SCIENTIFIC AMERICAN

PIPELINES

SIXTY CENTS

January 1967

17 ways a chemical company used First National City Bank in the last year

1

Investigated mineral properties—The bank assists chemical company in location and acquisition of properties around the world. In assaying potential acquisitions, trained Citibank petroleum engineers helped company evaluate engineering data. The bank's N.Y. office and branches rounded up information on production and mineral prospects in the Middle East, Africa and South America for company's management. A Citibank petrochemical specialist counseled with the company on technical and marketing problems in the industry.

2

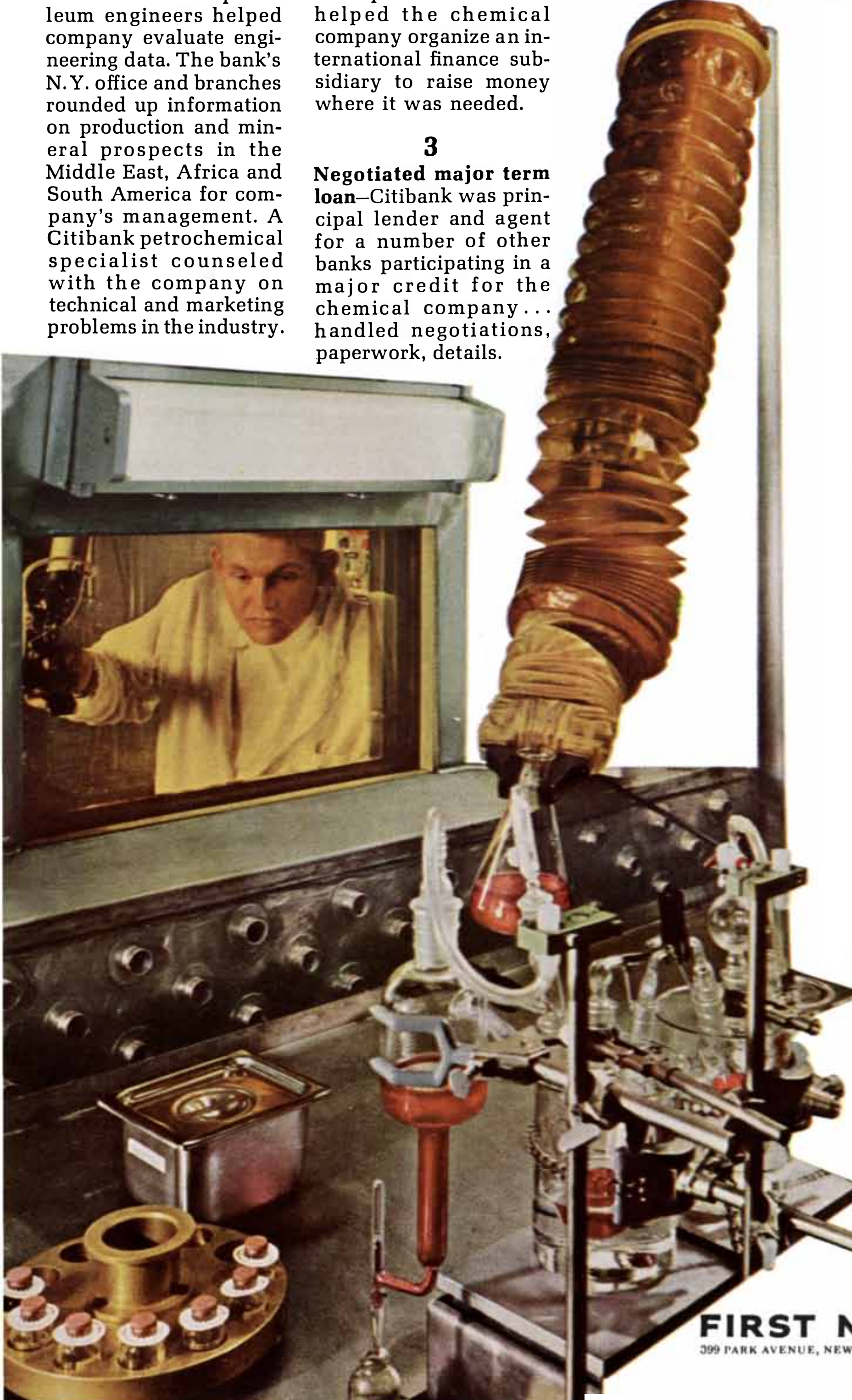
Set up international finance company—The company wanted to expand in Europe but the voluntary restraint program made U. S. funds unavailable. Citibank's European branches helped the chemical company organize an international finance subsidiary to raise money where it was needed.

3

Negotiated major term loan—Citibank was principal lender and agent for a number of other banks participating in a major credit for the chemical company . . . handled negotiations, paperwork, details.

4

900 credit checks—Citibank reported on credit and personal reliability of potential customers and raw material suppliers over 900 times in the last year . . . an average of 3 reports a day.



5

Top level counsel—Senior Citibank officers from overseas and New York discussed alternative ways of raising money for a new foreign subsidiary with company's president, at his headquarters.

6

Pension plans—Citibank is trustee for the company's foreign and domestic pension plans.

7

Located real estate abroad—The company wanted to find and buy land on a Caribbean island. Citibank's branch in the area saved company time and trouble with introductions to a local real estate agent, the Minister of Housing, the Minister of Finance and Tourism.

8

Financed new plants—The company planned installations in Europe and Latin America. Each plant and country presented different financing problems, most of them familiar to Citibank's local branches overseas. Branch officers were able to detail several solutions, including direct Citibank loans, transfer of company funds from other countries, Eurodollar loans, local finance companies.

9

Bid bond in Brazil—The chemical company wanted to sell salt to the Brazilian government which buys only on a bid bond basis. Citibank in New York immediately wired its Rio branch to issue the necessary credit.

10

Engineered individualized cash collection systems—Each of the company's divisions and subsidiaries—heavy chemicals, synthetic fibers, plastics, etc.—has distinct product distribution and cash flow problems. Together with company's treasurer, Citibank designed both domestic and overseas cash collection programs tailored for the divisions. Company has cut float, increased investable funds and income from interest.

11

Personal services—Citibank financed personal needs of transferred company employees . . . expedited loans through correspondent banks . . . arranged to negotiate checks of Hong Kong employees at local branch, avoiding usual wait for clearance of U.S. checks . . . Brussels branch helped locate home rental for transferred senior officer.

12

Kept checkbook balanced—Using punch cards and data processing equipment, the bank reconciled an average of 5,500 company checks each month.

13 to 17, etc.

Important routine services—Citibank supplied personalized letters of introduction for traveling personnel . . . bought CD's, commercial paper through Citibank's Wall Street money desk . . . transferred funds all over the world . . . sent Monthly Economic Letter and in-depth studies of business conditions.

We welcome inquiries about the many ways your company can use First National City Bank.

