *F*(*hkl*) depends only on the distribution of scattering matter in the unit cell, which it is the object of X-ray analysis to determine.

The theoretical basis for measuring values of *F*(*hkl*) was laid down by C. G. Darwin in two brilliant papers soon after the discovery of X-ray diffraction. In those early days the experimental observations were too approximate for a test of his theory, and a number of years elapsed before it could be applied.

Darwin's first calculation assumed the crystal to be "ideally perfect." Rough tests showed, however, that the efficiency of reflection was many times stronger than his theory indicated. Darwin correctly reasoned that the cause of the discrepancy was the departure of the crystal from perfection. It is a curious paradox that imperfect crystals reflect more efficiently than perfect crystals. In the latter case the reflection, which is almost complete over a few seconds of arc, comes from a thin superficial layer only; planes at greater depths cannot contribute because the uppermost layers have robbed the radiation, so to speak, of the component the lower layers would otherwise have reflected. Actual crystals, however, are in general far from perfect. They are like a three-dimensional crazy quilt of small blocks that differ slightly in orientation; as a result the crystal reflects over an appreciable angular range. Within this range rays penetrate into the crystal until they encounter a block at the correct angle for reflection, and the contributions from all such blocks add to the total reflection.

Darwin's second formula, therefore, applies to what is called an "ideally imperfect" crystal, and it is the formula always used. The intensity of the incident beam, or the amount of radiation per unit of time, is compared with the total amount of radiation received by the recorder as the crystal is swept through the reflecting range at a constant angular rate; this enables all elements of the mosaic to make their contribution to the reflection.

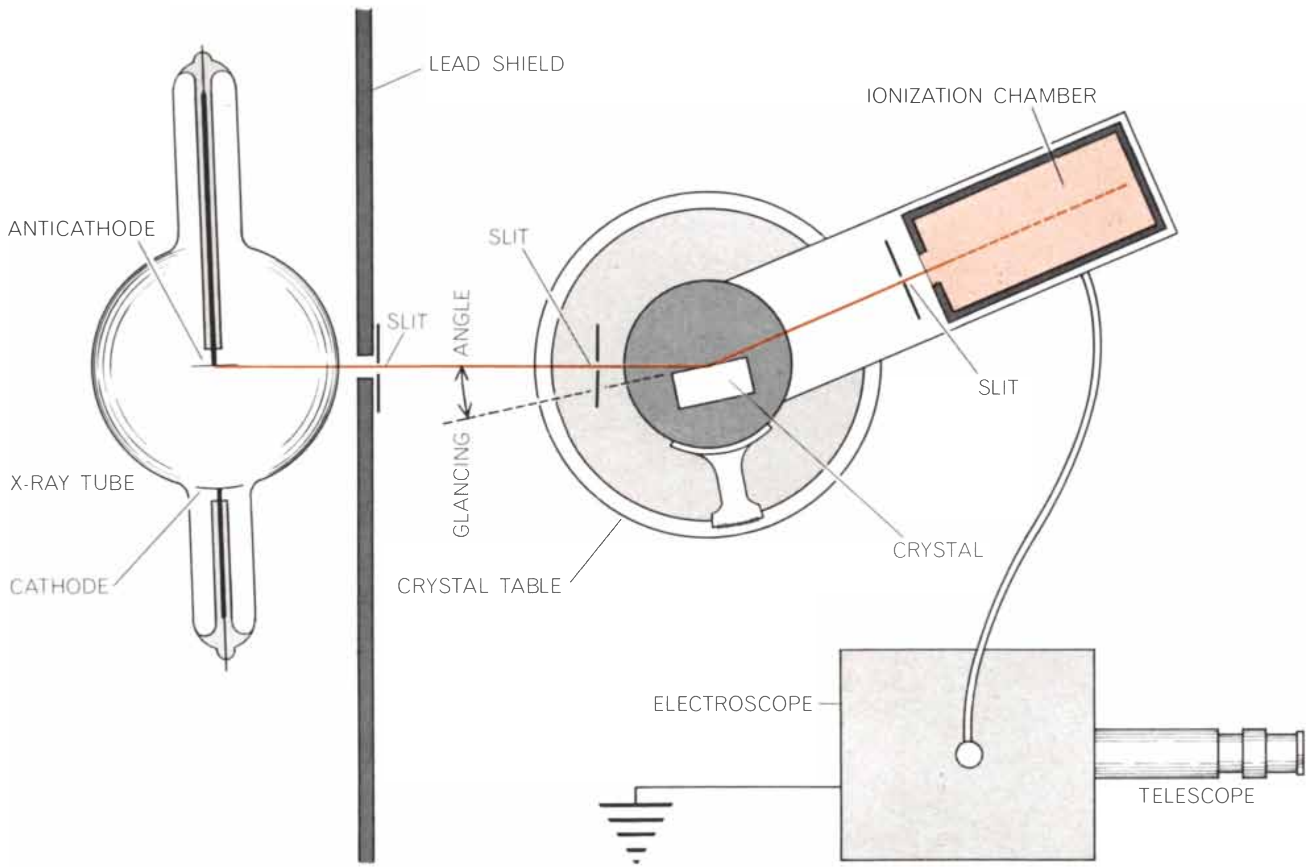
When calculating a value of $F(hkl)$ for a postulated atomic arrangement, it is necessary to know the contributions from individual atoms, which depend on the characteristic distribution of electrons in each atom. These distributions were calculated by Douglas R. Hartree in 1925 and are expressed as "*F* curves" typical of each atom. Intensity measurements were the subject of an extensive study by the University of Manchester school, culminating in the paper by Reginald James, Ivar Waller and Hartree on the zero-point energy of the rock-salt lattice. Amplitudes of thermal vibration can be measured by their effects in reducing *F* values; by extrapolating to absolute zero it was found that the atoms still had a vibration corresponding to a half-quantum, as theoretical studies had indicated.

Experimental Measurements

When a diffracted X-ray beam is recorded by an ionization chamber, a Geiger counter or a proportional counter, the orders are recorded one by one, by setting the crystal and the chamber at suitable angles. Alternatively the beams can be recorded as spots on a photographic plate or film by turning the crystal during the exposure so that a number of planes can reflect. In the early crystal determinations the ionization spectrometer measured orders individually. As more complex crystals were attempted and more orders had to be measured, the photographic method was favored because a single exposure registered a large number of orders. Recently automation has obviated the tedium of making numerous individual measurements, and the most advanced analyses are now performed with counters as recorders.

The original X-ray spectrometer designed by W. H. Bragg is a typical example of the first method [*see illustration below*]. A collimated beam from the X-ray tube fell on the face of the crystal and was reflected through slits into the recording ionization chamber, which was filled with a heavy gas (methyl bromide) to increase ionization. The outer case was at a potential of several hundred volts, and the ionization was measured by driving the charge onto a coaxial wire connected to a tilted gold-leaf electroscope. It was with this instrument that my father made his pioneer investigations on the X-ray spectra from anticathodes of a number of different metals, a project that formed the basis for H. G. J. Moseley's subsequent work on atomic number; the early determinations of crystal structure, for which I was mainly responsible, were also made with this instrument.

Considering the crudeness of the apparatus by modern standards, it gave surprisingly accurate results. A main trouble arose from the vagaries of the X-ray



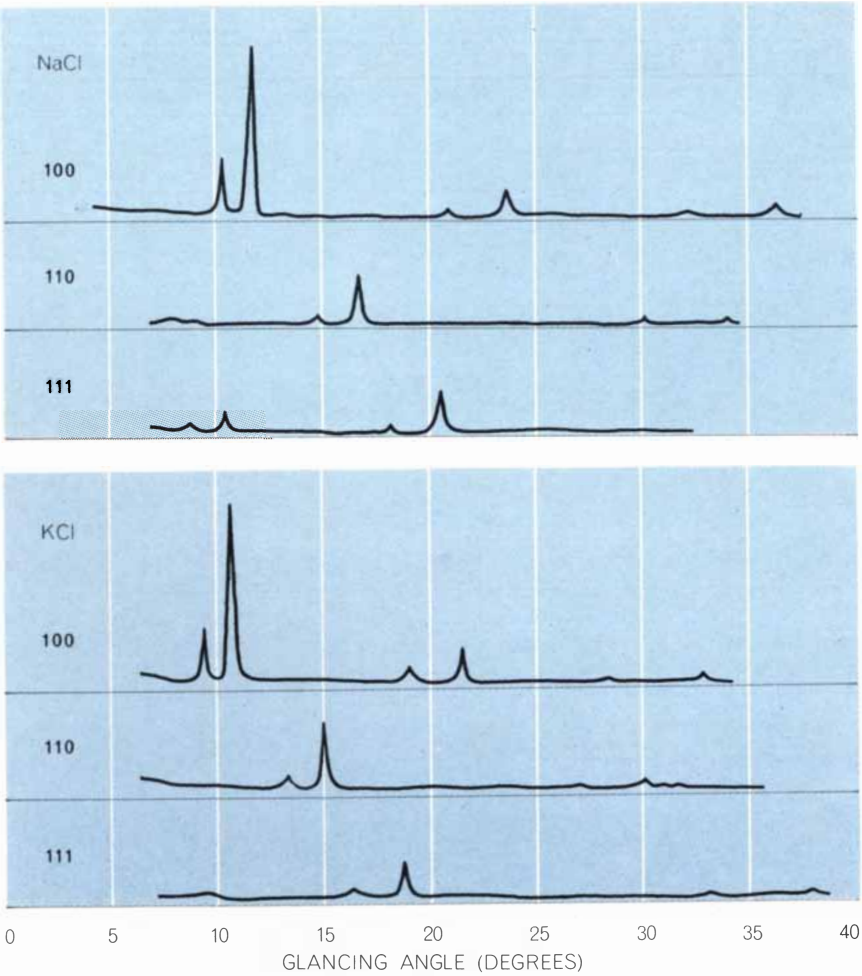
IONIZATION SPECTROMETER was the instrument used by the author's father, W. H. Bragg, to conduct the first investigations of the X-ray spectra from various metallic anticathodes and later by the author to make the early determinations of crystal structure.

tubes in those days. The tube was energized by a Rumkorff coil, first with a hammer switch and later with a mercury switch, which gave a steadier discharge. If the X rays from the tube got too hard, one held a match under a fine palladium tube attached to the main tube, which allowed some gas to diffuse in; if they got too soft, one sparked to a bunch of mica sheets inside, which absorbed some gas. The gold-leaf electroscope was also a tricky instrument for accurate work. I think that one of the main reasons why X-ray analysis developed in my father's laboratory at the University of Leeds, even though the fundamental discovery had been made in Germany, was that my father had so much experience in making accurate ionization measurements with the primitive apparatus then available.

When the diffracted beams are measured one by one, the indexing presents no difficulty because the crystal orientation that produces each beam is known. When many beams are recorded at the same time on a photographic plate, however, each of them must be identified. A number of ingenious methods have been devised for this purpose.

In general two types of X-ray photograph have been widely used. One type is called a "rotation" photograph [*see top illustration on next page*]. In this method the X rays fall on a small crystal, which is rotated around an axis that coincides with one of its principal crystal axes, and the diffracted beams are recorded on a cylindrical film. The images of the diffracted beams all lie on "layer lines"; for instance, if the crystal axis is along OC, the layer lines correspond to $l = 0$, $l = 1$, $l = 2$, and the spots have all values of h and k. If the spots are very numerous, it may be too difficult to sort them out and a Weissenberg camera is used. In this technique one layer line is singled out by a slit, and the film is translated as the crystal turns. If the film has been translated horizontally, the displacement of a spot along the horizontal axis tells the angle of setting of the crystal when it was recorded and so defines the other indices [*see illustration on page 66*].

Another elegant device in this category is the precession camera. Crystal, photographic plate and screen perform a sinuous dance in such a way that those spots, for instance, with a definite value of l and all values of h and k are recorded as a rectilinear net [*see illustration on page 59*]. This method is particularly suitable for crystals with large unit cells and consequently numerous values of the indices.

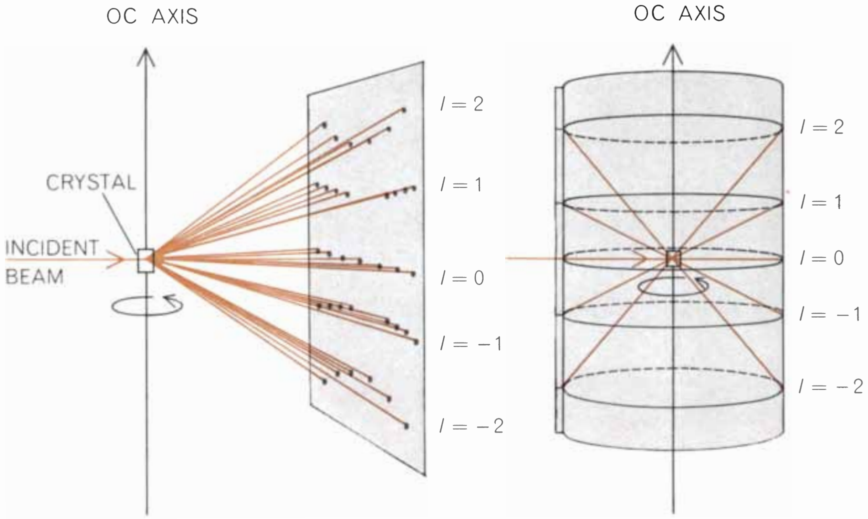


EARLY MEASUREMENTS of the intensity of the reflected X rays from sodium chloride (*top*) and potassium chloride (*bottom*) were made with the ionization spectrometer. The orders were reflected from crystal faces with crystallographic indices (100), (110) and (111). The two peaks seen on each order are the $K\alpha$ and $K\beta$ "lines" in the spectrum of the palladium anticathode, the $K\alpha$ line being the stronger of the two. For sodium chloride the order (111) is anomalously small, because the weak sodium contribution partially offsets the strong chlorine contribution, whereas for potassium chloride the order (111) is too weak to be observed, because the scattering powers of the potassium atoms and the chlorine atoms are so nearly similar. This comparison confirmed the structures assigned to the crystals.

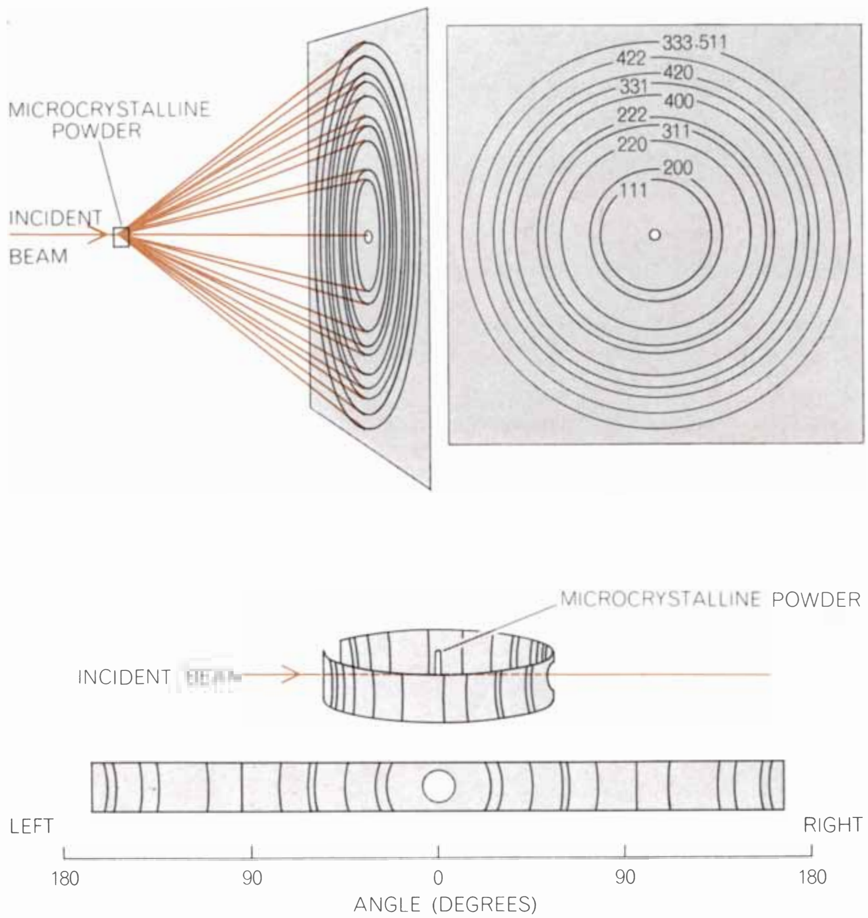
The second general method of X-ray photography is the powder method, developed independently in 1916 by Peter J. W. Debye and Paul Scherrer in Switzerland and by Albert W. Hull in the U.S. [*see bottom illustration on next page*]. The powder method is used when the material is available only in microcrystalline form. The X rays fall on a mass of tiny crystals in all orientations, and the beams of each order (hkl) form a cone. Arcs of the cones are intercepted by a film surrounding the specimen. In the powder photographs of sodium chloride and potassium chloride on page 65 one can see that in sodium chloride there is a weak series for odd (hkl) values, whereas in potassium chloride these disappear because the scattering powers of the potassium atoms and the chlorine atoms are so similar. In addition potassium chloride has a larger spacing than sodium chloride, hence the displacement of the arcs to smaller angles. The powder method has found its main use in the study of alloys.

Symmetry

The pattern of every crystal has certain symmetry elements that form a three-dimensional scaffolding on which the atoms are arranged, and these elements can be uniquely determined by the X-ray-diffraction method. In the early days of X-ray analysis, when the ionic compounds that were being studied often had a high symmetry, this fact was of great assistance in arriving at a solution. The possible schemes of symmetry



ROTATION PHOTOGRAPHS ARE MADE by aiming the X rays at a small crystal, which is rotated around an axis that coincides with one of its principal symmetry axes; the diffracted beams are recorded on either a flat plate (*left*) or a cylindrical film (*right*). The images of the diffracted beams all lie on "layer lines"; in this case the crystal axis is along *OC*, the layer lines correspond to $l = 0$, $l = 1$, $l = 2$ and the spots have all values of h and k.



POWDER PHOTOGRAPHS ARE MADE by aiming the X rays at a mass of tiny crystals in all orientations. The diffracted beams of each order (*hkl*) will then form a cone. If recorded on a plate perpendicular to the incident beam, each diffraction order will appear as a ring surrounding the central spot (*top*); the positions of the rings shown are typical of a face-centered-cubic crystal lattice. It is usually more convenient to employ a cylindrical photographic film whose axis is perpendicular to the incident radiation (*bottom*). Arcs of the cones are intercepted at all angles up to nearly 180 degrees; the film is then unrolled.

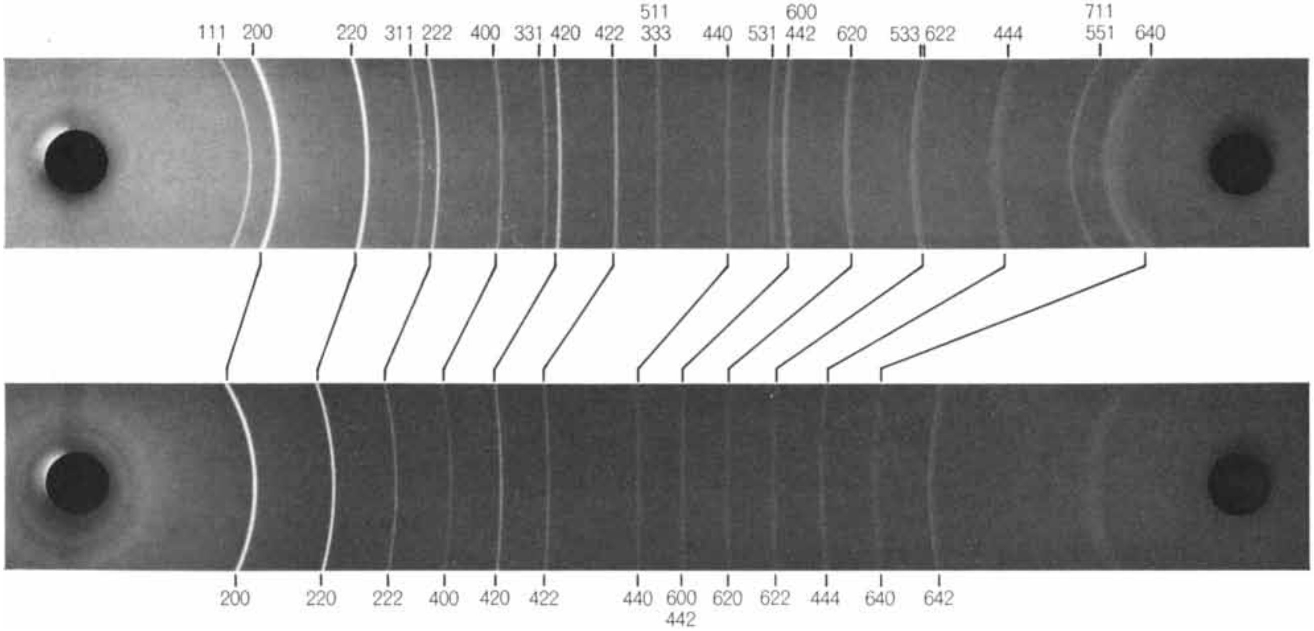
are limited by geometry, just as the possible number of regular solid figures are limited, although in the case of crystal symmetries the number, 230, is quite large. Symmetry axes and symmetry planes can be identified by noting regular absences of diffracted-wave orders; the presence or absence of symmetry centers can be determined by a statistical survey of intensities, as was first shown by A. J. Wilson; crystals with symmetry centers characteristically have many more weak reflections than crystals with no symmetry centers.

Finally, X rays can tell "which way around" a structure is. Optically active molecules can have two forms, one of which is the reflection of the other (the dextro and levo forms of the chemist). In general when the waves scattered by the atoms have phases as if coming from atomic centers, these two forms give identical X-ray diffraction, that is, the reflection from the right-hand side has the same amplitude as that from the left, although the phase is reversed. When the wavelength of the X rays is close to an absorption edge of an atom, however, there is an appreciable phase change. The atom scatters as if at one location for the one side and at another location for the other side, so that the resultant amplitudes are different. This enables dextro and levo to be distinguished; for instance, in the classic case of a tetrahedron with four different corners one could tell for each orientation whether one was looking at an apex or a base. J. M. Biyvoet was the first to distinguish between dextro and levo forms of the tartrate ion. There was a 50 : 50 chance that the traditional chemical convention for representing dextro and levo was correct; luckily it turned out to be right!

Inorganic Compounds

The first crystals to be analyzed by means of X rays were simple types. An approximate measure of the complexity of a crystal is the number of parameters that must be determined in order to define the positions of the atoms. In the case of an atom at a symmetry center, for instance, no parameters are needed; it must be exactly at the center. If the atom lies on an axis, its position along the axis is fixed by one parameter; if on a reflection plane, by two; if in a position of no symmetry, by three.

The early determinations were limited to one or two parameters; in fact, it was doubted whether more complicated crystals would ever be analyzed. The break-



POWDER PHOTOGRAPHS of the diffracted X rays from sodium chloride (*top*) and potassium chloride (*bottom*) confirm the earlier findings made with the ionization spectrometer: In sodium chloride there is a weak series for odd (*hkl*) values, whereas in potassium chloride these orders disappear. Potassium chloride has a larger spacing; hence the arcs are displaced to smaller angles.

through into much more complex structures was made in the early 1920's by the Manchester school, where analysis was extended to cases of 10 or 20 parameters, a great advance at that time. It was made possible by quantitative measurements and increasing experience in the nature of inorganic compounds.

One of the first successes of X-ray analysis was to show that these compounds are not built of molecules. They are ionic in character, with a regular alternation of positive and negative ions held together by electrical attraction. For instance, in the sodium chloride structure there are no sodium chloride groups but rather a chessboard pattern of positive sodium ions and negative chlorine ions. It was difficult in the early days to reconcile the new view of ionic compounds with classical chemical ideas, but once accepted the ionic view afforded a much fuller understanding of the construction of such compounds.

In an ionic compound the ions pack together as if they had characteristic sizes. Their dimensions are not completely fixed, but they vary only over a small range. On the whole the negative ions are by far the largest, because their electrons are more loosely held.

The packing of ions of characteristic size is a very useful concept when postulating various atomic arrangements, particularly when combined with a knowledge of the symmetry elements. The hexagonal symmetry of the crystal beryl ($Be_3Al_2Si_6O_{18}$), for instance, is of a high order, with sixfold, threefold and twofold axes, symmetry planes and symmetry centers. An atom cannot overlap itself, so that it must either lie exactly on one of these symmetry elements or be just off it. This restriction is so demanding that the structure of beryl could be immediately deduced once the symmetry was determined. The top illustration on page 67 shows the only possible way of packing the atoms of the beryl formula into the network of symmetry elements.

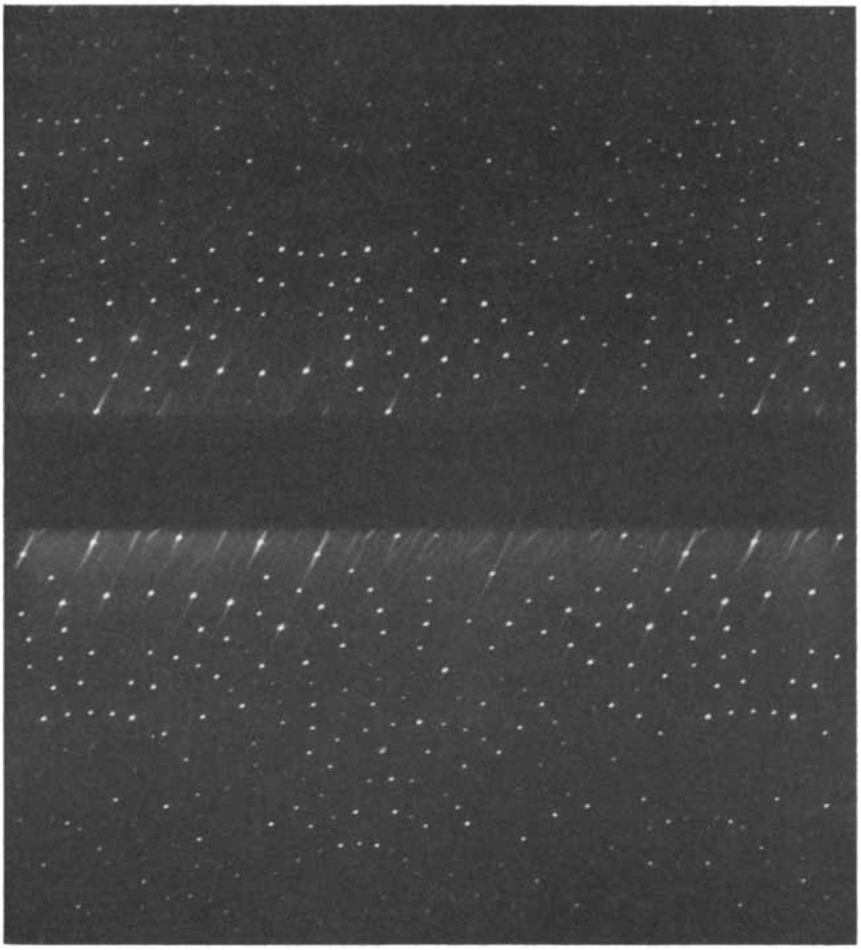
The laws governing the structure of inorganic compounds, established by Linus Pauling in 1929, afford another guide in seeking a solution. They also explain why some compounds are stable, whereas others that seem equally plausible from a chemical point of view do not actually exist. Pauling's rule is based on the requirement that for stability the energy of the compound must be as low as possible. Each small positive ion lies inside a cluster of larger negative ions; for instance, very small positive ions such as beryllium or boron are each surrounded by three oxygen atoms; silicon is surrounded by four oxygens, magnesium and iron by six oxygens and still larger ions by eight or more oxygens. If we picture electric fields in terms of lines of force, suppose the number of lines representing the charge on the positive ion is divided equally between the negative ions coordinated around it. Pauling's rule states that the total number of lines coming to the negative ion from all its positive neighbors just balances its charge. This might seem at first sight a simple rule, but it is powerful in excluding improbable structures. Its significance is that when Pauling's rule is obeyed, the lines of force between positive and negative ions stretch only over the very short distances between nearest neighbors, so that the energy of the electric field is at a minimum and the structure is stable.

The study of inorganic compounds culminated in the determination of all the common mineral forms, in particular the silicates. These compounds obey Pauling's rule rigorously, because they must be very stable in order to exist as minerals. The explanation of their composition proved to be very interesting. Their nature is determined by the silicon-to-oxygen ratio, ranging from SiO_4 in the basic rocks to SiO_2 in quartz. Although the ratio varies widely, the silicon ion is always surrounded by four oxygen atoms; the silicon-oxygen tetrahedrons may, however, share no corners, one corner, two corners, three corners or four corners by having an oxygen atom in common. In the SiO_3 silicates, for example, there are long strings of SiO_4 groups that run endlessly through the structure, representing infinite linear negative ions bound laterally by the positive ions. The silicate groups occur as sheet ions in the micas and clays, and as three-dimensional-network ions with metals in their interstices in the feldspars. This unexpected feature of minerals explains their composition in a simple and elegant way; it is one of the important new conceptions introduced by X-ray analysis.

Alloys

After the nature of inorganic compounds had been clarified, the next achievement of X-ray analysis was to explain the nature of metallic alloys, which had hitherto been so mysterious. The pioneer investigations into alloy structure were made by Arne F. Westgren in Sweden. They were developed by Albert J. Bradley and his pupils at Manchester, for the most part between 1925 and 1935. The powder method was used perforce, because the material was in microcrystalline form, and in Bradley's hands it reached a peak of perfection that has hardly been equaled since. The ground covered was so extensive that it is only possible to give the briefest summary.

In the first place, the determination of alloy structure provided the foundation on which a theory of alloy chemistry could be developed. When two metals unite in varying composition, they form a series of phases. These compounds are non-Daltonian, that is, they are not composed of some simple ratio of elements; on the contrary, each exists over a range of composition. William Hume-Rothery first pointed out that in different binary systems phases with very similar physical properties tend to have the same ratio of free electrons to atoms in their composition. Structure determinations showed that such phases have a closely similar atomic arrangement but with curious characteristics. The essential similarity lies in the positions occupied by atoms, not in the way the kinds of atoms are distributed among the places. Apparently the relation of atom to atom is relatively immaterial; it is the position of the atoms that is all-important. This in turn was explained by theoretical physicists in terms of Brillouin zones. Treating the free electrons as standing waves, the system has a low energy if the electrons of shortest wavelength are just too long to be reflected by the most marked reflecting planes in the phase structure. In the stable phase the atoms take up arrangements that create the strongly reflecting planes required for low energy. To put it broadly, an alloy is not a compound between one metal and another but rather a compound between all the metal atoms on the one hand and all the free electrons on the other. It is perhaps not too much to say that the X-ray determination of alloy structures led for the first time to a rational theory of metal chemistry.



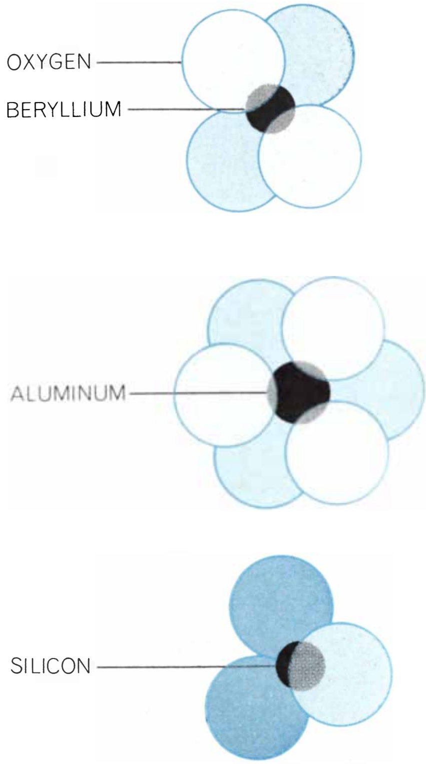
WEISSENBERG PHOTOGRAPH is a type of rotation photograph that is used when the spots are too numerous to sort out by the conventional method. In this technique one layer line is singled out by a slit, and the film is translated as the crystal turns. The displacement of a spot along the translation axis (in this case the horizontal axis) tells the angle of setting of the crystal when it was recorded and so defines the other reflection indices of the crystal.

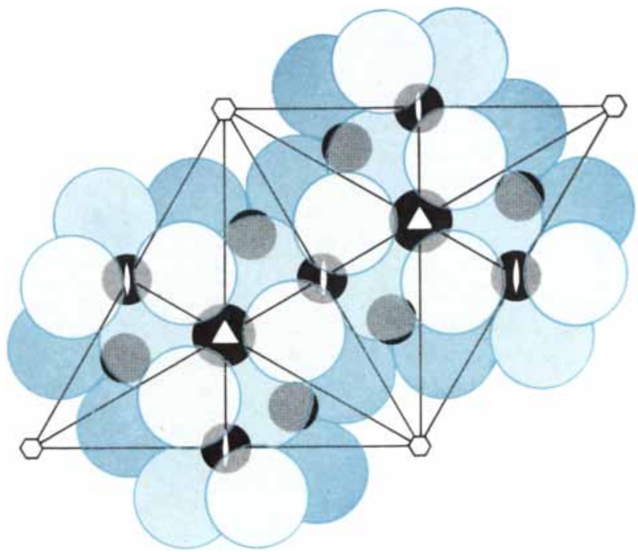
Equilibrium systems, or the phases produced by variations of composition, had previously been deduced from studies of polished and etched specimens, but they can be mapped out far more directly by X-ray analysis. Phases can be recognized by their powder photographs and the composition of the phase in any given case can, after some preliminary trials, be fixed by noting which spacings of the unit cell vary over the range. Ternary and even quaternary systems, which would hardly be amenable to metallographic methods, can be tackled by X-ray methods.

An interesting application in this area was found in the "order-disorder" systems. An example of such a system is the copper-gold alloy Cu_3Au, first studied by Gudmund Borelius of Sweden. At high temperatures all the points of the face-centered-cubic lattice of this alloy are occupied at random by gold or copper atoms; at low temperatures after slow annealing the gold atoms segregate into the cube corners, leaving the face centers to the copper atoms. The progress of the segregation can be followed by the appearance of new lines, corresponding to greater spacings, in the powder photographs. The variation of segregation with temperature presents interesting thermodynamic problems of second-order phase change, and the X-ray work did much to stimulate the study of corresponding changes in other systems.

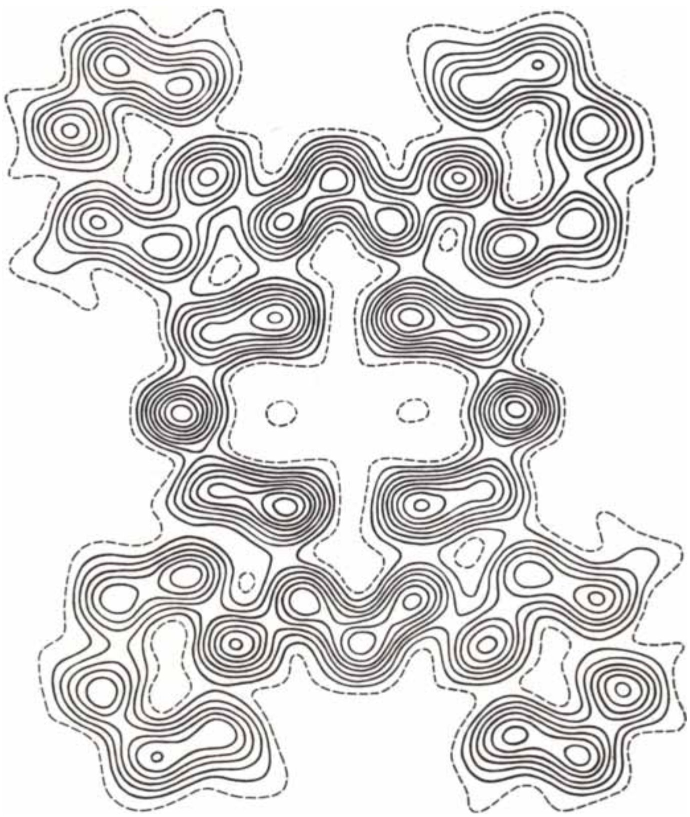
Another phenomenon studied intensively by Bradley was the splitting of a phase into regions with slightly different composition, which were nonetheless united in having a continuous crystal lattice. Such segregation sets up intense internal strains. It is characteristic of alloys used as strong permanent magnets, because the strains give the material a high magnetic retentivity.

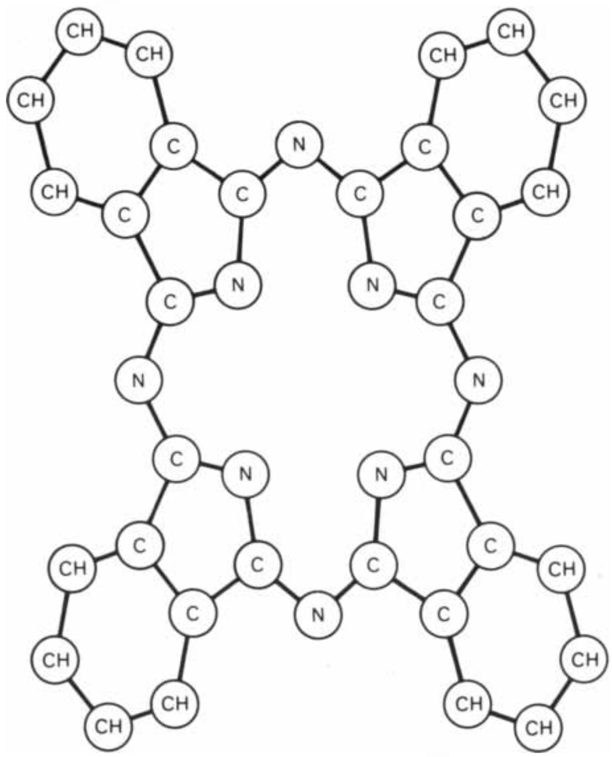
In general, X-ray analysis has provided a powerful new tool for examining the properties of alloy systems, an achieve-





STRUCTURE OF BERYL (*right*), a complex inorganic compound with the formula $Be_3Al_2Si_6O_{18}$, was deduced from a knowledge of the packing of the constituent ions (*left*) as soon as the basic hexagonal symmetry of the crystal was determined by X-ray diffraction. Since an atom must lie exactly on one of the symmetry elements or be just off it, there could be only one way of packing the atoms of the beryl formula into the network of symmetry elements. A key to the symmetry axes of the crystal is given at bottom.





FOURIER REPRESENTATION of the electron-density distribution in a molecule of phthalocyanine (*left*) was used to construct the atomic model of the molecule (*right*). The Fourier "density map" is arrived at by treating a molecular structure not as a cluster of individual atoms but as a continuous electron distribution capable of scattering X rays. The density distribution of the molecule as a whole is obtained by adding together the terms of a Fourier series, a mathematical expression that can be used to represent the periodic variation of sets of electron-density sheets in all directions. The Fourier method is ideal for analyzing organic molecules.

ment that has great technical importance as well as scientific interest.

The Fourier Method

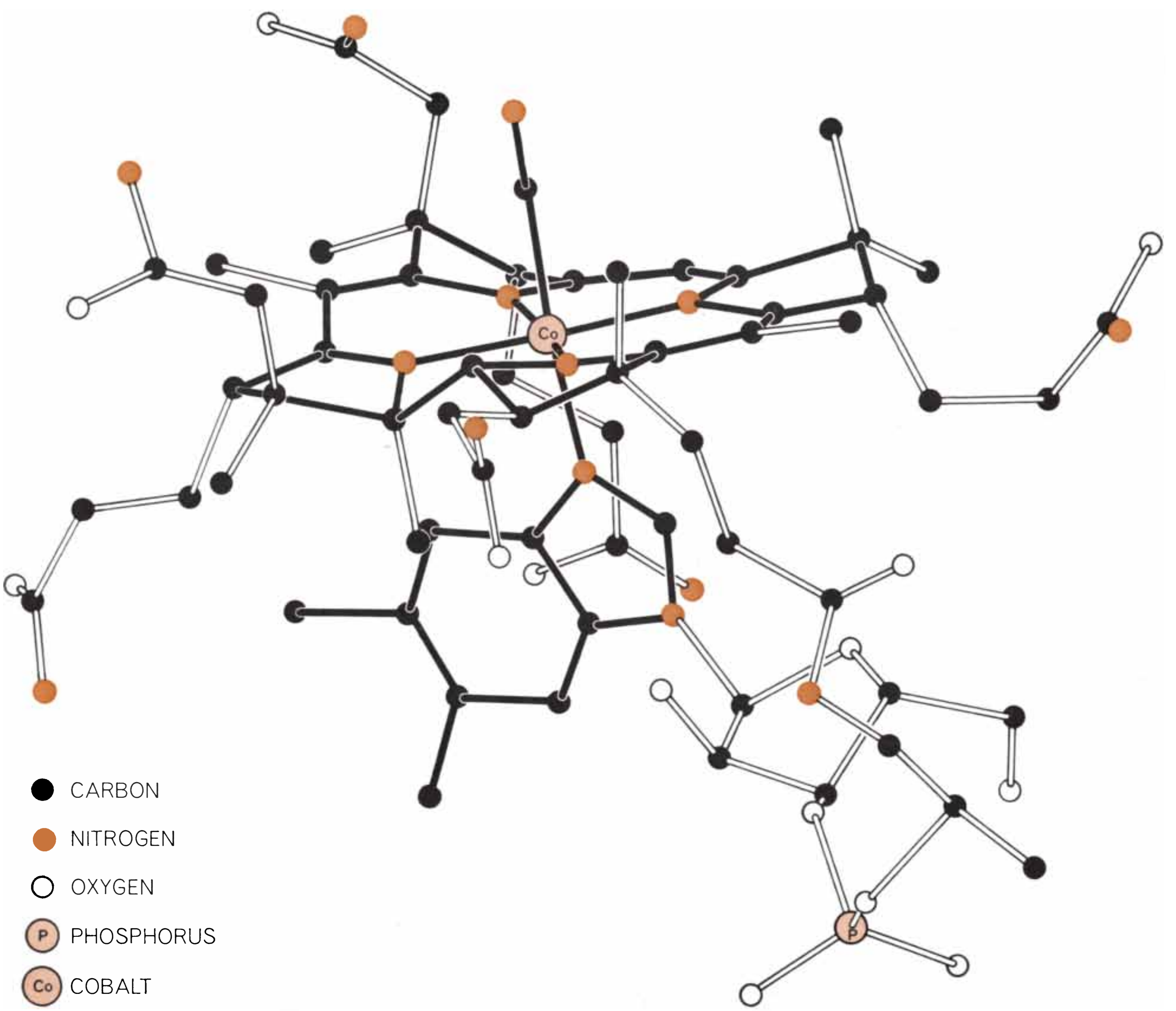
Another method of X-ray analysis attacks the solution of the crystal structure from a quite different angle. So far the crystal has been regarded as a pattern of atoms, each of which scatters X rays as if from its center with an efficiency determined by Hartree's *F* curves. The resultant of the waves scattered by these atoms is then compared with the observed amplitude of reflection, the position of the atoms being adjusted to give the best fit.

This method was successful as long as the number of atoms in the unit cell was small. As increasingly complex crystals were studied, however, it became more and more difficult to try adjustments of so many parameters simultaneously, even when the structure was approximately known. The refining of the structure to get the best fit became extremely laborious.

The Fourier method is in a sense a complete reversal of this process. A structure is treated not as a cluster of atoms but as a continuous electron distribution capable of scattering X rays. The investigator seeks to map this continuous distribution, and, if he is successful, he can then recognize the positions of the atoms by noting where the electron density rises to peak values. There is no juggling with the positions of atoms one by one; the density map shows the best position for all of them, however large their number.

The density distributions are mapped by adding together the terms of a "Fourier series," a mathematical expression that can be used to represent any quantity that varies periodically. Since a crystal is a periodic pattern in three dimensions, the electron density can be represented by a three-dimensional Fourier series. Each element of the series is a set of electron sheets, or strata, that vary periodically in density, and if the amplitudes and phases of these sheets (which crisscross in all directions) are known, they can be added and the result is a plot of the density distribution.

My father first pointed out, in his Bakerian Lecture to the Royal Society of London in 1915, that each of these periodic components reflects one corresponding order and only that order; moreover, the amplitude of the reflected waves is proportional to the amplitude of the Fourier component. Since changes in the phase of the reflected waves can still give the same X-ray effects, however, the only way of choosing the right phase



STRUCTURE OF VITAMIN B-12, solved by Dorothy Crowfoot Hodgkin in 1955, represented one of the outstanding achievements of what might be called the classical methods of X-ray analysis. The formula of vitamin B-12 molecule is $C_{63}H_{84}N_{14}O_{14}PCo$.

is to introduce some criterion of reality leading to a picture with the right number of atoms of the right kind in the unit cell. The Fourier method therefore centers around a "phase hunt." Once the phases are known the structure is "in the bag."

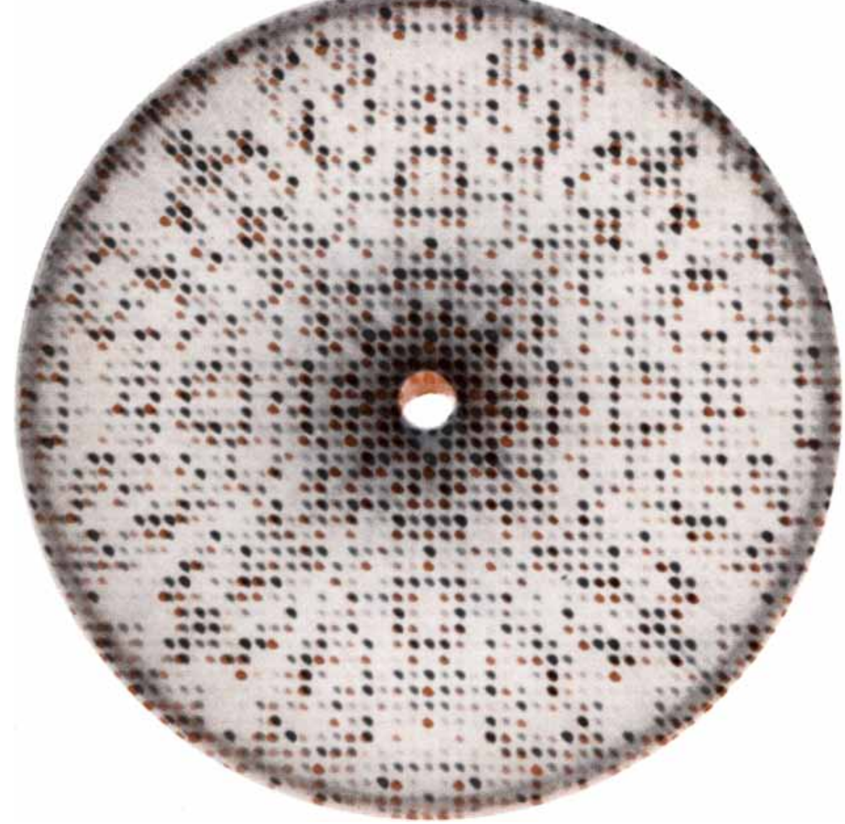
Organic Molecules

From 1930 onward the Fourier method was recognized as being ideal for analyzing organic molecules, and many were determined in this way. The first organic structures, naphthalene and anthracene, had been outlined by W. H. Bragg in 1922 at the same time that the study of inorganic structures was pursued at Manchester, and his laboratory at the Royal Institution concentrated on the organic field.

Initially most of the studies dealt with crystals that had symmetry centers. This is a great simplification of the problem, because the phases of the Fourier components with respect to such a center must by symmetry be either 0 or π; in other words, $F(hkl)$ must be either plus or minus. The advantage here is that calculations on the basis of a quite rough approximation of the structure generally make it clear which is the right sign, particularly in the case of the strong and therefore important orders. A Fourier series can then be calculated, the position of the atoms can be improved, further signs that were formerly doubtful can be fixed and a new Fourier can be summed. This process of refinement is rapidly convergent, and after a few stages the structure is accurately determined.

A three-dimensional Fourier series is a formidable affair, and in these attacks on organic structures the less ambitious task of using two-dimensional series and getting a projection of the structure on a plane was more usually undertaken. Projections on the three principal planes define the positions of the atoms in space. A pretty example of this was the analysis of phthalocyanine with 60 parameters, where the signs of the F's were found without any guesswork as to the nature of the structure [*see bottom illustration on page* 67].

It is possible to substitute a heavy atom at the center of the phthalocyanine molecule without any alteration in the crystal lattice. If a spot becomes stronger when the heavy atom is introduced, its original F value with respect to the center of the molecule must have been positive; if the spot becomes weaker, the F value must have been negative. All the signs were determined in this way and



ADDITION OF A HEAVY ATOM at a specific place among the molecules in a protein crystal provided the key that has led to the recent solution of several protein structures. In this illustration of the method two precession photographs of the same crystal of lysozyme are superposed with a slight relative displacement. The set of spots due to the native protein is printed in black. The set of spots due to the protein with the heavy atom is printed in color. Numerous changes in the intensities of corresponding spots can be detected.

used in a two-dimensional Fourier series. The result is shown as a contour plot of the electron densities.

In most cases the results of X-ray analysis confirmed the topography assigned to the molecules by organic chemistry, but the X-ray findings determined the bond distances and bond angles with great accuracy and so cast much light on the nature of the bonds.

The next stage in the study of organic molecules was to tackle far more complex structures, some of which had defeated the efforts of organic chemists to elucidate their stereochemistry. A forerunner of this stage was the solution of strychnine by Biyvoet in 1948, published independently at almost the same time that Sir Robert Robinson's researchers at the University of Oxford arrived at an identical structure by purely chemical reasoning. The outstanding examples are the solution of penicillin and vitamin B-12; in each case Dorothy Crowfoot Hodgkin of Oxford was the leader of the research. The latter investigation was a saga of X-ray analysis that took eight years. Not only was much chemical information about the molecule lacking but also conclusions arrived at on chemical grounds were actually misleading. The molecule, of formula $C_{63}H_{84}N_{14}O_{14}PCo$, is shown in the illustration on the opposite page.

The solution illustrates the curious and unique character of X-ray analysis, which is reminiscent of the solution of a code, or of an ancient form of writing such as Egyptian hieroglyphics or Minoan Linear B. It was first assumed that the phases of the F's were those of the cobalt atom (Co) at the center of the molecule and a Fourier series was formed on this hypothesis. Although it turned out that this is far from true, the phases are, as it were, weighted in this direction because the cobalt atom is so heavy compared with the other atoms. Fourier series have a surprisingly obliging way of trying to tell the investigator something with the most sketchy basis of information, and in this case the series outlined in a shadowy way the molecular structure immediately surrounding the cobalt atom. The information was used to adjust the phases, and a further series was formed and so the structure gradually began to emerge from the cobalt atom outward. The calculations would have been impossibly onerous had it not been for the availability of electronic computing of structure factors and three-dimensional Fourier series. The solution of vitamin B-12 represented the highest flight of what might be called the classical methods of X-ray analysis, and the Nobel prize awarded to Mrs. Hodgkin in 1964 was a well-deserved acknowledgment of her achievement.

Biochemical Molecules

We now come to a most dramatic turning point in the history of X-ray analysis. When vitamin B-12 was analyzed, with 181 atoms in the molecule, it seemed hard to imagine that much more complex structures could ever be tackled; it had taken eight years to complete and the difficulties increase as a high power of the number of atoms. And then, as the result of an investigation that had lasted for some 20 years, a way was finally found to solve the structure of the immensely more complicated molecules of living matter, the proteins. The first of these to be analyzed, by John C. Kendrew in 1955, was myoglobin, which has 2,500 atoms in its molecule.

By a curious paradox, the very size of such a molecule has opened up a new line of attack that is not possible in the case of simpler types, leading to a direct determination of phases without any element of guesswork or trial and error. The principle is the same as in the case of phthalocyanine described above, where the substitution of a heavy atom in the molecule enabled the signs of the F values to be found. A discovery made by M. F. Perutz in 1953 made it possible to generalize this method for the proteins. He found that heavy atoms such as mercury and gold, or complexes containing such atoms, can be incorporated at specific places in the framework of the protein crystal without affecting the arrangement of the molecules, which are so large and loosely packed that the added groups find places in the interstices. Further, Perutz showed that the added heavy atom produces changes in the F values large enough to be accurately measurable. It might at first sight appear strange that the addition of one heavy atom of mercury to a protein molecule with 2,500 atoms of carbon, oxygen and hydrogen should make an appreciable difference; it does so because the scattering comes from one center, whereas the random contribution from n atoms ranging over all phases is proportional to $\sqrt{n}$, not to n. The changes in intensity caused by the addition of a heavy atom can be seen when two precession photographs made with the same crystal are superposed with a slight relative displacement [*see illustration on preceding page*]. The black set of spots is due to the native protein, the colored set to the protein with a heavy atom, and a close examination will show numerous changes in the intensities of corresponding spots.

It is necessary to find some three or four heavy atoms that can be attached to definite sites on the molecule. Although the structure is initially unknown, direct methods are available for finding the relative positions of these "staining" atoms. The phase difference between the F value H due to the heavy atom and the F value P due to the protein can be found by comparing $F(P)$ with $F(P + H)$, because $F(P + H)$ must be the vectorial resultant of $F(P)$ and $F(H)$; the knowledge of the phase difference for several heavy atoms pins down the position of the Fourier component.

Because the solution is direct it can be found by giving instructions to a computer. The computer is essential because the complexity is so great. Some 100,000 or 200,000 intensities must be measured accurately by means of an automatic machine that sets the crystal and the recorder at the right positions for one order after another and lists the results. A corresponding number of equations must be solved to find the phases, and the Fourier series of many thousands of terms must be formed. This long series must be summed at perhaps a quarter of a million places in the unit cell to give the density at each point. The information is then automatically turned into contours, which are plotted on stacked transparent sheets, and the investigator has then to translate the density distribution into atomic arrangement.

The final result is impressive. Some half-dozen protein structures have so far been analyzed and they are already beginning to yield valuable information on such vital biochemical processes as the operation of enzymes. The second protein molecule to be analyzed successfully (after myoglobin) was the enzyme lysozyme (by David C. Phillips). The most recent success has been hemoglobin (by Perutz); the model of this protein contains 10,000 atoms. I confess that when I contemplate one of these models, I can still hardly believe that it has been possible to work out all its details by the optical principles of X-ray analysis, which half a century ago claimed sodium chloride as its first success.

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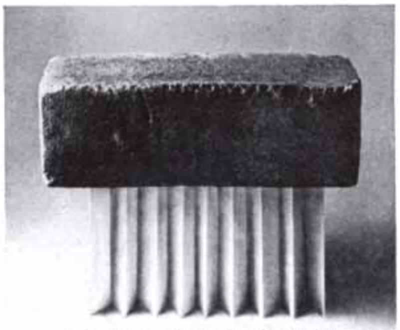
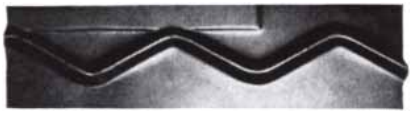

A PIECE OF PAPER CAN SUPPORT A 4½ lb. BRICK

To explain the next bit of gas-saving we've set up a little demonstration. *(above)*

Without those pleats, the same paper would never even support another piece of paper. That, in principle, is the kind of extra wrinkle we design into the steel structure of the Renault 10. It allows us to increase strength



and rigidity without increasing sheer dead weight. And by not increasing dead weight, again, we don't increase gas consumption.

Now, with your permission, a little documentation on how little scrimping there is on car. Included in the $1,745* price: Seats that have been compared with the seats in a Rolls-Royce. And which convert into twin beds. 11 cubic feet of trunk. Top speed, 85. Self-adjusting 4-wheel disc brakes. 4-wheel independent suspension. 4 doors. 4-speed synchromesh transmission.

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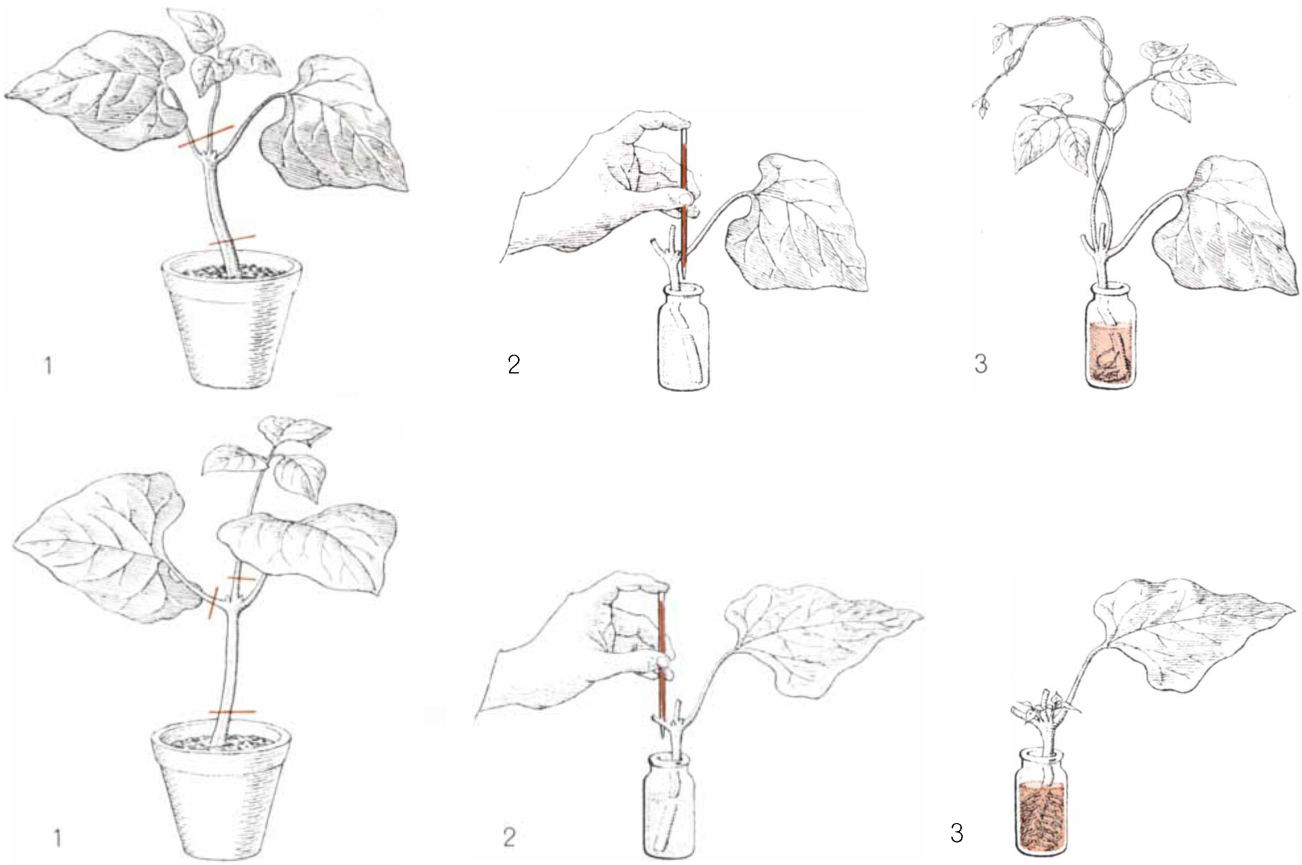
The Control of Plant Growth

The demonstration that the growth of plants can be turned on and off at will by treating them with the proper combination of promotive and inhibitory hormones suggests that this process also occurs in nature

by Johannes van Overbeek

The growth of a plant basically calls for light and water. Simple though these requirements may sound, plant growth itself is of course quite complex. In the green plant cell sunlight splits the molecules of water; this is part of the process of photosynthesis. The O of the H_2O is released into the air to provide the oxygen that all living things, including man, need for the process of respiration. The H_2 reacts with carbon dioxide and with nitrate to produce the major constituents of plant cells: sugar, starch, cellulose, protein and nucleic acid. When plant tissues are consumed by humans, these substances supply the building blocks of human cells and the energy needed for human life processes.

Normal plant growth and development will not take place without exceedingly small quantities of specific, in-



TWO TYPES OF PLANT-HORMONE ACTION were found in the author's early tests with dwarf bean plants. In both cases the original bean-plant cutting consisted of a piece of stem with one leaf and two nearly invisible buds (*step 1, top and bottom*); the fresh cuttings were then placed in small bottles of water. In one set of bottles a small amount of gibberellin, a naturally occurring plant-growth hormone, was dissolved in the water (*step 2, top*). Within a week the buds on these cuttings grew into long vinelike branches characteristic of pole beans (*step 3, top*); normally such branches would not appear at all in this particular variety of dwarf plant. In addition the normal amount of root growth in water was observed at the base of the stem. In the other set of bottles a small amount of indolebutyric acid, a synthetic auxin, was added (*step 2, bottom*). After a week bud growth was not promoted abnormally, but instead root development was greatly augmented, so that the base of the stem had the appearance of a bottle brush (*step 3, bottom*). A definite growth response was observed using as little as one part per billion of gibberellin or one part per million of indolebutyric acid.

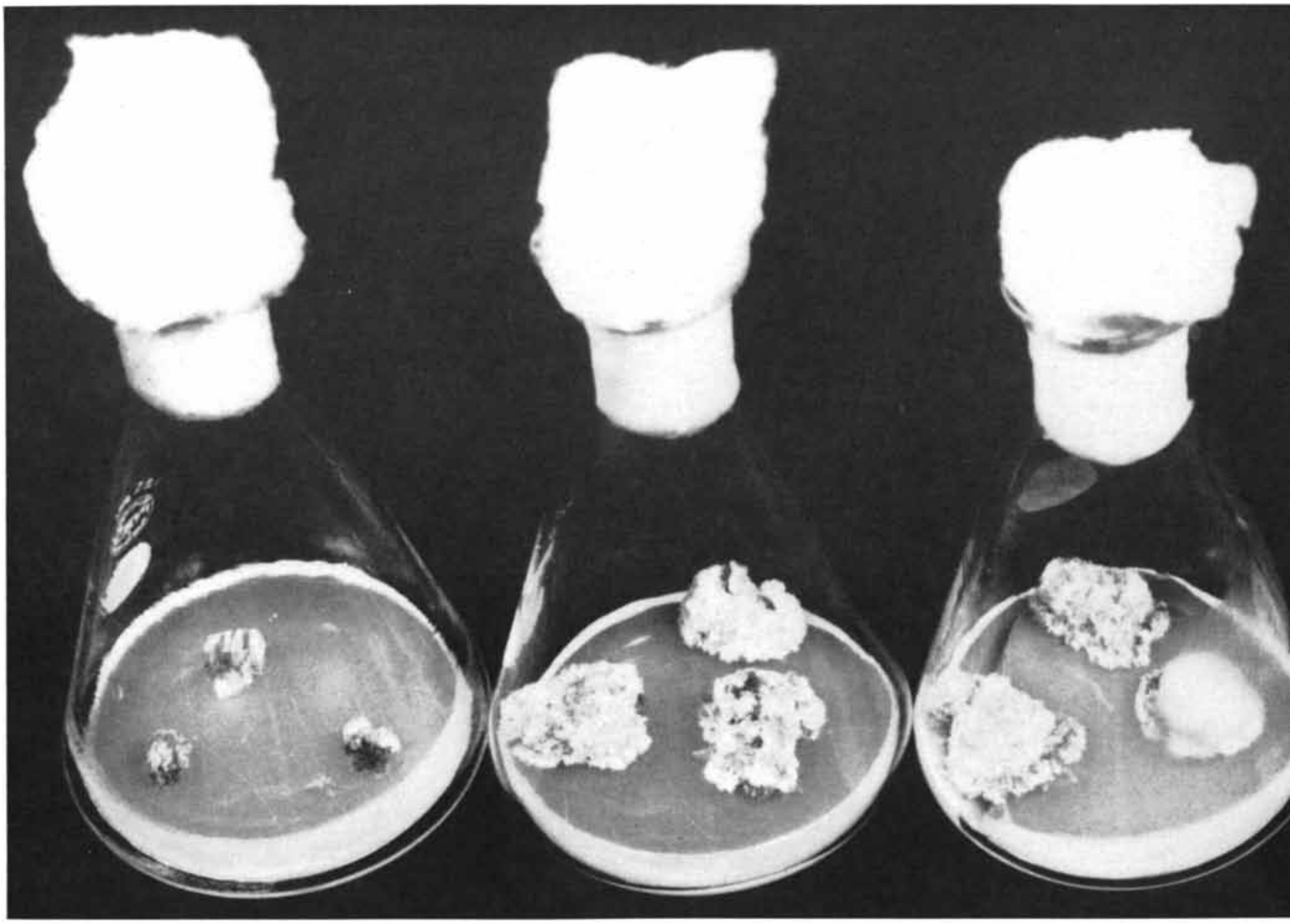
ternally produced substances: the plant hormones. This basic rule was discovered in the 1920's by Frits W. Went, who was then working in the Netherlands. It turns out that these hormones must not only be present; they must be available in the proper balance and at the right time. Although the chemical study of the plant hormones began 40 years ago, only recently has enough knowledge been acquired to allow experiments that demonstrate the real power of the hormones in a dramatic fashion.

The basic discoveries concerning the powers of plant hormones came about in various ways. One of them grew out of an investigation of dwarf varieties of corn. In the mid-1930's at the California Institute of Technology I tried to find a physiological link between the gene deficiencies of dwarf plants and the inhibition of their growth. Could their failure to grow to normal size be traced to a hormone influence or deficiency? The only plant hormones known at the time were the auxins, typified by indoleacetic acid. I experimented with these and found little evidence that auxins were critically involved in the dwarf plants' growth rate.

Twenty years later Bernard O. Phinney of the University of California at Los Angeles tested a new hormone on the same genetic dwarfs, and this time the outcome was different. The hormone was gibberellin, which had been discovered in Japan many years earlier but had just become available in the U.S. Phinney found that he could cause some of the corn dwarfs to grow into corn of normal size simply by placing a few drops of gibberellin solution in the center of the growing seedlings. Suddenly the old dream of being able to speed up the growth of plants at will had become an experimental reality.

The curious thing about gibberellin was that it had been discovered as the product of a fungus—a pathogenic fungus that made rice plants grow abnormally tall [see "Plant Growth Substances," by Frank B. Salisbury; SCIENTIFIC AMERICAN, April, 1957]. Strangely enough, although the fungus apparently does not require gibberellin for its own growth, its cells produce huge quantities of the hormone. (In fact, the commercial production of gibberellin today depends on the fermentation of this fungus in vats, similar to the way penicillin is produced in vats by the cultivation of a mold.) By an odd quirk of nature the gibberellin fungus produces a chemical for which it has no use itself but which serves a vital function in higher plants. It has since been learned that all the higher plants produce gibberellin and require it for normal growth and development. We shall look into gibberellin's roles later in the article.

Another potent group of plant hormones came to light in the mid-1950's. As it happens, I was involved in the early stages of this exploration also. About 1940 the geneticist Albert F. Blakeslee asked my help on a physiological problem. In the course of solving the problem I found, with my research associate Marie E. Conklin, that coco-



EFFECT OF CYTOKININ HORMONE on undifferentiated tissue from tobacco stems was studied by a group of investigators at the University of Wisconsin headed by Folke Skoog. By manipulating the concentration of the cytokinin in the growth medium they were

nut milk contains a new growth factor, which later turned out to be cytokinin. With the help of graduate students and chemists at Cal Tech we tried to isolate it, but after a year we had to give up. The active ingredient was always hidden in the dirtiest, stickiest residue.

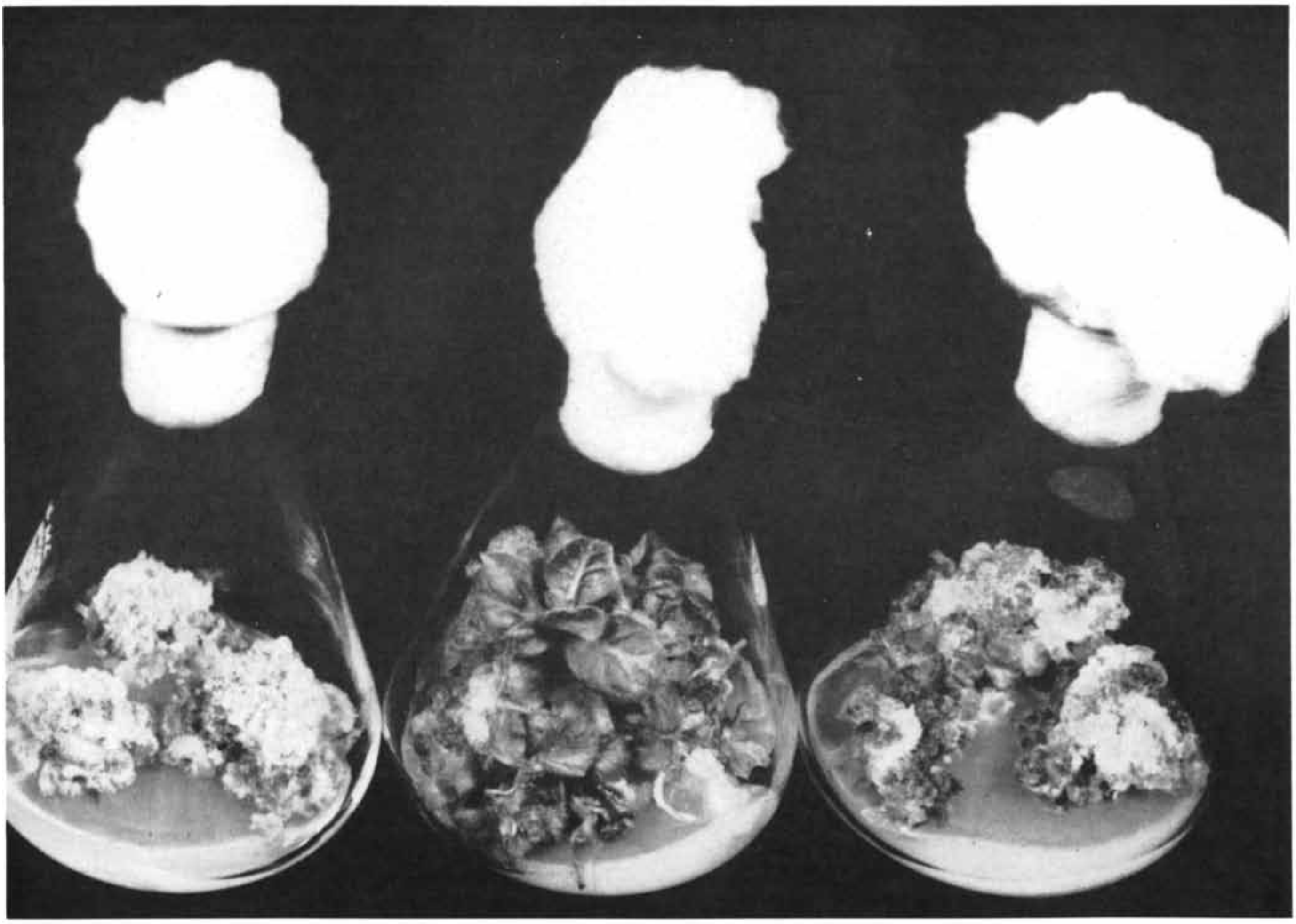
In the 1950's the University of Wisconsin biologist Folke Skoog and his associates took up the pursuit of the active factor. They had been using coconut milk to grow pieces of tobacco tissue in bottles, and in order to run down the active substance they turned to other possible sources. They found that it was present in a yeast extract in a soluble form. Absorption spectra and other markers of the active fraction suggested it was a purine. Recalling that nucleic acids contain purines, one of Skoog's associates, Carlos O. Miller, searched the laboratory shelves for bottles with a nucleic acid label. He found one marked "Herring Sperm DNA," and sure enough, this material proved to be capable of causing tobacco cells to grow and divide.

I am told that when this bottle was used up, a large supply of freshly prepared DNA was ordered, but to everyone's consternation it failed to show any biological activity. The Wisconsin biological laboratories were then ransacked for nonfresh samples of DNA, and all of these proved to be active. Miller therefore returned to the freshly prepared DNA and "aged" it rapidly in an autoclave, whereupon it became active. The logical conclusion was that the growth-promoting factor must be a breakdown product of nucleic acid!

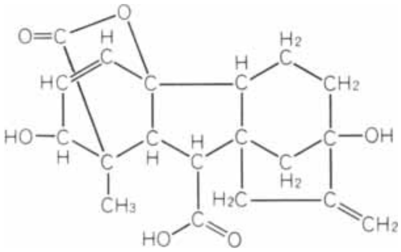
By beautiful teamwork the Wisconsin biologists led by Skoog and biochemists led by F. M. Strong then succeeded in isolating the factor. It turned out to be indeed a nucleic acid component—a derivative of adenine, one of the purine bases that make up nucleic acid. The Wisconsin group named the new hormone kinetin. They went on to synthesize several similarly active compounds, and collectively these hormones are now called the cytokinins.

Skoog and his students proceeded to experiment with combinations of cytokinins and auxins in the culture of tobacco tissues. Starting with stem tissue, they found that simply by manipulating the relative concentrations of cytokinins and auxins in the growth medium they were able to grow roots, shoots and even flowers from the original colony of stem cells. Their results overturned the old idea that there were specific hormones for the formation of roots, leaves and stems; instead it became evident that growth and differentiation in plants are determined by the interplay of at least two growth factors.

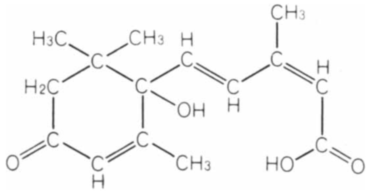
Further information on this subject has come to light within the past two years. The breakthrough was provided by a newly discovered hormone that was first identified three years ago by Frederick T. Addicott and a team of co-workers at the University of California at Davis. They found it in extracts from cotton bolls, and they named it abscisin II, because it was believed to be responsible for the premature drop (abscission) of bolls from the plant. Meanwhile the



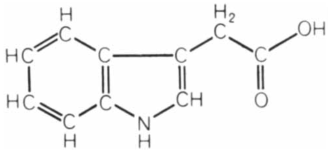
able to grow normal plants from the original undifferentiated cells. In the flasks shown the concentration was (*left to right*) 0, .04, .2, 1, 5 and 25 micromoles per liter. The cytokinin used was 6-(γ,γ-dimethyallylamino)purine. The growth period was six weeks.



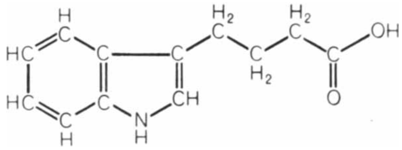
GIBBERELLIN



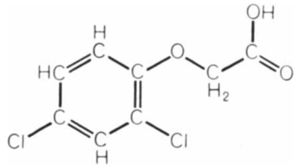
DORMIN



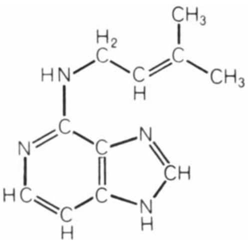
INDOLEACETIC ACID



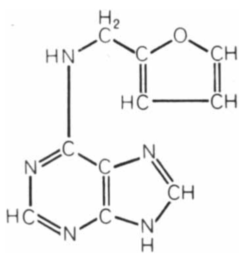
INDOLEBUTYRIC ACID



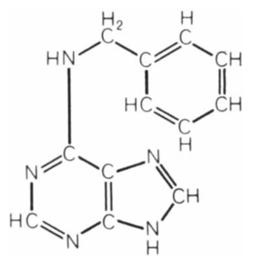
2,4-DICHLOROPHENOXYACETIC ACID



6-(γ,γ-DIMETHYLALLYLAMINO) PURINE



KINETIN



BENZYLADENINE

CHEMICAL STRUCTURES of eight of the plant-growth substances mentioned in the text are illustrated on this page. All are growth-promoting substances except for dormin, which is a growth-inhibiting hormone. Both gibberellin and dormin occur naturally; dormin has also been synthesized. Indoleacetic acid is a naturally occurring auxin. Indolebutyric acid and 2,4-dichlorophenoxyacetic acid are artificial auxins. 6-(γ,γ-dimethylallylamino)purine is a natural cytokinin. Kinetin and benzyladenine are artificial cytokinins.

same substance, found in maple leaves, was being investigated by the British chemist John W. Cornforth. It had been discovered by P. F. Wareing, an investigator of tree physiology; observing that it apparently prepared tree buds for their winter dormancy, Wareing named it dormin. Cornforth and his associates at the Milstead laboratory of Shell Research Ltd. soon succeeded in synthesizing the hormone and describing its stereochemical structure. Its full chemical name is 2-cyclohexene-1-penta-2,4-dienoic acid, 1-hydroxy-β,2,6,6-tetramethyl-4-oxo,cis-2-trans-4(d). Faced with the problem of selecting a short name for the hormone, the International Conference on Plant Growth Substances held in Ottawa in July, 1967, chose "abscisic acid." Unfortunately this name does not describe either the chemical structure or the physiological activity of the substance. I shall refer to it here as dormin, because that term is descriptive of its physiological effects.

Dormin is an inhibitor of plant growth. For that reason some biologists object to calling it a hormone—a term that literally means "arousing to activity." Physiologists are now inclined, however, to classify both the promotive and the inhibitory growth regulators as hormones, because they operate in the same way (as chemical messengers) and are complementary in their actions.

In 1966, after dormin had been synthesized, Josef E. Loeffler, Iona Mason and I began detailed studies to work out its mode of action. We found that ordinary duckweed was extremely sensitive to the hormone. As little as one part per billion of this substance in a culture solution would reduce the weed's growth rate, and one part per million was sufficient to keep this floating weed in a dormant state indefinitely. A striking feature of this action was its reversibility: as soon as the inhibiting hormone was removed, the plant tissues resumed their growth. Even after more than six weeks in the state of suspended growth, the culture could be revived simply by transferring it to a fresh medium in which the inhibiting hormone was absent.

In contrast to dormin, the cytokinins (but not auxins or gibberellin) strongly promoted the growth of duckweed cultures. We proceeded to study the mutual effects of dormin and a synthetic cytokinin (benzyladenine). Some 60 cultures were started in tubes under fluorescent light in a room at a constant temperature and were allowed to grow for a week, by which time their fresh weight had increased tenfold. Dormin, in the amount of one part per million, was then injected into some of the tubes. Within three days the growth of the cultures in these tubes slowed almost to a standstill. We now injected a very small amount of benzyladenine—one part per 10 million—in some of the tubes where growth had stopped. The cytokinin caused the cultures to resume their normal growth rate, although the dormin was still present. In short, the cytokinin overcame the dormin's inhibitory effect. We found that simply by supplying the growth medium with suitable concentrations of the opposing hormones we could apply stop-or-go control to the plant cells' growth.

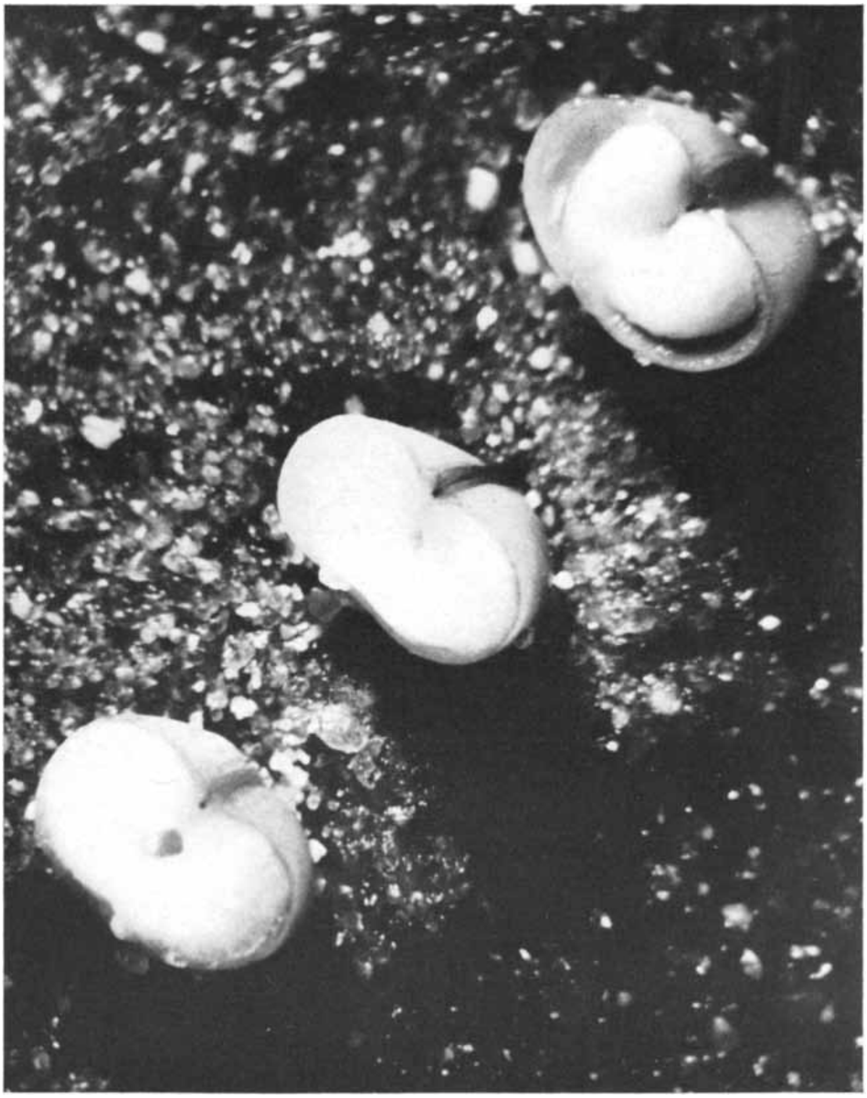
It seems reasonable to conclude that in nature the growth of plants is similarly regulated by a combination of promoting and inhibiting hormones. Thus growth is controlled by an interplay of counteracting mechanisms much like that involved in driving a car. Just as we would not dream of operating a car with an accelerator and no brakes, so a plant apparently needs brakes for proper control. Dormin furnishes the brake. The accelerator, according to the particular plant and the conditions, may be cytokinin, gibberellin and/or auxin. Dormin has been detected in many plants in nature. We can speculate that the bursting forth of buds in the spring may be due in part to the decline of dormin and in part to the production of accelerating hormones such as the cytokinins.

How do the accelerating and the braking mechanisms work in the plant? By means of tracer studies with radioactive phosphate we discovered that dormin inhibits the synthesis of nucleic acids by the plant cells, and this is followed by a slowdown of growth. Conversely, the injection of cytokinin greatly accelerates the synthesis of nucleic acids. We therefore conclude that cytokinin speeds up the growth of the duckweed by increasing nucleic acid production and dormin retards it by reducing this production.