FIRST NATIONAL CITY BANK

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Established 1845 **SCIENTIFIC AMERICAN** January 1967 Volume 216 Number 1

ARTICLES

DEPARTMENTS

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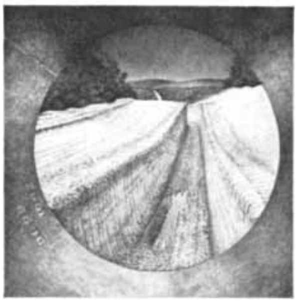

THE COVER

The painting on the cover depicts the laying of a 20-inch oil pipeline (see "Pipelines," page 62) as seen through the pipeline itself. The trench and the bare-earth areas to the left and right of it comprise the right-of-way obtained by the pipeline company. The road at left is used by vehicles and the various machines involved in digging the trench, placing the pipe alongside the trench, preparing the pipe by such steps as bending, welding and coating, lowering the pipe into the trench and then refilling the trench from the bank of earth at the right. The numbers in the section of pipe being lowered into the trench are symbols for the size and grade of the pipe.

THE ILLUSTRATIONS

Cover painting by Eric Mose

Page	Source
26	Sol Mednick
27	James Egleson
28–30	Joseph F. Kubis, Fordham University
31	Richard A. Sternbach, University of Wisconsin Medical School
33–34	Joan Starwood
35	James Egleson
36–38	Joan Starwood
39–42	James Egleson
43	Joan Starwood
44	Bunji Tagawa
45–46	Joe Ben Wheat, University of Colorado Museum
47–49	Bunji Tagawa
50–51	Joe Ben Wheat, University of Colorado Museum
52	Bunji Tagawa
56	National Aeronautics and Space Administration (*left*), Lick Observatory (*right*)
63	Edward J. Blood
64–65	Eric Mose
66	Tennessee Gas Pipeline Company (*left*), Bechtel Corporation (*right*)
67	Bechtel Corporation
68–69	Eric Mose
70	Petroleum Extension Service, University of Texas
72	Eric Mose
78–82	Thomas Prentiss
83–85	Jo Ann Beechel
87	Allen Beechel (*top*), Sol Mednick (*bottom*)
88–96	Allen Beechel
98–108	R. O. Blechman
110	Bunji Tagawa
111	William J. Hadlow, National Institutes of Health
112–113	Bunji Tagawa (*top left and bottom*); Robert W. Leader, Rockefeller University (*top middle and right*)
114	Bunji Tagawa
115	Dorothy B. Windhorst and Alvin S. Zelickson, University of Minnesota
119–120	Jo Ann Beechel
124–128	Roger Hayward

HOW TO CUT THE "CHATTER" AND FREEZE THE FLASH.

Frames from FASTAX high-speed camera show flash during interruption of the circuit in low-voltage circuit breaker. Film was shot without illumination to accentuate flash.

Undesirable "chatter" or bounce can create problems in low-voltage circuit breakers. So can excessive flash or display given off during interruption of the circuit. But Allis-Chalmers solved these problems when they designed a new line of circuit breakers. How did they do it? With a FASTAX high speed motion picture camera.

In the detection of "chatter" and behavior of the contact assembly, Allis-Chalmers filmed the circuit breaker in action. By stopping the motion with high speed photography, they could study the problem in detail and come up with an answer. Then they made a high speed film of the amount of flash during interruption of the circuit. By freezing the flash on film, Allis-Chalmers evaluated the interrupting capacity of the circuit breaker.

FASTAX cameras are available in 8mm, 16mm, 35mm sizes with speed range of 18,000 frames per second. (3M also has a full line of precision optics. Everything from prisms and zoom lenses to tracking telescopes.) For more information about Fastax Industrial Photographic Products, see your authorized dealer, or write: 3M Company, Dept. FMA-17, St. Paul, Minn. 55119.

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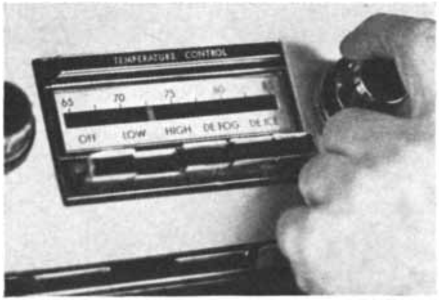
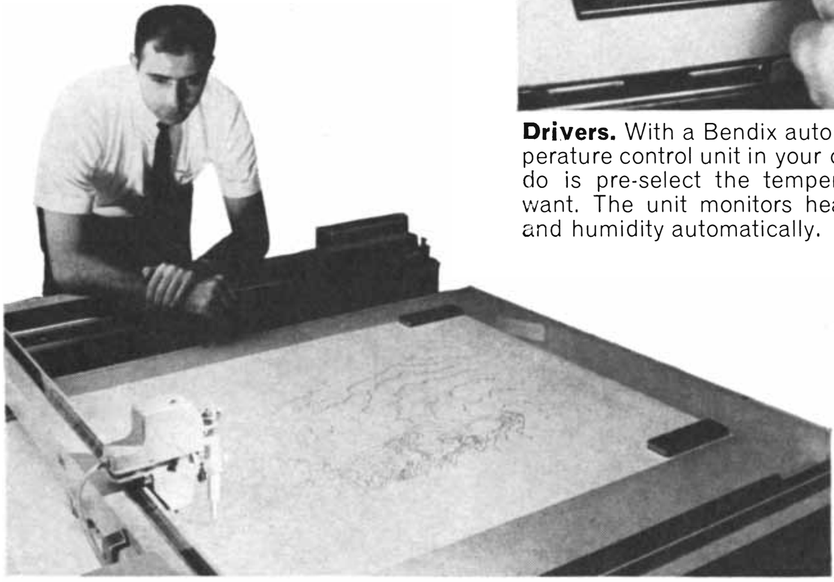
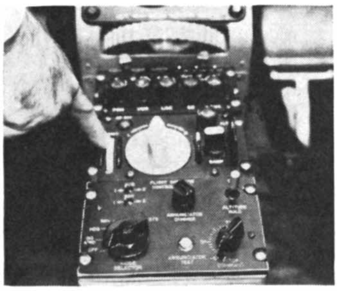


Drivers. With a Bendix automatic temperature control unit in your car, all you do is pre-select the temperature you want. The unit monitors heat, cooling and humidity automatically.



Mapmakers. Give this Bendix equipment a pair of aerial stereo photos and it will automatically draw you a contour map. It's been developed for the Rome Air Development Center of the Air Force Systems Command.



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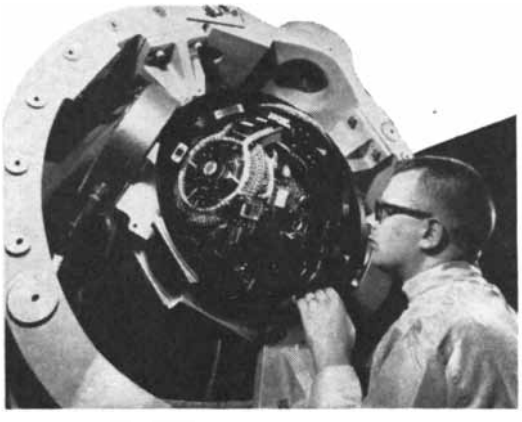
Look at all the automatic devices and systems you take for granted today. Bendix is behind a good share of them —from self-adjusting brakes in cars to automatic landing aids in airplanes. And more and more manufacturers are relying on Bendix automatic inspection and assembly machines to increase production, reduce scrap, and improve product quality and reliability. Our capability in automation demonstrates again that the heart of our business is creating new ideas and developing them to maximum usefulness—whether we're serving as creative engineers . . . manufacturers . . . or professional problem-solvers for industry and government.



Lunar voyagers. Bendix-built inertial platforms are scheduled to help guide NASA's Saturn V and three astronauts to the moon before 1970. Our platforms helped guide Saturn 1 and 1B flights too.

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LETTERS

Sirs:

I was pleased to see William C. Livingston's article on solar magnetic fields in your November issue and to read his lucid account of the elements of the theory of the sun's magnetic cycle that I had published in 1961.

The purpose of this letter is mainly to call attention to a draftsman's error that originated in the second of three diagrams in Figure 5 of my paper (*Astrophysical Journal,* Vol. 133, pages 572–587, 1961) and that seems to have been carried over to Figure 6 (*a, b, c*) of Livingston's article (page 58). According to the theory, the twist of the submerged magnetic-flux ropes should have at all times predominantly one sign (that of a right-hand screw) south of the sun's equator, and vice versa; the twist should not reverse where the flux rope breaks the surface and a bipolar magnetic region is formed, as in the diagram.

According to the model, the flux ropes become twisted through the shearing or overriding effect of the (supposedly) shallow material of the equatorial belt of the sun (the well-known "equatorial acceleration"). This part of the theory finds confirmation, as I pointed out in my paper, in the finding of G. E. Hale (*Nature,* Vol. 119, page 708, 1927) and later R. S. Richardson (*Astrophysical Journal,* Vol. 93, page 24, 1941) that a majority of chromospheric filamentary whirls surrounding sunspots in the Northern Hemisphere have the same sense of spiraling independent of the magnetic polarity of the spot or of the parity of the 11-year sunspot cycle, and that the opposite sense of spiraling prevails in the Southern Hemisphere. Hale (1927) showed that the prevailing sense of rotation of the chromospheric whirls is as if the equatorial edge of the central spot moves ahead in the direction of the sun's rotation.

Perhaps I may also point out that several features of the theory were developed as a result of extended observations with the magnetograph by Harold D. Babcock between 1952 and 1960. One crucial finding was that bipolar magnetic regions on the sun's surface are compact and intense when first formed, but that they disappear by expanding; this, as was emphasized in 1961, necessarily implies that the sun is continually expelling magnetic-flux loops that expand outward into interplanetary space.

HORACE W. BABCOCK

Mount Wilson and Palomar
Observatories
Pasadena, Calif.

Sirs:

In the article "Time-sharing on Computers," by R. M. Fano and F. J. Corbató [SCIENTIFIC AMERICAN; September, 1966] it is stated that Christopher Strachey first proposed a time-sharing system in 1959. This implies a faster development than actually occurred.

I have been unable to find a reference earlier than my article in the March 1957 issue of *Automatic Control,* which stated:

"One or several computers, much larger than anything presently contemplated, could service a multitude of users. They would no longer rent a computer as such; instead they would rent input-output equipment, although as far as the operation will be concerned they would not be able to tell the difference. Using commutative methods, just as motion pictures produce an image every so often for apparent continuity, entire plant operations might be controlled by such super-speed computers. Few computer manufacturers will deny the feasibility, even today, of super-speed and interleaved programs."

There is another reference prior to Strachey's paper of June, 1959. This is an article by W. F. Bauer in *Proceedings of the Eastern Joint Computer Conference* (December, 1958), where he proposed:

"Each large metropolitan area would have one or more of these super computers. The computers would handle a number of problems concurrently. Organizations would have input-output equipment installed on their own premises and would buy time on the computer much the same way that the average household buys power and water from utility companies."

If any of your readers do know earlier references, I would appreciate being made aware of them.

R. W. BEMER

Computer Department
General Electric Company
Phoenix, Ariz.

Sirs:

It has been brought to our attention that our article entitled "Time-sharing on Computers" in the September 1966 issue of *Scientific American* gave the incorrect impression that the work at the M.I.T. Computation Center had its sole root in the paper presented by Christopher Strachey at the 1959 UNESCO Congress. In fact, the idea of time-sharing a large computer grew simultaneously and independently at the M.I.T. Computation Center. The implementation of a time-sharing system was proposed in an internal memorandum by Professor John McCarthy, dated January 1, 1959, entitled "A Time-sharing Operator Program for Our Projected IBM 709." Strachey's paper is, to our knowledge, the first formal publication that proposed and discussed in substantial detail the design of a general-purpose time-sharing system. Of course, computers already had been time-shared for special purposes, as in the SAGE air defense system in the early 1950's. General-purpose systems, however, did present a host of new, difficult problems. Thus there is no question that Strachey's paper had a very significant effect on the development of general-purpose time-sharing systems at M.I.T. as well as elsewhere.

R. M. FANO
F. J. CORBATÓ

Massachusetts Institute
of Technology
Cambridge, Mass.

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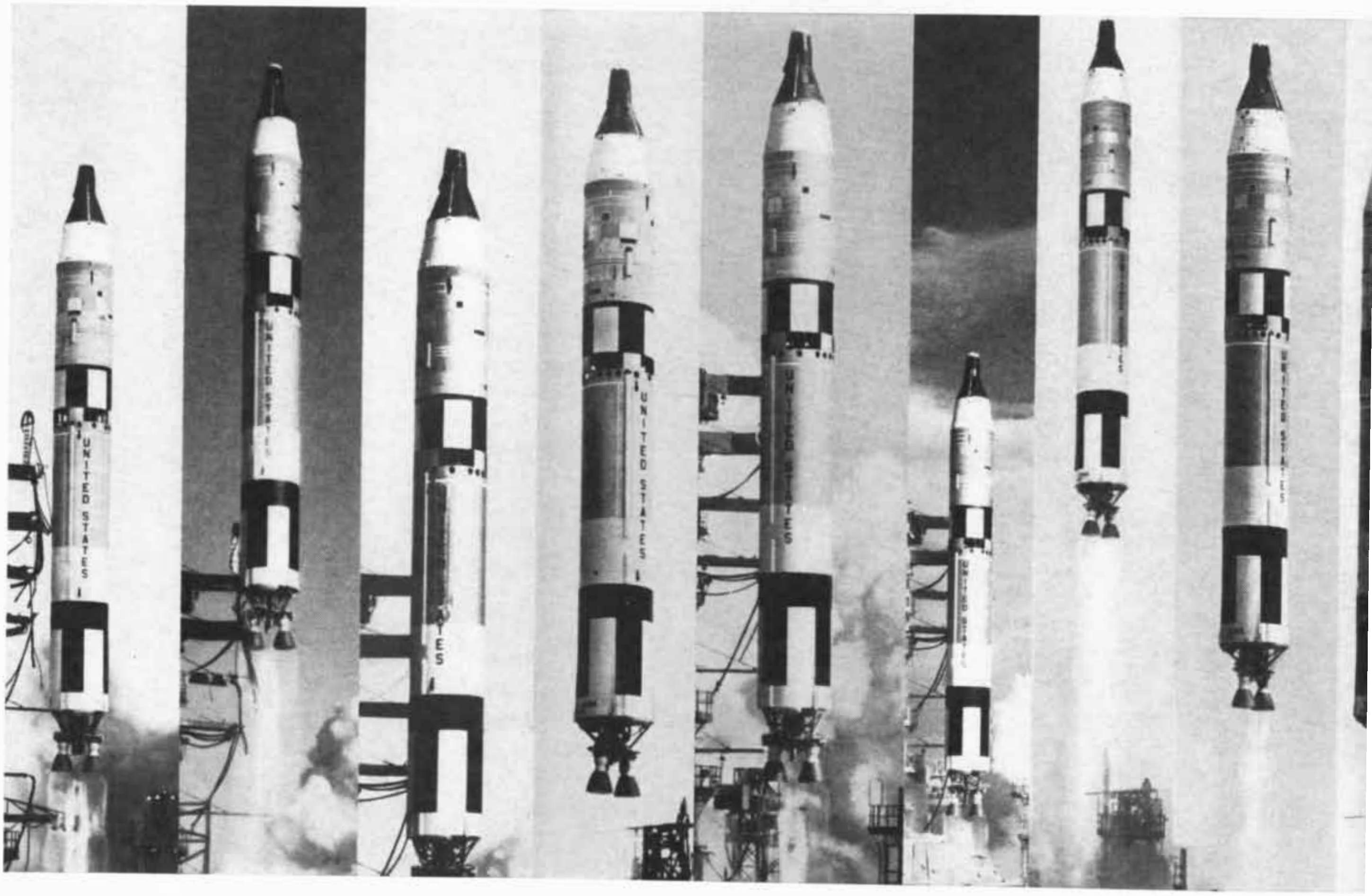
12 flights into history.