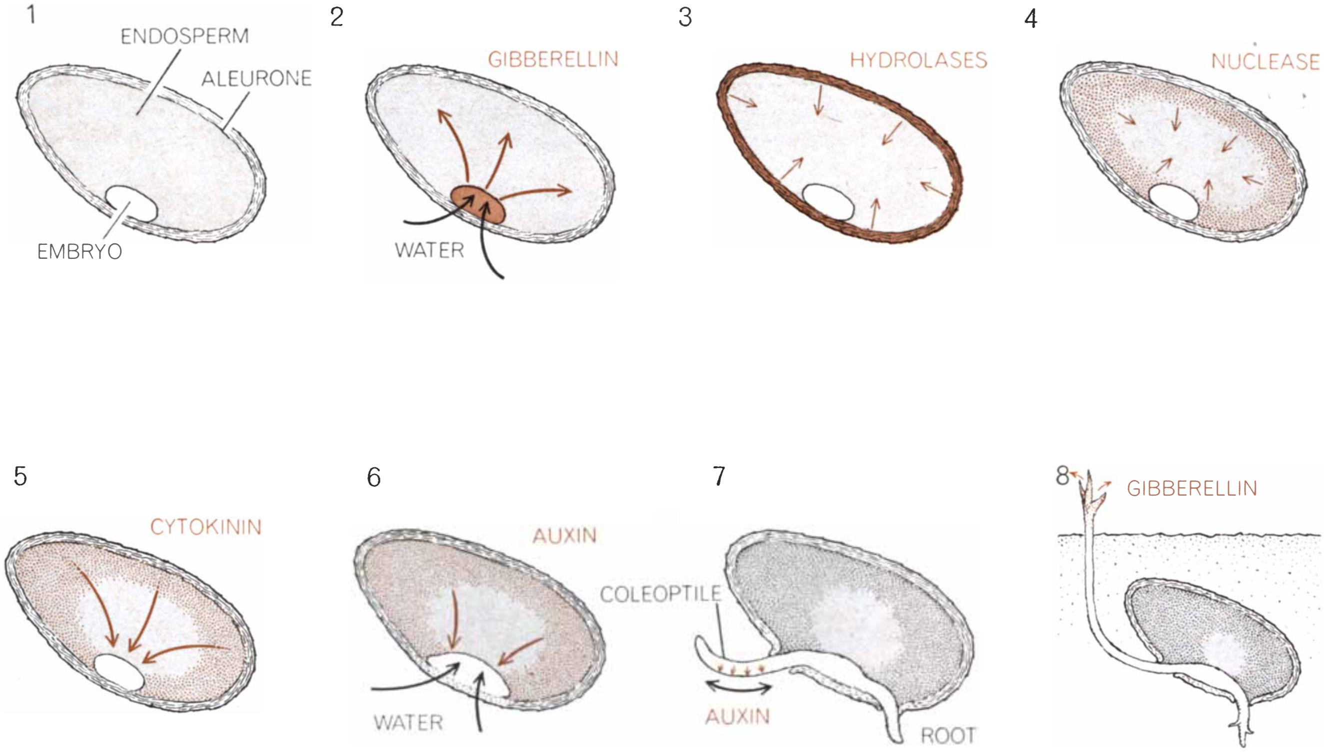
Even before our experiments Skoog's group at Wisconsin had demonstrated in the early 1950's that auxins increase the rate of nucleic acid synthesis. Our finding that dormin slows this rate has since been confirmed by Wareing, who presented the confirmation at a symposium on plant-growth regulators in London last winter. Obviously, since cell division and the growth of tissues require the production of nucleic acids (the cells' genetic material), this evidence of the involvement of the promoting and inhibitory hormones goes far toward explaining their effects on growth. It appears that the plant hormones control the fundamental biochemistry—the nucleic acid chemistry—of plant life.

We now have enough information in hand to put together a coherent picture of how the hormone system may start the growth of important crop plants such as wheat, oats, barley and rice. What happens when we sow a dry cereal seed in moist soil? The seed consists of two parts: the germ, or embryo, from which the plant will develop, and a store of food, called the endosperm, that will nourish the developing seedling until it puts out green leaves that will enable it to produce its own food by photosynthesis. The stored food, initially in solid, undissolved form, is locked up in the endosperm cells. As the Austrian botanist Gottlieb Haberlandt showed many years ago, some action by the embryo is needed to release the food and allow it to become liquefied. What, then, is the key in the embryo that unlocks the food cellar? In 1960 Haraguro Yomo in Japan and L. G. Paleg in Australia independently discovered that the key is gibberellin.

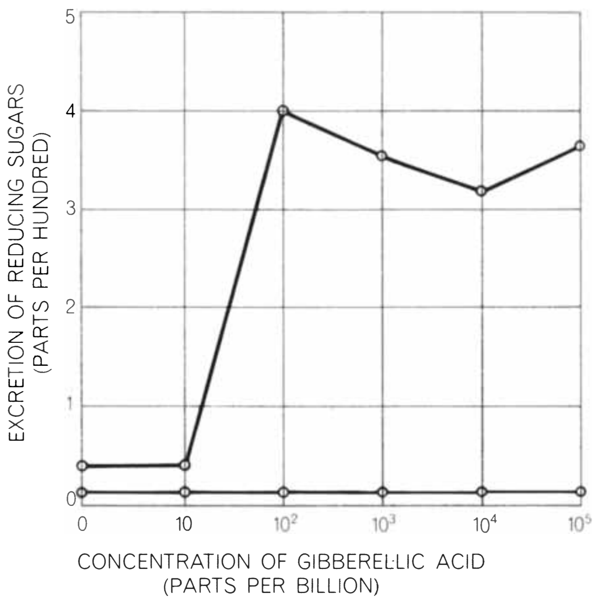
Apparently the absorption of water



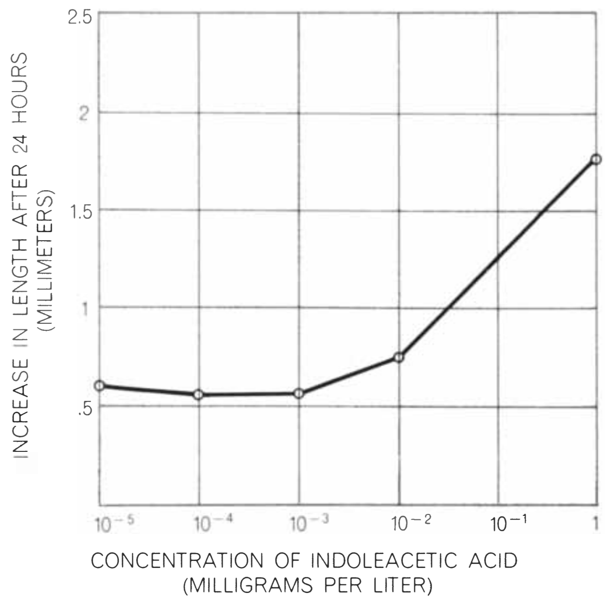
ROLE OF GIBBERELLIN in the germination process of a cereal seed is elucidated by this photograph, made by Joseph E. Varner of Michigan State University. The three barley seeds in the photograph have been cut in half and their embryos have been removed. Normally it is the embryo that produces gibberellin, which regulates the hydrolysis, or digestion, of the food-storage cells of the endosperm. The open surfaces of the three seeds have been treated with plain water (*bottom*), a solution of gibberellin in water at a concentration of one part per billion (*center*) and a solution of gibberellin in water at a concentration of 100 parts per billion (*top*). The photograph, taken 48 hours later, shows that in the gibberellin-treated seeds the digestion of the starch-filled storage tissue is already taking place.



GERMINATION OF A CEREAL SEED below the surface of the soil (*1*) is regulated by a number of hormones working in sequence. First the absorption of water from the soil causes the embryo to produce a small amount of gibberellin (*2*). The gibberellin then diffuses into a layer of aleurone cells that surrounds the endosperm's food-storage cells, causing them to form enzymes (*3*) that in turn lead the endosperm cells to disintegrate and liquefy (*4*). Cytokinins and auxins formed in this process (*5, 6*) then promote the growth of the embryo by making its cells divide and enlarge. If the shoot is pointing down into the soil, the auxins tend to migrate to the lower side of the seedling, causing it to grow faster and hence turning the growing point of the shoot upward toward the surface of the soil (*7*). Once the shoot has broken into the sunlight the plant begins to produce its own food by photosynthesis (*8*).



EVIDENCE OF GIBBERELLIN ACTION is contained in this graph, which relates the excretion of reducing sugars from barley endosperm tissue to the amount of gibberellin applied. The top curve shows the results when the endosperm cells are accompanied by aleurone cells; the bottom curve shows the results without the aleurone cells. Evidently the gibberellin acts on the aleurone cells to secrete the enzymes that hydrolyze the starch to form the sugars.



EVIDENCE OF AUXIN ACTION is contained in this graph, which shows the growth response of oat coleoptiles to various concentrations of the auxin indoleacetic acid (IAA). To obtain the results three-millimeter-long sections of the coleoptiles were floated on the surface of a shallow layer of hormone solution consisting of varying amounts of indoleacetic acid in distilled water. The measurements of length were made after a growing period of 24 hours.

from the soil causes the embryo to produce a small amount of gibberellin (of the order of a fraction of a part per million), which then diffuses into a layer of aleurone cells that surrounds the endosperm's food-storage cells. The gibberellin initiates a series of events that has been investigated in detail by the biochemist Joseph E. Varner at the Plant Research Laboratory of Michigan State University. Under the influence of the hormone the aleurone cells soon begin to synthesize enzymes. One (amylase) hydrolyzes the starch in the food cells into sugar; others break down those cells, disintegrating their nucleic acids and proteins. In brief, this is what happens: (1) in response to the uptake of water the embryo secretes gibberellin, (2) the gibberellin in turn causes the aleurone cells to form enzymes, (3) the enzymes go to work on the food-storage cells and cause them to disintegrate and liquefy.

Now we can reason that in the course of these events cytokinins and auxins are formed. The splitting of the nucleic acids by the newly formed enzymes can be expected to generate cytokinins, which as we have seen are derived from the breakdown of nucleic acid. Similarly, the breakdown of proteins can give rise to auxin; Skoog showed many years ago that the amino acid tryptophan is converted to indoleacetic acid in the cells of the coleoptile (the protective sheath around the seedling).

The newly generated hormones now proceed to promote the growth of the embryo. The cytokinins make its cells divide. The auxin assists by facilitating enlargement of the cells—the other requisite for cell growth. It does so by weakening the cell walls so that the cells take up water by osmosis and thus expand. The process by which auxin softens the cell walls is complex; Joe L. Key and his associates at Purdue University have found that it involves the synthesis of nucleic acids.

So finally we have our seedling growing. The shoot may, however, be pointing down into the soil. How does it make its way up to the surface and the sun? Again auxin is involved. By some geotropic process not yet understood auxin tends to migrate to the lower side of a seedling that is lying on its side. This causes the lower side to grow more rapidly than the upper, and hence the growing point of the shoot turns upward toward the soil surface. Once the shoot has broken through into the sunlight the leaves unfold, photosynthesis takes over and the self-sustaining life of the plant begins.

As biologists we study plant hormones primarily because they can teach us a great deal about the process of growth. A fuller understanding of such life processes is the basic motivation, of course, for the work of any biologist. At the same time, plant scientists are always mindful of the practical implications of their studies. The green plant is, after all, the essential link to the sun's energy that sustains all life on the earth. It is the ultimate source of all man's food, and in itself it could supply our every food requirement. The Dutch horticulturist G. J. A. Terra has shown, for example, that calorie for calorie green leaves are as rich in essential proteins as the best of meats. A full appreciation of that fact in tropical countries could rescue those peoples from the ravages of the common protein-deficiency disease kwashiorkor. With the world population now growing very rapidly, plants have become more important than ever to man. There is no doubt that in order to cope with the increasing need for food we shall have to improve the efficiency of our agriculture. In several ways this is already being accomplished by the use of plant hormones, natural and synthetic.

One of the most useful of these, of course, is the synthetic weed killer known as 2,4-D. This substance, an auxin that retains its activity in plants much more persistently than the natural indoleacetic acid, can upset a plant's hormone balance so that growth occurs at places in the plant where it should not. It can cause roots to form on the stems in the air and at the same time slow down the normal root development underground. These abnormalities eventually lead to the death of the plant. Fortunately 2,4-D is selective in its action; it particularly attacks a number of useless weeds. As little as 500 grams per hectare (about half a pound per acre) can produce abnormal growth in a susceptible weed. Cereal plants, on the other hand, are relatively insensitive to 2,4-D; they inactivate the hormone, possibly by tying it to their proteins. Consequently the use of 2,4-D as a weed killer in grain fields has increased crop yields significantly. Synthetic auxins of the 2,4-D type have also been applied to other uses—for example to stop the premature drop of apples and pears. One might list a number of other applications of hormonal aids, for instance the use of auxins such as naphthaleneacetic acid and indolebutyric acid to propagate plants from cuttings and the use of gibberellins to speed up the malting process and to increase the size of grapes.

Studies of the potential uses of the newer hormones—the cytokinins and inhibitors such as dormin—are just beginning. I have obtained a patent for the utilization of cytokinins for preserving fresh vegetables. A cytokinin produced in the Shell laboratories has been found to be capable of generating viable seeds from Persian-grape plants that normally produce only male flowers; the hormone changes the developmental pattern of the flower from male to perfect hermaphrodite.

What uses dormin will have remains to be seen. Artificial growth inhibitors have been employed for some time and have produced interesting results. Materials such as CCC, B-Nine and so on have shown that flowering and fruiting can be promoted by slowing down vegetative growth. Azalea growers in the Eastern U.S. produce neat little plants that look like veritable balls of flowers by treating the plants with dwarfing agents. In the Netherlands I have seen young apple trees made to bear fruit two years before they would normally do so, simply through the use of growth inhibitors. The synthetic inhibiting chemical TIBA is widely used in the U.S. to shorten soybean plants and make them produce more branches so that they will bear more seeds.

In the long run, however, probably the most effective results will be obtained not by spraying chemicals on plants but by breeding them to produce a suitable balance of hormones of their own making. A good example of such a plant is the marvelous new variety of rice called IR-8, which has a short stem, is open in structure and gives a high yield of grain. This semidwarf variety, developed at the International Rice Research Institute near Manila, may have a genetic constitution that tips the hormone balance in favor of a vegetative-growth inhibitor. One can guess that its growth promoter may be a gibberellin and its inhibitor may be a dormin; that question remains to be determined by further research.

In the future we may measure the quality of a plant in terms of its hormone balance, just as we now define the nutritional value of a protein by its amino acid composition. Plant breeders will then be able to produce plants with specified properties by deliberately selecting genes to provide a particular ratio of growth promoters such as gibberellin or cytokinin and growth inhibitors such as dormin.

The Beginnings of Wheeled Transport

Mankind has traveled on wheels for at least 5,000 years. The recent discovery of ancient wagons at sites in the U.S.S.R. casts doubt on the accepted hypothesis that vehicles were invented in Mesopotamia

by Stuart Piggott

Professor Marshall McLuhan, in one of his oracular pronouncements, defined the relationship of the automobile to modern man as that of the mechanical bride. Recent archaeological studies help to trace the earliest stages in man's romance with the wheel that ultimately led to this strange, if not unholy, consummation. Like all first courtships, it was inexpert and tentative in its beginnings, but more than 5,000 years ago the bride of wheeled transport had been won in Eurasia. For whatever reason, the early Americans failed to duplicate this invention.

It is not excessively determinist to suggest that certain prerequisites are needed for the development of wheeled vehicles. The vehicles will be invented only in societies that have a need to move heavy or bulky loads considerable distances over land that is fairly flat and fairly firm. A suitable raw material, such as timber, must be on hand for building the vehicle. And a prime mover stronger than a man must be available to make the wheels turn. In the Old World the power problem had been solved at least 7,000 or 8,000 years ago by the domestication of cattle. Once it was realized that castration produced a docile, heavy draft animal, oxen were available for traction; their strength and patience more than compensated for their slowness. Timber was available in quantity in the parts of the Near East that were neither desert nor steppe. These are the regions that saw the emergence of the earliest agricultural communities, beginning about 9000 B.C. The same communities were among the first to possess polished stone axes and adzes and, soon thereafter, copper and bronze tools suitable for elaborate carpentry.

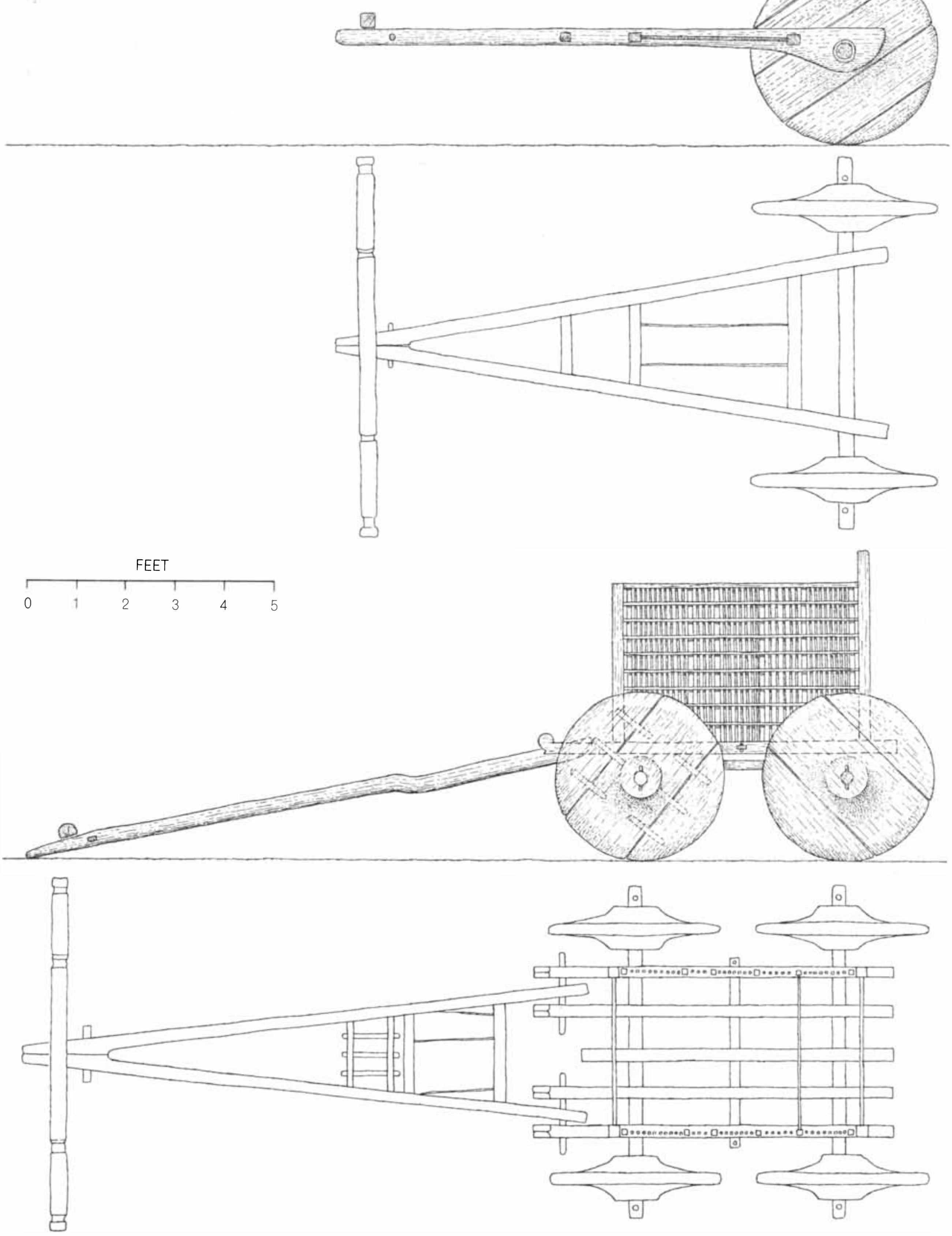
The archaeological evidence shows that the first stages of wheeled transport depended on heavy vehicles with disk (as opposed to spoked) wheels. The wheels were either cut from a single massive plank or were made from three (and occasionally more) planks doweled and mortised together. Light vehicles with spoked wheels, harnessed to swift draft animals, were a later development that combined an advanced technology in bronze tools—and thus in the wheelwright's craft—with the domestication of the small wild horse of the steppe. Such vehicles first appear in the Near East in response to military needs during the first half of the second millennium B.C. Here, however, we are concerned mainly with developments earlier than the second millennium, when vehicles were usually drawn by oxen.

From the standpoint of the archaeologist wood is a miserable material; it is resistant to decay only in exceptional conditions of waterlogging or desiccation. Under normal circumstances to detect and recover traces of wood encountered in an excavation calls for a high degree of technical skill. It may therefore surprise the reader to learn that in Europe and Asia nearly 50 wheeled vehicles—or their wheels—have been recovered from sites that predate the second millennium B.C. This type of direct evidence concerning early vehicles is supported by discoveries of other kinds, such as models of vehicles or their wheels made from pottery, which of course is much less susceptible to disintegration than wood.

The earliest examples of wheeled vehicles have all been found within a region no more than 1,200 miles across centered between Lake Van in eastern Asia Minor and Lake Urmia in northern Iran. Presumably the first wheeled vehicle originated somewhere within this region. The oldest evidence dates back to the final centuries of the fourth millennium B.C., indicating that wheeled transport came into existence somewhat more than 5,000 years ago.

The region within which wheeled vehicles made their first appearance embraces desert and open steppe as well as forested slopes along the mountain belt that includes the ranges of the Taurus, the Caucasus and the Zagros. Deciduous timber does not grow below the 1,000-foot contour of these mountains and often not below 3,000 feet. A mosaic of communities, with economies based on mixed agriculture and copper or bronze metallurgy, flourished in the region from about 3000 B.C. onward. In Mesopotamia to the south the population was already literate and urban societies were beginning to form. To the north the zone of farming communities probably merged gradually into the area occupied by the pastoralists of the steppe beyond the Caucasus. All three societies were ones in which wheeled transport would constitute a valuable technological addition to the existing economy.

Our earliest evidence for vehicles with wheels, as opposed to simple sledges that could be dragged overland, is provided by symbols in the pictographic script of Uruk, a Sumerian city in southern Mesopotamia. The Uruk pictographs represent man's earliest known writing; they are believed to date from somewhat before 3000 B.C. Some Uruk signs depict a schematized profile view of a sledge; others show the sledge pictograph with two little disks added below it—an abbreviated symbol for a four-wheeled vehicle. Beginning about 2700 B.C. in Mesopotamia the evidence is no longer symbolic but concrete. By that time the Sumerians and their neighbors buried vehicles along with their dead; sometimes the vehicles even contained the dead. The vehicle remains often survive as nothing more than stains in the soil such as have been de-



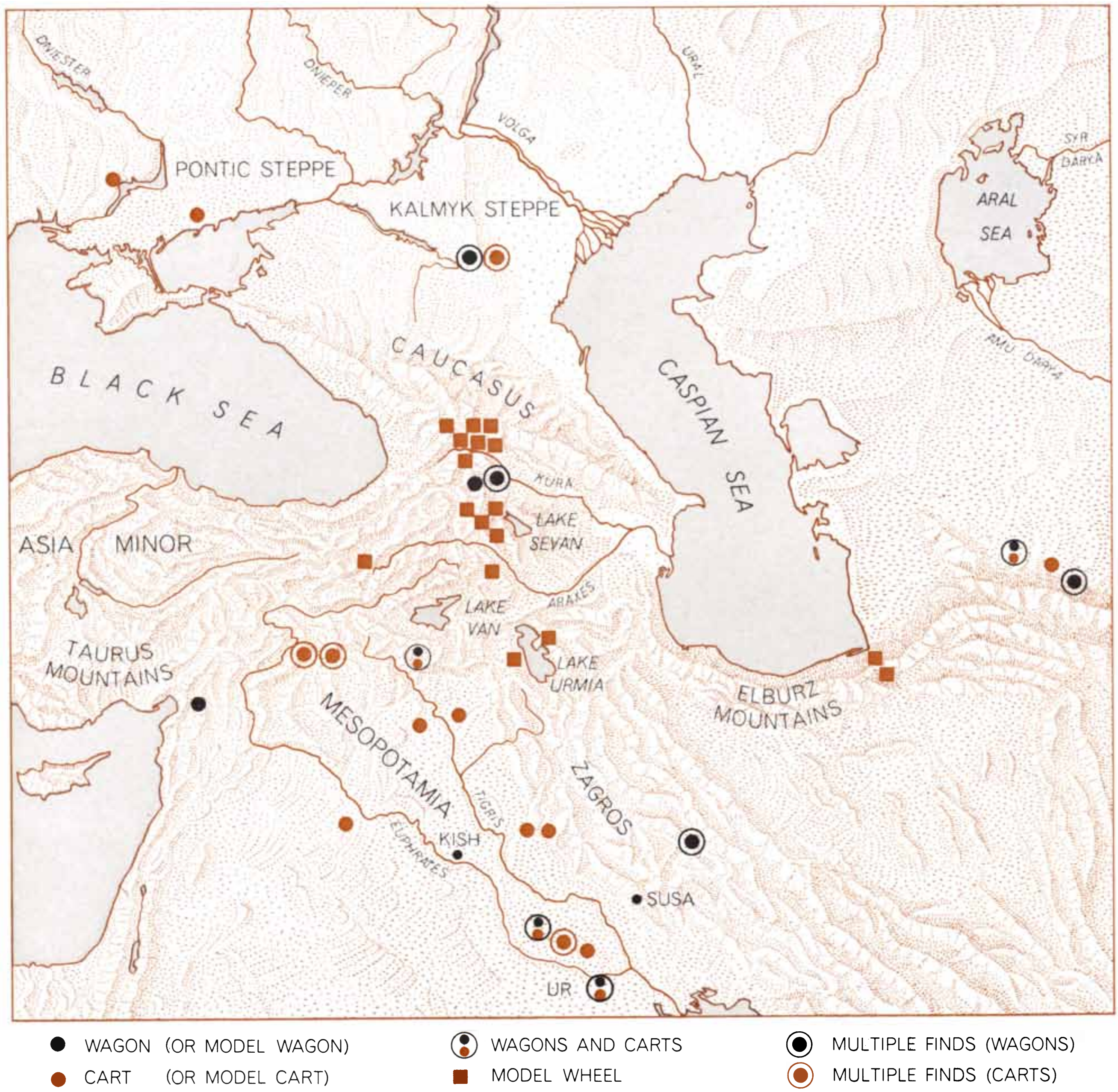
CART AND WAGON from the latter half of the second millennium B.C. were found by Soviet archaeologists in tombs at Lake Sevan in the Armenian S.S.R. They closely resemble the wheeled vehicles of much earlier times. The simple design of the A-frame cart (*top*) suggests that these vehicles came into being through the addition of an axle and wheels to a two-pole "slide car" that was formerly dragged along the ground by draft animals. The wagons at Lake Sevan (*bottom*) were complex and utilized mortise-and-tenon joining. Their draft poles, however, were apparently nothing more than cart A-frames, pegged to the wagon's chassis.

tected in the Royal Tombs at Kish and Ur and at Susa in Elam. They are of two kinds: vehicles with two wheels (carts) and vehicles with four wheels (wagons).

Carts and wagons alike were drawn by oxen or by Asiatic asses (*Equus onager*), cousins of the horse that the early Mesopotamians had managed to domesticate. The vehicles' wheels were light disks made by joining three planks. The representations in Mesopotamian art and the model vehicles that have survived from this period and the periods that follow it show that disk-wheeled vehicles were known both in Mesopotamia and among the nonliterate peoples along the Mesopotamian frontier, from Asia Minor on the west to Turkmenia on the east. The vehicles were present along most of the periphery before 2000 B.C.; soon thereafter they were common throughout it.

It had been assumed until recently that the adoption of wheeled transport among peoples to the north and west of the central zone outlined above, as well as the eventual adoption of vehicles by the peoples who inhabited Europe, were events that took place measurably later than adoption of vehicles within the central zone. Indeed, the spread of wheeled transport is often cited as a classic example of diffusion from a primary center. Since World War II, however, the picture has changed as archaeologists in southern Russia and in the Soviet republics of Georgia and Armenia have unearthed large quantities of new prehistoric material.

Among the discoveries are more than 25 burials in which vehicles were included; these apparently date from at least 2500 B.C. up to about 1200 B.C. Indirect evidence from several Soviet sites for even earlier knowledge of wheeled



VEHICLES built before 2000 B.C. in a zone between the Black Sea and central Asia are found in two main concentrations. One is Transcaucasia and the open steppe to the north. The other is Mesopotamia, including the headwaters of the Tigris and Euphrates. It was formerly believed that the first wheeled vehicles were made in Mesopotamia. The discovery that such vehicles were made in Soviet Georgia and Armenia before the second millennium B.C. diminishes the probability of a Mesopotamian origin of wheeled transport.

vehicles—in the form of model wheels made from pottery—pushes the starting date back perhaps as far as 3000 B.C. Nothing has been found at the new Soviet sites that is demonstrably as old as the pictographs from Uruk. Nonetheless, the Soviet evidence considerably weakens the case for absolute priority in the invention of wheeled transport previously conceded to Mesopotamia. The challenge is a serious one because the Mesopotamian claim rests on the pictograph of a modified sledge and on nothing else.

Because the recent evidence from the U.S.S.R. is little known outside that country it is worth describing in some detail. By way of preface I should explain that a number of excavations in Transcaucasia—the region between the Black Sea and the Caspian Sea lying south of the greater Caucasus—have made it evident that this region was once occupied by a single homogeneous culture. Marked by a complex of sedentary mixed farming, village settlements and some copper-working, the culture extended from the river valleys of the Kura and the Araxes in Georgia and Armenia, southward to Lake Urmia and westward well beyond Lake Van [*see illustration on opposite page*]. The period during which the Kura-Araxes culture flourished is known on the basis of carbon-14 determinations. It began about 3000 B.C., continued until sometime after 2500 B.C. and may even have lasted down to the end of the third millennium B.C. Pottery models of disk wheels with well-marked hubs are found at a number of Kura-Araxes sites. They are identical with the wheels of model vehicles unearthed in the Near East; evidently the existence of wheeled transport was at least known in Transcaucasia at the same time that actual vehicles were being entombed at Kish and Ur.

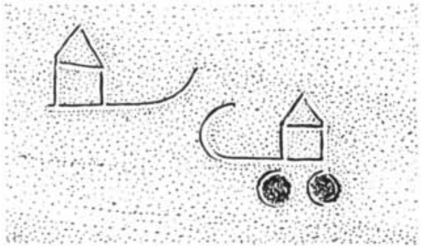
As a matter of fact the Kura-Araxes culture possesses vehicle burials of its own. One tomb at Zelenyy, in the Tsalka region of the Georgian S.S.R., was found to have contained a wagon. It had evidently been interred in working order, since the floor of the tomb bore long grooves made by the vehicle's wheels. The burial at Zelenyy, a pit grave covered by a round kurgan, or barrow mound, belongs to a style of burial that moved into the Caucasus from the southern Russian steppe. On the steppe the burials have given their name to the Pit Grave culture, which flourished during much of the third millennium B.C. Similar burials—including in two instances the remains of wagons—have been unearthed at Trialeti, another site in the Tsalka district.

The waterlogged soil of one of these tombs, excavated in 1958, contained a wagon with massive three-piece wheels. The wagon had an A-shaped draft pole, of which the stumps were preserved. It had apparently been equipped with an arched canopy to shelter its occupants. As we shall see, several more or less complete examples of similar "covered wagons" have been found elsewhere. The Trialeti burial probably took place sometime before 2000 B.C., although the date is not known precisely.

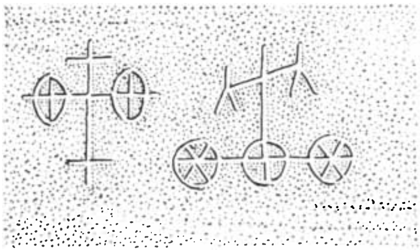
Some 350 miles north of the Tsalka district, beyond the passes of the greater Caucasus range and well into the southern Russian steppe, Soviet archaeologists have unearthed several other buried carts and wagons. The sites are located in the Elista region of the Kalmyk Steppe, no more than a month's ox-trek distant from Transcaucasia. The first Elista burials were found in 1947; others were located in 1962 and 1963. They belong to the final phase of the Pit Grave culture or to a culture that overlapped and succeeded it, and appear to be dated between 2400 and 2300 B.C.

The carts buried in the Elista graves are represented by pairs of wheels and by one pottery model of a cart with an arched canopy. The most interesting of the Elista burials, however, are those containing four-wheeled wagons. Like the model cart, the Elista wagons had arched canopies; in some cases remains of the wickerwork of which the canopies were made have survived. The Soviet excavators maintain that one of the Elista wagons had a pivoted front axle, a device that would have permitted steering the wagon. This is remarkable. If accepted, the Elista innovation antedates by many centuries the first previously known appearance of a most important advance in vehicle design. Heretofore no ancient vehicle was known to have a pivoted front axle until the time of the Celtic ritual wagons at Djebjerg in Denmark, in the first century B.C. Indeed, the very existence of the feature before medieval times has sometimes been called into question, and we are certain of pivoted axles only from the Middle Ages onward.

The resemblance between the Elista vehicle burials and vehicle burials in the Georgian S.S.R. is not the only evidence that implies contact between the steppe and Transcaucasia. Near the Black Sea and the Dnieper River in southern Russia, an area that also lies within the ancient boundaries of the Pit Grave culture, two more vehicle burials



OLDEST PORTRAYAL of a vehicle with wheels is a Sumerian pictograph used shortly before 3000 B.C. It is derived from the sign for a sledge (*left*). The addition of two circles (*right*) turns it into the sign for a wagon.



CHINESE PICTOGRAPHS for a chariot or cart, apparently with spoked wheels, are first seen in inscriptions of the Shang dynasty, somewhat later than 1500 B.C. Two inverted "y" strokes (*top right*) represent the horses.

have been found. The graves were dug late in the third millennium B.C.; in both instances the vehicles are carts with one-piece disk wheels.

In 1956 the initiation of a hydroelectric project at Lake Sevan in the Armenian S.S.R. lowered the lake's level by many feet. Near Lchashen, as the level fell, a number of formerly submerged tombs were revealed; in them were found nearly a dozen carts and wagons. The vehicles are comparatively recent, having been buried over a period of some centuries, beginning about 1400 B.C. They are so well preserved, however, and have so many features in common with carts and wagons of much greater age that they merit special attention. Each burial was made in a huge boulder-lined pit, originally with a sloping ramp at one end. The vehicles were apparently maneuvered down the ramps and the pits were then covered with stone cairns. Soon afterward the level of Lake Sevan rose and immersion preserved the wood of the vehicles. In addition to vehicles with three-part disk wheels some of the tombs contained light carts—virtually chariots—that had spoked wheels.

From the viewpoint of technological development two-wheeled vehicles are more primitive than four-wheeled ones. In spite of their relatively late date the

MESOPOTAMIAN CHARIOT, pulled by Asiatic asses, was modeled in copper by an artisan at Tell Agrab around 2800 B.C. Although such vehicles were used for sport and war rather than for cartage, their three-piece disk wheels are identical with earlier cart wheels.

Lchashen carts reflect this. They are of the simplest kind and embody a design that is still found today among nonindustrialized peoples in parts of Europe and Asia from the Iberian peninsula and the Mediterranean coast to Asia Minor, the Crimea, the Kalmyk Steppe and the Caucasus. (The same simple carts are found even farther east, of course, but their distribution in the Orient need not concern us here.) The basic design is an A-frame. The design presumably evolved from a simple travois, or slide car, made by lashing the butts of two poles together and letting the tips of the poles trail along the ground behind the draft animals. The addition of an axle and a pair of wheels near the wide end of the A-frame turns such a travois into a cart.

Wagons, on the other hand, are comparatively complex structures. With their intricate frames and often elaborate ornamentation, the Lchashen wagons were plainly vehicles of prestige just as much as today's Cadillac. The tombs at Lchashen contained six wagons in all. Four of them had arched canopies and one had upright wickerwork sides and a decorated panel at the back. Their complicated carpentry testifies to the need for adequate coachbuilders' tools. One covered wagon was an assembly of 70 component parts; the parts were either pegged together or joined by a mortise-and-tenon system that required cutting no fewer than 12,000 mortises. (The frame of the canopy alone required 600.) In spite of the excellence of their workmanship, the Lchashen wagons must have been slow and clumsy: the estimated unloaded weight of the wagon with the wickerwork sides is two-thirds of a ton.

Although the covered wagons of Lchashen are nearly 1,000 years younger than the steppe vehicles of the Elista region, they have counterparts among them. Moreover, the same form of wagon was common in the Near East during the third millennium B.C., as is indicated by pottery models unearthed in northern Iraq and Syria. The draft poles of the Lchasen wagons provide a lesson in vehicle evolution. They are plainly derived from cart A-frames; each wagon looks as if a cart A-frame had been pegged to the front of its chassis [*see illustration on page 83*]. This suggests continued to use the familiar A-frame cart was the earliest form of vehicle known and that, when four-wheeled wagons came to be built, the designers continued to use the familiar A-frame shape instead of devising a single central pole for the draft animals.

What do the various Soviet discoveries signify as far as the beginning of wheeled transport is concerned? One way of interpreting this evidence is to suggest that during the third millennium B.C. the wagon found its way to Transcaucasia from the Russian steppe to the north, along with a funeral rite that required the burial of the vehicles in pit graves. At the time of the wagons' emergence, however, wheeled transport must already have existed in Transcaucasia, perhaps in the form of A-frame carts (the evidence for this being the pottery models of wheels found in Kura-Araxes sites of earlier date). Another interpretation might suggest instead that the covered wagons came to Transcaucasia from the south and that their presence in the Pit Grave sites represents an exotic intrusion into the steppe that has its ultimate origins in the early civilizations of the Near East.

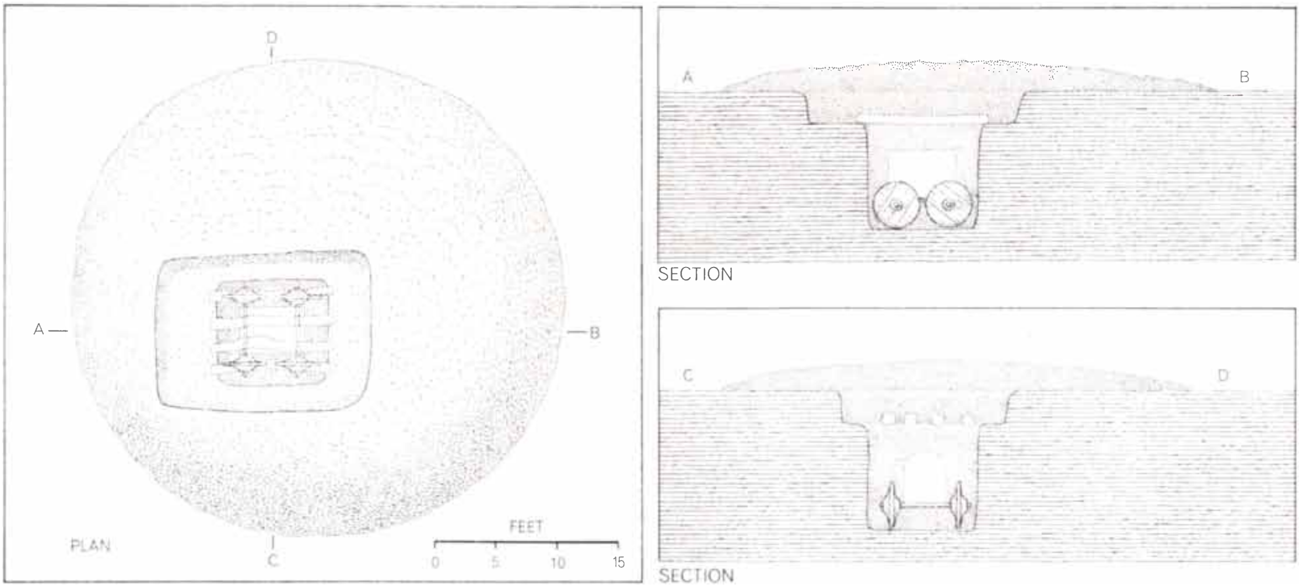
The problems presented by such alternative explanations will be discussed later. Meanwhile one should remember that the Caucasus do not in fact form an insuperable barrier to movement across them in either direction. There are good passes through the greater Caucasus, particularly the one through which the Georgian Military Highway runs from Tiflis to Ordzhonikidze. Whichever way the current of diffusion may have run between urban and barbarian zones during the third millennium B.C., carts and wagons with one-piece and three-piece wheels certainly were in use throughout the region well before 2000 B.C.

Let us now turn to the spread of wheeled transport into prehistoric Europe and see how, if you will, the West was won by the covered wagons of antiquity. Recently a number of large one-piece disk wheels have been discovered in the Netherlands. Carbon-14 determinations indicate that they were made a century or so before 2000 B.C. Two similar disk wheels, slightly earlier in date, have been found in Denmark. The wheels that most closely resemble the Dutch and Danish discoveries are ones found in the cart burials of the Pontic Steppe in southern Russia. This area is some 2,500 miles removed from the North Sea, even as the crow flies, and is considerably farther in terms of feasible overland routes of travel. What connections can be found between two such widely separated areas?

In all the land between the steppe and the North Sea the only direct evidence of the ancient use of wheeled vehicles consists of model wheels made of pottery and of a single model wagon. The pottery objects all appear to have been made before the end of the third millennium B.C., although precise dating is difficult. The model wagon, equipped with disk wheels, was found in a cemetery of the copper-using Baden culture, located at Budakalasz, on the outskirts of Budapest. It has a stunted one-piece draft pole. Above the chassis the wagon's sides rake outward; their concave upper edges suggest a body made of matting, supported by four corner poles [*see lower illustration on page 89*].

The Baden culture appears to have flourished in the period between 2700 and 2300 B.C. Chronologically this is not far removed from the era that saw wagons being buried at Ur, and it is contemporary with the vehicles found to the north and south of the Caucasus. The pottery models of single wheels are distributed at random. The one found deepest in central Europe was unearthed near Brno in Czechoslovakia; in general they are all contemporary with the later centuries of the Baden culture.

These few bits of clay constitute our only direct evidence of linkages between Europe and the steppe, but they are not the only evidence. In the Baden culture and in other roughly contemporaneous societies that flourished in what are now



WAGON IN A TOMB was unearthed by Soviet archaeologists at Trialeti, in the Tsalka district of the Georgian S.S.R., in 1958. The wagon's wooden wheels and parts of its draft pole and chassis were preserved in the burial pit's waterlogged soil (*see illustration below*). Traces were found of an arched canopy that sheltered the occupants. The wagon probably was buried before 2000 B.C.

TRIALETI BURIAL PIT resembles a bog as the diggers probe for remnants of an entombed wagon. The vehicle's distinctive three-piece wheels have been almost wholly exposed. Trialeti is one of two Caucasus sites containing vehicles that predate 2000 B.C.