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1917: "However long the world war may last, it is probable that the closing months of the year 1916 will mark the highest peak of German accomplishment. That this great military power will fight with valor and skill to the very end of the war, whatever be its length, goes without saying, but the growing belief that the crushing of little Rumania will mark the last successful offensive of the Central Powers has been strengthened by their sudden, absolutely unexpected move in the direction of peace. The conviction that Germany has reached the maximum of her possible achievement is based upon the conviction that if she is beaten it will be because of her failure in manpower; and there are many indications that the diminution in numbers and decline in quality of her effectives, relative to that of the combined armies of the Entente, has already begun."

"The past 12 months have witnessed the keenest rivalry between the aircraft designers and builders of the Entente and Teuton camps. The earlier months saw the ascendancy of the Fokker monoplane on the Western fighting front, contemporaneous perhaps with the Teuton command of the air; but toward the middle of the year the British and French constructors came to the fore again with superior fighting machines, reestablishing the undeniable supremacy of Allied airmen in France, Flanders and Alsace. Several types of swift, highly flexible battleplanes have made their appearance on the fighting fronts as an effective answer to the Fokker, among them the Spad monoplane of Blériot with a speed said to surpass that of all other flying machines. But the credit for the year's only innovation belongs to the British constructors, for it was in England that the odd combination dirigible-aeroplane machines, or 'blimps,' were conceived, constructed and adopted. These diminutive dirigibles are now being used successfully for scout and patrol duty over the waters of the British Isles."

"A recent address by Prof. T. E. Mason called attention to the immense amount of mathematical research that is going on in the world, as evidenced by the growth of mathematical literature. A very conservative estimate would place the number of contributions to mathematics published each year at about 2,000, not including works that contain no new matter. It is estimated that during the first 15 years of the present century the published results of mathematical research amount to about one-fifth as much as during all time before."

"Mr. Harlow Shapley reports that a star in the southern globular cluster Messier 9 (NGC 6,333) shows a conspicuous short-period variation, with a range exceeding a magnitude. As the photographic magnitude of this star at its maximum is less than 16.5, it is probably the faintest variable star thus far discovered."

Scientific American.

JANUARY, 1867: "Dr. Jenner in his remarks on Nov. 12th at the opening session of the London Epidemiological Society, of which he is President, advocated the introduction of sanitary science as a regular part of a liberal education. We would go further and urge its adoption as an element of common-school education in its simpler laws and principles, and in its philosophy as an essential of professional education, equally with chemistry, for example. Dr. Jenner's arguments are abundantly forcible for our conclusion. The difficulty in the present state of general education of spreading practical sanitary knowledge and of inducing men to act so as not to destroy themselves and their neighbors is all but insuperable. Constant and indefatigable iteration on the part of the few—line upon line, precept upon precept, example on example, warning on warning—offer the only hope of gradually awakening and instructing the present generation with regard to the common laws of health and disease. The next generation might be and should be better indoctrinated. Meanwhile every press and every public instructor of whatever kind should give prominence to the daily lessons of experience and science on this all-important subject."

"Modern discoveries of the correla-

tion of forces have elevated the cosmogonical hypothesis of Laplace to a theory. As now accepted, this nebular theory holds that all atoms in the beginning were diffused through infinite space, but by the action of gravity collected and arranged around different centers of attraction, they now constitute the millions of suns and the planetary system."

"Besides 'the thousand natural shocks that flesh is heir to' smokers are liable to peculiar attacks upon the senses of sight and hearing and on the faculties of will and memory. Paralysis of the optic nerve, and torpor, coldness and hissing noises in the ear, premonitory of paralysis of the auditory nerve, are the forms in which nicotine attacks these two organs. Medical observers have often remarked the failure of memory and also a general characteristic of irresolution or indecision in habitual smokers. Exceptions are abundant, but this pathological characteristic of the drug is undisputed."

"A friend who has recently visited the pneumatic passenger tube in process of construction in the bed of the Thames reports the work rapidly approaching a successful completion. The simplicity and undoubted feasibility of this mode of transit have already, we are told, prompted the organization of a company of heavy capitalists for the purpose of laying tubes from New York to Brooklyn and Jersey City and from the lower to the upper end of Manhattan Island. Wilder predictions have been uttered—and fulfilled—than that some of the men who assisted at the laying of the Atlantic cable may live to see the tubular sub-marine railway in operation alongside of it."

"In 1866 the expenses of the city of Paris amounted to $46,000,000. In return for this seemingly large expenditure the Parisians had the cleanest and best governed city in the world, together with an astonishing development of great improvements, in the opening of broad spacious streets and in the erection of splendid public buildings. New York City expends about $18,000,000 and gets in return dirty streets, a brutalized swindling political ring and no improvements that are worth mentioning. During the past 10 years enough money has been stolen from our burdened tax-payers to have furnished this city with museums, art galleries, monuments, etc., that would have attracted the attention of the whole world."

ELIMINATING INCLUSIONS

Modern techniques that remove harmful oxides from molten steel greatly improve steel quality. One method involves adding metallic elements. The newest is the vacuum degassing process.

by R. A. Walsh, Research Manager

Quality is an elusive term, and quality in steel is particularly so. While steel quality, in general, can easily be described in terms of satisfactory performance of the end product, a really accurate definition must include a detailed analysis of the entire steelmaking process. A quality steel, then, is the culmination of painstaking care and attention at every step in the process, from the molten steel to the product delivered to a customer's plant. The processing begins with the melting of a heat of steel. In the basic steel industry, this is accomplished in electric arc, basic oxygen, or open hearth furnaces. While each of these melting processes has its own individual characteristics, they have one thing in common, the presence of dissolved gases in the molten steel, notably hydrogen, nitrogen, and oxygen.

Hydrogen is not a problem of any general consequence in plain carbon steels. However, it can be a critical problem in large forging ingots where it can give rise to the defect known as flaking. Nitrogen may or may not be desirable depending upon the specific steel that is being melted. Oxygen is rarely regarded as beneficial, and the inexorable laws of thermodynamics dictate that it can be present in molten iron in amounts up to as much as 0.16 percent by weight, in commercial practice.