Poland and East Germany it was not uncommon to give ceremonial burial to animals as well as to men and women. Frequently the buried animals were pairs of cattle; more than 15 such burials belonging to the third millennium B.C. have been unearthed. One of them was found in the same Hungarian cemetery that yielded the model wagon. There a pair of oxen occupied one end of a long grave and human remains occupied the other end. In other cases paired oxen have been found lying at one end of a grave that was dug longer than necessary to accommodate the animals alone.

One inference to be drawn from the burials is that we are seeing pairs of draft animals; the discovery in Poland of two models of yoked pairs of oxen, of about the same age as the animal burials, lends weight to the inference. It is uncertain, however, whether we are seeing burials that originally included wheeled vehicles. The vehicles might have decayed without leaving a trace, or the traces could have gone unrecognized by the excavators. There also could have been no buried vehicles at all; the oxen may have been plow teams or animals that pulled a sledge. Nonetheless, if we take into account the burials of vehicles that have survived elsewhere, it seems most probable that burial of pairs of oxen is

PRESENCE OF WAGONS in Europe before 2000 B.C. is shown by the discovery of one-piece disk wheels in the Netherlands and in Denmark that yield carbon-14 dates earlier than the second millennium B.C. Direct evidence, in the form of pottery models of wheels and a single pottery model of a wagon, suggests that some vehicles entered central Europe via the Ukraine, the Romanian plain and Hungary. Indirect evidence, in the form of buried pairs of oxen and models of yoked oxen, suggests that another influx of wagons moved northwest from the Ukraine, skirting the Carpathian Mountains and arriving in the forested plain of northern Europe.

another variant of a general funeral rite in which at times a vehicle and its animals were buried together (as at Uruk), and at other times the animals were buried alone as a token representation. Accepting such an interpretation tentatively, we find that the indirect evidence of the animal burials fits in well with the direct evidence provided by the model wagon and model wheels. Both lines of evidence give added substance to a picture of Europe in which wheeled transport was used from the middle Danube to the Low Countries and Jutland at least by 2500 B.C. and probably earlier.

Thus, as in the Soviet excavations, we see that new or reassessed archaeological evidence, given the secure dating provided by carbon-14 analysis, is serving to narrow the ancient Near East's supposed margin of priority in the innovation of wheeled transport. What remains to be seen is whether valid inferences can be drawn with respect to two interlinked questions. The first question is whether or not the available evidence is sufficient to test the traditional diffusionist hypothesis about wheeled vehicles. This is the contention that the first such transport originated in a restricted region of western Asia where other technological innovations were under way among the precociously developing societies that immediately preceded the literate civilization of Sumer and Elam. The other question is more restricted in scope but is nevertheless important: Assuming that the area can be found in which wheeled vehicles were first used, by what routes and in what context of prehistory was the technology transferred from the point of innovation to Europe?

The answers to both questions depend heavily on the acceptability of the estimated ages of many archaeological finds and even of the actual dates of past events. In the context where the evidence is most needed, alas, it is not precise. For example, the date assigned to the earliest Uruk pictographs is derived from reasoned guesses and historical computation backward from the 24th century B.C., the point at which history of a sort begins in Mesopotamia, along with a glance at one or two relevant carbon-14 dates. Yet physicists have recently questioned whether "carbon-14 years" are exactly equivalent to calendar years during the period in question. The carbon-14 readings apparently give "true" dates that are several centuries earlier than the ones now in use, and correlation of the historical time scale with the carbon-14 time scale is fraught with difficulties. Even if carbon-14 dates themselves are no more than expressions of statistical probabilities, comparison of one with another should still provide a good relative scale. In this way, for example, one could validly equate part of the Kura-Araxes culture with part of the Baden culture. The scarcity of carbon-14 determinations for the Soviet vehicles is particularly regrettable when one considers the wealth of wood available for analysis. In spite of these handicaps, however, it is hard to escape the conclusion that the closely spaced dates of early wheeled vehicles unearthed from the Caucasus to the Netherlands must reflect a basic reality that indicates a rapid transmission of ideas over great distances.

Where was the first wheeled vehicle made? Let us return briefly to some of the factors considered at the outset. Timber would be needed both for the

HEAVY WHEEL, fashioned from a single massive plank of wood, was found by Dutch archaeologists in Overijssel in 1960. Carbon-14 analysis dates it earlier than 2000 B.C.

MODEL OF A WAGON was found in a Hungarian cemetery that contains remains of the Baden culture. The Baden culture flourished in the middle of the third millennium B.C.

wheels and for the chassis; thus one is inclined to look toward regions adjacent to natural woodlands. In the case of Mesopotamia, timber would have had to come from the Zagros Mountains or from the Kurdish highlands. In support of Mesopotamia as the scene of the invention we should bear in mind that the Sumerians themselves seem to have come down from hill country, perhaps as early as the sixth millennium B.C.

Alternatively, the first wheeled vehicles could have been made within easy reach of the timber of the Caucasus. From there the invention could have been transmitted on the one hand to Mesopotamia (in the context of long-standing Sumerian ancestral relationships with the mountain peoples) and on the other into the treeless steppe to the north. Without drawing on resources beyond its bounds, however, the steppe itself certainly could not have been the birthplace.

In the light of our limited present knowledge it seems prudent to assume that the invention of wheeled vehicles took place in a wide area rather than a narrow one. The area should include Transcaucasia. Furthermore, the inventors should have not only access to raw materials but also suitable draft animals and adequate metal tools. Finally, the possibility of multiple invention is not beyond imagining. A vehicle of Sumerian design, with small one-piece wheels, could have provided a starting point. Later such developments as the covered wagon, with its heavy three-piece wheels, may well have taken place elsewhere and then been introduced into Mesopotamia. Mesopotamian wagon wheels are of noticeably lighter construction than those of the steppe; they can hardly have been the prototypes of the massive, doweled and mortised wheels of Transcaucasia. They could, however, represent a timber-saving version of a Transcaucasian original.

As for tracing the routes by which a knowledge of vehicles, or for that matter the vehicles themselves, moved westward into Europe, we must depend largely on inference. The evidence for cultural connections between the southern Russian steppe and the areas to the north and west is general rather than specific. Moreover, a new technological addition to a culture, such as the use of wheeled transport, does not necessarily carry any other traits of the parent culture with it. In spite of these caveats it has long been recognized that the cultures of the Hungarian plain in the late third millennium B.C. possess features that are difficult to explain on a basis of evolution from indigenous antecedents alone. A likely source for at least some of the obviously intrusive elements, such as new types of copper implements that resemble Caucasus copperwork, is southern Russia. The route of the intrusion could have been by way of the Ukraine and the plains of Romania, and thence into Hungary either over the mountains or by way of the Danube's Iron Gate. Along this route too could have come knowledge of the first wheeled vehicles.

The evidence of buried oxen in Poland and buried wheels in the Netherlands and Denmark may be related to an entirely separate intrusion. The pattern of cultures in the northern European plain around the middle of the third millennium B.C. includes a culture complex characterized by cord-ornamented pottery, stone battle axes and the custom of burying the dead in single graves covered by earth barrows. It has long been held that the complex is an intrusive one and is ultimately to be derived from sources in southern Russia related to the Pit Grave culture, although this interpretation has recently been disputed, and a case has been made instead for indigenous evolution.

The championing of local origins arises perhaps in part as a healthy reaction to earlier, overworked models of European prehistory that too strongly emphasized "invasions" and "folk movements." Nevertheless, even if some features of early northern European cultures can better be explained in terms of local growth, there still remains ample evidence of contact between southern Russia and northern Europe during the period. Dutch archaeologists have sought the origin of their disk-wheeled vehicles in Russia with good reason. A practicable route for the contact would also involve the Ukraine steppe, but from there it would cross the forest steppe and run beside the Dniester River, skirting the northern slopes of the Carpathian Mountains until it reached northern Europe's forested plain.

As in all questions of prehistory, we can at most advance working hypotheses that seem, in accordance with Occam's law, to account most economically for the archaeological facts. Indeed, what we call the facts are themselves only inferences derived from the surviving material culture of extinct communities. The investigation is nonetheless worthwhile, since it was during prehistoric times that the foundations of all our technology were laid down. No innovation was more fraught with ambiguous consequences than the invention and development of wheeled transport.

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Field Level Detection and Measurement Of Hydrocarbons As Air Pollutants

A new sensor which detects and measures the concentration in automobile exhaust of smog-forming hydrocarbons makes possible simple, continuous, inexpensive measurements in the field.

Unfortunately, progress toward control of air pollution has been handicapped by the difficulty encountered in identifying and quantitatively measuring the concentrations of the individual pollutants.

It is generally known that five major pollutants contribute 98% of the pollution in our urban centers. They are carbon monoxide, hydrocarbons, particulate matter, oxides of sulfur and oxides of nitrogen.

Each is harmful in its own way. Carbon monoxide is obviously injurious to health. Particulates cause damage and soiling and in some situations can affect health. The oxides of sulfur are known to damage vegetation and when combined with moisture in the air form sulfuric and sulfurous acids while the oxides of nitrogen in combination with moisture in the air form nitric and nitrous acids. All these acids have corrosive characteristics.

Hydrocarbons are thought to cause smog by a complicated series of photochemical reactions with normal atmospheric components. Among these are peroxyacyl nitrates, skin and eye irritants.

Each of the five pollutants can be identified and measured under laboratory conditions. Yet practical enforcement of regulatory agencies' standards for maximum permissible levels of concentrations of pollutants requires measurement at the source and in the open air by continuous, simple measurement devices. It is necessary to inexpensively and quickly measure pollutants and their concentrations at a smoke stack, from an automobile's exhaust and in the ambient air. Complicating the measurement problem is the fact that concentrations cover a wide range; for example, hydrocarbons may range from 0 parts per million in clear air to 10,000 parts per million in an automobile exhaust.

Honeywell is doing research on the sensing and measurement of these pollutants and has recently developed a particularly interesting device for detecting and measuring hydrocarbons in auto exhaust.

It is known that gases and vapors absorb electromagnetic radiation. It happens that ultraviolet radiation is strongly absorbed by most unsaturated hydrocarbons and is not absorbed to an appreciable extent by other gases or vapors normally found in air. Therefore if one starts with a known amount of ultraviolet radiation it is most likely that any decrease that is measured in an air sample will be due to absorption indicating the presence of hydrocarbons.

Ultraviolet radiation generators are not difficult to devise but simple, inexpensive ultraviolet detectors haven't been available.

Honeywell scientists believed that the Geiger counter philosophy offered real possibilities for ultraviolet detection although a Geiger counter detects photons in the high energy range while ultraviolet radiation would have to be sensed at the 6 electron volt level.

In developing a detector tube they modified the Geiger counter approach by using a configuration in which the discharge is initiated not in the volume but at a cathode made of a material that emits electrons only when ultraviolet radiation impinges on it.

Typical hydrocarbon detector unit includes ultra-violet source, detector, sample chamber, meter and recorder output terminals.

It took ten years of experimental work with different envelopes, geometries, materials, gas fills and processing techniques in order to attain the high degree of selectivity whereby the tube would not respond to anything except ultraviolet radiation. The results were so successful that the final tube is actually blind to solar energy reaching the earth. The tube, with its high internal gain, is small and inexpensive but will conduct enough current to operate an ordinary meter upon sensing 5 to 6 electron volt ultraviolet radiation.

Applied to Honeywell's hydrocarbon detector, the sensor actuates a meter which reads the percent of ultraviolet absorbed by the hydrocarbons in the air sample being tested. With a proper conversion chart the concentration of hydrocarbons in parts per million is easily obtained.

A series of instruments covering a range of sensitivities has been developed. Each includes an ultraviolet generator, sensor and meter. Each is portable, reliable and relatively inexpensive. The most sensitive instrument can detect and measure hydrocarbons in concentrations as low as two parts per million.

Honeywell scientists are deeply involved in research on the detection and measurement of the other four pollutants with some solutions in view. Hopefully, further work will lead to additional portable measuring devices to provide needed field measurements for pollution detection and control.

If you are interested in learning more about Honeywell's research work in the detection and measurement of air pollutants or about its new hydrocarbon detector, you are invited to correspond with Dr. Frank Hughes, Honeywell Research Center, Hopkins, Minnesota. If you have an advanced degree and are interested in a career in research at Honeywell, please write to Dr. John Dempsey, Vice President Science and Engineering, Honeywell, 2701 Fourth Avenue South, Minneapolis, Minnesota 55408.

Honeywell
AUTOMATION

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We mean it.

The air in this bottle could have come from New York on any muggy morning.

But it didn't come from New York. It came from a complex rig at the Esso Research Center, where they can now simulate the atmosphere of any city in the world.

The apparatus that does the simulating is a surrealist array of pipes, vessels, lights and meters. A big transparent drum swelters under artificial light. A car on a test bed spews exhaust into the drum. Simulated solar radiation does its worst. And, at the end of it all, a collection of plants quivers in a miniature gas chamber.

The metering system is so precise, it can detect and identify airborne molecules down to five parts per billion. Thus, the air we breathe is being scrutinized as it has never been scrutinized before.

The smog problem is the first order of business.

What causes it? What does the sun do to the hundreds of chemical compounds in the air? What turns leaves brown?

in August

What irritates your eyes? And finally, the big question. Since nature itself contaminates the air – what exactly is healthy air?

The answers to these questions will affect us all.

In the next few years, more and more laws will surely be passed to control air pollution.

These may comfort our souls. Do's and don'ts usually do. But no regulation can be any better than the knowledge on which it is based. Jersey's affiliate, Esso Research, is determined to help supply such knowledge.

There is much to be found out. But the air pollution problem will be solved. A recent finding supports our optimism.

Air pollution from cars reached its zenith in 1967. It has been getting less and less ever since. This news may not rate three cheers. But it may justify two. One from you. And one from us.

Meanwhile the work goes on.

Standard Oil Company (New Jersey)

FLUIDIZATION

Many chemical and physical reactions can be carried out by suspending a bed of solid particles in a stream of gas. The technique is widely used for the catalytic cracking of petroleum and much other technology

by H. William Flood and Bernard S. Lee

Take a quantity of sand, put it in a vertical container with an opening at the top and force air up through the sand. When the flow of air attains sufficient velocity, the bed of sand will rise from the base of the container and remain in turbulent suspension near the base. In that condition the sand exhibits many of the properties of a liquid. It will flow through pipes; its surface will remain horizontal if the container is tilted, and ripples will appear on the surface if the wall of the container is tapped.

Any material that can be put into a suitably granular form can be "fluidized" in this way by any kind of gas. Because the fluidized particles are separated from one another by the gas, the opportunities for intimate contact between the particles and the gas are enormous. Hence a bed of fluidized particles is an excellent medium for the transfer of heat or mass between solids and fluids.

Carrying out such reactions, particularly on a large scale and under carefully controlled conditions, is hardly as simple as forcing air up through a bed of sand. Not until the oil industry, in need of an improved method of cracking petroleum during World War II, worked out suitable engineering techniques did fluidization come into wide use as a means of physical and chemical processing. It now underlies a substantial technology. Most of the catalytic cracking of petroleum is done by means of fluidized beds. Many metallic ores are roasted in fluidized beds for the removal of sulfur. Fluidization is used to prepare a large number of intermediate products for the plastics industry. Recently fluidization has come into use in the processing of foods and the disposal of wastes. Several other applications appear likely to result from work that is now in progress.

A typical system for a fluidizing process has as its basic element a cylindrical tank [*see illustration on page 104*]. Inside the tank the solid particles rest on a perforated base known as the deck. Gas is introduced through the deck at a rate of flow sufficient to put the particles into the fluidized state in which the desired processing is accomplished.

In some applications the solid particles participate in the process. An example is a catalytic cracker of petroleum, in which the solid particles constitute the catalyst that acts on the vaporized petroleum being put through the system. In other applications the solid particles are materials to be processed. A case in point is the transformation of limestone into lime: crushed limestone is fed into the vessel, where it is fluidized by hot gases that drive off carbon dioxide, producing lime that is withdrawn from the system.

Because the fluidized particles have the properties of a liquid, they can be moved in and out of the system by means of pipes and valves. A fluidizing apparatus is therefore likely to have an array of such fluid-handling equipment. By means of this equipment a fluidized process can readily be made continuous, with new supplies of solid particles being fed into the system as processed or spent particles are withdrawn.

Gas that has made its way up through the fluidized bed is discharged through an exhaust pipe. The exhaust system contains a dust collector that captures any of the solid particles that have become entrained in the gas. Particles thus collected can be returned to the fluidized bed through a pipe.

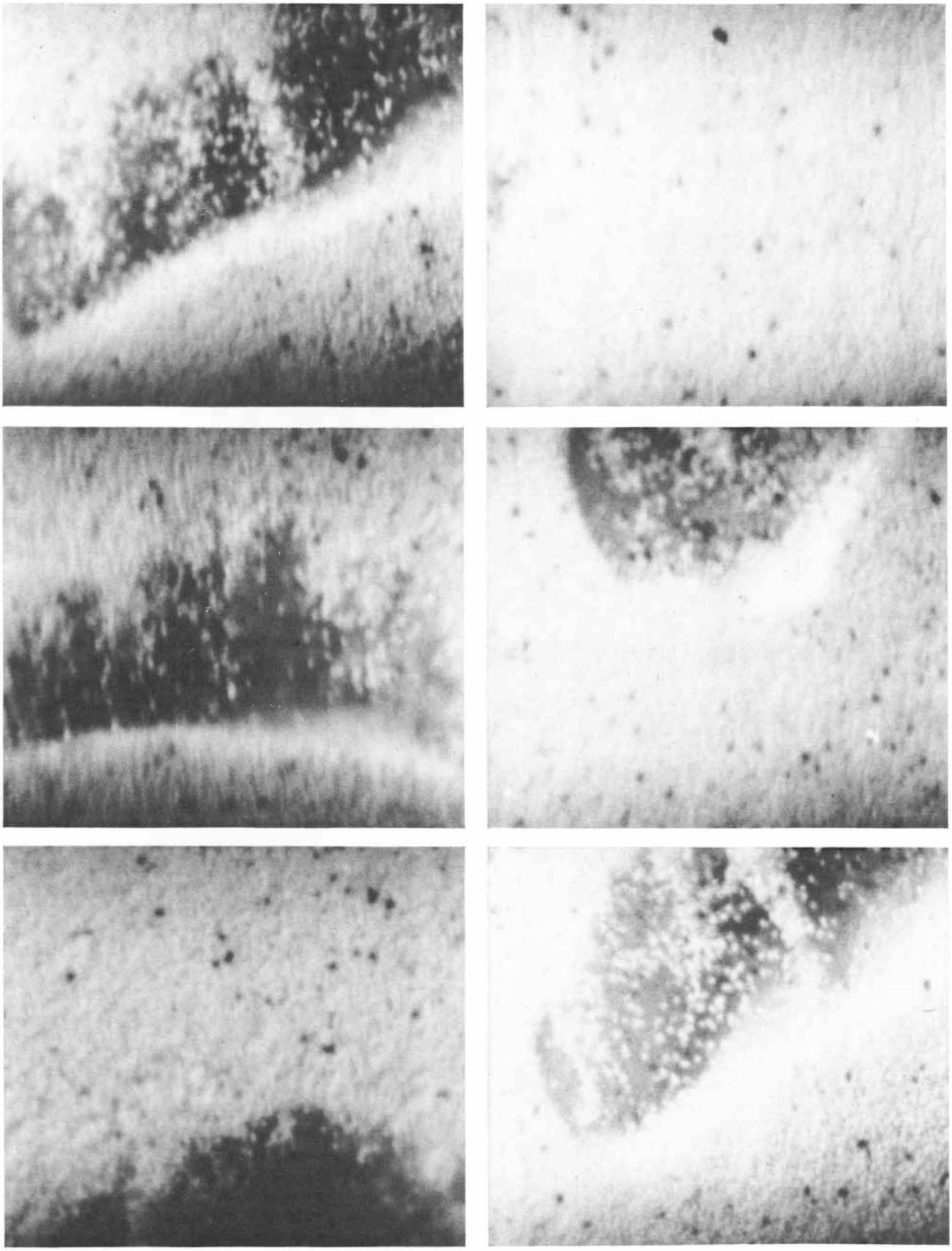
A large variety of processes can be carried out in a fluidized system. One rather simple example will suffice to indicate the kind of work that can be done. Suppose it is desired to transform Glauber's salt, a naturally occurring substance that contains more than 50 percent water, into dry granular salt—a process employed to provide salt in a form used by manufacturers of paper. The bed is started with previously dried particles of salt. Fluidization is provided by natural gas burned with air in a combustion chamber below the deck.

The Glauber's salt, which melts at 90 degrees Fahrenheit, is fed into the bed of violently agitated solids. The salt melts and thinly coats the dehydrated material in the bed. Then the heat in the bed dehydrates the coating, driving off water, which is carried away with the exhaust gas. The slightly cooled particles of solid material in the fluidized bed are reheated by the hot combustion gases, so that they are able to melt and dehydrate more feed material. The dry salt cake is displaced by freshly formed particles and removed as the end product of the fluidizing process.

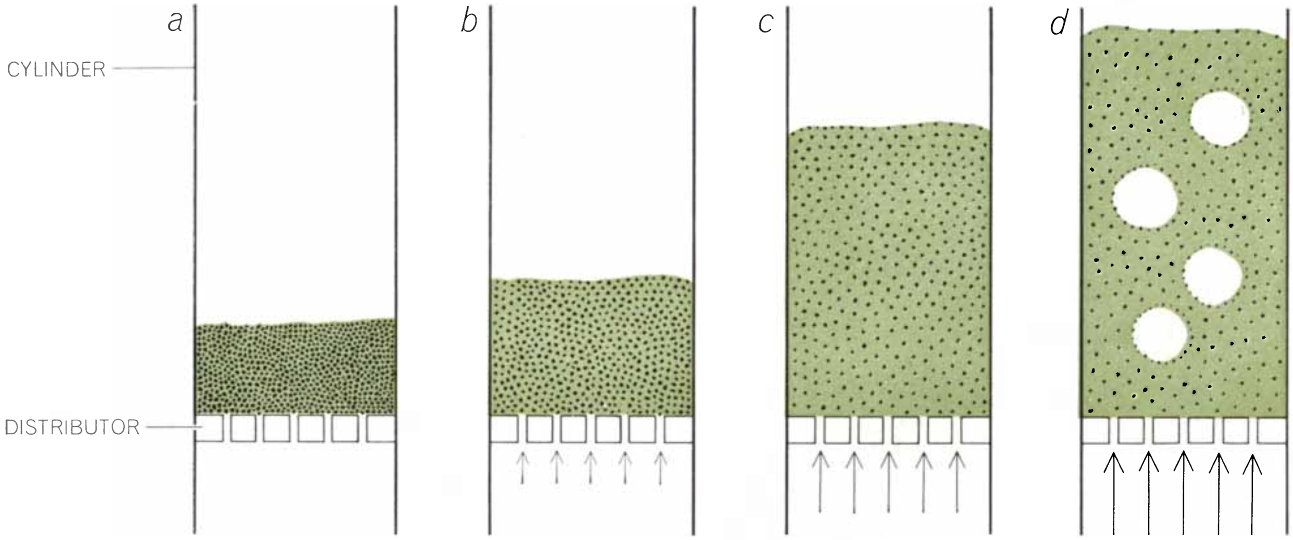
Toward the end of this article we shall describe a few more of the many processes in which fluidization is used. They can best be understood, however, against a background of the theoretical and engineering considerations that must be taken into account in the design and operation of fluidized systems.

Four distinct physical states can be achieved by forcing a gas up through a bed of solid particles. If the rate of flow is low, the gas simply percolates through the bed. The bed expands slightly, but the particles remain essentially stationary. The result is a fixed-bed state, which is useful for certain kinds of processing.

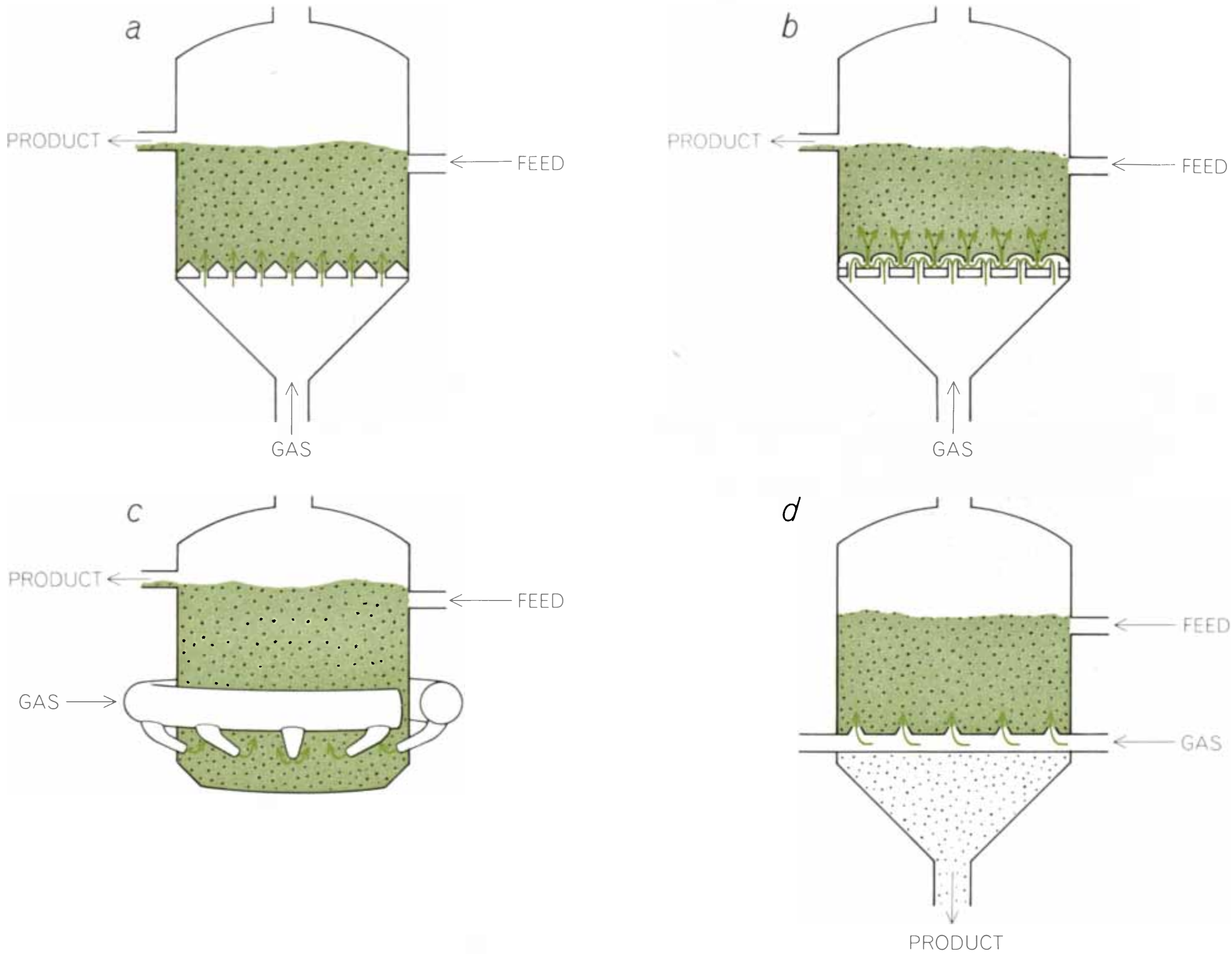
The stage at which the particles start to be lifted by the gas, so that they are just loosened from their packed state and can move around their original positions, is known as incipient fluidization.



PARTICLES OF ALUMINA in the form of a fine powder are fluidized by air in an experimental apparatus in the laboratory of J. W. Westwater of the University of Illinois. Air forced up through the column puts the bed of powder in suspension, with individual particles mixing turbulently. Frames from a motion-picture film show (*bottom to top*) a bubble rising through the bed. Small bubbles promote mixing of particles and gas, thereby aiding the chemical or physical reactions that are carried out in a fluidized system.



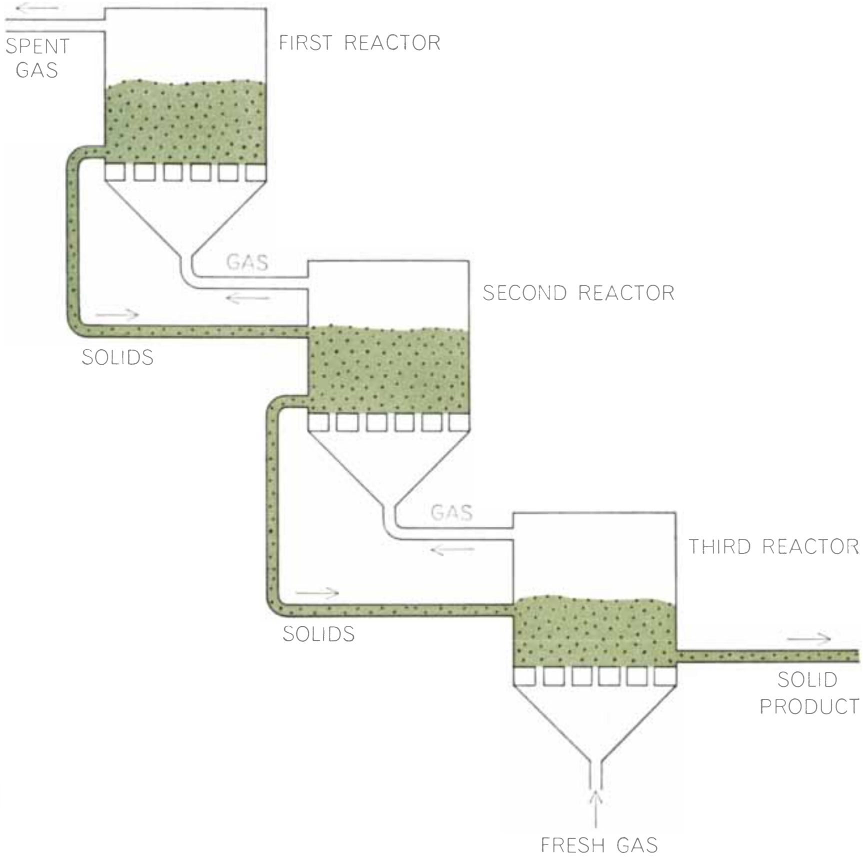
STAGES OF FLUIDIZATION are depicted schematically. When there is no flow of gas (*a*), the solid particles rest on the deck, or perforated base, that distributes the gas. If gas is forced up into the cylinder at a low velocity (*b*), the bed of particles remains essentially stationary and the gas simply percolates through it. Such fixed-bed conditions are used in certain industrial processes. An increase in the rate of flow (*c*) causes the bed of particles to rise from the deck. When the flow of gas is sufficient to keep the entire bed suspended (*d*), with individual particles in vigorous random motion, the condition called normal fluidization exists. The solid particles exhibit much of the behavior of a liquid, which often seems to be boiling because of the bubbles that appear in the bed.



GAS DISTRIBUTORS in fluidized reactors vary according to the pattern of flow desired and the type of processing being done. A distributor of the orifice type (*a*) is for use in a high-temperature fluidized reactor; its orifices are shaped by ceramic or refractory materials. A bubble-cap distributor (*b*) gives a nozzle effect. In a reactor with a solid base (*c*) the gas is distributed by tuyere nozzles around the sides of the vessel. A gas distributor can also be designed in such a manner as to function in an open-bottom reactor (*d*).

At that point the weight of the particles is balanced by the upward thrust of the gas. Increasing the flow of gas puts the particles into the state called normal fluidization. The height of the bed expands further, and the particles are set in violent, chaotic motion. Thereafter, if the flow is maintained at the same rate, there is no net motion of particles, although each individual particle is agitated briskly within the bed.

Nearly all practical applications of fluidization take place in the normal state. If the flow of gas is further increased, particles begin to be blown out of the system. One thus progresses beyond fluidization into pneumatic transport.



SERIES OF BEDS is used when it is desirable to have solids and gas moving in opposite directions in a fluidized system. Fluidized reactors are arranged vertically. Fresh solid material is fed into the uppermost reactor and fluidized by gas that has already passed through the other reactors. Partly processed solids are drawn off through a pipe; they flow by means of gravity down to the next reactor and then to the bottom one for further processing.

The capacities of a normally fluidized bed with respect to heat are remarkable. Since the individual fluidized particles are small, an enormous surface for the transfer of heat is available in a given volume of solids. For instance, a bed of particles averaging 60 microns (.002 inch) in size offers as much as 15,000 square feet of surface per cubic foot of bed volume. Moreover, the mixing of particles in a normally fluidized bed is rapid and thorough, so that uniformity of temperature is quickly achieved and steadily maintained. In experiments at the Battelle Memorial Institute gas at a temperature of 12,000 degrees F. was injected into a fluidized bed; within a vertical distance of one inch the temperature had dropped to 2,000 degrees F. Indeed, fluidized beds have demonstrated as much as 100 times more thermal conductivity than silver, which is the most conductive of metals.

If a cold gas is passed through a hot fluidized bed, the gas will remove heat from the solids and will emerge uniformly heated to the temperature of the bed. Similarly, a hot gas can be quickly quenched to the temperature of the bed by being passed through a bed of cold solids. A fluidized reactor is therefore an excellent apparatus in which to carry out chemical or physical reactions at uniform temperatures—even when the reactions involve the absorption or release of large amounts of heat. Most applications of fluidized beds in industry depend on this characteristic.

In addition a fluidized bed is useful for transferring heat to or from a solid surface that is in contact with the bed. A coil submerged in the bed is an example. The operating temperature of a fluidized bed can be precisely controlled by the use of heating and cooling surfaces in the bed. For this reason the fluidized bed is useful in many chemical reactions that depend on control within a narrow temperature range.

Mass transfer is another area in which the capabilities of a fluidized bed can be exploited. Mass transfer involves the movement of material to and from the substances affected by a chemical or physical process. As coal burns, for instance, the transfer of oxygen to the surface of the coal is an important mass-transfer process in the combustion reaction. In the cooling tower of an air-conditioning unit the evaporation of water to humidify and cool the air is an example of mass transfer in a physical process.

In most of the apparatus used for the treatment of solids the transfer of mass is hindered by a stagnant layer of gas next to the solid surface. A case in point would be a fixed-bed reactor. In a fluidized bed the hindrance to mass transfer is much lower because the vigorous agitation among the solid particles reduces the thickness of the stagnant boundary layer on each particle of the solid.

Lest we convey the idea that a fluidized reactor represents perfection to the process engineer, we should point out that a fluidized system has a number of inherent drawbacks. A fundamental disadvantage is that particles larger than a quarter of an inch or smaller than a thousandth of an inch—that is to say, larger than peas or smaller than grains of flour—are difficult to fluidize satisfactorily. Larger particles require inconveniently high velocities of gas, and smaller ones are too easily blown out of the system. Waxy or sticky materials are not usually suitable for fluidization, nor are fibrous, stringy or needle-like materials. Materials that tend to fuse or agglomerate at operating temperatures are unsuitable. Soft or breakable materials may be unsatisfactory if the violent movement in the bed damages them more than is desirable in a particular application.

Another disadvantage arises from the large bubbles of gas that tend to form in a fluidized bed. Up to a point bubbles are useful because they promote the agitation of solids, thereby improving the uniformity of temperature in the bed. If a reaction between the gas and the solid is wanted, however, bubbles—particularly if they are large—tend to impede it because the gas trapped in the bubbles cannot come in contact with the solids in the bed.

A third disadvantage appears in applications where a countercurrent pattern of flow between solids and gas is desirable. In such a pattern the gas and the solids move in opposite directions. The pattern is preferable in a number of heat-exchange processes and chemical reactions. It is achieved in such devices as fixed-bed reactors, rotary kilns and distillation towers.

The flow in a fluidized reactor, however, is by nature concurrent. If the improvement in yield or better utilization of fuel justifies the cost, countercurrents can be incorporated into a fluidized system by combining a number of fluid beds in series [*see illustration on preceding page*]. Each bed is vertically separated from the rest, so that the gas flows up through the solids in one bed, through another gas distributor and through the solids of the bed above, and so on. The solids meanwhile flow downward from one bed to the next through pipes.

In most cases the vessel in which fluidized processes are carried out is a cylindrical or rectangular metal tank. The sizes vary widely; there are laboratory units with beds as small as an inch in diameter and commercial units with beds up to 50 feet in diameter. A reactor can be built for high-temperature operation by lining it with a heat-resistant material such as firebrick. Systems can be designed to work at high pressure, and for handling dangerous gases or solids the system can be tightly sealed.

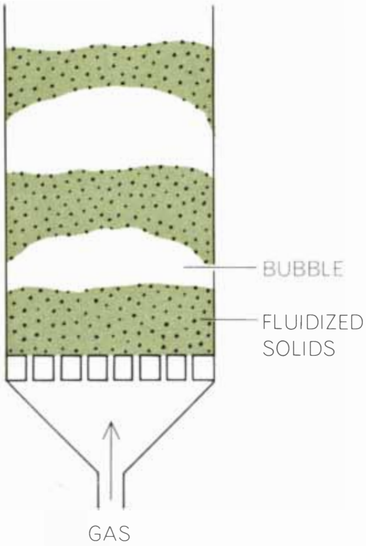
The deck, which serves both as support for the bed of particles and as the gas distributor, can be made of any of several materials, depending on the weight of the particles and the temperature at which the processing is to be done. The openings in the deck are designed to produce the desired pattern of gas flow over the entire cross section of the reactor. They may be slots or circular holes.

Gas is usually supplied to the reactor by a compressor or a blower. If the reactor has a shallow bed, the gas can be drawn up through the system by an induced-draft fan in the exhaust system. Heat can be added to the reactor by burning fuel directly in the bed or in a combustion chamber coupled to the bed. Heat can be added to the reactor indirectly through heat exchangers, such as tubes or coils, placed in the bed. Similarly, heat can be removed from the system directly by the circulation of cold gas through the bed or indirectly through heat exchangers.

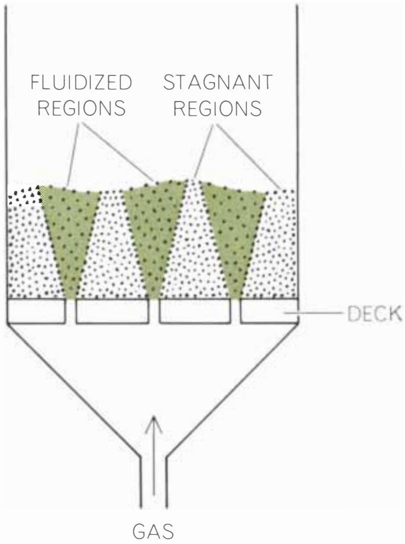
The instrumentation on a fluidized reactor is simple and adaptable to automatic control. Since a fluidized bed behaves like a fluid and exerts a hydrostatic pressure, the height of the bed can be measured by ordinary mercury manometers or pressure gauges. The height of the bed can be regulated by pressure controllers that operate devices to add material to the bed or discharge material from it.

Temperature is virtually uniform throughout the bed. Because the fluidized particles behave like a liquid, solids can be withdrawn from the system at any point in the bed by means of commonly used fluid-handling methods. The reactor has no moving mechanical parts in contact with the solids or the gas, so that maintenance is fairly simple.

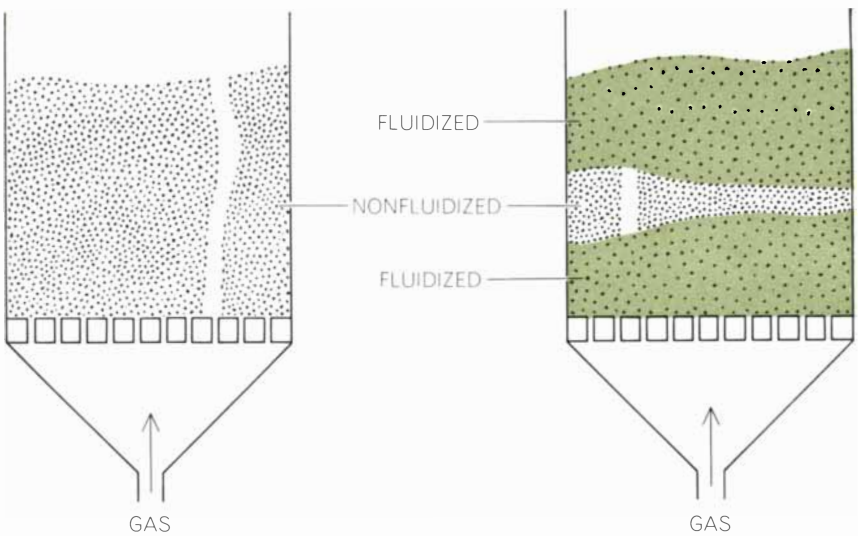
The proper operation of a fluidized reactor depends on a number of factors. A very important one is the ratio between the height of the fluidized bed and the diameter of the bed. A long, thin bed results in a high ratio and may therefore be prone to an undesirable phenom-



LARGE BUBBLES in a fluidized bed give rise to the undesirable condition called slugging. Bubbles reach the full diameter of the reactor and move upward, pushing slugs of solid material. Such large bubbles impair the mixing of solids and gas in the system.



STAGNANT REGIONS can develop in a fluidized bed that is too shallow. Only the particles of solid material near the holes of the gas distributor are well fluidized. Stagnation develops in other parts of the bed, and the mixing process is unsatisfactory.