As steel solidifies in an ingot mold, oxygen is rejected from solution. When this happens, bubbles of carbon monoxide may form and rise up through that portion of the ingot which is still liquid. Oxygen which does not react with carbon in this manner ultimately reacts with iron or other metallic elements in the steel to form liquid or solid oxides, generally termed inclusions. Some of these will rise through the liquid steel, forming a slag, but some inevitably are entrapped in the body of the ingot. In order to minimize the presence of oxide inclusions in the steel, metallic elements which have a great affinity for oxygen are usually added to the furnace or the ladle. Silicon and aluminum are prime examples. When added at the ladle or furnace stage, these elements quickly form oxides. The steel is molten and sufficient time is allowed for the oxides to levitate and thus escape from the melt. The oxygen which remains dissolved in the molten steel is thus lowered and the amount of oxide inclusions precipitating in the ingot when it solidifies is proportionately reduced. This can be expressed typically as:

$$Fe + 2\underline{Al} + 4\,\underline{O} \rightarrow FeO{\cdot}Al_2O_3 \qquad (1)$$

which simply says that aluminum and oxygen dissolved in molten iron combine with each other to form hercynite. When more than one metallic deoxidizer is present, the situation becomes more complex. For instance, manganese and silicon together are capable of producing a lower oxygen level than either used alone. Other combinations such as silicon-aluminum or manganese-aluminum-silicon exhibit a similar trend. Not only is the dissolved oxygen content of the steel affected, but the chemistry and physical nature of the deoxidation products vary according to the specific deoxidizers used.

Another method of deoxidizing or degasifying steel is vacuum degassing. In this process, molten steel is exposed to a vacuum which favors the reaction:

$$\underline{C} + \underline{O} \rightarrow CO \qquad (2)$$

Reactions of the type represented by equation (1) are little affected by pressure, but in equation (2) the product of the reaction is carbon monoxide, a gas. For reaction (2)

$$\frac{a_c \times a_o}{P_{co}} = K$$

and at 1600°C, $K \sim 2 \times 10^{-3}$. If we have, say, an 0.2 percent C melt and have a partial pressure of CO of an atmosphere and assume for simplicity that activities equal weight percent, then

$$[\%0] = \frac{2.0 \times 10^{-3} \times 1}{0.2} = 10^{-2}$$

But if we expose the same steel to a vacuum of say 76 microns Hg, then

$$[\%0] = \frac{2.0 \times 10^{-3} \times \dfrac{76 \times 10^{-3}}{760}}{0.2} = 10^{-6}$$

Such extremely low oxygens are not attained in practice for a number of reasons; among them, melt-crucible reactions, ferrostatic pressure of the melt and factors associated with the nucleation of the CO bubble.

The example illustrates clearly, however, the manner in which vacuum serves to promote deoxidation through the formation of CO.

Youngstown has recently installed a vacuum degassing unit as the latest step in a continuing search for better understanding of deoxidation phenomena, improved practice, and stringent control in production.

The work in eliminating inclusions is only a small part of the constant research going on 24 hours a day at Youngstown's research center. If you believe Youngstown can help you, call at your convenience. Or, write Department 251C6.

Youngstown Steel

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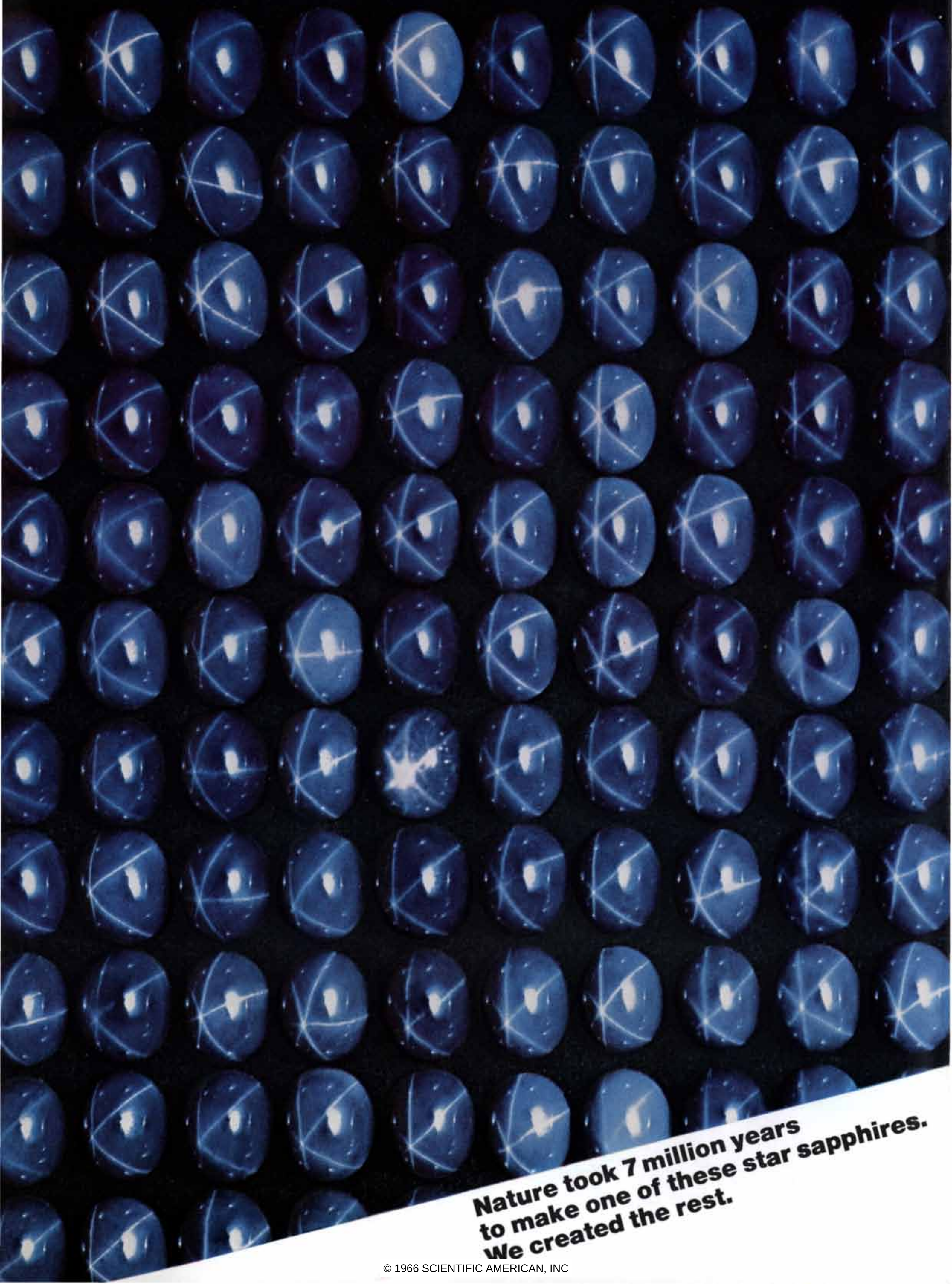
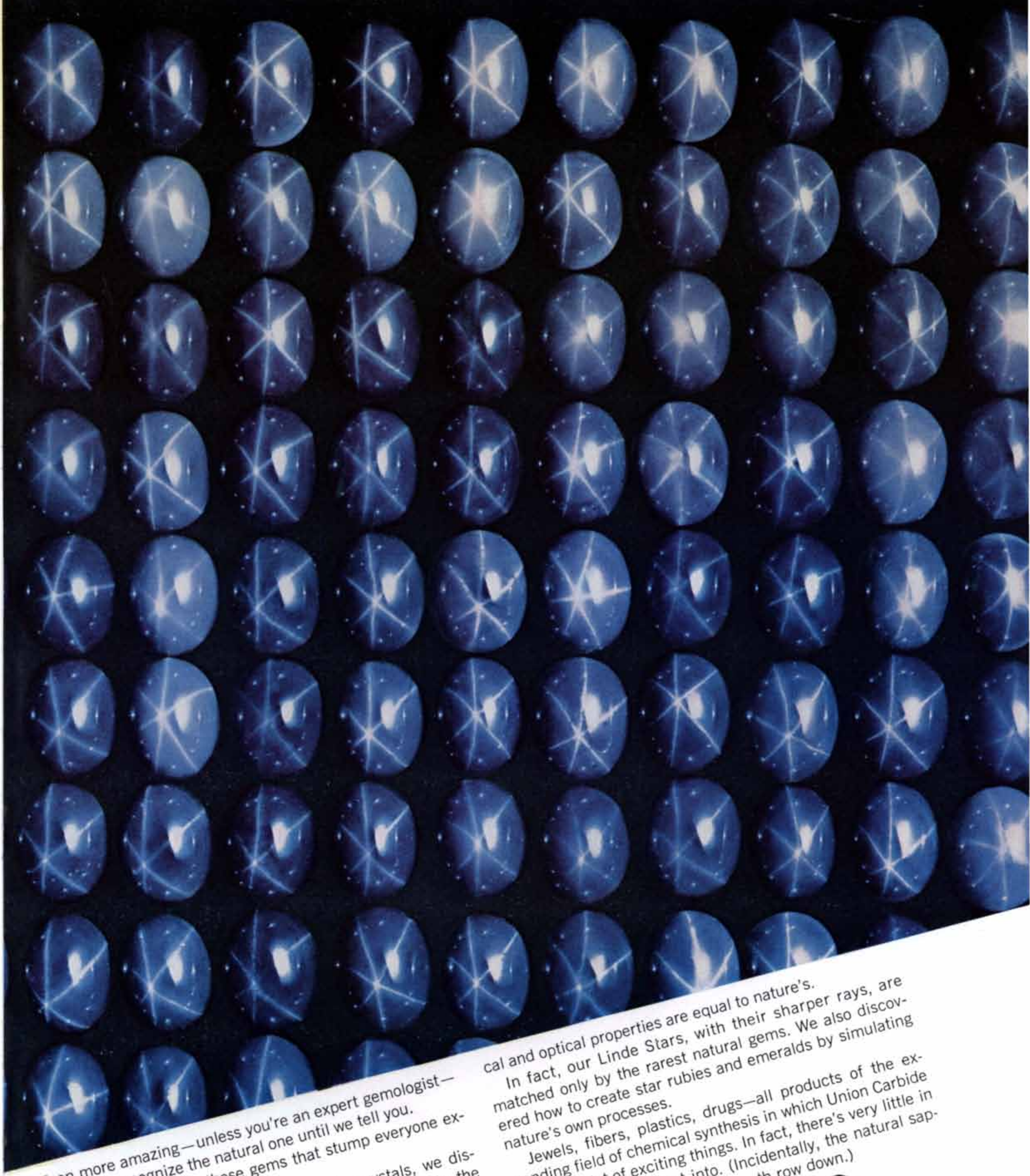