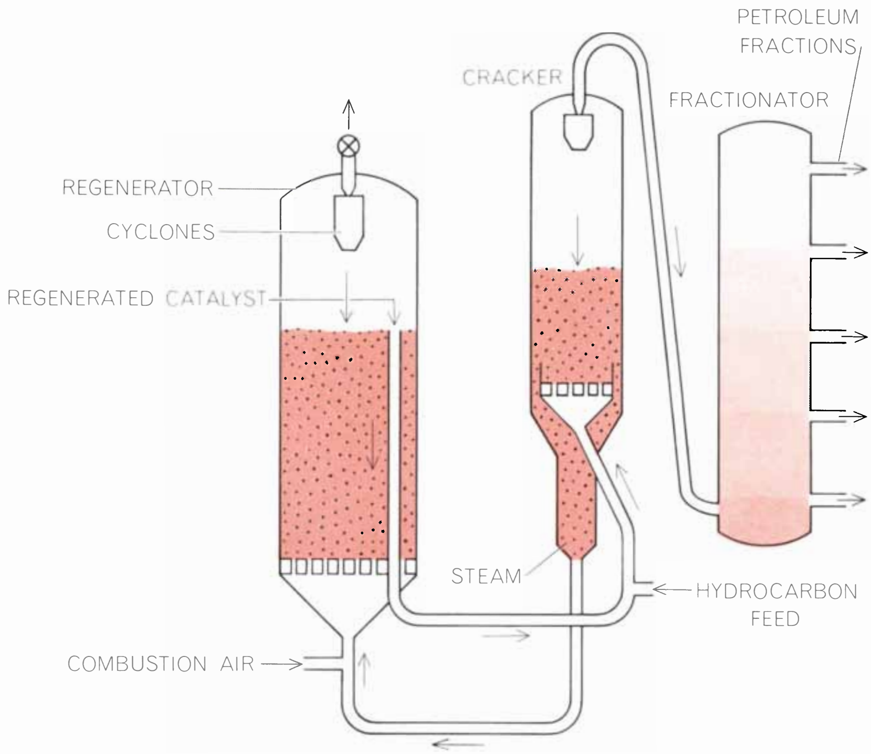
POOR DISTRIBUTION of gas in a fluidized bed can result in a condition called channeling. It leads to poor contact between gas and solids and to nonuniform bed temperature.

enon called slugging [*see illustration at upper left on opposite page*]. Slugging develops when bubbles of gas grow to the full width of the reactor. Each bubble then moves upward, pushing slugs of solid material ahead of it. At the top of the reactor the bubbles collapse and the solids drop back into the bed. No solids are lost, but the mixing of gas and solids becomes highly inefficient.

At the other extreme a bed that is too shallow is also undesirable because the solids tend to be adequately fluidized only in the immediate vicinity of the holes in the gas distributor. The solids do not attain the lateral movement needed to create a good pattern of mixing [*see illustration at upper right on opposite page*]. In commercial reactors the diameter of the bed is generally slightly greater than the depth of the bed (when normally fluidized) and in some cases may exceed 10 times the depth.

A second factor of importance to the operation of fluidized beds is the average time a particle stays in the bed. It is statistically predictable that some particles will leave with the product before they have been fully treated. The phenomenon is called short-circuiting. In practice it is controlled, within limits, either by putting the discharge pipe as far away from the feed inlet as possible or by maintaining a large amount of bed material with respect to the rate at which new material is introduced. For example, if 95 percent of the solids are to be held in the bed for at least one hour in order to complete a reaction, the ratio of the hourly rate of feed to the weight of the bed should be .05. In other words, a feed rate of five pounds per hour into a reactor with a bed weight of 100 pounds will ensure that 95 percent of the material will remain in the bed for at least one hour.

A third factor to be considered in the operation of a fluidized bed is the extent to which the fluidizing gas comes in contact with the solid particles. When a bed is not uniformly fluidized, the result is a condition known as channeling [*see bottom illustration on opposite page*]. The usual cause is poor distribution of gas. The solution is to design the gas distributor in such a way that the gas takes no preferential path through the bed.



CATALYTIC CRACKER OF PETROLEUM makes use of a fluidized bed in which the solid particles are fluidized by gas and petroleum vapor and serve to catalyze the reaction that breaks the petroleum into its lighter fractions, including gasoline. The reaction coats the particles with carbon, rendering them ineffective. Therefore they are drawn off to a regenerator, where the carbon is burned off, and then returned to the reactor for reuse.

The necessity of coping with these and other problems explains why it took a long time for the idea of fluidization, which appears to have been first put forward in the 1870's, to evolve into a commercial process. Probably the first application of fluidization on a commercial scale took place in Germany some 40 years ago in a process that created a fuel gas from coal. In this process finely ground coal was fed continuously into a tanklike reactor, where it came in contact with a mixture of steam and air introduced at the bottom. The coal was partially burned, producing carbon monoxide and hydrogen, which was withdrawn from the top of the unit while ashes from the coal were withdrawn from the bottom.

It was the demand during World War II for better yields of gasoline from the cracking of petroleum that finally brought fluidization into its own. A fixed-bed catalytic cracking process had been introduced commercially in 1937. It was a substantial improvement over earlier thermal methods of cracking, but it presented several difficulties.

In the fixed-bed process oil vapor was passed through one of a pair of beds until the catalyst had been fouled with carbon formed in the reaction. Then the oil vapor had to be switched to a different bed while air was passed through the fouled bed to burn off the carbon and regenerate the catalyst. It seemed plausible that a more efficient process would be to regenerate the catalyst and crack the petroleum in one continuous operation.

This was achieved in the fluidized-bed catalytic process that resulted from studies of gas-solid fluidization made by the Standard Oil Development Company and the Massachusetts Institute of Technology. The process makes use of two vessels joined by pipes. One of the vessels is the reactor, in which the long carbon chains in the heavy petroleum fractions are broken down into shorter chains to yield hydrocarbons of lower molecular weight, notably the hydrocarbons of gasoline. The other vessel is the regenerator, in which the spent catalyst is cleaned of its carbon deposits so that it can be returned to the cracking reactor [*see illustration above*].

In the regenerator carbon is removed from the particles of solid catalyst by burning. The combustion heats the particles, so that when they are circulated back into the cracker they provide the heat necessary for the breakdown of the hydrocarbons being fed into it. Hot active catalyst from the regenerator flows down a standpipe, is picked up by the feed vapor and is carried into the cracker. Carbon-coated spent catalyst then

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flows down a standpipe, is picked up by air used for combustion and is carried back into the regenerator to complete the cycle.

The intimate contact obtained between the solid catalyst particles and the hydrocarbons, plus the uniformity and controllability of the reaction temperature in the cracking bed, made the new process immediately successful in improving the yield of gasoline from the cracking operation. The fluidized-bed technique is now the principal means of catalytic cracking of petroleum. Fluidized-bed systems crack more than a million barrels of petroleum daily and represent the major application of the fluidization process.

A fluidized bed used for the roasting of metal ores has as its objective the conversion of the metal in sulfide form to an oxide form, from which the metal can then be readily recovered. Among the

PETROLEUM CRACKERS using the fluidized-bed technique are operated by the Humble Oil & Refining Company in Baton Rouge. Two crackers are shown here. In each case the cracker and regenerator are combined in the tall tower with two pipes emerging from the top. Shorter towers to right of each unit are the fractionators where the cracked petroleum is separated into fractions.

metallic ores thus treated are copper, nickel, zinc and iron. A roasting operation takes place in a single reactor [*see illustration on next page*]. The solid is the ore, introduced as a slurry or a dry concentrate. The fluidizing gas is air, which supplies the oxygen necessary for the oxidation of the sulfides. Because this reaction is accompanied by the release of large amounts of heat, the excellent heat-transfer property of a fluidized bed is particularly well suited to controlling the temperatures of the roasting reaction.

Sulfur dioxide produced as a by-product of the roasting process can be used in the production of sulfuric acid. About 150 fluidized-bed ore-roasting plants throughout the world are so used. They produce some seven million tons of sulfuric acid annually.

Another application of the fluidized-bed technique is in the calcining, or heating, of limestone to drive off carbon dioxide and produce lime. This is a case in which a series of reactors is desirable to produce a countercurrent flow. Two such plants, consisting of five stages each, are operated by Charles Pfizer and Co., Inc.

The top three stages are shallow fluidized beds for preheating the crushed and screened limestone entering the system. The source of heat is gas coming from the fourth stage, where a deeper calcining bed is fired directly with fuel oil injected into the bed. The fifth and lowest bed receives the hot lime, which in being cooled serves to preheat the air entering the system. The consumption of fuel oil in such a system is about two-thirds of the amount used in rotary-kiln calciners of similar capacity.

Many other ways in which fluidization is used on a commercial scale could be cited. Instead, we should prefer to touch briefly on a few of the promising applications that are in the experimental stage. Prominent among them are efforts to use fluidization for the reduction of low-grade iron ores, so that they can either be used economically in blast furnaces or be transformed into iron without going through a blast furnace.

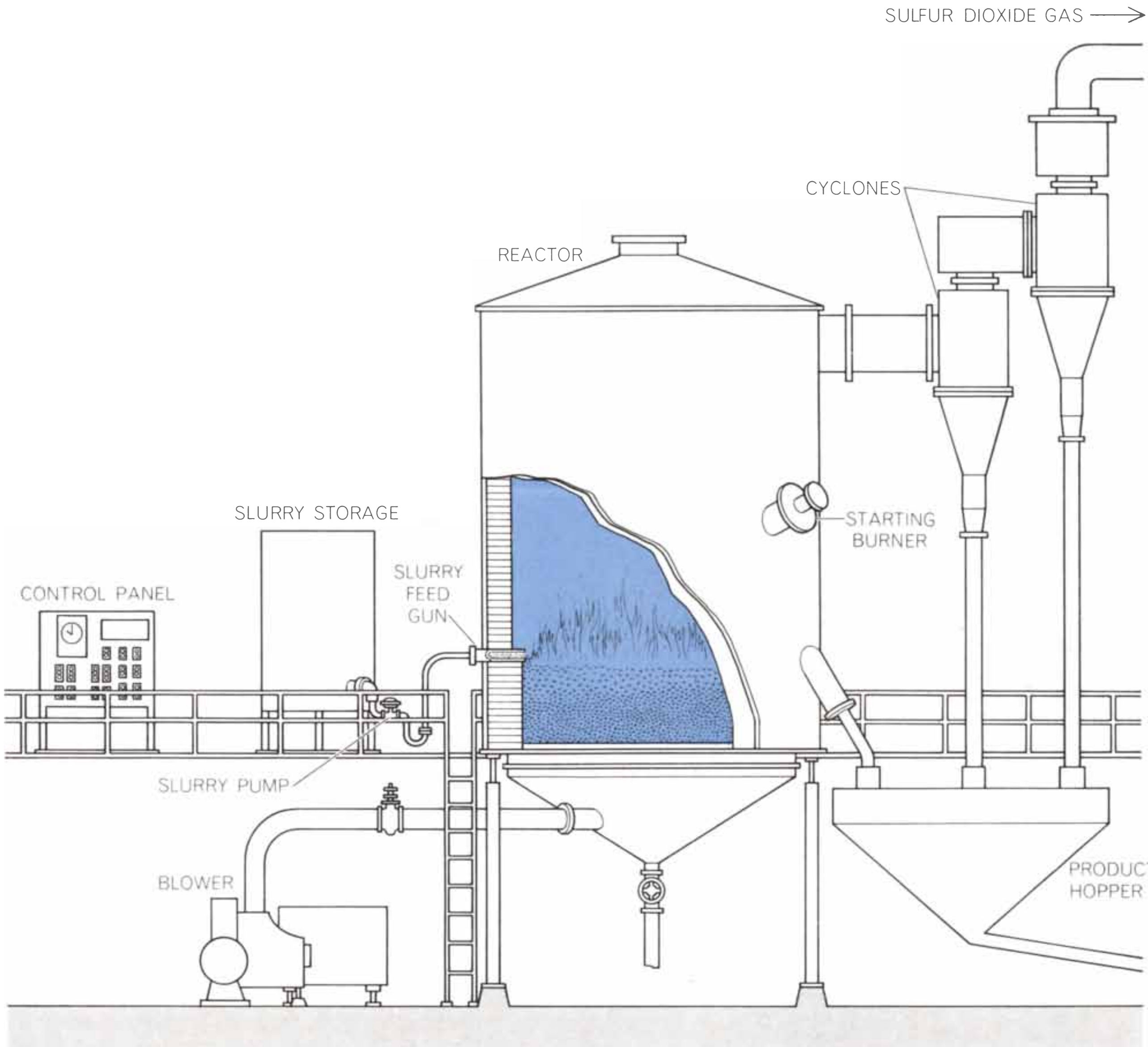
Typical of the direct-reduction techniques is the one being developed by Arthur D. Little, Inc. It makes use of three fluid beds. The upper one preheats the raw ore containing hematite (Fe_2O_3) and reduces it to wüstite (FeO). The two lower stages complete the reduction of wüstite to metallic iron. In this system the solid is the raw ore and the gas is a mixture of hydrogen, carbon monoxide and nitrogen. The gas does double duty as both the fluidizing element and the reducing agent.

Fluidization is under investigation as a means of cooking and freezing foods. Cooking is done by immersing the food in a bed of hot fluidized particles. The process has been described as French-frying without oil. The material used as solid particles has included salt, sugar, limestone and rice. The gas is usually air, although nitrogen and carbon dioxide have been used. Among the foods thus cooked are peanuts, potatoes and breaded shrimp.

Freezing can be done in a fluidized bed if the food is particulate in shape or can be put into particle form, as in the case of peas, corn and carrots. A bed of peas on a perforated metal tray can be fluidized and quickly frozen by a stream of air at a temperature of about −35 degrees F. The process can be made continuous by the steady introduction of unfrozen peas as frozen ones are withdrawn for packaging.

Fluidization also shows promise as a technique for disposing of certain troublesome liquid wastes, such as the kind produced by pulp and paper mills. Waste liquor is first concentrated by evaporation so that it consists of about 35 percent solids and can be burned. This slurry is sprayed into the top of a fluidized-bed furnace. It coats the solid particles already there (a residue from earlier burnings), is burned and leaves an adherent solid residue, so that the particles grow. The organic components of the liquor are burned to carbon dioxide and water. Remaining are pellets of inorganic salt that can be used as particles in the bed, processed for the recapture of their chemicals or discarded.

Our catalogue of actual and potential applications of fluidization is far from complete. We have sought only to suggest the capabilities of the fluidized-bed technique. It is highly probable that many of the further developments of the technique will surprise even those who are experts in the field.



ORE ROASTER is a fluidized-bed reactor in which the solid particles consist of ore in the form of a slurry or a dried, granular concentrate. The particles are fluidized by hot air in a reaction that oxidizes the ore, producing sulfur dioxide and preparing the ore for further treatment. The sulfur dioxide can be used to make sulfuric acid. Ores thus treated include copper, nickel and iron.

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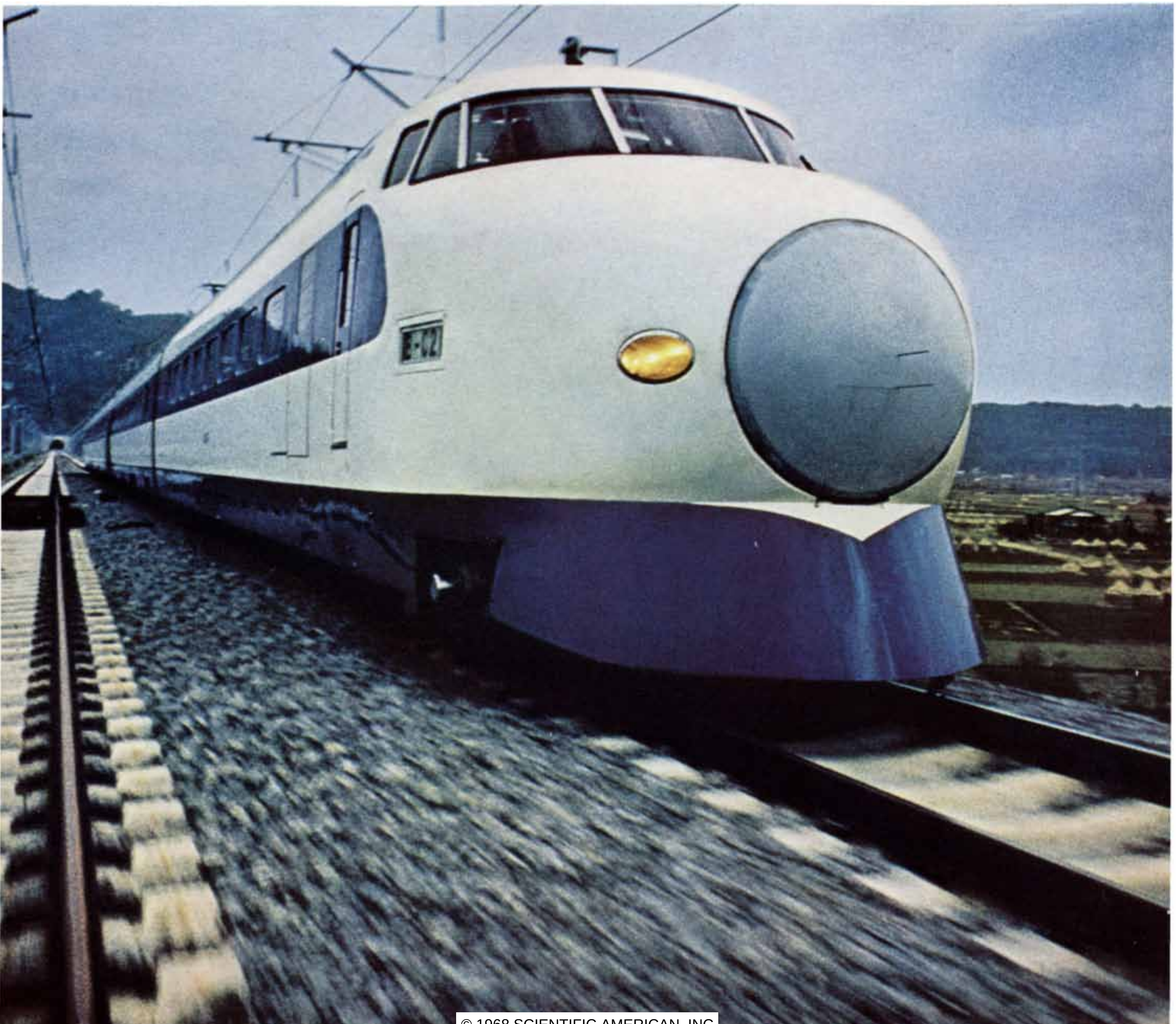

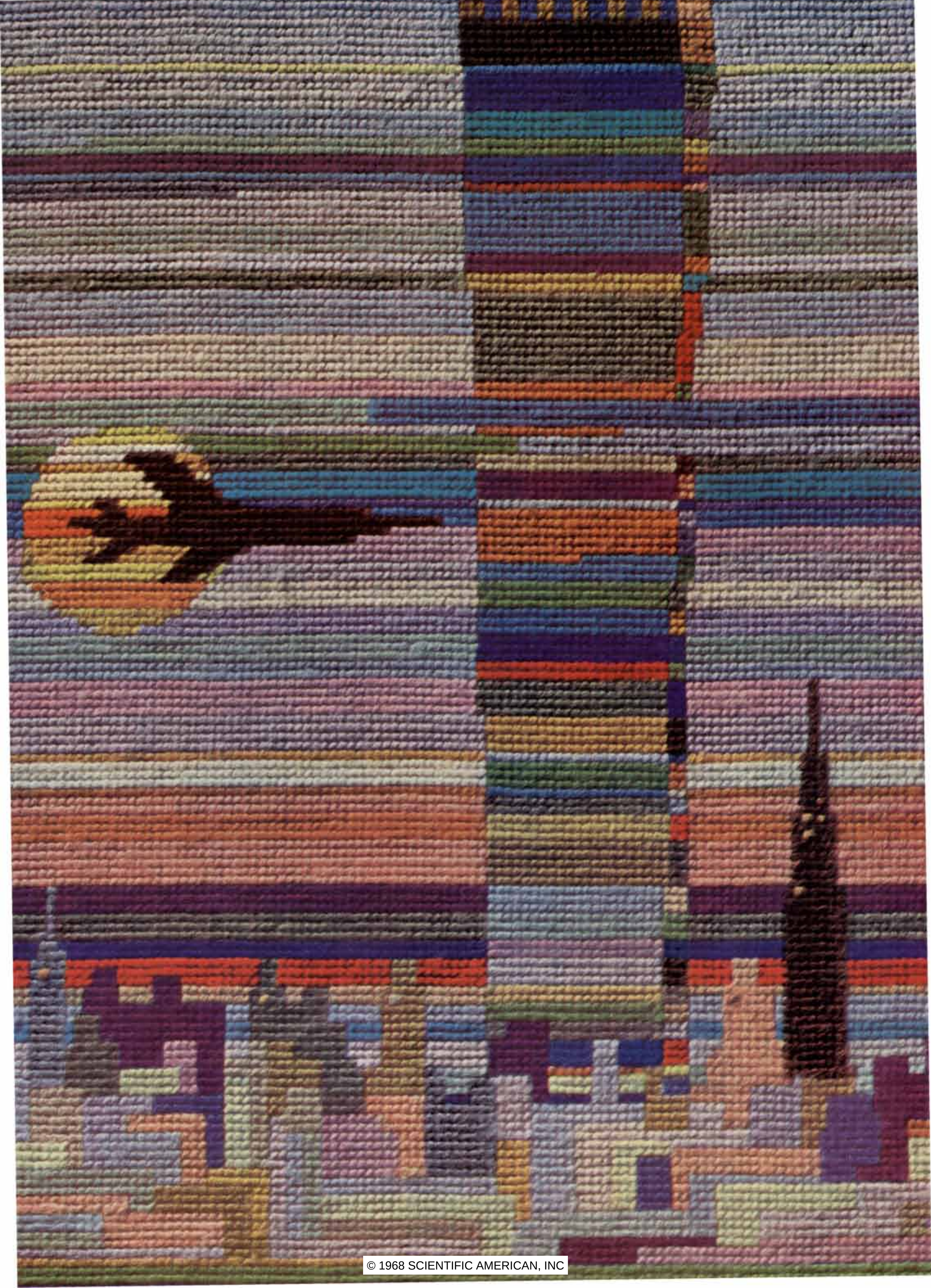

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HIDDEN LIVES

Concealed at the surface of the ground, dwelling in conditions of maximum security, are a multitude of small invertebrate animals. Some may well retain the form in which life on land first appeared

by Theodore H. Savory

A few inches above and below the surface of the ground lie the boundaries of a space wherein countless multitudes of small animals live the whole of their lives "in the dark and the damp." Lift, if you will, a rotting log and you will find sheltering under it a group of woodlice; raise a half-buried piece of rock and you will disturb a resting centipede; stir a heap of fallen leaves and a dozen of the insects that are aptly called springtails leap to sudden activity.

One does not remember having seen woodlice or centipedes running in the fields like spiders or basking in the sunshine like butterflies. They are examples of the many small animals that lead hidden lives; they are some of the cryptozoa, the animals in hiding. The name cryptozoa was suggested for them in 1895 by Arthur Dendy, an Australian naturalist.

The cryptozoa form an assemblage of invertebrates unrelated in terms of conventional systematics but united ecologically by their occupation of a particular environment. This environment is the immediate neighborhood of the earth's surface, where there are leaves and humus, mosses and stones, fungi and soil and salts. It may be called the cryptosphere. It is a region as well defined as any other ecological zone; it is universal and because it is largely responsible for the existence of the cryptozoa its physical nature may be described first.

The most significant components are illumination, humidity and temperature, the first two being represented in the phrase from J. L. Cloudsley-Thompson quoted in my opening sentence: "the dark and the damp." Light is less vital to animals than it is to plants; indeed, most small animals tend to shun the light rather than to welcome it. The bacteria and fungi, on whose cooperation the cryptozoa largely depend, are organisms of the darkness rather than of the sunshine.

But darkness is not so essential as dampness. Almost every class of terrestrial animals can be traced back to an aquatic ancestor, and all have been compelled from the first to face and to overcome the risk of desiccation. The problem of avoiding or limiting water loss is one that is encountered again and again in the study of the cryptozoa.

Temperature is clearly a condition that affects this matter. The relative constancy of temperature in the cryptosphere is one of its favorable features, since less elaborate adaptations are necessary to secure control of escaping water. Incidentally, the region challenges experimental biologists to exercise ingenuity in the design of apparatus for recording humidity and temperature in inaccessible spots.

The most significant fact about the physical conditions of the cryptosphere is their approach to constancy; there is in general only slight change in illumination, temperature and humidity in this obscure and sheltered world. Perhaps only in the remotest parts of large caves and in the greatest depths of the oceans are the physical conditions of the environment less subject to variation, either daily or seasonal.

The advantage to the cryptozoa themselves is obvious. Few stimuli fall on their sense organs, which in many instances are simple in form and function. Thus the cryptozoa are not obliged to move frequently in response to external impulses, which is only another way of saying that in the cryptosphere there is protection against all those unpleasant climatic changes that can collectively be summarized by the word "exposure." There is freedom in a life that is predictable to the point of monotony.

The stage having been set, let us turn to the players. They are readily discernible if one shakes fallen leaves in a wide-mesh strainer while watching a white sheet spread below it. One is likely to be struck, first, by the number of creatures that are thus revealed; second, by their variety, and third, by their size.

Firstly, as to numbers. Simple sifting does not provide a reliable record of the population. More sophisticated methods, carried out with the help of devices such as the Berlese funnel (which enables one to extract all the fauna from a ground sample) and backed by statistics of sampling that have no place here, have yielded results that are frankly bewildering. A few examples can be quoted in illustration.

In 1936 W. R. S. Ladell estimated the insect population near Cambridge to be nearly 48 million per acre on fallow land and 96 million per acre on grass. At the Rothamsted Experimental Station four years later K. D. Baweja gave a figure of more than 100 million for the number of insects per acre, and the amazing figure of 1,400 million insects per acre was computed at Cambridge in 1948.

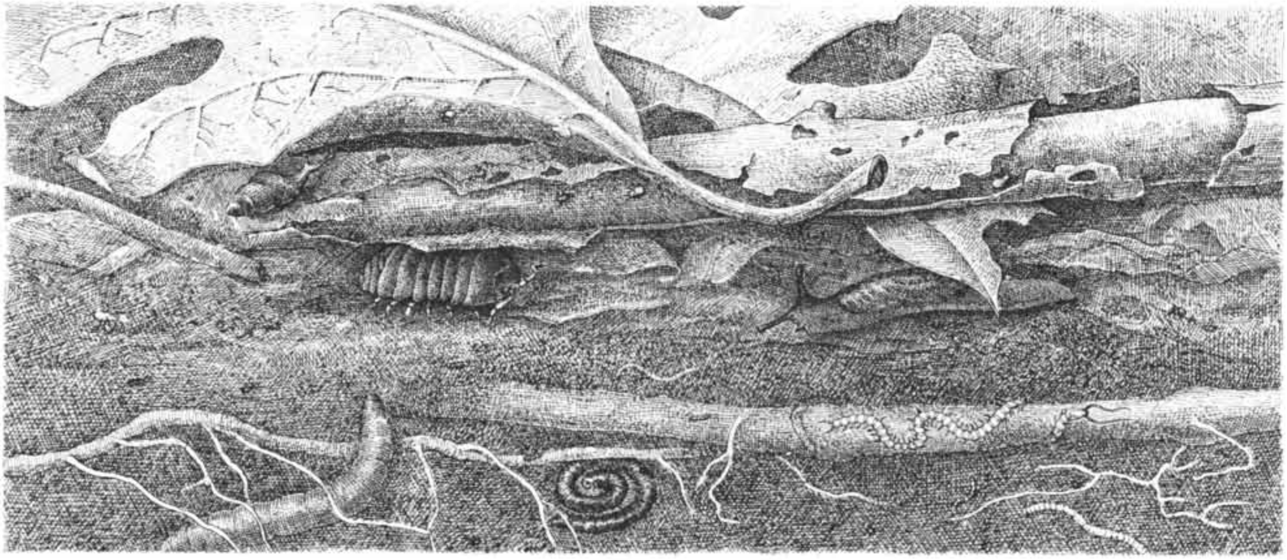
A little rumination on these population densities leads to a balanced view of the animal population of the world. Estimates are often made of the numbers of various interesting animals the world contains—animals such as elephants, ostriches, giraffes and gorillas—and the figures that are given generally run from some tens of thousands to hundreds of thousands. Comparing such estimates with the totals of the various cryptozoa in one's own garden leads to the conclusion that most of the animals in the world are securely hidden in obscurity.

This planet is undoubtedly and overwhelmingly adapted to the support, protection and survival of its cryptozoa.

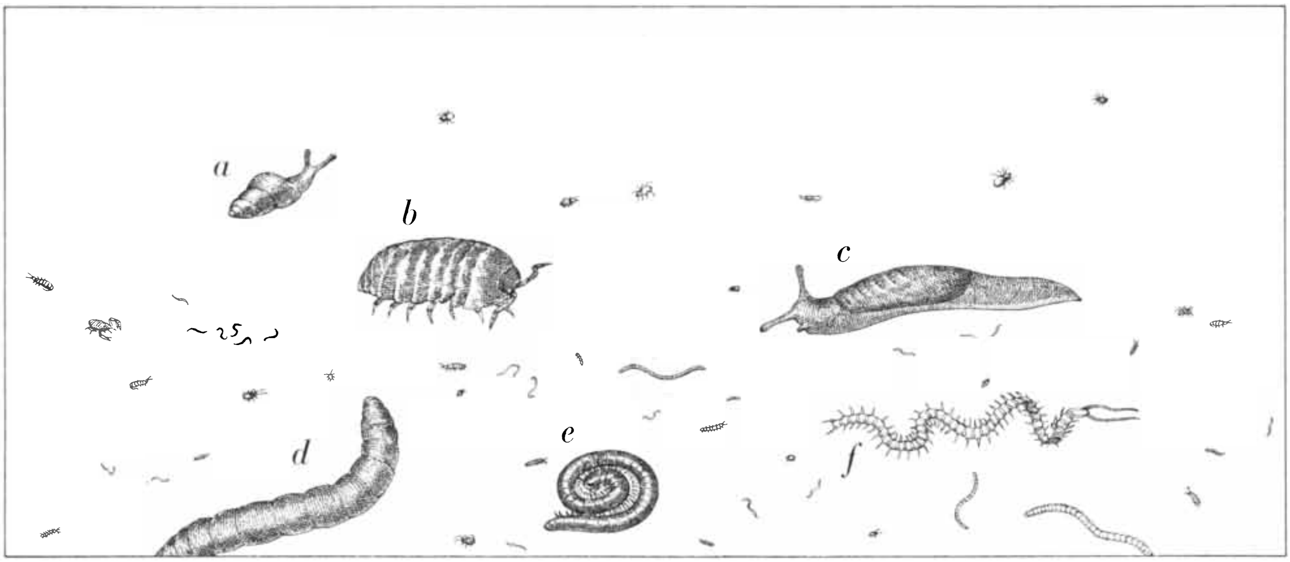
Secondly, as to diversity. The class or order to which each specimen on the collecting sheet belongs may not always be obvious, but almost every naturalist will at once perceive the dominance of the phylum Arthropoda (which includes the arachnids, the crustaceans and the many-legged "myriapods," as well as the insects) and the presence of a few representatives of other groups.

R. F. Lawrence of the Natal Museum in Pietermaritzburg, who has studied the cryptozoic fauna of South Africa, emphasizes the surprising fact that (excluding the Protozoa) only five phyla are represented: these are, in addition to the Arthropoda, the Platyhelminthes, Nematoda, Annelida and Mollusca. More interesting than this are the proportions in which they are found. The worms (flatworms, roundworms and earthworms: Platyhelminthes, Nematoda and Annelida respectively) do not exceed 3 percent of the total. The snails (Mollusca) and woodlice (Crustacea) account for about 4 percent each. Of the remaining nine-tenths about half are Arachnida, a third are Insecta and the rest are myriapods of different kinds. Evidently the cryptosphere is predominantly the domain of the Arachnida.

To these generalizations let us add some analysis of the chief classes of the five phyla that are represented. Most of the insects are wingless and accordingly belong to the subclass Apterygota, the present-day representatives of the first insects that came into existence. In



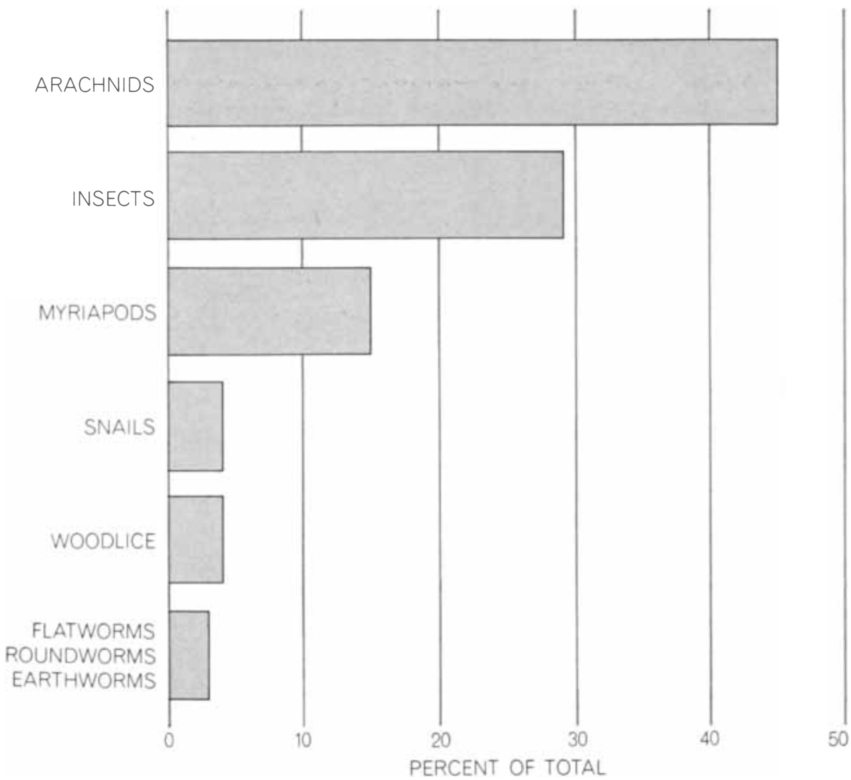
THE CRYPTOSPHERE, a distinct ecological region where diverse invertebrate animals dwell in seclusion, extends a few inches above and below the surface of the ground. Depicted here is a typical section of the cryptosphere in a wooded area in the Temperate Zone. The relative proportions of the various fauna in such an area are not indicated; the fauna are shown about twice actual size.



INHABITANTS OF THE CRYPTOSPHERE appear apart from their natural environment. Often found in woodland debris and just below the ground surface are the land snail (*a*), the woodlouse (*b*), also known as sow bug and pill bug, and the slug (*c*). Usually inhabiting lower levels of the cryptosphere are the earthworm (*d*), the millipede (*e*) and the centipede (*f*). The smallest cryptozoic animals (not labeled in the drawing) include mites, roundworms, false scorpions and wingless insects, such as the springtail.

PHYLUM	CLASS	ORDER
ARTHROPODA	ARACHNIDA	ACARI (MITES AND TICKS)
		ARANEIDA (SPIDERS)
		PALPIGRADI
		PSEUDOSCORPIONES (FALSE SCORPIONS)
		RICINULEI
		SCHIZOMIDA
	CRUSTACEA	ISOPODA (WOODLICE)
	INSECTA SUBCLASS: APTERYGOTA (WINGLESS)	COLLEMBOLA (SPRINGTAILS)
		DIPLURA
		PROTURA
		THYSANURA (BRISTLETAILS)
	MYRIAPODA: CHILOPODA (CENTIPEDES) DIPLOPODA (MILLIPEDES)	
	PAUROPODA	
	SYMPHYLA	

PRIMITIVE ORDERS predominate among the arthropods of the cryptosphere. For example, arachnids of the orders Palpigradi, Pseudoscorpiones (false scorpions) and Schizomida have a fully segmented abdomen. This is a characteristic of primitive arthropods.



DISTRIBUTION OF THE CRYPTOZOA is based on the studies in South Africa of R. F. Lawrence of the Natal Museum in Pietermaritzburg. The dominant phylum is clearly the Arthropoda, the Arachnida accounting for approximately half of the total number of species.

other words, the cryptosphere houses the primitive orders rather than the specialized forms with wings and no distaste for daylight.

Among the myriapods there is a large proportion of the simpler centipedes and millipedes, but one's attention is distracted from such familiar creatures by the knowledge that certain others may be present. Here, and here only, are to be found the two rather unfamiliar classes: Symphyla and Pauropoda. A few lines on each will be justified, to underline the lesson they teach.

A symphylid has 12 pairs of legs and looks like a tiny centipede; like a centipede, it has a pair of long antennae. Since their discovery in 1762 they have been found all over the world wherever the minimum temperature is above 15 degrees Fahrenheit. These myriapods are generously supplied with four pairs of mouthparts and, on their last segment, a pair of spinning tubules. They are vegetarians and surprisingly are often inclined to feed on the surface of the ground, even in strong sunshine.

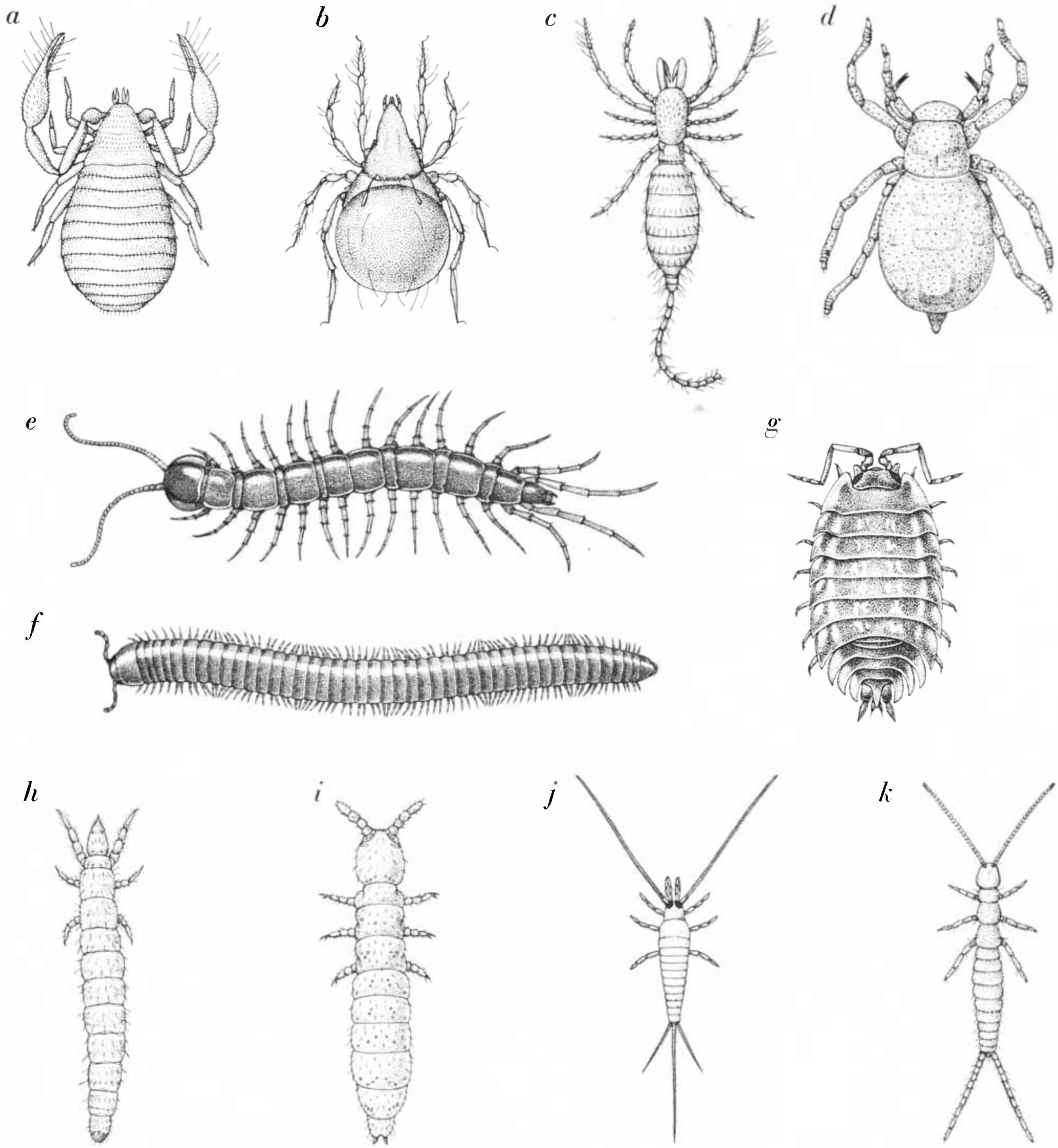
The Pauropoda are not so well known, perhaps because there are only two million to the acre, less than one-tenth of the number of the Symphyla. Also vegetarians, they resemble millipedes, having the sex orifice on the third segment of the body. They have nine pairs of legs and their antennae fork at the tip.

It is difficult to resist the temptation to see in the Symphyla the representatives of the ancestors of the centipedes and in the Pauropoda the representatives of the ancestors of the millipedes. Whether this is wishful thinking or not, these two small classes direct us to the fundamental characteristic that unites such a large proportion of the cryptozoa, namely their primitive nature.