Nature took 7 million years
to make one of these star sapphires.
We created the rest.



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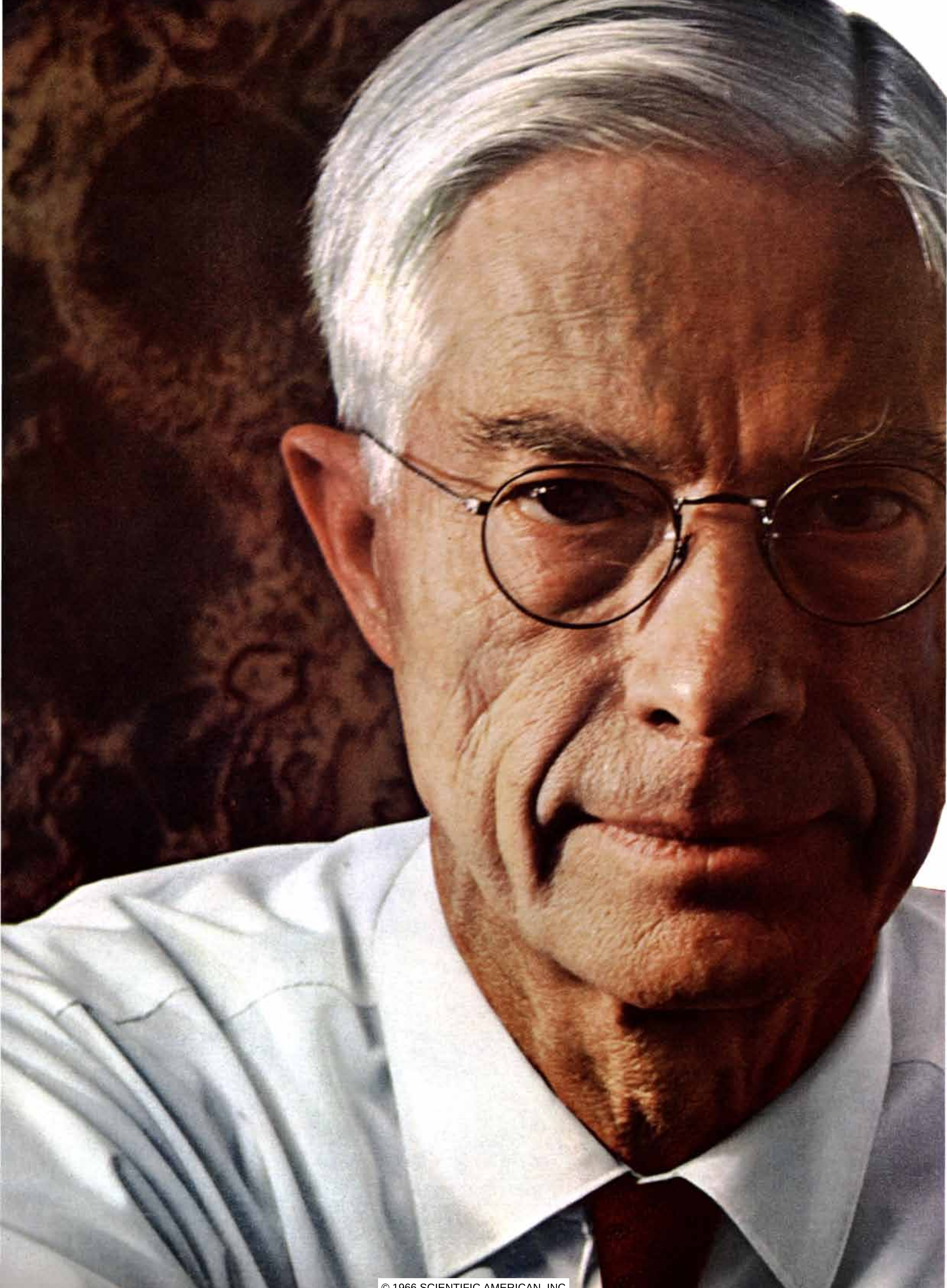

This astronomer studies the moon's orbit for clues to the universe.