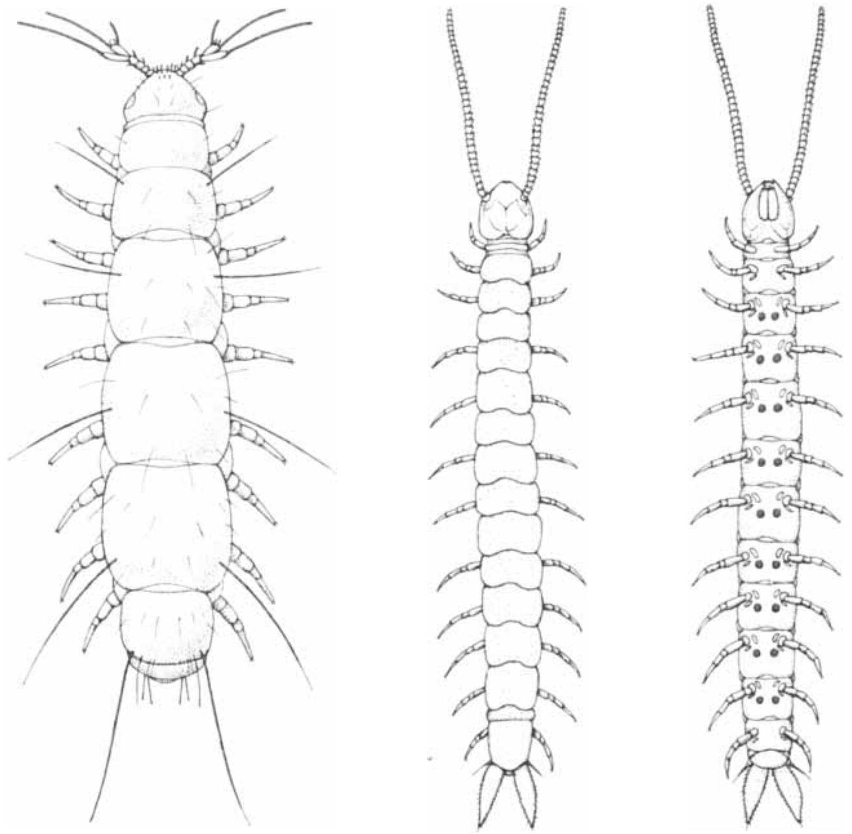
For instance, the class of Arachnida is chiefly represented by mites of the family Oribatidae and, among other orders, by the Pseudoscorpiones, Palpigradi and Schizomida. The false scorpions, which look like tiny tailless scorpions, are the most familiar of these. The fully segmented abdomen is the most obvious evidence of their primitive organization [see "False Scorpions," by Theodore H. Savory; SCIENTIFIC AMERICAN, March, 1966]. In the Palpigradi and Schizomida segmentation also survives in the cephalothorax (the joined head and thorax that constitutes the forward portion of the body). There the carapace is divided into three parts; the abdomen has 11 visible segments in the Palpigradi and 12 in the Schizomida. The bodies of all these cryptozoa, whether they are insects, myriapods or arachnids, are indisputably of the type known as primitive.

Thirdly, as to size. Manifestly one cannot expect the animals of the cryptosphere to be other than small. And, in fact, Lawrence finds that 95 percent of the cryptozoa are less than half an inch long and that some 30 percent are less than a millimeter long.

The small size of all cryptozoic animals is virtually the governing factor in their behavior and their general biology. In the first place a thin, partially sclerotized exoskeleton (a partially hard outer cuticle) usually serves to protect their small bodies, affording them sufficient support without undue increase in weight. These animals thereby avoid one of the first problems that confront larger



THE CRYPTOZOA depicted here are grouped by taxonomic class. The arachnids are represented by the false scorpion *Chelifer* (*a*), the mite *Belba* of the family Oribatidae (*b*), the palpigrade *Koenenia* (*c*) and *Ricinoides* (*d*) of the order Ricinulei. Below them appear the centipede *Lithobius* (*e*) and the millipede *Arctobolus* (*f*). The woodlouse *Oniscus* (*g*) is a crustacean. At bottom are representatives of the four orders of wingless insects: *Acerentomon* (*h*) of the Protura; *Achorutes* (*i*) of the Collembola, or springtails; *Petrobius* (*j*) of the Thysanura, or bristletails, and *Campodea* (*k*) of the Diplura. The organisms are not drawn to actual scale.



EARLY FORM of the millipede and centipede may be preserved in the pauropod (*left*) and the symphylid (*center*). In the ventral view of the symphylid (*right*) the eversible sacs (*color*) can be seen. The sacs' function is unknown; they distinguish many cryptozoic animals.

seldom to be seen abroad by daylight, but people who have the enthusiasm to search for slugs after sunset find them in incredible numbers. The searchers maintain emphatically that a windy night, more than anything else, keeps the slug community at home.

Here, then, is the simplest way in which animals that are sensitive to desiccation have come to avoid its effects: they have perforce assumed a habit of life in which conditions or circumstances favoring water loss are shunned. Since the heat and the light of the sun are inseparable, most members of the cryptozoa have acquired a rhythmic mode of living; they limit their activities to the hours after sunset, thereby acquiring the superficial description "animals of nocturnal habits."

The changes that follow the setting of the sun are obviously important to the cryptozoa. The larger predators (such as birds) are more easily avoided in the dark; on the other hand, the predatory cryptozoa find their own tiny prey easier to secure in the busy after-dark traffic. The fall in temperature brings about a rise in the relative humidity and as a result a decreased evaporating power of the atmosphere. Here are ideal conditions for the ordinary activities of the ill-protected bodies of the cryptozoa.

Ulterior consequences are well known. Rhythmic behavior, which originated as a direct response to change in physical conditions, eventually becomes ingrained, or, as it is called, endogenous. Endogenous rhythms are found to persist when these animals are kept in artificially constant surroundings. Even without complex laboratory equipment an example can be seen in the nightly web-spinning of many spiders, which are, in fact, less subject to the risk of desiccation than other cryptozoa.

An alternative and very different method of water conservation is possible. This is the production of a layer of wax in the epicuticle, or outermost layer of the exoskeleton, where it acts like a raincoat in reverse, serving to keep water not out but in. A wax layer is found on many flies and spiders, which, because of its presence, are able to live in the open and often show no great tendency to avoid the sunshine. Other members of the cryptozoic population are not so lucky; they show a limited tolerance to unfavorable conditions, indicating a less efficient protection. They can perhaps charitably be described as "potentially diurnal."

By means of these adaptations the small animals of the cryptosphere avoid

land animals, many of which, arriving on dry land from an aquatic ancestry, encounter a set of problems in vital mechanics when they are no longer surrounded and supported by water.

The thin cuticle is also permeable to gases; it allows the diffusion of oxygen directly into the body tissues and the escape of carbon dioxide in the same way. Thus in many cryptozoa respiratory organs are either absent or simple and rather ineffective; for this reason the animals have little or no control over the rate of respiration in response to changes in external circumstances. But since the chief characteristic of the cryptosphere is the constancy of its physical conditions, its inhabitants can be said to be slightly restricted by their inefficient respiration rather than seriously handicapped.

The loss of carbon dioxide through the cuticle, however, argues a simultaneous escape of water vapor, a much more important matter. The area of surface per unit of volume is greater for a smaller animal than it is for a larger one, and this in turn bears on the problems of the loss of heat by radiation and the loss of water by evaporation. It is scarcely an exaggeration to say that these problems are governing considerations in the lives and in the evolution of every group in the cryptozoic fauna.

The loss of water is at once the simplest and the commonest way in which the internal conditions of the body are upset. The different aqueous solutions contained within a body must of necessity remain in osmotic balance. The preservation of this state of equilibrium, homeostasis, is secured by various devices or organs described as osmoregulatory. These embrace a wide range of mechanisms: simple contractile vacuoles, or cavities, in amoeba; somewhat more complex "flame" cells (named for their beating cilia) and solenocytes in flatworms; nephridia in annelids and, finally, kidneys in vertebrates.

For invertebrate animals excessive loss of water is nearly always fatal, and this unwelcome desiccation is hastened by exposure to wind, by remaining in the direct rays of the sun and by an increased metabolic rate within the animal itself. Wind is rare in the region we have called the cryptosphere. Among the cryptozoa few are more vulnerable to wind exposure than slugs. They are the direct action of the sun's rays. Let us compare their situation to that of birds and mammals, creatures that are normally several degrees warmer than the air surrounding them. They are constantly losing heat, but through various devices, such as fur, feathers, blubber or fat, they tend to prevent or control it. This is harder for the small mammal or bird with its relatively large surface; every student of physiology is told that a ton of mice eat 10 times as much food as a ton of horses. But for the cryptozoa the case is reversed: their need is to keep heat out because a rise in temperature hastens evaporation. It also produces an expansion of the liquid contents of the body, causing pressure against the exoskeleton and a possible occlusion of the blood vessels or other conduits. Thus it is that many of these creatures die quickly if they are forced to remain in the sun.

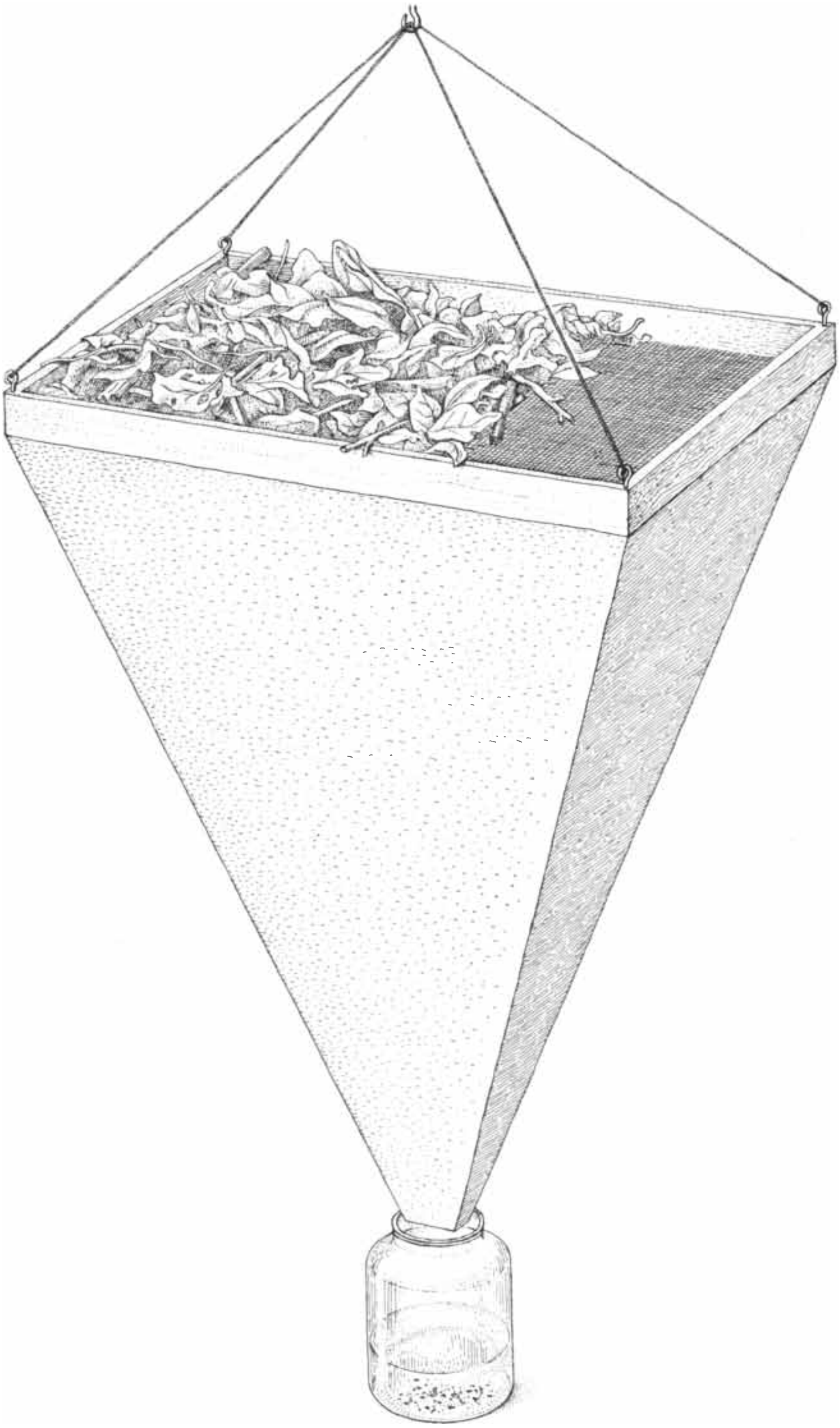
There is another source of heat that inevitably promotes the loss of water: the production of heat internally by sustained activity. The muscular actions needed to escape from any source of danger are clearly limited at least in part by the size of the running creature. Hence a large spider compelled to run by gentle prodding is exhausted sooner than a small spider, whose greater ratio of surface to volume enables it to cool more quickly.

Evidently the conditions under which the cryptozoa live are in their way as definite and as exacting as the apparently more rigorous conditions of the littoral zone, the arctic or the desert. Is there perhaps a general cryptozoic pattern or form—a consequence of the factors described above—by which a zoologist could say with confidence, "This is one of the cryptozoa"?

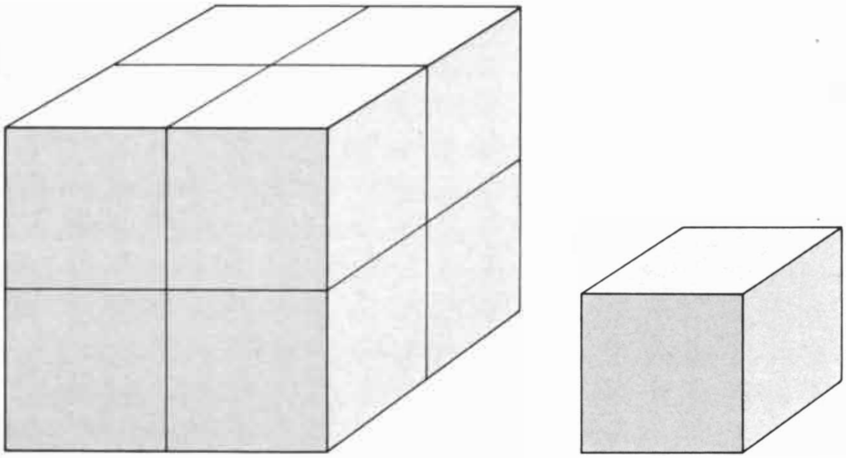
The answer to this question is more suggestive than definitive. A cryptozoan is an animal that is not more than five millimeters long, is fully segmented, weakly sclerotized, devoid of color or pattern, with small eyes or none but with sensitively tactile antennae, and with no conspicuous respiratory organs. Such an animal possesses all the characteristics that are most widely distributed among the cryptozoa.

In addition to these distinguishing marks I should mention the remarkable and mysterious organs usually vaguely termed "eversible sacs." They are found below certain segments of the body or legs in Symphyla, Palpigradi, wingless insects and some other groups. Their function is uncertain but if any one organ can be said to indicate a cryptozoic life, this is probably it.

By these steps we are led to another conclusion. The cryptozoa not only include the greater number of the world's animals, they also preserve for us the form in which life on land, as distinct from life in water, made its first appearance. Early marine arthropods must have crept ashore from seas that were overcrowded and were becoming intolerable. They must luckily have found it possible to feed on the plants they met, and undoubtedly they must have survived only if they constantly hid themselves from the scorching sun. Today



BERLESE FUNNEL, named after its inventor, the naturalist Antonio Berlese, separates fauna from a sample of organic debris. Heaped on wire mesh fitted across the funnel, the debris gradually dries out; the cryptozoic fauna in the debris, seeking dark, moist conditions, move downward; ultimately they fall into the bottle of killing liquid below the funnel.



SURFACE AREA per unit of volume is greater for the smaller entity than for the larger one. Thus the small animals of the cryptosphere are particularly vulnerable to the loss of water by evaporation. To avoid desiccation they have been forced to develop nocturnal habits.

their descendants occupy the same stable environment; they have been described as prisoners in a cul-de-sac, unable to evolve in their conditions of protective security.

On this opinion two comments may be made. The first is that the optimum conditions of the cryptosphere are not likely to have urged its inhabitants to seek a change; hence the primitive groups are still represented among them. Not every order of insects or arachnids can, however, be traced back to cryptozoic ancestors; therefore one must suppose that on occasion there appeared mutants that found an open-air life tolerable. One imagines that such must be called, in contrast, the phanerozoa—the animals open to view.

Second, some of the present-day cryptozoa show definite specializations that can best be regarded as modifications of or additions to the primitive forms, but which have neither enabled them nor driven them to seek the world above. The false scorpions, for example, are an order of the Arachnida, with the fully segmented abdomen that is a sign of a primitive arthropod. They have evolved silk-secreting glands in the small organs near the mouth known as the chelicerae; their pedipalps, or pincers, have grown into large and formidable weapons; their life history is unusually complex. But essentially they remain hidden. The same is true of the much rarer arachnid Ricinulei, one of whose secondary characteristics is the great thickness of the exoskeleton, another the elaboration of male organs on the tips of the third pair of legs.

The Symphyla too show signs of specialization: they have developed spinning organs on the last segment and have also acquired an unusual escape reaction that enables them to reverse direction rapidly by rotating their bodies with the last segment as a pivot. Is it more than a coincidence that false scorpions are also addicted to suddenly rushing backward?

Clearly the cryptozoa can be described as a self-sufficient society, on the whole decidedly primitive in form, that continues to exploit successfully the favorable circumstances in which it has established itself. What is true of myriapods and arachnids may also be true of other groups. There are phyla and classes in the animal kingdom in which the course of evolution is not easy to detect. The progress from a primitive to a specialized type is obscure, often made more conjectural by uncertainty as to the start. All species of animals alive today have their own specializations accrued during past centuries; it has been wisely said that there are now no primitive organisms but only some primitive organs. Therefore when the question arises, "What is the nearest living representative of the primitive arachnid, of the primitive insect, of the primitive myriapod?" a helpful suggestion can be offered. These genera should be sought in the cryptosphere; if they have left recognizable descendants, they are likely to be found among the cryptozoa.

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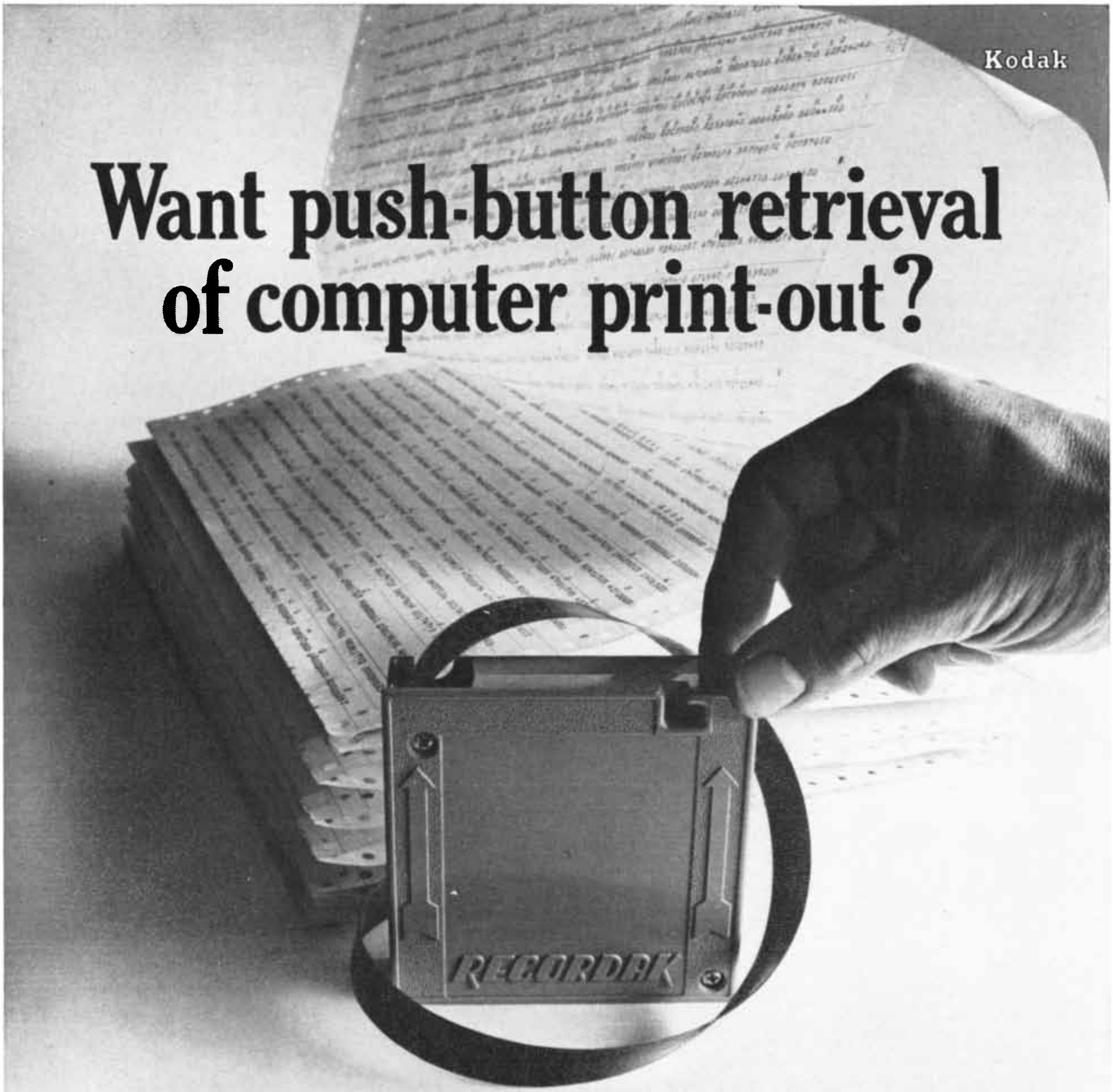

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MATHEMATICAL GAMES

On the meaning of randomness and some ways of achieving it

by Martin Gardner

A book called *A Million Random Digits with 100,000 Normal Deviates* was prepared by the Rand Corporation and published in 1955 by the Free Press, now a division of Macmillan. A specimen page consists of nothing but repetitions of the 10 digits, 0 through 9. They are printed on the page in very orderly fashion, in groups of five, but the *sequence* of digits is as disheveled as Rand mathematicians could make it.

"The production of such a book is entirely of the twentieth century," writes physicist Alfred M. Bork in an article titled "Randomness and the Twentieth Century" that appeared in *The Antioch Review*, Spring, 1967. "It could not have been produced in any other era. I do not mean to stress that the mechanism for doing it was not available, although that is also true. What is of more interest is that before the twentieth century no one would even have thought of the *possibility* of producing a book like this; no one would have seen any use for it. A rational nineteenth-century man would have thought it the height of folly...."

It is Bork's thesis that preoccupation with randomness has permeated 20th-century culture. This preoccupation has several 19th-century scientific sources—chiefly thermodynamics, in which entropy is a measure of disorder, and the theory of evolution, in which natural selection imposes orderly development on random mutations. Early in this century randomness became the bedrock of quantum mechanics, an irreducible chance element in the microstructure of the world. Eventually it may turn out that behind this apparent haphazardry there are nonrandom laws (as Einstein believed; he found displeasing the notion, as he once expressed it, of God's playing dice), but at present no one knows what those laws are and, if they *are* ever found, quantum theory will have to be replaced by a radically different theory. Bork sees an influence of these scientific ideas on the random art of abstract expressionism, in the random music of such composers as John Cage, in the random wordplay of such books as *Finnegans Wake* and in William Burroughs' technique of cutting up the pages of a novel, shuffling the pieces and then printing them in a random order.

Perhaps, too, some artists find in haphazardry a relief from the excessive orderliness of modern technology. Lord Dunsany has a beautiful description (in his *Tales of Three Hemispheres*) of a visit to New York City during which he becomes oppressed by the monotonous right-angled regularity of the city's streets and the dull orthogonal arrangements of the windows of its tall buildings. Slowly dusk comes and those windows begin to glow in irregular patterns. "Surely if modern man with his clever schemes held any sway here still he would have turned one switch and lit them all together; but we are back with the older man of whom far songs tell, he whose spirit is kin to strange romances and mountains. One by one the windows shine from the precipices; some twinkle, some are dark; man's orderly schemes have gone, and we are amongst vast heights lit by inscrutable beacons.... Here in New York a poet met a welcome."

A random pattern of lighted windows is a geometric counterpart to a sequence of random digits. What exactly is such a sequence? It is curiously hard to say. One ordinarily calls a finite series of digits random if, given all but one digit in the series, there is no rule by which the missing digit can be guessed with a probability of better than 1/10. But this is a subjective definition, based on one's ignorance of possible underlying patterns. Is there any objective, mathematical way to define a completely random series? Apparently there is not. The best one can do is to specify certain tests for types of randomness and call a series random to the degree that it passes them. For example, one can insist that a series meet the following formal criteria: each digit, or "atomic unit," appears with a frequency of 1/10, each permutation of digits taken two at a time appears, among all couplets in the series, with a frequency of 1/100, each permutation of digits three at a time appears with a frequency of 1/1,000, and so on for all higher "molecular units." The couplets, triplets, quartets and so forth are not confined to adjacent digits. A test for the randomness of, say, triplets could pick three digits separated by any specified intervals.

An infinite decimal fraction between 0 and 1 that satisfies such a test (of course in practice there can only be minute partial testing; a complete test would require an infinite time) is said to be a "normal number." Clearly the decimal expression for any rational fraction is not normal; it endlessly repeats a sequence, such as 1/3, which keeps repeating 3, or 1/97, which repeats a sequence of 96 digits. But the decimal expressions of irrational numbers such as the square root of 2, and such famous transcendental irrationals as pi and *e*, are believed to be "normal." (A transcendental number is an irrational number that is not the root of an algebraic equation but must be expressed as the limit of an infinite converging series.) At least they have so far passed all tests for normality.

It has been proved that among the infinite number of decimal expressions for the real fractions between 0 and 1 infinitely more are normal than not. Pick a real number at random and the probability is zero (here *probability* is used in a special sense) that you will pick one that is not normal. Can we say that the sequence of digits in a normal decimal fraction is random? Sometimes. Put a decimal point in front of the first of Rand's one million random digits and you have the beginning of an infinite number of normal decimal fractions. On the other hand, the decimal expression of pi, calculated in 1961 to 100,265 places, has satisfied all tests for normality and yet cannot be called a random sequence because it can be constructed as the limit of simple formulas. Every next digit in pi is predictable with certainty. Because it is pi, therefore, it is highly ordered, although aside from being pi it seems to have no discernible regularities.

It may surprise some readers to know that it is easy to construct infinite decimal fractions that are irrational but have obvious patterns. A simple example using only 0 and 1 is

$$.101001000100001000001\ldots,$$

in which the first 1 is followed by one 0,

A random pattern of lighted windows in a photograph made by Andreas Feininger

07600	88293	45401	12350	19040	81561	01155	85253	49479	66144	36486
07601	74400	78899	06127	24365	88646	03944	87215	27085	16372	53548
07602	87891	01263	68595	82315	46193	33306	66011	32972	92802	15708
07603	03275	22982	83272	43570	29817	17323	45466	20498	08228	69682
07604	95126	94417	09943	03316	64978	79651	97371	17634	62956	17714
07605	40601	87085	51394	58140	80641	11547	57397	79825	62665	78796
07606	78981	34943	92315	98737	85007	17558	77808	03537	46872	63504
07607	54784	95754	48786	94402	62005	16589	08267	61878	69562	52089
07608	24596	32468	84259	39563	77353	36180	34350	53331	18863	25424
07609	45777	74383	58012	32923	44106	52121	30948	98812	39109	30748
07610	94305	58672	25440	61911	16594	96747	73515	02587	72237	03004
07611	74423	24195	01270	62733	08841	92999	82907	48049	05309	81854
07612	87243	87076	04321	45628	31593	19783	24674	39222	37639	97573
07613	95279	96674	37550	92395	17821	47986	56822	50499	37384	59050
07614	10669	10427	09299	84045	39184	37102	94060	37288	30669	51740
07615	13983	63696	08604	96115	34877	93673	16767	37258	32137	88081
07616	25520	13548	78676	39472	41957	58478	45877	84216	79001	11734
07617	81754	89975	07744	82864	63632	81103	66748	28539	81244	71407
07618	99249	06587	10989	74629	17264	09220	16293	21958	99275	33075
07619	25692	49122	53820	61407	66479	50095	43462	66380	52481	17731
07620	71062	25537	03787	00508	70346	72869	66697	66426	92430	03241
07621	98835	64436	73086	73216	37983	82543	88681	78385	26327	23654
07622	31631	10493	96276	59088	17480	13347	60948	92191	33074	18170
07623	48222	82827	64181	51377	39636	28938	83204	89441	06125	58756
07624	97700	56405	25858	42033	11729	91962	62762	16535	61465	59891
07625	02050	26216	39216	73287	56887	26522	20127	64522	58368	00710
07626	75973	65876	36777	52742	08272	03969	14125	68998	93575	95479
07627	01373	65250	08317	65902	05034	12660	92903	11015	52893	11155
07628	83866	83199	85406	39590	17954	62519	87775	56581	74495	67094
07629	12597	05140	36748	15697	43206	03194	47216	45552	19465	09413
07630	33387	64696	72102	44081	67644	91011	54737	95279	96971	81654
07631	76084	35282	10085	53580	28924	87971	56631	72301	11510	75086
07632	73769	66032	11119	88801	30169	73856	09346	25188	54381	24477
07633	04307	32351	86338	86420	10259	55707	52711	02482	41349	78143
07634	29933	72064	94327	94859	18890	84470	58420	55774	74052	88976
07635	83787	23267	80357	20523	58215	19706	45552	81944	90820	48073
07636	00437	77777	57832	01058	25654	59456	36924	17398	72197	19795
07637	87816	27435	01573	42907	98043	21332	21732	42079	91177	01928
07638	82756	67233	82534	40832	48525	53269	26225	89933	32494	84807
07639	70426	94290	17064	68483	64842	47695	13623	55646	29305	51719
07640	42711	61143	40516	12203	14367	95095	44703	64297	13381	40965
07641	76510	88343	65246	28697	10606	83368	24310	90199	84181	33045
07642	57261	17829	07486	29959	71893	99581	39680	13235	11465	41203
07643	99713	22576	71336	09523	09491	18354	69516	29568	16788	95639
07644	51808	19367	76265	97323	96197	72764	60674	51051	76627	51398
07645	00180	75937	95135	68397	27720	23011	58415	18328	39360	64450
07646	24387	70467	99776	54982	87625	30810	34591	20667	09254	04537
07647	44516	44771	71969	11540	51710	40042	19607	72235	29191	98230
07648	23436	83139	43405	03055	14175	05963	91920	06619	99717	46565
07649	30311	13461	76003	22280	12694	95205	12666	86677	85569	76320

A page from the Rand Corporation's book of random numbers (lines of table are numbered at left) the second 1 by two 0's, the third by three 0's and so on. Since there is no repeating sequence the number is irrational. This is one of innumerable ways that irrational numbers with simple regularities can be written.

Many patterned numbers of this type can even be proved to be transcendental. Indeed, the first proof that transcendental numbers existed was given by a 19th-century French mathematician, Joseph Liouville, who found an infinite set of such numbers—now called Liouville numbers—that he proved to be transcendental. An interesting example of a number that has been proved both normal and transcendental, yet is so simply patterned that a child can write it, is obtained merely by putting down the counting numbers in order:

.12345678910111213141516171819....

Most mathematicians now agree that an absolutely disordered series of digits is a logically contradictory concept. A series can no more be patternless than an arrangement of stars in the sky can be. The reason in both cases is that as a series of digits or an arrangement of points comes closer and closer to satisfying all tests for randomness it begins to exhibit a very rare and unusual type of statistical regularity that in some cases even permits the prediction of missing portions. To take a simple instance, suppose you are asked to fill 10 spaces in a row with digits and do it in a completely disordered way. If you duplicate one or more digits, the series will be ordered in the sense that it shows a bias toward those digits. On the other hand, if it is completely free from *that* kind of bias, it will contain each of the 10 digits. Such a series will satisfy absolutely the criterion that there be no bias for any one digit, but for this a price has been paid: the series is now so strongly "patterned" that, given any nine digits, the missing digit can be guessed with a probability of 1. Similar contradictions turn up in connection with any random series. If it gets too random, a "pattern of disorder," so to speak, appears.

We thus face a curious paradox. The closer we get to an absolutely patternless series, the closer we get to a type of pattern so rare that if we came on such a series we would suspect it had been carefully constructed by a mathematician rather than produced by a random procedure. We can speak of a series of digits as being disorderly only in a relative sense, that is, disordered with respect to tests of certain kinds but not to tests of other kinds. The whole matter is spattered with profound difficulties. G. Spencer Brown, in his book *Probability and Scientific Inference* (1957), pointed out some of these paradoxes and showed how easily one could take printed tables of random numbers and find various kinds of order if one looked hard enough. Many of the published results of extrasensory-perception testing, Brown argued convincingly, are examples of patterns that are inevitable in any long series of random results. When such patterns fail to turn up, ESP proponents are unlikely to publish the results, not having found evidence for ESP; when they do find such patterns, they publish. Perhaps if the total picture could be surveyed, the published patterns would be less surprising.

As a puzzle interlude at this point (the answer will appear next month) the reader is invited to study the following apparently patternless arrangement of the 10 digits:

7480631952.

By what rule are those digits ordered? Hint: The arrangement is cyclic. Think of the head and tail of the sequence as being joined to make a circle.

It is possible, of course, that such a sequence, or any other strongly ordered sequence of 10 digits, might accidentally turn up somewhere in Rand's one million digits. If a series of random digits is long enough, such surprising patterns are certain to be found in it. Some philosophers have argued that the universe is like this: an accidental segment of order in a vast, infinite sea of chaos. Jorge Luis Borges, the Argentine writer, has given this a classic metaphorical expression in his famous short story "The Library of Babel." Existence is a nonsense collection of all possible combinations of whatever the basic micro building blocks are. The little spot of accidental order that is our universe is like the sequence 123456789 in an infinite series of random digits.

At this point an ancient philosophical controversy arises. Why is a pattern such as 123456789 in a table of random digits "surprising"? It is neither more nor less probable than any other permutation of nine digits. Certain pragmatists and subjectivists have argued that the concept of "pattern" in any arrangement of parts cannot be defined except with reference to human experience. The only reason we say the first one million decimals of pi are ordered and the Rand digits are not is that pi is a useful constant for man.

"Order and disorder," wrote William James in his *Varieties of Religious Experience* (he later changed his mind), "are purely human inventions.... If I should throw down a thousand beans at random upon a table, I could doubtless, by eliminating a sufficient number of them, leave the rest in almost any geometrical pattern you might propose to me, and you might then say that that pattern was the thing prefigured beforehand, and that the other beans were mere irrelevance and packing material. Our dealings with Nature are just like this. She is a vast *plenum* in which our attention draws capricious lines in innumerable directions. We count and name whatever lies upon the special lines we trace, whilst the other things and the untraced lines are neither named nor counted."

To this argument the realist replies that it is just the other way around. Instead of our brain's imposing its patterns on nature, the brain is at birth merely an intricate net of random connections. It acquires its ability to "see" patterns only after years of experience during which the patterned external world imposes its order on the brain's *tabula rasa*. It is true, of course, that one is surprised by a sequence of 123456789 in a series of random digits because such a sequence is defined by human mathematicians and used in counting, but there is a sense in which such sequences correspond to the structure of the outside world. Starting at a given point of time in the distant past, before life existed on the earth, the moon circled the earth once, then twice, then three times and so on, even though no human observers were there to count. At any rate, ordinary language as well as the language of science enables one to make such statements, and my own view is that only confusion results when one tries to adopt a language in which one cannot speak of the universe as patterned apart from human observation.

All of this, however, is a bit out of place in a column on recreational mathematics. Let us get back to a less metaphysical question. How are tables of random digits produced? It is no good just scribbling digits on paper as fast as they pop into your head; humans are incapable of producing them at random. Too many unconscious biases creep into such a series. You might suppose you could take a table of, say, logarithms or the populations of American cities in alphabetical order, and copy down the first digits of those numbers. But it was discovered about 20 years ago that the

Random patterns in a detail from Jackson Pollock's oil "Free Form. 1946"

first digits of *any* table of random numbers show a marked bias: the lower the digit, the higher its frequency in the table! Warren Weaver has an excellent exposition of this astonishing fact in his 1963 paperback *Lady Luck: The Theory of Probability*, pages 270–277.

The best way to get a series of random digits is by using a physical process involving so many variables that the next digit can never be predicted with a probability higher than $1/n$, where n is the base of the number system used. Flipping a penny generates a random series of binary digits. A perfect die randomizes six symbols. A 10-position spinner will randomize the 10 digits. A regular dodecahedron is an excellent randomizer for the 12 digits of a base-12 number system. One can even get down to the chance level of quantum mechanics and base a randomizer on the timing of the clicks of a Geiger counter as it records radioactive decay.

There are many other ways. In 1927 L. H. C. Tippett published 41,600 random numbers by taking the middle digits of the areas of parishes in England. In 1939 a table of 100,000 random digits was produced by M. G. Kendall and B. Babington Smith. They used a roulette wheel with a rim marked off into 10 parts. While the wheel spun rapidly they illuminated it by hand with flashes of light and recorded the digit at a certain spot. In 1949 the U.S. Interstate Commerce Commission extracted 105,000 random digits from freight waybills. Rand's one million digits were obtained by electronic-pulse methods that produced random binary digits, which were then converted into decimal digits. To remove slight biases found by intensive testing, the one million digits were further randomized by adding all pairs and retaining only the last digit.

When a computer needs random numbers for solving a problem, it is usually best to let the machine generate its own series rather than take up valuable memory storage space by feeding it a published table. There are hundreds of ways in which computers can generate what are called "pseudo-random" digits. It will not do, of course, to let the machine calculate an irrational number such as pi or the square root of 3 because such a number may be involved somehow in the problem to be solved. An early procedure, proposed by John von Neumann, was the "middle of the square" method. The computer starts with a number of n digits, squares it, takes the middle n digits of the result, squares that, takes the n middle digits again, and in this way continues to generate groups of n digits. This method is no longer used because it was found to introduce too many biases. Birger Jansson, in his book *Random Number Generators* (1966), calls attention to some amusing anomalies that turned up. If you start with the number 3792 and square it, you get 14379264, so that your "random" series proves to be 3792 3792 3792 .... The same thing happens if you start with such six-digit numbers as 495475 and 971582. Modern techniques for generating pseudo-random numbers are much more sophisticated and fantastically rapid, and they vary from one computer center to another.

A final word about the increasingly important uses for random numbers. They are indispensable in the designing of experiments in agriculture, medicine and other fields where certain variables must be randomized to eliminate bias. They are used in game and conflict situations in which the best play is obtained by a random mixing of strategies. Above all they are essential to the Monte Carlo method for solving a variety of difficult problems involving complex physical processes [see "The Monte Carlo Method," by Daniel D. McCracken; SCIENTIFIC AMERICAN, May, 1955].

The answer to the first of last month's combinatorial card problems is that the set of 25 cards cannot be arranged to make five poker hands each of which is a straight or better. The key to the proof is the four of hearts. There is no three or five in the set, so that the four of hearts cannot be part of a straight. There are only three other heart cards, so that it cannot be part of a flush. It is the only four, so that it cannot be part of a full house. Finally, there is no set of four cards of like value, and so the four of hearts cannot be the fifth card accompanying four of a kind.

The second problem was to prove that, starting with a row of four face-down cards, you cannot turn up one card at a time and run through all 16 possible permutations of face-up and face-down cards, ending with four face-up cards. The proof uses a simple parity check. Each time a card is turned, it changes the parity of the face-up cards from odd to even or vice versa. At the start the parity of face-up cards is even (zero is an even number), therefore the 16th and last permutation must be odd. The problem specified, however, that the final permutation must be four face-up cards, an even number; consequently the problem is unsolvable.

The third problem was to solve C. L. Baker's order-2 solitaire game with the initial layout shown last month. Here is a 54-move solution. (Each time a card changes position it counts as a move.) I shall report later if any reader solves it in fewer moves.

1. K to *T* cell.
2. J, 10, 9, 8, 7 on Q of hearts.
3. A, 2, 3, 4, 5 to *P* cell.
4. J, 10, 9, 8 on Q of spades.
5. 4, 3, 2 on the 5 of spades.
6. 7, 8, 9 (all hearts) start new *B* columns.
7. 8, 7 on 9 of hearts.
8. 10 to empty *T* cell.
9. J and Q start new *B* columns.
10. 6, 7, 8, 9, 10, J, Q, K (all hearts) on 5 of hearts in *P* cell.
11. K, 7 start new *B* columns.
12. A, 2, 3, 4, 5 to empty *P* cell.
13. 8, 9, 10 start new *B* columns.
14. J, Q to *T* cells.
15. 6, 7, 8, 9, 10, J, Q, K on 4 of spades in *P* cell.

THE AMATEUR SCIENTIST

How to make electrets, devices that hold electrostatic charge

Conducted by C. L. Stong

In 1925 the Japanese physicist Mototaro Eguchi discovered a fascinating puzzle. While attempting to make an electret—a device that permanently retains an electrostatic charge—he let a container of molten wax solidify between high-voltage electrodes. After shutting off the power he found that the wax had become electrified. This was not surprising, nor was Eguchi astonished when the charge disappeared after a few hours. Dielectrics ordinarily lose their charge in time. The surprise came with the next observation: the discharged wax spontaneously acquired a new charge of reversed polarity! Within hours the new charge increased to the point at which it was twice as strong as the original one. Then, over a period of weeks, it gradually declined to about the magnitude of the original charge and became permanently locked in the wax.

What happened? A number of investigators have worked on the puzzle. One of them is S. L. Khanna, professor of physics at York College in York, Pa. He became interested in electrets as a student of D. R. Bhawalkar of the University of Saugar in India. Khanna writes:

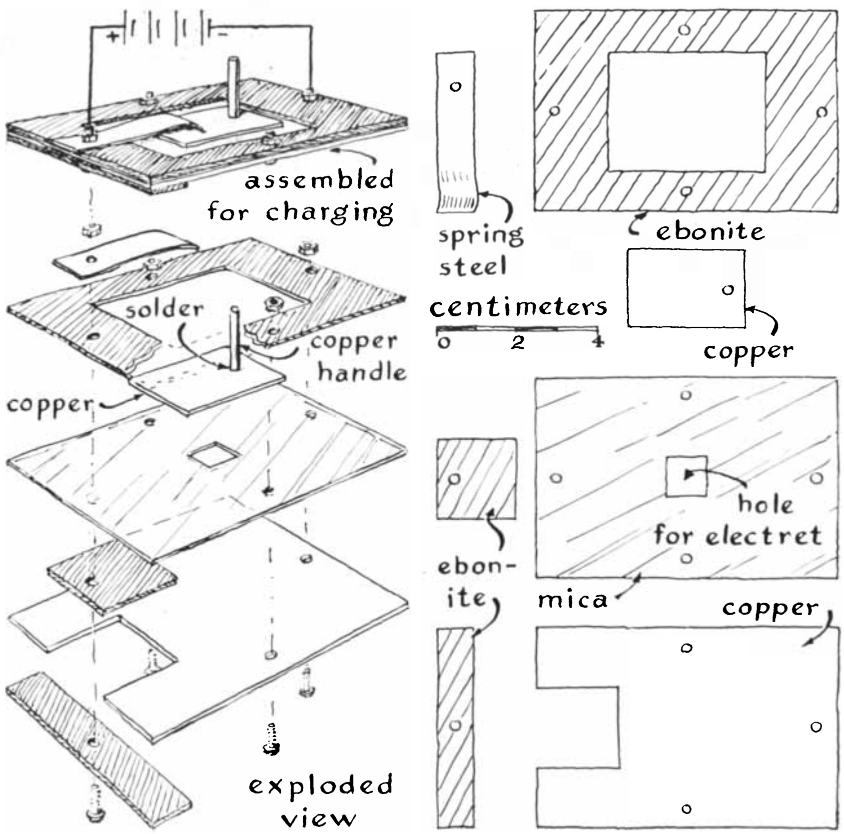
"The idea of constructing a device capable of retaining electrostatic charge was not new when Eguchi made his experiment. The possibility had been foreseen a century earlier by Michael Faraday. No one, however, anticipated the remarkable behavior exhibited by Eguchi's electret.