What's he doing at IBM?

Dr. Wallace J. Eckert has developed a theory of lunar motion that predicts the path of the moon 100 times more accurately than ever before.

But, in comparing his theory with precise observations of the moon, Dr. Eckert finds a small difference in the rate of rotation of the moon's orbital plane. No one knows why.

"It's an intriguing problem," says Dr. Eckert. "When we find the answer, it's more than likely we will have improved our understanding of the laws of nature." Computers are speeding that process.

Dr. Eckert was one of the first men to apply computers to the solution of scientific problems. And he has had a major role in guiding other scientists in their use. In fact, his work in this field and his theory of lunar motion earned him an award from the National Academy of Sciences that has been given only 19 times in 92 years.

The computer's potential as a problem-solving device in science is just being tapped. To push the computer to its limits, IBM has scientists in many fields—men like Dr. Eckert.

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THE AUTHORS

BURKE M. SMITH ("The Polygraph") is associate professor of neurology and psychiatry (clinical psychology) and chief clinical psychologist at the School of Medicine of the University of Virginia. He received all his formal education in Durham, N.C., where he was born; after progressing through the public schools he went to Duke University, where he obtained a bachelor's degree in biology in 1934, a master's degree in psychology in 1937 and a doctorate in psychology 10 years later. From 1947 to 1960 he was with the Veterans Administration, first as chief clinical psychologist at the mental hygiene clinic in Durham and then as chief of the clinical psychology service at the Veterans Administration Hospital in Roanoke, Va. He has held his present positions since 1961. Smith writes that most of his research activities "would come under the heading of psychophysiological" and that he is working now on "a comparative study of the effects of several drugs on the behavior of patients in interviews."

GEOFFREY EGLINTON and MELVIN CALVIN ("Chemical Fossils") are respectively senior lecturer in chemistry at the University of Glasgow and professor of chemistry at the University of California at Berkeley. Eglinton obtained a Ph.D. from the University of Manchester in 1951. He writes: "I once mountaineered in the Alps and the Rockies but now feel nervous peering through the protective glass at the top of the Empire State Building." Calvin, winner of the Nobel prize for chemistry in 1961 for his work in elucidating the chemical pathways of carbon in photosynthesis, is a member of the President's Science Advisory Committee and a foreign member of the Royal Society. He was graduated from the Michigan College of Mining and Technology in 1931 and received a Ph.D. from the University of Minnesota in 1935. From 1935 to 1937 he was a research fellow at the University of Manchester; he joined the faculty of the University of California at Berkeley as an instructor in chemistry in 1937.

JOE BEN WHEAT ("A Paleo-Indian Bison Kill") is professor of natural history at the University of Colorado and curator of anthropology at the University of Colorado Museum. He was graduated from the University of California at Berkeley in 1937 and obtained a Ph.D. from the University of Arizona in 1953. Wheat has done archaeological work with three agencies of the Federal Government—the Works Progress Administration, the Smithsonian Institution and the National Park Service—and has been involved in a number of archaeological expeditions. He taught at the University of Arizona before joining the faculty of the University of Colorado in 1953. Wheat writes that he "first became interested in archaeology at about the age of nine through collecting arrowheads and other artifacts from the sand dunes near the town of Van Horn, Tex."

E. J. JENSEN and H. S. ELLIS ("Pipelines") are research officers with the fuels division of the Research Council of Alberta. Jensen, a native of Copenhagen, was graduated from the Technical University of Copenhagen in 1942 and worked in private industry in Denmark and Sweden before moving to Canada in 1954. He did research on coal before taking up his present work on the development of pipelines for transporting solids. Ellis was graduated from the University of London in 1938 and worked in England for several years before moving to Canada. Both authors have spent the past six years on research in the transport of slurries and capsules in pipelines and have written extensively on the subject.

S. A. BARNETT ("Rats") is a senior member of the department of zoology at the University of Glasgow. He took a first in zoology at the University of Oxford in 1937 and remained there doing research on chemical embryology. During and after World War II he did research for the British government on pest control and helped to fight plague in the Mediterranean region. He went to the University of Glasgow in 1951. His particular research interests are the physiology of social stress in wild rats and the physiology, behavior and genetics of breeding mice in an environment kept at −3 degrees centigrade. His book *Instinct and Intelligence* is scheduled for publication in the spring.

MARTIN POPE ("Electric Currents in Organic Crystals") is associate professor of chemistry at New York University. He was graduated from the City College of the City of New York in 1939. After four years of military service he resumed his studies in 1947, obtaining a doctorate in physical chemistry from the Polytechnic Institute of Brooklyn in 1950. He spent five years in industrial employment before going to New York University, where he has worked in the radiation and solid-state laboratory of the physics department. He writes that some of the work described in his article "has been carried out with the collaboration and assistance of H. Kallmann; other aspects of this work enjoyed the collaboration and assistance of R. Laupheimer, J. Burgos, J. Giachino and S. Fox."

MARTIN GARDNER ("Can Time Go Backward?") has conducted the "Mathematical Games" department of SCIENTIFIC AMERICAN since December, 1956. That is only one of his numerous activities. He has written several books (including *Relativity for the Million, The Ambidextrous Universe* and *The Annotated Ancient Mariner*), compiled three books from his "Mathematical Games" columns and edited two other books. His extensive writings include short stories. He is also keenly interested in magic as a hobby. Born in Tulsa, Okla., Gardner was graduated in 1936 from the University of Chicago, where his major subject was philosophy. His first work was as a reporter for the Tulsa *Tribune* and then, until World War II, he was in the public relations department of the University of Chicago. After service in the Navy during the war he began his career as a free-lance writer.

ROBERT W. LEADER ("The Kinship of Animal and Human Diseases") is associate professor of comparative pathology at Rockefeller University and head of the university's laboratory of comparative pathology. Leader, who describes himself as "a native of the rain forest of the State of Washington," obtained the degree of doctor of veterinary medicine from Washington State University in 1952. After postdoctoral work there and at the University of California at Berkeley he spent several years on the faculty of Washington State University, beginning as assistant professor and ending as professor of veterinary pathology. In 1965 he was invited to establish the laboratory of comparative pathology at Rockefeller University.

RUDOLF E. PEIERLS, who in this issue reviews *The Conceptual Development of Quantum Mechanics*, by Max Jammer, is Wykeham Professor of Theoretical Physics at the University of Oxford.

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The Polygraph

The use of such an instrument as a "lie detector" raises two types of question: scientific and ethical. Some answers to the first kind of question clearly point to the greater significance of the second

by Burke M. Smith

The Bedouins of Arabia once required conflicting witnesses to lick a hot iron; the one whose tongue was burned was considered to be lying. The ancient Chinese, it is said, made someone who was being questioned chew rice powder and spit it out; if the powder was dry, the suspect was guilty. In ancient Britain a suspect who could not swallow a "trial slice" of bread and cheese was also found guilty. All these tests were based on the early observation of a physiological change that often accompanies emotional tension: the flow of saliva decreases and the mouth becomes dry. Today too physiological changes are sometimes taken as a sign that the person in whom the changes occur is not "telling the truth." The changes are measured—rather more accurately than by a hot iron, rice powder or bread and cheese—by the device called the polygraph or, quite incorrectly, the "lie detector." Such devices are used in law enforcement and private investigation and by government and industry for checking the reliability of employees. In the past few years both the methods of "lie detection" and the polygraph itself have been subjected to increasingly critical scrutiny.