"Electrets are analogous to magnets in some respects, but they also differ in striking ways. All electrets are manmade, whereas magnets are found in nature. When magnets are stored properly, they can last indefinitely, but the lifetime of electrets appears to be limited. If an electret is severed between its poles, each part retains the electrical properties just as the parts of a broken magnet do. The electret is not destroyed even if the surface layer is scraped off, although the new surface is less strongly charged than the original one. This result shows that the electrification is not a surface phenomenon, like frictional electricity, but a volume effect.

"The electret will remain charged for years if it is wrapped in metallic foil, which short-circuits its charged surfaces, much as magnets are protected by placing a bar of iron across their poles. When an electret is stored without a wrapping of foil, the charge decays, but it will reappear if the unit is short-circuited for a time. Electrets can be made of many kinds of dielectric material, including ceramics. Ceramic electrets retain their charge even when stored without a 'keeper' of metallic foil.

"All electrets are destroyed by melting and are sensitive to humidity. When an electret is placed in humid air, it loses charge temporarily, but it regains charge after being dried. The temporary loss of charge is ascribed to the microscopic layer of moisture that forms on the surfaces and acts as an electrostatic shield. I have found that units are permanently damaged by prolonged exposure to humid air.

"In addition to the electrostatic effect, electrets exhibit pyroelectric and piezoelectric effects. The distribution of charge can be altered by the application of heat or pressure to selected areas of the units. It is important to mention that an electret is not a battery. It supports



S. L. Khanna's fixture for forming electrets an electrostatic field but cannot perform work.

"After Eguchi described the device, numerous experimenters searched for dielectric substances that exhibit the electret effect. Almost all waxes work. A favorite formula consists of 45 percent carnauba wax, 45 percent water-white rosin and 10 percent white beeswax.

"It has been my experience that carnauba wax works better than most other waxes, but the experimenter should try as many kinds of wax as he can get. Waxes that become hard and brittle at room temperature may crack. To prevent damage of this kind I usually add some beeswax as a softening agent, particularly when making electrets thinner than one millimeter. At the other extreme, one should avoid making electrets of waxes so soft that they sag out of control.

"It is now believed that all solid insulators exhibit the electret effect to some extent. Electrets have been made from plastics such as polystyrene, Plexiglas, nylon and Teflon, from hard rubber (ebonite), naphthalene, sulfur and sugar. I have not tried ice, which might work because molecules of water are highly polarized. Recently it has been shown that stable electrets can be made from inorganic ceramic dielectrics such as the titanates of calcium, magnesium, zinc, strontium and barium. The barium titanates, which appear to retain the strongest charge, represent the closest electrical analogy to magnetic iron.

"The performance of an electret is determined by a number of factors including the material of which it is made, the temperature at which it is formed, the interval during which it is immersed in the electric field, the intensity of the field and the thickness of the dielectric material. The optimum combinations of these factors must be determined experimentally.

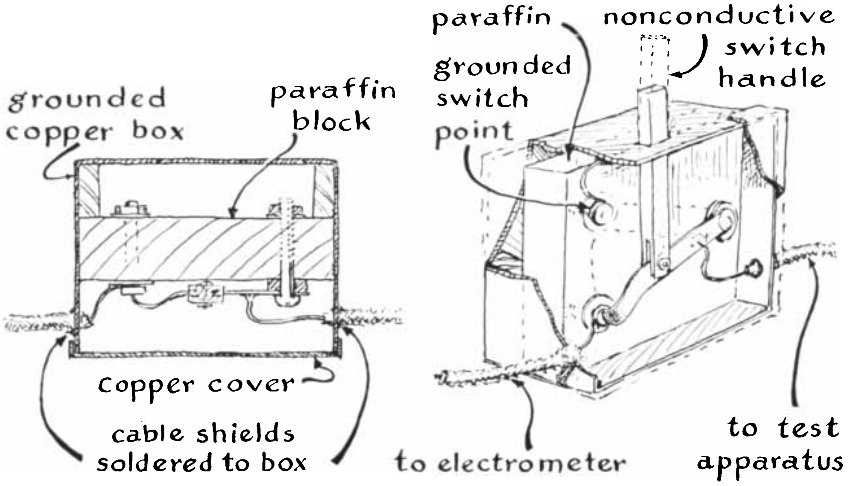
"After Eguchi's experiments many investigators applied polarizing fields of the order of 1,000 volts per millimeter of electret thickness. More recently units have been formed with fields of lower intensity. Fields in excess of about 1,200 volts per millimeter do not increase the maximum charge retained by electrets. At the other extreme, electrets have been made in fields of only 10 volts per millimeter.

"As Eguchi found, immediately after the electret is removed from the field the wax surfaces carry charges of a sign opposite to the sign of the adjacent electrodes. Wax in contact with the positive electrode acquires an initial negative charge and wax in contact with the negative electrode acquires a positive charge. Andrew Gemant of the University of Oxford has applied the term 'heterocharge' to the initial effect and 'homocharge' to the field of reversed polarity that appears after the heterocharge decays.

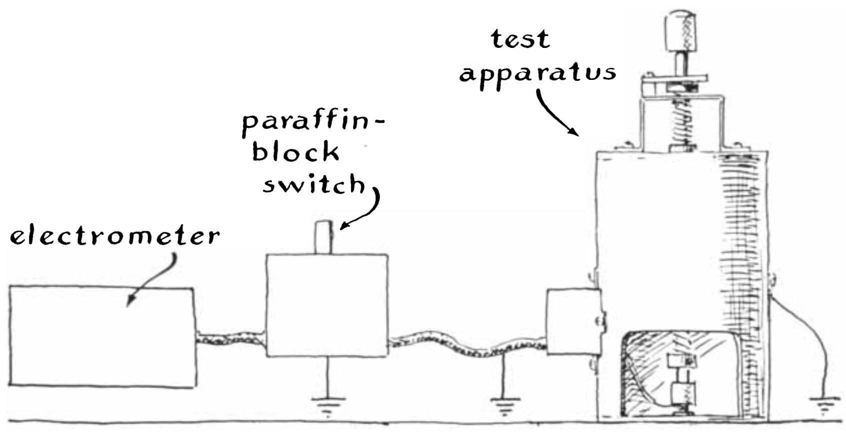
"The terms are useful for emphasizing an important distinction between electrets formed by high voltage and those formed by low voltage. Electrets that are formed in fields of less than about 1,000 volts per millimeter of dielectric thickness usually exhibit a heterocharge that decays to some constant value within 10 to 20 days. The magnitude of the charge is proportional to the polarizing field. No homocharge appears. On the other hand, electrets prepared with polarizing fields of 1,000 volts or more per millimeter are characterized by an initial heterocharge that usually decays into the stronger homocharge.

"The unpredictable nature of electrets accounts for part of their fascination. For example, it has been reported that electrets have been made by letting a mixture of wax and rosin solidify between sheets of tinfoil without a polarizing field. The charge carried by the resulting units showed no sign of decay after a storage period of six months. Stable electrets have also been formed at room temperature, far below the melting point of the dielectric material. The resulting charges were relatively weak and decayed more quickly than the ones formed in the molten state.

"The performance of the completed units cannot be increased by heating the dielectric material much above its melting point. It has been reported that the final charge is less than maximum if the polarizing field is removed before the dielectric solidifies or if it is maintained for an extended period after the dielectric solidifies. To make electrets of the highest charge I switch off the field when the dielectric has cooled to within five



Details of the switch



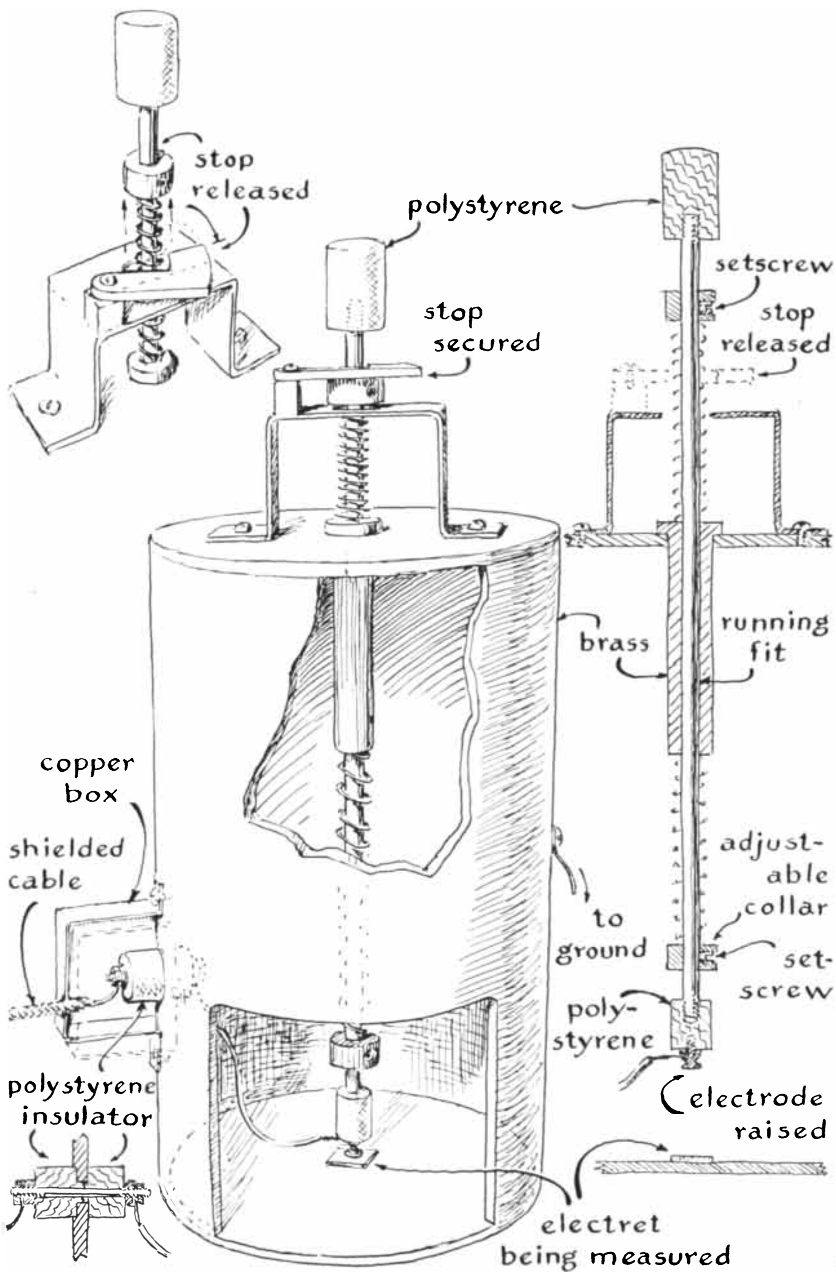
Arrangement of the testing apparatus

degrees centigrade of room temperature.

"I have been interested chiefly in investigating the properties of thin electrets on the assumption that they might be more useful than thick ones in practical applications. Electrets made by Eguchi and many other workers have for the most part ranged from eight to 20 millimeters in thickness and from 50 to 500 millimeters in diameter. Eguchi's electrets were made in the form of disks. Edwin P. Adams of Princeton University developed a cylindrical type in which the dielectric was sandwiched between a pair of concentric metal cylinders.

"My electrets are rectangular, 10 millimeters square. They range in thickness from a fraction of a millimeter to five millimeters. They are formed within a rectangular perforation 10 millimeters square cut in a sheet of mica; they remain permanently attached to the mica at the edges. The mica serves as a mechanical support and a convenient fixture for handling the charged dielectric. A sheet of stiff plastic, such as Formica, could be substituted for the mica. Mica is convenient for investigating thin electrets, however, because it can be split easily into sheets of any desired thickness.

"When making wax electrets, I lay the mica over a small rectangle of tinfoil placed so that the foil is covered by the rectangular perforation, thus forming a small container with mica sides and a foil bottom. The melted wax is poured into the container and covered by pressing a second sheet of tinfoil on top. The upper and lower foils remain attached when the wax solidifies; they serve as electrodes. Electrets made of plastic such as Plexiglas, nylon and Teflon are formed in much the same way. Plastic in square sheets piled to the desired thickness is placed in the container, covered with tinfoil and pressed while being heated in an oven and during subsequent cooling.



Details of the testing apparatus

"A simple fixture was improvised for holding and simultaneously pressing thin electrets during fabrication. The fixture consists of a multilayered sandwich of copper and ebonite fastened together at the edges by four machine screws [*see illustration on page 122*]. I made the bottom layer out of flat sheet copper 50 millimeters wide, 75 millimeters long and two millimeters thick. The lower electrode of tinfoil is placed on top of the copper at the center. The sheet of perforated mica, which is also 50 millimeters wide and 75 millimeters long, is placed on top of the tinfoil and the copper.

"The top layer of the sandwich consists of a sheet of ebonite perforated by a rectangular opening 30 millimeters wide and 40 millimeters long. This opening provides access to the cavity formed by the perforated mica and the lower tinfoil. The upper rectangle of tinfoil is pressed into contact with the mica by a copper plate 20 millimeters wide and 30 millimeters long. This plate, which is two millimeters thick, is held in place by a 40-millimeter length of flat spring steel attached at its outer end by one of the machine screws with which the sandwich is fastened.

"The screw that secures the steel spring must be insulated electrically from the copper plate at the bottom. I insulated it by cutting a rectangular notch in one end of the copper plate and fitting a piece of ebonite into the opening. The ebonite member is held in place by a strip of ebonite placed under the copper plate. The binding screw passes through the middle of this strip, the ebonite insert, the mica, the ebonite top and the end of the spring. A small handle of copper rod was soldered to the copper pressure plate for convenience in handling the piece.

"The copper plates must be made as flat as possible. Mine were squeezed between the jaws of a press and then lapped with fine abrasive. Tinfoil can be flattened by sandwiching the metal between paper, placing the sandwich on a sheet of glass and stroking the paper with a pressure of a few ounces applied by a fingertip. To make electrodes without bending the flattened foil, cut the sandwich into rectangles of the required size before separating the foil from the paper.

"Make the foil that will serve as the upper electrode slightly larger than the copper pressure plate. Place this foil on a flat surface, center the pressure plate on top of it and bend the corners of the foil up over the copper. Place the foil that will serve as the lower electrode on top of the copper plate at the bottom of the fixture and adjust its position so that the foil will be covered by the edges of the perforation in the mica. If either piece of foil tends to bow into the perforation, press it back into contact with the copper plate. The production of electrets of uniform thickness requires that both foils be flat.

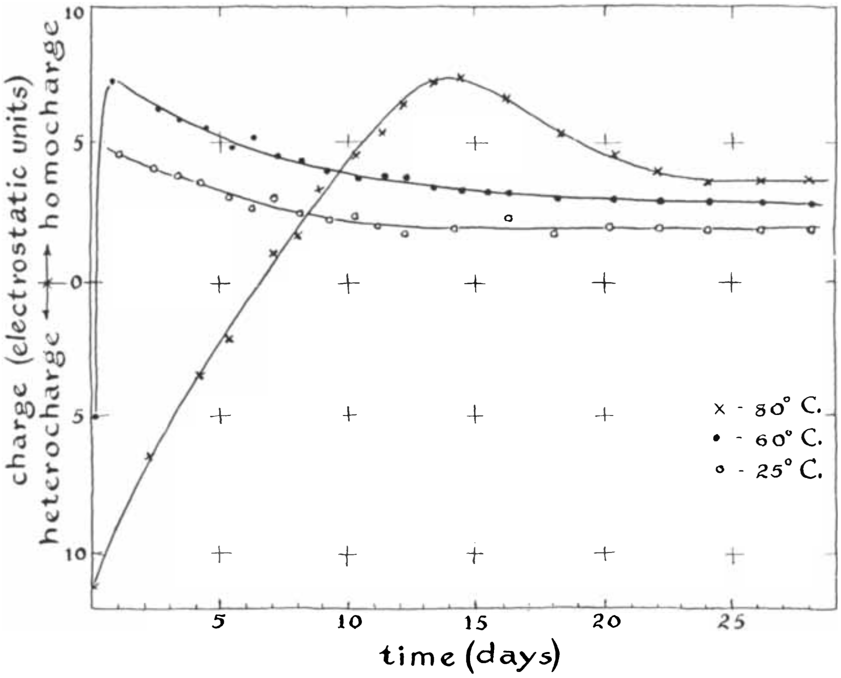
"To make an electret of wax, melt the wax in a clean beaker. Simultaneously heat the fixture in an oven to a temperature slightly above the melting point of the wax. An oven equipped with a thermostatic control is convenient but not essential.

"Fill the cavity of the fixture with melted wax until the upper surface bulges slightly above the upper surface of the mica. Place the upper electrode on top of the wax. The higher temperature of the pressure plate will cause the wax to melt into contact with the foil of the upper electrode. Secure the pressure plate in this position by means of the flat spring. Some wax may be squeezed out around the edges of the pressure plate. Remove it with a flat wooden toothpick or some other spatula.

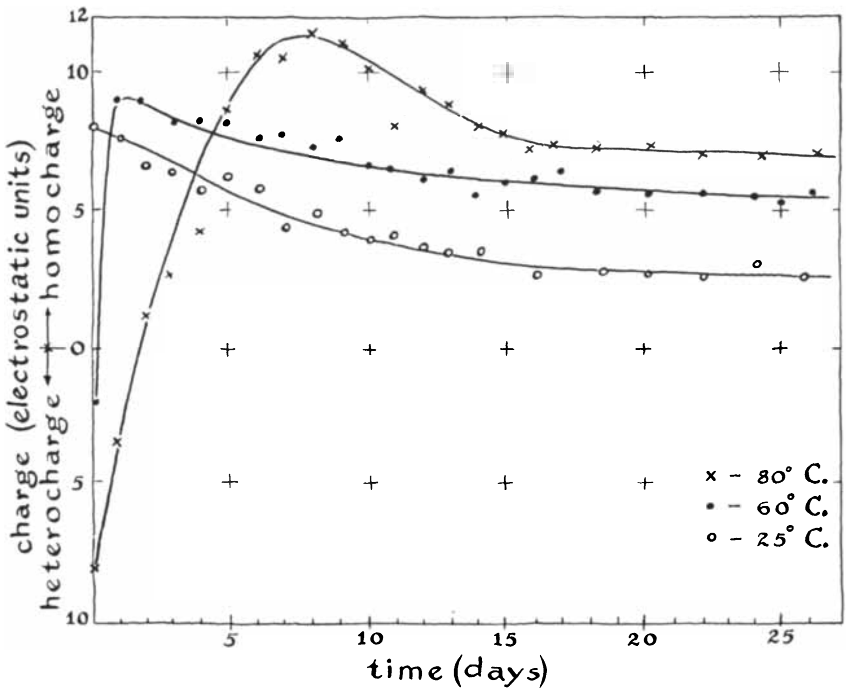
"Electrets of plastic are similarly assembled. Cut the plastic into 10-millimeter squares. Place in the perforation of the heated fixture as many squares as necessary to build up an electret of any thickness. Cover the plastic with the pressure plate and the foil, apply the spring and put the assembly in the preheated oven. (The oven should be preheated to the temperature at which the plastic yields under the applied pressure. Determine this temperature experimentally.)

"Polarizing potential is applied to the fixture by a pair of leads that are insulated by a covering of asbestos. Wire of this type is commonly used in household appliances such as toasters and is available from dealers in electrical supplies. The polarizing energy must be provided by a direct-current source. I use dry batteries.

"A power supply could be improvised by rectifying and filtering the output of a step-up transformer. The rectifier can consist of a 1B3 diode connected in series with one output lead of the transformer. The filament of the diode can be heated by a 1.5-volt dry cell connected in series with a 1/4-ohm, one-watt resistor. The anode of the tube should be connected to the output lead of the transformer. Adequate filtering can be provided by connecting a high-voltage capacitor of the 'cartwheel' type (commonly used in television sets) to the re-



Characteristics of a .5-millimeter electret



Characteristics of a one-millimeter electret maining grounded lead of the transformer and the filament of the tube.

"To control the output voltage connect a string of 12 one-watt resistors of one megohm each across the capacitor. Connect the grounded side of the power supply to the copper plate of the electret fixture and with an alligator clip connect the top electrode of the fixture to a resistor selected according to the voltage desired. A second capacitor of the same type connected across the leads to the electret would provide additional filtering. The maximum output voltage of the power supply will be equal to the voltage shown on the nameplate of the transformer multiplied by 1.414. The polarizing potential need not exceed 1,000 volts per millimeter of electret thickness, although it is interesting to compare the performance of electrets formed at higher and lower voltages.

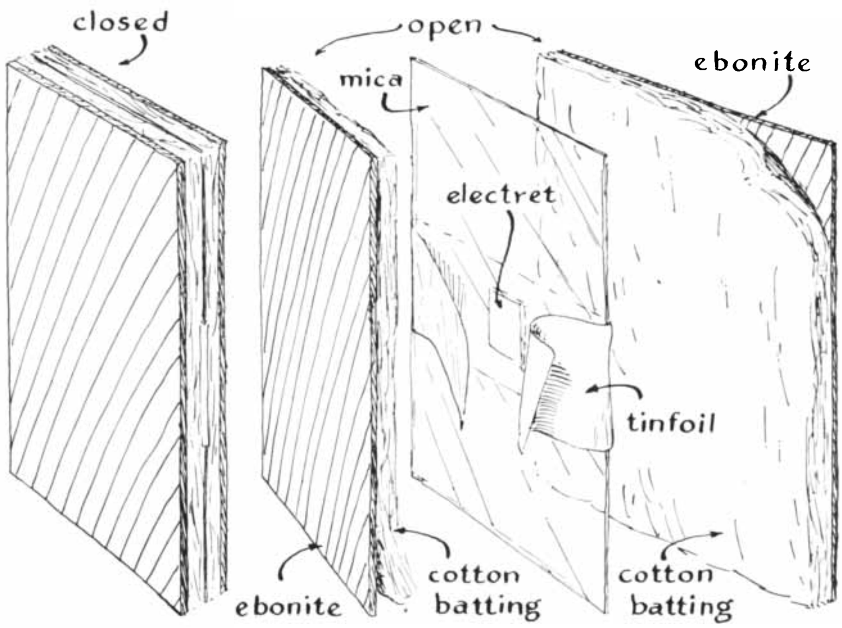
"A typical wax electret is formed by applying the polarizing potential and heating the fixture at constant temperature for three hours. The heat is then turned off. My oven cools to room temperature in six hours. I then switch off the power and short-circuit the leads to the electret. The tinfoil of the upper electrode is unfolded, the pressure plate is removed and the mica is lifted from the fixture with both foils intact. The electret is quickly short-circuited by wrapping a narrow strip of foil around the unit so that it makes contact with both electrodes. The foil electrodes should be removed only at the time of measuring the charge. In the case of very thin electrets the lower tin electrode should not be removed at all, otherwise the sample will come out of the mica perforation.

"The charged electret cannot perform work. The device simply supports an electrostatic field. The electret can, however, be used for generating (by induction) electrical energy that can perform work.

"To generate electrical energy in a brass disk, I connect the disk to ground and place it in contact with one surface of the electret. The other surface is grounded. Electrostatic force either drives electrons out of the disk and into the ground or attracts electrons from the ground into the disk, depending on the polarity of the electret's field.

"I then break the ground connection to the disk, thereby preventing further displacement of the electrons, and lift the disk away from the electret. Work must be performed to separate the disk from the electret against the force of electrostatic attraction; energy thus stored in the disk can be expended to perform work. The amount of energy so generated varies with the strength of the electret and with the amount of the disk's separation from the electret.

"I improvised an apparatus that consistently lifts the disk at a predetermined rate to a predetermined height. The amount of energy generated by this apparatus varies only with the charge on the electret. I measure the charge by connecting the output of the apparatus to an electrometer.



Means of packing electrets for storage

"The apparatus consists of a cylindrical container that supports on its axis a movable rod of brass terminating in an insulated disk of brass [*see illustration on page 124*]. The rod is supported at any intermediate position by a pair of adjustable helical springs and is locked at the limit of its downward excursion by a latch. When the latch is operated, the springs lift the rod to its elevated position.

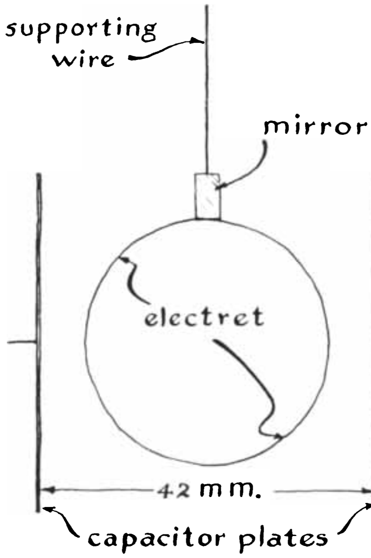
"An electret to be tested is placed on the metal plate that forms the base of the apparatus; the position of the electret should be directly below the rod and its terminal disk. The rod is pushed down so that the disk makes contact with the surface of the electret; in this position the rod is latched. The external switch is operated to ground both the disk and the electret and is kept in this position for one minute to let the electret become electrically stabilized. The output of the apparatus is then switched to the electrometer and the latch is operated, thus transferring the surface charge of the electret to the disk by induction. The magnitude of the resulting pulse of energy, as indicated by the electrometer, is observed and tabulated.

"The temperature at which electrets are formed influences the charge they acquire. The two accompanying graphs [*page 125*] depict the performance of six electrets made of 75 percent carnauba wax mixed with 25 percent beeswax. Three of the units were .5 millimeter thick and three were one millimeter thick. All electrets were formed by a polarizing potential of 1,000 volts per millimeter of thickness.

"In a typical case I adjusted the oven to a temperature of 80 degrees C. The fixture containing the dielectric was placed in the oven and voltage was applied. After three hours the heat was shut off. The oven cooled to room temperature in six hours. The high voltage was then turned off. Electrets were similarly prepared at 60 and 25 degrees C.

"To store electrets I wrap a ribbon of tinfoil completely around the mica holder, cover both sides of the mica with a uniform layer of absorbent cotton and place the assembly between a pair of ebonite plates bound together by a rubber band. The units are stored in a desiccator containing anhydrous calcium chloride.

"A variety of applications may eventually be found for the electret, although at present it is little more than an interesting plaything. Gemant at Oxford has used an electret as the active ele-



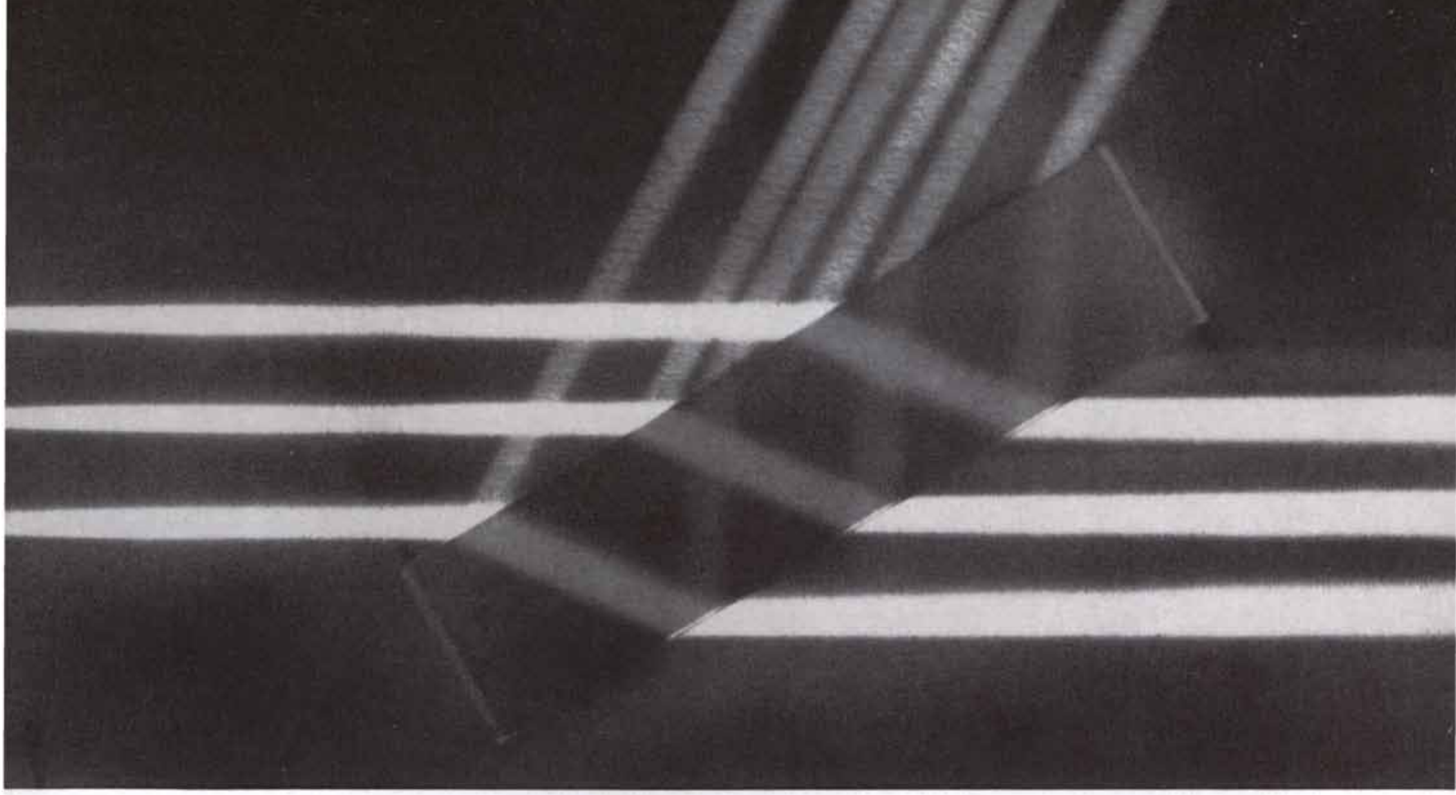
Arrangement of electrometer

ment of a simple electrometer. With a fine wire he suspended an electret 30 millimeters in diameter and six millimeters thick between a pair of metal plates 60 millimeters square spaced 42 millimeters apart [*see illustration above*]. A small mirror attached to the electret reflected a spot of light to a scale 115 centimeters from the apparatus. A potential of one volt applied to the plates caused the spot of light to move 3.5 millimeters. The sensitivity could doubtless be improved by substituting for the supporting wire a thin fiber drawn from quartz or glass.

"Alternating currents can be generated by vibrating a metal plate close to an electret. Microphones and loudspeakers have been based on this principle. Other potential applications of electrets include motors, timing instruments, hearing aids and similar devices.

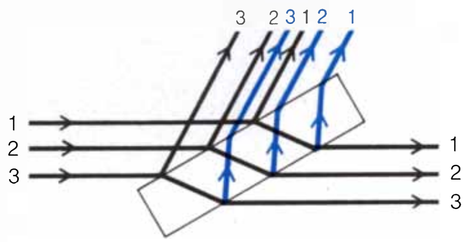
"Certain dielectric materials can be polarized by exposure to light. Devices so made are known as photoelectrets and have been used for making electrostatic recordings that are analogous to recordings of sound made on magnetic tape. Because electrets made of ceramic materials show piezoelectric and pyroelectric effects, they may find application as timing devices and as memory elements in computers."

Amateurs intending to experiment with electrets will find that some of the supplies are not readily available in most localities. Carnauba wax, for example, is rarely stocked in stores. All supplies needed for experiments with electrets can be obtained, however, from Jay T. Nichols, P.O. Box 161, Wilmette, Ill. 60091.



PHOTOGRAPH BY BAUSCH & LOMB.

Three beams of light are reflected from the surface of a glass (at an angle equal to the angle of incidence) and refracted as they enter and issue from the glass (at an angle fixed by the ratio of the speed of light in air and in the glass). The beams are also reflected from the interior surface of the glass and refracted as they issue into air (colored lines in diagram at right).



SCIENTIFIC AMERICAN

Announces a single-topic issue devoted to

LIGHT

To be published in September, 1968

a measure of progress

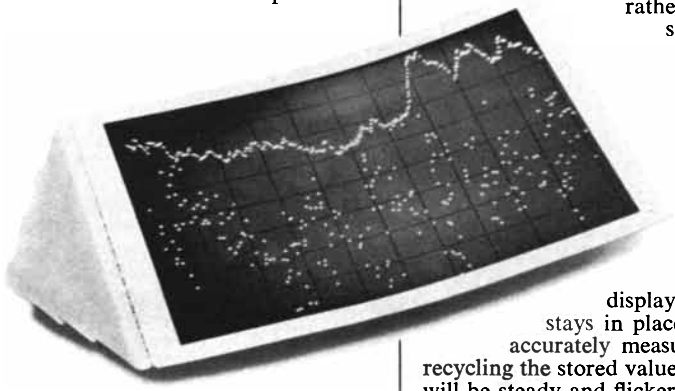
1. Signals buried in noise
2. A computing calculator
3. Hot-carrier diodes
4. Neutron activation analysis
5. Electronic patient monitoring

1. Averaging out body static

Someday your doctor or a specialist may want to know in minute detail exactly what's going on in your brain, your heart, a specific muscle or nerve. With very sensitive instruments he can tune in on the electrical signals these organs constantly generate. The problem is, your whole body generates a veritable electric cacophony that may mask the signal he wants. Noises that can't be filtered out by any simple means.

To help medical researchers, Hewlett-Packard has developed a signal analyzer which ferrets out signals buried in noise—using to advantage the random nature of noise itself. The signal is sampled repetitively by being broken up into a thousand short segments whose values are deposited into memory cells. The noise, sometimes plus and sometimes minus, tends to cancel itself out. The repetitive, information-bearing signal is progressively strengthened.

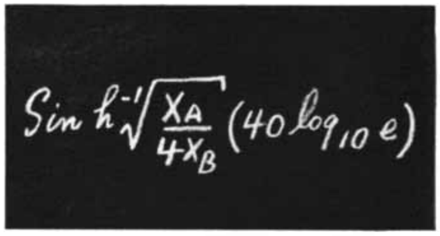
To keep a steady, calibrated display, the HP 5480A Signal Analyzer computes the average, rather than simply summing. The display on the scope stays in place and can be accurately measured. And by recycling the stored values, the display will be steady and flicker-free, regardless of how often the samples are taken.



Other candidates for signal averager assistance are seismology, fluorescent-decay studies, and numerous other laboratory applications. Whenever there's a repetitive signal and a synchronizing signal, an averager can improve signal-to-noise ratio by as much as 60 dB. The HP 5480A sells for $9500. The whole story is told in the April, 1968, issue of the HP JOURNAL. Write for a copy.

2. Hyperbolic functions on a desk calculator

The new Hewlett-Packard computing calculator is no ordinary calculator—though it is about the size and weight of an ordinary typewriter. There's scarcely a mathematical problem you—or your son or your scientists—couldn't solve with it. In fact, it's almost like having a large computer on your desk. The difference is, it's designed from the outside in, with the user in mind. We started with the keyboard.



Suppose you want to solve the problem shown on the blackboard. We've locked into the machine's memory the value of *e*, the log routines, the trig routines and the necessary hyperbolic routines. All you do is push buttons which call these functions into action in the proper sequence. Once you've set up the problem, you can store the operation on a wallet-sized magnetic memory card. The next time you need the program, insert the card and key in the measured values. Each card will hold two 196-step programs. And you don't need to know any programming language.

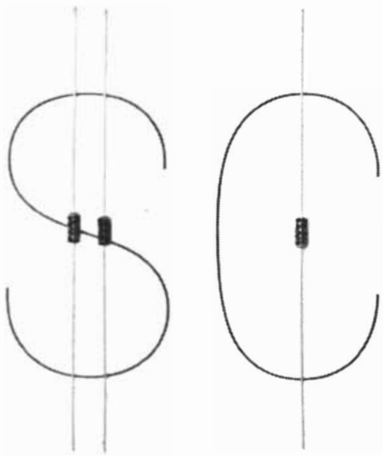
For $4900 you can do fixed or floating-point arithmetic, coordinate conversions, regression analysis, coordinate geometry, transcendental equations, numerical integration, network analysis, differential equations, branching and looping operations, business calculations—or anything else that's in our growing program library. You can speed your work with a 1.6 microsecond memory cycle, and handle numbers as small as 10^{-98} or as large as 10^{99}, simultaneously.

To find out more about the versatile Hewlett-Packard 9100A Computing Calculator, write for our fully illustrated brochure.

00803

3. Spreading a good diode around

One of the significant advances in recent electronics history is the hot-carrier diode—a tiny device that can switch off and on in one ten-billionth of a second. That makes it an almost perfect switch or an ideal detector. But it was priced at five dollars, which limited it to esoteric or military uses.

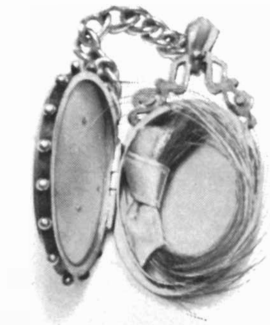


Before **After**

Now Hewlett-Packard is producing these instant switches by the millions—to sell at 55 cents each in quantities of 1000. At this price they might be used to speed up commercial computers or make home TV sets more reliable.

The price reduction was made possible by a combination of new design and new manufacturing techniques. First, our engineers eliminated a cat-whisker contact by using junction diode construction. This got rid of the expense of hand-probing for an active area on the diode surface. Then they developed a hybrid combination of a molybdenum metal barrier to gain speed and a graded pn junction to gain stability.

The hybrid technique isn't limited to 55 cent diodes. It could be used in integrated circuits, as well. We're already experimenting with devices that will have higher operating temperatures, higher breakdown voltages and higher forward threshold currents. If you'd like to experiment with the new HP 5082-2800 Diode, we'll sell you one for 99 cents. Or we'll send you Data Sheet 2800 for free.



4. Information from next-to-nothing

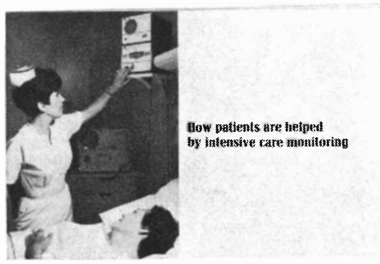
It was just a relic of hair from Napoleon's head. But could it tell if he had been slowly poisoned to death with arsenic? A technique known as neutron activation analysis led to that suspicion—without harming even the smallest hair.

The technique used pumps neutrons into the hair to activate the different elements present. Then the hair starts pouring out rays of energy. What kind of rays, how many there are, and how strong they are produce an exact signature of each element in the hair. In the case of arsenic this technique can detect 10 billionths of a gram. In some cases the traces can be as small as a millionth of a millionth of a gram—next to nothing.

The technique depends on an instrument capable of measuring and recording the radiation spectrum. First, the activated sample is placed in a detector which gives off an electrical pulse for each ray—a pulse whose strength is proportional to the strength of the ray.

A Hewlett-Packard multichannel analyzer can then separate the pulses into a thousand distinct energy levels and count the number in each. The count is displayed on a screen as a graph, and the signature of each element can be recognized. The analyzer will also measure the amount of energy given off in a specific time period—another clue to a material's identity.

The 5400A Multichannel Analyzer is one of the fastest, most accurate and versatile systems available for spectrum analysis. It sells for $9500. For a complete discussion of this instrument and this technique, write for the March, 1968, issue of the HP JOURNAL.



5. Bedside sentries

Suppose you were in a hospital recovering from major surgery or a heart attack. You wake up—and find yourself surrounded by electronic instruments, with wires of all sorts leading from them to you. It could be frightening. You could feel far worse than you are. And your family might think you've taken a turn for the worse. Not so, and here's why.

An electronic patient monitoring system is measuring, transmitting, displaying and recording heart rate, blood pressure, temperature, and respiration. Second-by-second it forms a continuous communications link between your body's vital functions and the medical staff. Even so, it could still scare you.

But one day a nurse who knows us well suggested another way Hewlett-Packard might help hospitals and their patients. We're old hands at building and installing monitoring systems for hospitals. Why couldn't we publish a booklet telling people how these systems work? A booklet to allay the fears of patient and family alike. We did. It's pictured above. If you'd like, write for a copy.

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OVERVIEW

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BOOKS

Truth, truth, what is truth (about how the structure of DNA was discovered)?

by André Lwoff

THE DOUBLE HELIX, by James D. Watson. Atheneum ($5.95).

"I have often thought," writes George Beadle in *Phage and the Origins of Molecular Biology*, "how much more interesting science would be if those who created it told how it really happened, rather than report it logically and impersonally as they so often do in scientific papers. This is not easy, because of normal modesty and reticence, reluctance to tell the whole truth, and protective tendencies towards others." Beadle's wish is now fulfilled. A talented worker has told how it really happened and has enabled Beadle to judge how good his idea really was.

During an examination the professor asked the candidate what he knew about *Les Mémoires d'Outre Tombe* and received the following answer: "Sir, *Les Mémoires d'Outre Tombe* was written by Chateaubriand after his death." In a sense it is often thus; many memoirs have come from "beyond the grave" in that they were published—not necessarily written—after the author's death. This allowed the writer to express his impressions and judgments concerning his contemporaries without hurting them or their friends.

Nowadays everyone expects to get instant information about almost everything: politics, war, economics and the physical measurements of movie stars. Permanent intrusion into the privacy of the individual has become the rule and for many provides the salt of life. Prominent writers, philosophers and statesmen publish their memoirs during their lifetime, as if they were eager to inform the world about the events of their existence, to establish their importance and perhaps to have the pleasure of observing reactions. So far scientists have mostly succeeded in avoiding the disease. One of them has now unconsciously performed his own rape, or autopsy—as you wish.

Here we are confronted with the work of a young scientist, not long out of adolescence at the time of participating in a great discovery. It is not a confession in the sense that the author has deliberately exposed his soul, but it nevertheless reveals a great deal about him. The book is the history of a scientific endeavor, a true detective story that leaves the reader breathless from beginning to end. It describes ideas, life in the laboratory, intellectual and personal interactions and also the events of everyday life insofar as they pertain to the "affair": the structure of DNA. An interesting combination of intellectual strength and of sensitivity, a student has been transplanted from the Middle West into the most sophisticated scientific environment.

Five characters are on stage. Four of them are almost always present: Francis Crick and James Watson of the Cavendish Laboratory in Cambridge, and Rosalind Franklin and Maurice Wilkins of King's College in London. The fifth character, Linus Pauling, is remote from the scene but is no less important: his very existence is a threat that precipitates the action and resolves the plot. Here James Watson will be Jim, as he has always been for me.

It is not by accident that Jim is involved in the discovery of the structure of the genetic material. As a senior in college he desires to learn what a gene is. As a graduate student at Indiana University he hopes that the gene problem can be solved "without my learning any chemistry." Jim's main interest has been birds, and he has carefully avoided taking courses in physics or chemistry, which look difficult and boring. Blessed idleness! (Jim's personal career as a chemist had been interrupted when he used a Bunsen burner to warm up some benzene.) It seems that it is at Indiana that Salvador Luria, the professor of microbiology, recognized Jim's talent and in spite of (or because of) his lack of chemical training sponsors him for a fellowship abroad. So Jim goes to Copenhagen in order to work with Herman Kalckar and to learn some biochemistry. Soon, with the complicity of Kalckar, Jim "illegally" joins Ole Maaløe's group and works happily with Maaløe and with Gunther Stent.

When, during the spring of 1951, Jim decides to go to Naples, it is with the vague excuse (for himself and not for the fellowship board) that the sun will help him. Having received the board's blessing and check, Jim leaves for Italy, feeling slightly dishonest. Profitable dishonesty! In Naples, Jim meets Maurice Wilkins and learns about the X-ray analysis of DNA. A decisive step. The way toward the discovery is opened. Wilkins is somewhat reluctant. Jim dreams of using his sister as bait, of making her marry Wilkins and then, having acquired the right brother-in-law, of beginning a fruitful collaboration.

From the start in Naples until the denouement Jim is constantly dreaming; he even writes ahead of time the first section of "the paper." Nevertheless, his feet remain firmly on the ground. Having returned to Copenhagen, he quickly realizes that the Cavendish Laboratory is "the place." So Jim writes to Washington, explaining that X-ray crystallography is the key to genetics and requesting permission to work in Cambridge. Feeling certain that the fellowship board cannot but yield to the force of this argument, Jim goes to Cambridge before receiving an answer. Alas, the fellowship board decides that Jim is totally unprepared and unqualified to embark on crystallographic work (it was, of course, perfectly true), and permission is refused. Had it not been for the personal intercession of Max Delbrück and Luria, Jim's guardian angels, the fellowship would have been canceled. It is a tale to be meditated on by those who rule over the fate of young scientists. Jim is probably the only scientist who has made a great discovery while holding a fellowship. This happened because he did not stick to the rules imposed on him: because he abandoned Kalckar and went to work with Maaløe and Stent, because he visited Naples without good reason and there met Wilkins, because he asked for permission to work with Roy Markham in order to be able to work in another laboratory, the Cavendish. For an administrator it was a dreadful succession of catastrophes, and yet one wonders whether the bitter fruits of the lesson have ripened in the minds of members of fellowship boards. Jim has set a bad example. It is now clear that if a board wants to be sure not to prevent a discovery, fellows should be allowed to do what they decide to do.

Fellowship or no, Jim migrates from Copenhagen to Cambridge and starts working. At the Cavendish, where he is adopted by John Kendrew, the great encounter takes place: Jim meets Francis Crick. A collaboration begins and will not end until the fruit has been plucked. The work does not always develop under favorable conditions. First, there is some incompatibility between Sir Lawrence Bragg and Crick. Sir Lawrence even decides at one point that Crick and Watson have to give up the study of DNA! There is a succession of ups and downs. In the background there is the formidable shadow of Pauling, far away in the West but nevertheless represented in Cambridge in the form of his son. Peter Pauling works in the Cavendish, receives detailed letters from Pasadena and informs his colleagues of the evolution of his father's work, seemingly without telling his father what Crick and Watson are up to. Freud would have been interested in the situation.

Francis and Jim work with confidence. The confidence is based on a few hypotheses. "Pauling's [discovery of the α-helix] was a product of common sense [and] his reliance on the simple laws of structural chemistry.... The main working tools were a set of molecular models.... We could thus see no reason why we should not solve DNA in the same way.... Worrying about complications before ruling out the possibility that the answer was simple would have been damned foolishness."

Jim has different moods. "I went ahead spending most evenings at the films, vaguely dreaming that any moment the answer would suddenly hit me.... Even during good films I found it almost impossible to forget the bases." "Much of our success was due to the long uneventful periods when we [F. C. and J. D. W.] walked among the colleges or unobtrusively read the new books that came into Heffer's Bookstore."

The work in Cambridge is interrupted by frequent journeys abroad, particularly to Paris. A chapter of the book records Jim's impressions of the 1952 phage meeting at the Abbaye at Royaumont. Here I shall record a personal memory.

It is evening in the solemn drawing room of the Abbaye. In the room is a 15th-century oak table, on which there is a bust of Henry IV. A young American scientist, wearing shorts, has climbed on the table and is squatting beside the king. An unforgettable vision!

Trips are brief, however; the Cavendish is the scene of the battle, and the war must be won. It is a matter of honor, for the Cavendish itself, for Cambridge and for Britain. The Cavendish is at war with Pauling, who is trying to solve the riddle of DNA, and hence also with the California Institute of Technology and with the U.S. Pauling has discovered the alpha helix of proteins. The structure of DNA *must* be a British victory. If Maurice Wilkins and Rosalind Franklin do not move ahead fast enough at King's College, somebody else should take over the task.

At King's the workers are deeply involved in the time-consuming experimental work. Watson and Crick play with the data from King's. Here an extraordinary story is told. Francis Crick and Jim have conceived a stereochemically reasonable configuration and no longer fear that it would be incompatible with the experimental data.

"By then it had been checked out with Rosy's [Rosalind Franklin's] precise measurements. Rosy, of course, did not directly give us her data. For that matter, no one at King's realized they were in our hands. We came upon them because of Max's [Max Perutz'] membership on a committee appointed by the Medical Research Council to look into the research activities of [Sir John] Randall's lab. Since Randall wished to convince the outside committee that he had a productive research group, he had instructed his people to draw up a comprehensive summary of their accomplishments. In due time this was prepared in mimeograph form and sent routinely to all the committee members. As soon as Max saw the sections by Rosy and Maurice, he brought the report in to Francis and me."

It is a highly indirect "gift," which might rather be considered a breach of faith. Jim writes somewhere in his account that fair play is typically British, and that such a thing does not exist in the U.S. and in France. Perhaps. At the Cavendish fair play is clearly—at least in Jim's book—a matter of circumstances. The battle is raging; it must be won, and quickly. Pauling must be beaten. Whoops! The discovery is a matter of weeks or days. Hurry! The results gathered by Wilkins and Rosalind Franklin are sucked out of King's College. Tally-ho! What is good for Crick and Watson is good for the Cavendish. Honi soit qui mal y pense! Stockholm is emerging out of the northern fogs.

The problem is not yet solved, but Crick and Watson are helped by Jerry Donohue, who shares a desk in their office and plays a crucial role by disclosing that the nucleic bases are not in the *enol* but in the *keto* form. The X-ray pictures made by Rosalind Franklin and Wilkins show that the DNA is a helix, not a simple helix but probably a double or triple one, and that the phosphoric acid residues are on the outside. Crick rules out the structure that implies a pairing of like with like, for crystallographic reasons and also because it gives no explanation of Erwin Chargaff's rule: adenine/thymine = guanine/cytosine = 1.

For a long time the idea of the formation of a complementary structure from the original one had been, as Jim notes, "in the air." Chargaff's rule could have led to a model of a DNA molecule made of two complementary chains. In actuality this model is derived from the attempt to load the dice in favor of the X-ray pictures. It is only at the very end of the work that Chargaff's rule provides an essential key.

Jim cuts cardboard representations of bases. The like-with-like structure leads nowhere. Then Jim starts playing with the bases, and ultimately writes the most thrilling page of his book. "Suddenly I became aware that an adenine-thymine pair held together by two hydrogen bonds was identical in shape to a guanine-cytosine pair held together by at least two hydrogen bonds. All the hydrogen bonds seemed to form naturally; no fudging was required to make the two types of base pairs identical in shape."

DNA is two complementary chains, one being the template for the other. It is a unique and hitherto unknown type of structure, able to replicate by separation of the two complementary chains and copying of each. It is a unique type of molecule able to divide into two different, albeit complementary, molecules and to reproduce two identical molecules. The laws of stereochemistry, the crystallographic data and the chemical data are satisfied by the model, as are the biological requirements for the genetic material.

The double helix is born. The scientific world is present at the death and transfiguration of the problem and rejoices in the new molecule. Although a few morose scientists regard the helix with suspicion, most are rushing toward the open door. Molecular biology glows with a new intensity.

Now the book has been closed. The scientist is satisfied, but the layman is abashed. He wonders. Is this the mysterious universe of science? Are these the perfect intellectual machines protected from emotional disturbance? Is this the passion entirely oriented toward one goal? Is this the mind devoid of concern about means?

In the work of an accomplished artist what is apparent is the craft and the style, not the human personality. The discovery of the structure of the genetic material is the subject of *The Double Helix*. Yet Jim's book is much more than its title. He has written with such absolute sincerity and innocence, and recorded his impressions with such candor, that he becomes transparent. Through the portraits of "the others" the reader gets a glimpse of Jim's and discovers a peculiar and interesting character.

The picture of Francis Crick, the most important figure in the story, is revealing. "I have never seen Francis Crick in a modest mood." "Already for thirty-five years he had not stopped talking and almost nothing of fundamental value had emerged." Jim has picked out Crick's oddities and weaknesses or failures of behavior, and he writes them down candidly. A casual reader might think that this is a sign of dislike. It is not. Jim recognizes all he owes to Francis, who has taught him the elements of crystallography and "has shaped his part in the discovery of the DNA structure." Watson and Crick work in perfect harmony; they have cordial personal relations and Jim is often a guest at the Cricks'. Moreover, it is clear that Jim admires Francis' brilliant mind. In view of all this, Crick's portrait by Watson is somewhat astonishing. On reexamining the book one finds that Jim's cold objectivity is applied to persons he likes, admires or respects as it is to crystals or base-pairing. Very few are spared. May God protect us from such friends!

The reader may also have the feeling that something is missing with regard to Jim's other mentors. The most critical phase for a young scientist is the start of his career. In Jim's case a key role is played at this point by Luria and by Delbrück. At the right time they introduce Jim to the right people. Once known, Jim is accepted. Those who knew Jim "before" never had the slightest doubt concerning the future of this strange broomstick-shaped fellow, inhabited by an intense flame. Luria and Delbrück are of course mentioned in the book, but more or less incidentally, Luria as "the professor of microbiology" and Delbrück as "the German-born scientist."

Jim behaves as a pure intellectual, an attitude that has its advantages. One is protected from all sorts of dangers, and time and energy are spared. Moreover, one's pronouncements on one's fellow man can be completely lacking in restraint. As a consequence the book is sprinkled with humorously ferocious remarks, such as: "Moreover, there was his godlike quality of each year expanding in size, perhaps eventually to fill the universe." The reader should be reassured: Joshua Lederberg stopped expanding a number of years ago, and although he is far from being as slim as Jim, he looks perfectly normal.

Here is another example of Jim's regard for people. Like many Americans working in Britain, Jim suffered greatly from the lack of adequate central heating. According to Jim in *The Double Helix* the only warm building in Cambridge was the Molteno Institute, which was well heated because of "the asthma of David Keilin, then ... Director." This passing comment, unkind, trivial and inaccurate, is the only mention in the book of the man who founded cellular physiology. In such a context the many who have admired, respected and loved David Keilin will be shocked. I am. (Incidentally, the reason for the existence of adequate central heating in the Molteno was the love of comfort of the late George F. Nuttall, the creator of comparative immunology and a great parasitologist, who was born in California. He laid down the plans of the Institute, and he never displayed the slightest symptom of asthma. In any case, the absence of central heating is one of the charms of British comfort.)

In the foreword to Jim's book Sir Lawrence Bragg writes that "those who figure in the book must read it in a very forgiving spirit." Jim appears to be ignorant of the fact that the naked truth can be a deadly weapon, even to those who are dead and have no way to forgive. He seems completely unaware of the injuries he inflicts, completely unaware of the harm he can do his friends, to the friends of his friends, to say nothing of those he dislikes. His portrait of Rosalind Franklin is cruel. His remarks concerning the way she dresses and her lack of charm are quite unacceptable. At the very least the fact that all the work of Watson and Crick starts with Rosalind Franklin's X-ray pictures and that Jim has exploited Rosalind's results should have inclined him to indulgence.

Some remorse is shown in the appendix. Rosalind having died at the age of 37, Jim notes: "Since my initial impressions of her, both scientific and personal...were often wrong...." If they were wrong, why not eliminate them? Death is a high price to pay for rehabilitation. It should be added that Jim's attitude toward "Rosy," as he calls her, is far from being unequivocal. He fears this strong personality and finds her unattractive but at the same time tries to imagine how she would look if she were better dressed and had her hair set differently.

Jim has received golden gifts: the aptitude to formulate, attack and solve important problems; the power of abstraction from the outer world; the power to "dream" the problems. Intuition and logic are seldom both present in one person at such high level. The brain functions with remarkable efficiency. Moreover, Jim has risen above his great discovery and continues to work with success. It would appear that these brilliant gifts are not balanced by an equal development of affectivity.

Jim has described himself, at the age of 25, as being an "unfinished member of the young generation." This is, or was, probably true. In the book he speaks of "the girls" as if he were a boy of 14. Moreover, the way Jim treats those he respects, admires or likes gives the impression that his affectivity is undeveloped, although it is certainly not totally absent. Great kindness is expressed throughout the book for his sister Elizabeth. She seems to have been the principal object of her brother's attachment and potentiality for affection. Another appears to have been the mother of his friend Avrion Mitchison, Naomi, who received Jim at her house in Scotland during a Christmas holiday and to whom the book is dedicated. Still, whether from indifference or from bashfulness, little of Jim's feelings show through. All things considered, it seems as though Jim's heart has not been nurtured and touched long enough by a loving and beloved person. Surely maturation is largely a matter of interaction.

Jim's lack of affectivity is balanced, or unbalanced, by his highly developed intuition and sensitivity to people—but not to things. This last remark is based essentially on the absence of any reaction to Italy in general and Paestum in particular. During an excursion to Paestum, Jim notes that Wilkins invites his sister Elizabeth to lunch, but there is not a word about anything else. This is astonishing; neither the aerial lightness of the ruins of Segeste nor the perfect harmony of the Parthenon are as deeply moving as the simple beauty of Paestum's temples. One wonders if it would have been different if the columns had been helical.

Jim's sensitivity applies only to some people. Narcissus takes pleasure in looking at his reflection in the shimmering water. Jim allows himself to be sensitive only insofar as the person involved reflects his own interests. The contact must be rewarding or the character is neutral; the sensitivity is not triggered. It is an efficient defense mechanism. Jim's undeviating course is directed to the be-all and end-all. A remark about a colleague caught in the midst of a gallant conversation is characteristic: "It was all too clear that the presence of popsies [Jim's word for pretty young girls] does not inevitably lead to a scientific future."

We have to keep coming back to Jim's sensitivity. When Jim is interested in one specific person, he "feels" the human being and perceives his most subtle vibrations with considerable acuity. This acuity is in contrast with Jim's lack of insight. His description of the relations between Rosalind Franklin and himself on the one hand and between Rosalind and Maurice Wilkins on the other is remarkable, as is his description of the change in Maurice's attitude toward him as a consequence of Rosalind's attack on him. The analysis is worthy of a first-class novelist. Incidentally, the behavior of both males when they face Rosalind is bewildering, but that is another story.

The peculiarities of Jim's friends are felt and described with artistry, indeed with such skill that their individuality emerges with unusual intensity. Since he is inclined to dwell mostly on abnormalities, a diagnosis can often be made. One of the victims is clearly a hypochondriac.

Let us apply Jim's methods to himself. His characteristics are essentially cold logic, hypersensitivity and lack of affectivity. A psychiatrist might be inclined to think that he shows some immaturity and a slight tendency toward paranoia. The reader should not be alarmed by the word. We all are paranoiacs, more or less, in one form or another, deficient in this or that, and delusive too. How else could it be? The fight in the laboratory is hard. Problems, grants, competition, tension, strain, the discoveries of others, jealousy, the prize, frustration. It may be that some scientists enjoy a normal life, but even normality merges insensibly with pathology. Where is the boundary? Mental balance is at best a precarious state.

Cold logic, hypersensitivity, lack of affectivity. The layman may conclude that Jim is representative of scientists in general, and the reputation of the scientific community will be harmed. In actuality, of course, very few scientists could express themselves so ingenuously with such absolute candor and sincerity. But the very repression of primitive feelings and reactions is the beginning of affectivity. And where does affectivity lead? It leads to a loss of freedom. Friendship is a millstone around the neck. Most people would not write down everything that came into their head about a friend—about, say, his private life. The opposite view is: What does it matter? What is important is the fun and the success. To hell with the victims! Good feelings are conducive to bad literature. Which view is worse? If Jim were a different person, *The Double Helix* would lack the spice of scandal.

The truth is that Jim is not as bad as he appears to be. He has not worked for the sadistic pleasure of beating Pauling and Wilkins. He has not worked, as the reader might be inclined to think, in order to win the prize from the top of the greasy pole. His taste for scandal, although revealing, is certainly not the main characteristic of this dedicated scientist. His most profound motivation was, and still is, his fascination with life and its secrets.

A few months ago the rumor spread in the gossipy scientific world that Francis Crick would bring a suit for libel against Jim. As a friend of mine has suggested, it is rather Jim himself who should bring an action for libel against the author of *The Double Helix*.

James Watson, together with Francis Crick, is responsible for the great discovery of biology. Jim is a clever and successful scientist. *The Double Helix* is a fascinating book. For the first time all the steps and circumstances of a major contribution to science are described with precision and accuracy. Sensitivity, sincerity, frankness and freshness are among the obvious qualities of the writer. The style is colloquial and therefore direct. The stories have the ingenuousness and charm of youth, and also its cruelty. Because Jim is a talented writer as well as a talented scientist, he may be forgiven. He will certainly not be forgiven by everyone. Too much damage has been done. Perhaps someday Jim will learn that all impressions, however witty they may seem, are not necessarily suitable for publication, that human beings are easily hurt and that the wounds, particularly those to self-esteem, are painful and slow to heal.

Creation, whether scientific, artistic or literary, is the order of the day. Jim has put his seal on the double helix. There may be some who are waiting for *The Golden Helix*, by Francis Crick, or perhaps for *The Other Side of the Story*, by Maurice Wilkins. Yet it is clear that *The Double Helix* has lost, together with its literary virginity, most of its attractiveness as a model for a work of art.

In the Alps, while climbing a mountain, our hero once met a colleague who said, "How is Honest Jim?" and went. Yes, how is Honest Jim?

Short Reviews

MOUND BUILDERS OF ANCIENT AMERICA: THE ARCHAEOLOGY OF A MYTH, by Robert Silverberg. New York Graphic Society Ltd. ($8.95). The building of a nation needs myths even more than railroads. This fascinating book is a history of a special branch of archaeology, the gradual growth of understanding about the mounds that spread still over the wild valleys from the Ohio River to Wisconsin and Illinois and to Alabama and Florida. There was in reality no deep mystery about them; 50 years after Columbus, the men of de Soto, visiting villages along the Alabama and the Arkansas, saw temple mounds in use, if a little in decadence, and wrote of what they saw. But the Northern mounds were first found by the pioneers who cleared the forest of trees—and of Indians—about the time of the Revolution. English barrows of the ancient peoples were well known, and many a landed gentleman rifled them for their grave goods. Now colonial America too had her splendid antiquities.

By 1820 the myth was republican but ornate. An Ohio Homer—Caleb Atwater, the postmaster of Circleville—apostrophized: "Have our present race of Indians ever buried their dead in mounds? Have they constructed such works...? Were they acquainted with the use of silver, or iron, or copper...?" No, the mounds were the last relics of some ancient and glorious people, far superior to those treacherous and ignorant redskins we were busily engaged in dispossessing, and very possibly a race akin to ourselves—of "giant Jewish Toltec Vikings," to conflate the various theories. Thomas Jefferson had not been deceived; he himself dug "barrows," so reasonably that he anticipated the key techniques of the trial trench, the digging to reach virgin soil, the meticulous recording of the finds in their geometric relationship. He concluded that the Virginia mounds were the slowly accumulated cemetery structures of the Indians. His voice was drowned for a century. Here is the whole story, complete with skeptics and believers, forgeries of inscribed tablets, carved otters mistaken for manatees, and bears taken for tuskless mastodons.

The writings of Joseph Smith himself, intimate of the angel Moroni, explain the mounds as the battlefield mortuaries of the ancient wars between the once godly Nephites, now given over to idolatry, and their still less worthy relatives, the Lamanites. Although both of these peoples were descended from the builders of Mesopotamian Babel, the Lamanites were punished by God by being given dark reddish skin!

So much for the myths, on which religions have been founded and from which genocide itself was rationalized. The volume is illustrated with excellent photographs and many contemporary engravings, including the beautiful maps of the great study of the mounds by two able Ohio amateurs, which became the first book published by Joseph Henry's new Smithsonian. The mounds are pretty well understood now; the Adena, Hopewell and Temple Mound cultures in the tradition of the Indians of the woodlands become clearer and clearer. We still find exciting new things today, often in the wake of the bulldozer. Salvage archaeology is our style.

A stirring chapter in the marvelous history of man is here displayed in the subtle and rich work of the Ohio Hopewell people, who traded over an entire continent for the shells, the mica, the silver, the copper and the meteoritic iron they delighted in working 1,000 years before Leif the Lucky sailed for Vinland. This is a good time for a revival of our old interest in the mounds; Silverberg's book will break the path for many readers. There is beauty and poignancy in the easily visited, quiet, grassy, flower-strewn mounds along the Ohio. A myth of the Cherokees tells of ancient mound burial, ending with "All the old things are gone now and the Indians are different."

AUTOMOBIL REVUE: CATALOGUE 1968. Hallwag AG, Berne (14.80 Swiss francs). The automobile show in Geneva is celebrated each year by a giant issue of the Swiss weekly *Automobil Revue*, which this year is about the heft of the Boston telephone book and much more colorful. The heart of the work is a bilingual French and German catalogue, complete with prices and technical details, listing all the passenger cars available on the catholic Swiss market. It is a veritable *Jane's* of automobiles, with laconic accounts and photographs of most of the models of about 200 makes. A new Turkish car? Certainly; called the Anadol A 1, it has a Ford engine and a plastic body.

There is a thorough look at Detroit's offerings; American Motors' racy new "hardtop fastback coupé" made under the label AMX is an eye-catching example. The words "hardtop" and "fastback" are nowadays as genuinely continental as *coupé* and *sedan* are now American. The Russian Maxi is here, at least in prototype; it is really a mini for city traffic, with sliding doors. The novelty of the year is that of the German company NSU, which has now put out a sedan driven by twin Wankels, strange little engines with a single rotating "piston." There is a handsome cutaway drawing in color of this basically simpler engine, whose performance squarely equals that of the comparable high-compression multipiston engines, although it uses low-octane fuel.

There are a dozen big full-color shots of events of the racing world, and others of the newest elegancies of Jaguar and Pininfarina. For those who dream, the newest Aston Martin DBS coupé is termed "ravissant," and with reason; current British speed limits, however, have deprived it of a promised new eight and kept it to a top speed of 150 m.p.h. with the same old six cylinders. A knowing review of the world automobile market closes the book, making it plain how the automobile world is changing. The U.S. has about twice as many cars per person as the countries of western Europe have, but for the second year North America has not made the majority of the world's new cars. The Japanese made more than a million cars for the first time in 1967, up 50-odd percent from the year before.

ACCIDENTS AND HOMICIDE, by Albert P. Iskrant and Paul V. Joliet. Harvard University Press ($5). All flesh is grass; this compact statistical study is the first of a projected series of a score of monographs using the 1960 census, the first detailed census of the U.S., to study the flashing blade of death cause by cause. Accidents and homicide (with war adding 10 or 15 percent to the total in the past few years) kill about 120,000 Americans per year. Nonmotor accidents have fallen more or less steadily since 1915 (excluding war, which again adds about 10 percent, averaged over the four big wars during the period), while those from motor-vehicle accidents rose to reach an irregular plateau in the late 1930's, where we still remain. Among

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SIGNETICS CORPORATION, 811 EAST ARQUES AVENUE, SUNNYVALE, CALIFORNIA 94806. A SUBSIDIARY OF CORNING GLASS WORKS young Americans, those between 15 and 24, accidents cause the majority of all deaths; for the whole population under 35, accidents remain the leading single cause, ever since tuberculosis was mastered (or faded away) in the late 1940's.

There is a brief comparison by countries, which is very curious. Among about 50 countries reporting to the World Health Organization for the period 1960–1962, 11 have an overall rate exceeding that of the U.S. All of them except Chile are lands with plenty of motorcars, and of motor-vehicle deaths. In the U.S. and similar wheeled countries one can count on about 40 percent of all accidental deaths being the result of automobile accidents. Austria leads in automobile death rate. The steep, cold countries suffer the most from falls, the Swiss at twice the U.S. rate. The fishing and seaside countries show the most drownings, Japan and Finland losing at three times the rate of the U.S. Only Canada and New Zealand lose more persons per 100,000 to machinery accidents than we do; in this country, and probably in those two as well, it is farm machinery, largely the tractor, that costs the most lives. These are not surprises, although the United Arab Republic reports a loss to fire and explosion triple that of any other country. (Perhaps it is an error, or possibly it reflects one or a few conflagrations; why should fires be so common there?)

Surprises, however, are not absent. The book centers around three topics: the "host" to the accident, the agent or type of accident and the factors of time and space. The death rate from fire and explosion among nonwhites in the rural counties of the U.S. almost equals the U.A.R. anomaly mentioned above. Home fires from leaking kerosene stoves in the deep South are probably the chief contributor. (To come to specific conclusions requires more than cross-comparison of the somewhat enigmatic tables, which list so much in such blandly constant categories: age, sex, color, state, type of accident and so forth.) Stationary motor vehicles injure two million persons per year: cars fall from their jacks, doors slam, children fall when climbing over the car, and so on. Preschool children suffer about a fourth of the deaths from poisoning "by solid or liquid substances." Aged under one year, the children ingest indiscriminately: medicines, cosmetics, cleaners. For four-year-olds the majority of poison deaths come from taking too much of some proper internal medicine, mainly aspirin. Finally one comes to "therapeutic misadventures"—the slip of a scalpel or the wrong dosage of a drug. There are about 1,400,000 such accidents per year; one may estimate that at least a couple of thousand of these victims die. For comparison, homicides take about 8,000 lives a year. It is an inescapable paradox that an ideal therapy, curing all ills, would make medical errors the major cause of death.

The Gallipolis *Tribune* once wrote: "The number of . . . accidents is appalling. Fractured skulls, . . . mutilated faces and ears torn off . . . almost . . . every accident is the result of fast and reckless. . . ." The year was 1897; the agent was the bicycle.

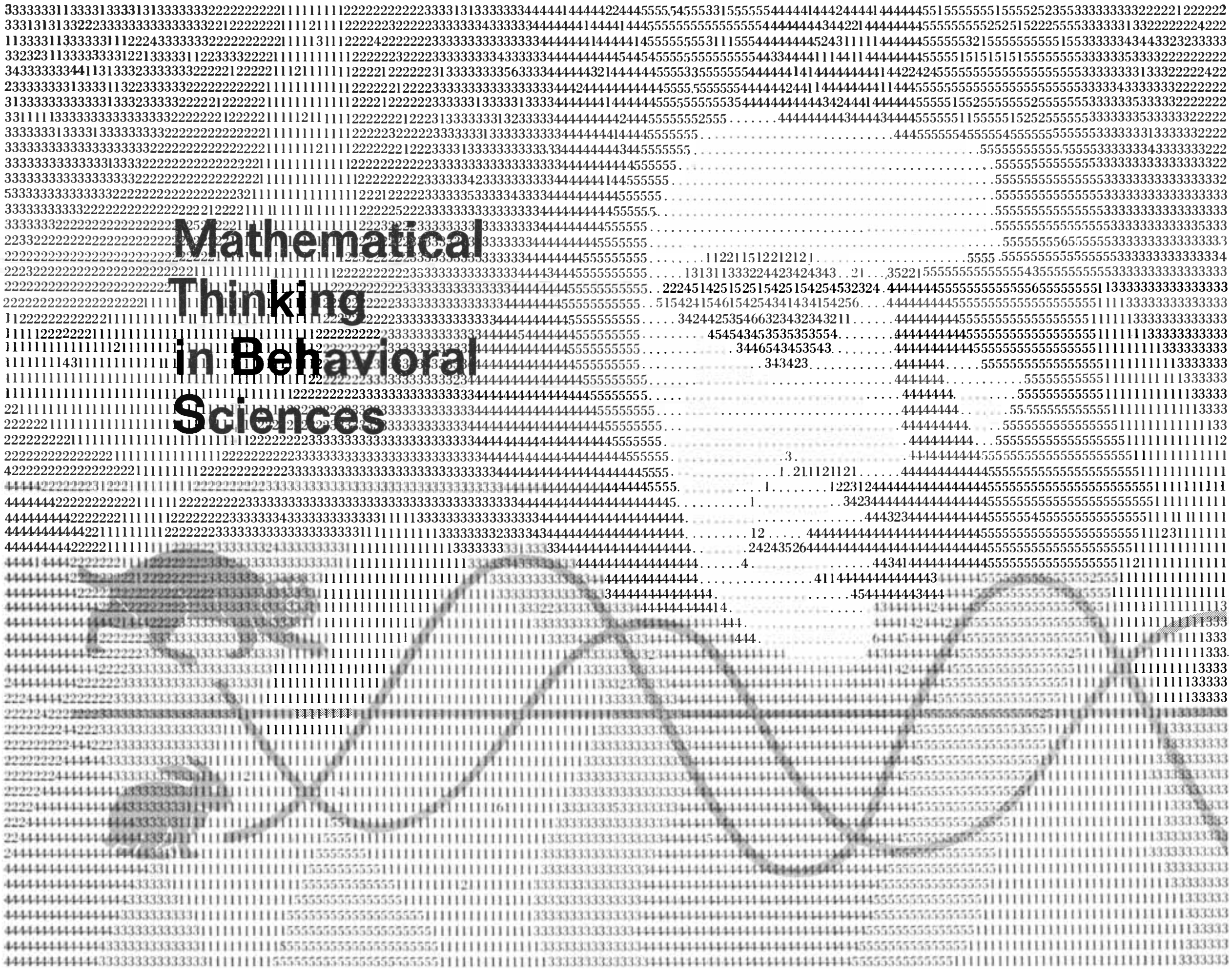
THE RIDDLE OF GRAVITATION, by Peter G. Bergmann. Charles Scribner's Sons ($7.95). Graceful and daring, this book bears the mark of the school of Einstein. Its author, once assistant to Einstein himself, has for a generation stood in the forefront of those who have investigated the intricate and surprising consequences of Einstein's 50-year-old theory of gravitation. In this book for the serious reader he uses almost no mathematics, and indeed presupposes only the most general acquaintance with physics. The book begins with an introduction to the world of Kepler and of Newton, and promptly proceeds to make it relativistic. The method is straightforward discourse; we are told about two events, one happening above New York, the other an hour later above Washington. The events are clearly far apart. Suppose, however, they are leaks in the gasoline line of an airliner's engine? They may be leaks forming only a few inches apart on the copper tube, one an hour after the other. It all depends on your frame of reference.

Extending this notion to time intervals, not merely to space intervals, and then uniting the two, the text leads us to Minkowski space. We do not stay there long. Gravitation demands a more complicated theory; indeed, we cannot even find a gravity field if we can measure only locally—all objects fall the same way. Worse than that, the mass that is the source of gravity changes with motion, unlike that splendidly conserved quantity electric charge. Only gravitational nonuniformities are seen by all observers. We are led to general covariance and parallel transport in curved space-time, plausibly if compactly described.

So much is good, if not quite new. Novelty is the main offering. The concept of an event horizon is described; for one example, two receding and accelerating observers will never see each other once they start far enough apart, because then they recede fast enough to beat out the frustrated light signals. It is at least plain that they can detect only the reddest and faintest of mutual signals. On this base is erected the discussion of the genuine surprises of gravitational collapse, of motion in the field of a small massive object, of contemporary cosmology with open and closed universes, of possible relevance to such enigmas as the quasars.

Gravitational radiation is described, and the brave efforts to find it. In all of this no formula—outside of the appendixes—enters that is more advanced than the Pythagorean theorem. The text is reflective, careful and invariably intelligent, but it is not always concrete or clear. The reader will see no scales at all on the graphs; he will be told about tensors and vectors without much notion of what those animals are; he will have to count components and unknowns with the aid of a glossary of meanings. If the reader is thoughtful enough, and if he is willing to accept the argument in the spirit of mathematics, as a logical arrangement of basic elements not very well known, he can go far. Perhaps even better, if he has learned some of this material from a more explicit and technical study, he will find here a richness and depth of connection missing from many courses. In the end, even from Professor Bergmann, "to him that hath shall be given."

THE JUNE BUG: A STUDY OF HYSTERICAL CONTAGION, by Alan C. Kerckhoff and Kurt W. Back. Appleton-Century-Crofts ($2.95). June is a crucial month in the production of that most perishable commodity, women's clothing. Plenty of overtime work is required to finish the fall line in time for shipment. A modern air-conditioned plant in a small Southern city, somewhat tentatively beginning to carry out the whole complex process from spinning thread to pressing the finished dresses, with a thousand workers—nearly all of them white and two-thirds of them women—came to grief in 1962 because of the "June bug." The June bug was not the bumbling beetle of the early summer night; it was a tiny insect rather like a white worm—or was it a black gnat?—whose bite was sometimes felt and sometimes only known after the fact but brought severe nausea, fainting, numbness, panic. The doctor saw in a few days 60-odd patients, all but one or two of them women, all white, all but three on the day shift, most of them working in the big dressmaking department. After 40 or 50 cases the plant was closed. The



Readings from SCIENTIFIC AMERICAN

With Introductions by DAVID M. MESSICK,
University of California, Santa Barbara

Available August 1968, clothbound $10.00,
paperbound $4.95

During the last twenty-five years behavioral and social scientists have relied increasingly on mathematics as a tool to facilitate understanding of the phenomena they deal with.

This collection of twenty-seven readings from SCIENTIFIC AMERICAN, reproduced with full text, full illustration, and full color, emphasizes the two mathematical accomplishments that, more than any others, have found great success in behavioral sciences: the theory of probability and the digital computer. Some specific topics covered are feedback, the principle of optimization (the comparison of actual and ideal levels of performance so explicitly illustrated in game and decision theory), the extent to which machines are capable of performing activities typically considered unique to living systems, and the ways in which digital computers have contributed to the understanding of behavioral phenomena.

The readings communicate interesting, often sophisticated concepts in such a way as to make them comprehensible to readers with limited mathematical backgrounds and can easily be used to supplement formal training in quantitative methods. Introductions to the five sections interrelate the readings and suggest some of the ways that mathematics and contemporary technology have combined to open new possibilities for behavioral research.

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hospitals treated a dozen or so, who slowly improved. A few days of intense epidemiology followed, with experts gravely flown in from elsewhere; after intense fumigation the plant reopened, and the June bug had gone.

This is the decent, painstaking, analytic account of the study made after a lag of two months—the quickest academic reaction one can hope for—by two Duke University psychologists, a study of what was surely a case of hysterical contagion, as close as any to a "pure behavioral event." There had been some insects about, or at least a belief in them; they were a minor nuisance for weeks before June. Then the nuisance suddenly changed to a threat. It was a threat to women working too hard, who were in conflict over the neglect of small children, who had no trust in their supervisors, who by chance knew well *two* of the first handful of affected persons. The diagram of the lines of contact among all the affected persons is one of the most interesting bits of data in the book. The insect legitimized leaving the plant. That was what the anxious women wanted, at least unconsciously. The Negro women pressers, who were socially and by their work rather distinct, believed as firmly as the others in the bugs, but they did not fall ill. They felt still more strongly the strain of the work, but they needed the job still more, they were still less secure, they were strong enough to stick out the menace and they did not share the social contacts that spread the contagion.

The authors are judicious: "It is not reasonable even in this case to rule out the possibility of 'real' physically caused illness.... In some [epidemics] the balance is...on the side of some definable external toxic element...and in others ...on the side of the effect of some shared source of unresolved tension." The June bug was a credible threat—potent, mysterious, possibly foreign. It would be good to send these research men over to Congress sometime.

ENERGY FLOW IN BIOLOGY, by Harold J. Morowitz. Academic Press Inc. ($9.50). This brief and lively monograph is a rarity; it is a tentative essay on a subject that has brought out much nonsense from the eminent. In contrast to the many powerful and clever texts that now describe, often very deeply, the "fascinating hardware of life," this one modestly limits its biochemistry mainly to a list of the "ubiquitous compounds." They—coenzymes, sugar, amino acids—are very sensibly defined and presented on two pages, with another page on the bond changes in polymer formation. It is above all a look at the forest, not at the trees, however sturdy and fruitful. The theme of the book is the application of the key methods of statistical mechanics and thermodynamics to the hard questions of biology: How do chemical systems work when they are not at equilibrium but in a flow of energy? How do they form interacting and cyclic networks of matter and energy? (Cycles arise naturally, Morowitz shows.) How does order arise and how is it to be measured? Not all these questions are seriously tackled, and perhaps none of them is finally answered. It is still early in the day to be wise. Nonetheless, the entire argument, with its helpful pedagogical appendages, is presented at a level of great appeal. Even biologists innocent of physical chemistry, say, will enjoy it if they will either study or skip the harder symbolic passages. For the reader to whom Gibbs free energy is no closed book the six chapters will be enlightening throughout, not least where the reader may disagree. The quantum arguments that find a profound paradox in the existence of complex reproducing systems are not adequately confronted; it is quite plain that the author sees no paradox, and his approach is persuasive. Yet he never says so plainly, perhaps because he does not want to take on the opposition arguments explicitly.

Sharp results are not the outcome of this book. It is a book of viewpoint, of constraints on every theory, of unification. When it talks of ecology, for instance, one reads: "The principle we appear to be missing is...which of all the possible systems will...arise...in a given energy flow situation. It may turn out that there are no general principles... and that each case must be worked out in full kinetic detail." On the last page, however, we learn of Morowitz' hope that the steady state reached will be that one which is "maximally far from equilibrium. The biosphere may be a necessary state of the terrestrial surface, not an accidental one." Phase space seems too big for that claim; perhaps a theorem on *a* biosphere, not on *the* biosphere, may in the end fill the bill.

HOW TO WRAP FIVE EGGS: JAPANESE DESIGN IN TRADITIONAL PACKAGING, by Hideyuki Oka. Harper & Row, Publishers ($15). The Japanese sensibly trade by fives and tens, not by the dozen. When the farmers of one prefecture sell half a ten of eggs, they wrap them in a kind of cage tied out of rice straw, the eggs held tangent one above the other, gleaming through the three strands of the wrapping. There follow page by page in this beautiful and loving book 200-odd full-page photographs, some in color, of how specific packages, mainly holding good things to eat, are made here and there in Japan, and were made before the rise of blister packs or vinyl squeeze bottles. All the packages were taken from a 1964 national exhibition arranged by the devoted author for the commercial artists of Japan. They fall into classes: those that are merely wrapped in simple and honest beauty by rural sellers—true folk packages—and those from cities such as Nara, or great centers such as Tokyo or Kyoto, where a special shop has, sometimes for centuries, packaged its wares in a triumph of wood, white coopering or pottery.

To leaf these pages with any interest in how things are done is to spend a heartwarming hour. The objects are beautiful and right; they combine homely materials—straw, paper, bamboo, cloth, earthenware—in the Japanese way. They do not stay wholly within the low-key mode of Japanese country folk; they show very often the colorful, strong, clamoring look of the eager shopkeeper. Here is a hand-cut wooden box, copied from the style of a box used for an individual gold coin in feudal times, marked with bold black hand-brushed characters and a faint carmine seal, holding toothpicks. A few pages on you see a warm, rough pottery jar, held closed by an end-cut slab of wood, fastened by a purple cord across a twisted vine handle. It contains a special soy pickle, and of course it is kept for later use.

The author is no pessimist. He sees, unlike the American designer George Nelson, who writes an enamored but gloomy foreword, that we can have hope, we can still work. "If the craftsmen and 'designers' of old Japan could create beauty with *their* materials, are we today to accept defeat when faced with *ours*?" If our technology is ever to lift and not to depress the spirit, we need to face this question squarely. We need to learn to pay for the luxury of good looks, of honest work, of detail outside the commonplace, of time-honored excellence in small things. The Japanese have always understood—at least until now—that it is better to splurge some, to have rare extravagances, than it is to face every day the mediocrity of mere expanding G.N.P. or the shoddy fad. The machine and the artist can meet the artisan's challenge; it is the managers and their clients who raise our doubts. Packages, in this particular year, are certainly not the most important issue on our minds, but these utter a sharp comment.

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