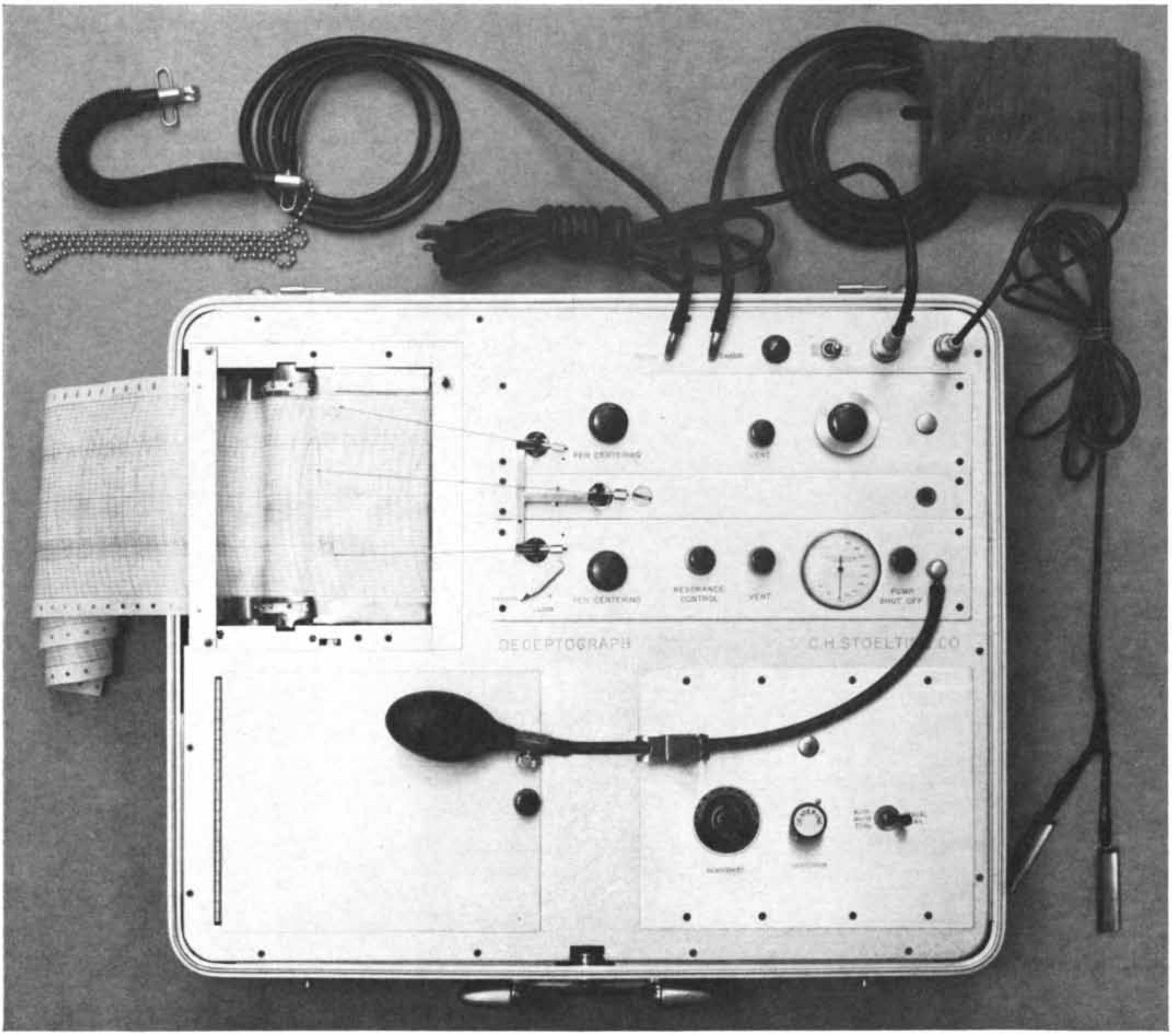
In reality the use of the polygraph in the effort to detect deception is only one rather special application of one version of a broad class of instruments. The word "polygraph" correctly describes any device that writes a number of things, that is, an instrument that records several events or processes at once. A device that simultaneously records temperature, humidity and barometric pressure is a polygraph; so is one that records engine revolutions and oil pressure. The term is commonly applied, however, to instruments that record various measurements of physiological activity in medical diagnosis, personality studies and other psychological or physiological research. The "lie detector" polygraph is a simple version of such an instrument.

"Lying" is a complex phenomenon with philosophical and psychological aspects beyond the scope of this article. The ordinary concept of lying, on which investigative polygraphy is based, is that the liar knows his assertion is a lie, that he lies deliberately and purposefully and that his effort at deception is accompanied by one or more emotional responses such as guilt, anxiety and fear. These emotional responses are accompanied by physiological responses—the most obvious are changes in salivation, heart rate, breathing and skin temperature—under the involuntary control of the autonomic nervous system. (Many of these responses are also, although to a lesser extent, under voluntary control, a fact that complicates lie detection.) Some of the grosser physical manifestations of emotional tension are hesitation, stammering, fidgeting, perspiration and reddening of the face. It is such clues that almost automatically come to the mind of anyone who is trying to decide if someone else is telling the truth.

The first attempt to record with instruments the physiological accompaniments of the emotional experience of lying was made in 1895 by the Italian criminologist Cesare Lombroso. He measured changes of pulse rate and blood pressure in suspected criminals who were being interrogated, and reported some success in identifying guilty individuals. In 1914 another Italian, Vittorio Benussi, announced that he was able to connect changes in the rate of breathing with deception. The following year William Moulton Marston, a criminal lawyer and a student of the American psychologist Hugo Munsterberg (who had suggested the possibility of detecting lies by recording physiological changes), undertook research at Harvard University into the correlation between lying and changes in systolic blood pressure. He reported successful results in 1917. During World War I a National Research Council committee proposed that his method be applied in counterintelligence work, but the idea was not pursued. It did, however, attract the attention of John A. Larson, a police officer with psychological training, who in 1921 constructed the forerunner of the present "lie detector" polygraph. It made a continuous recording throughout an interrogation of the three processes dealt with by Lombroso, Benussi and Marston—blood pressure, pulse rate and respiration. Leonarde Keeler, an associate of Larson's on the police force in Berkeley, Calif., refined the device and went on to develop polygraph-interrogation techniques in the crime detection laboratory at Northwestern University.

The Keeler instrument, in one version or another, has become the standard commercial polygraph: a simple, compact and often portable machine that records pulse rate, relative blood pressure, the rate and depth of breathing and often the resistance of the skin to the conduction of electricity. The cardiac variables—pulse rate and relative blood pressure—are picked up by a pressure cuff such as physicians use to take absolute blood pressure, placed around the upper arm and inflated so as to impede but not quite cut off circulation. Changes in the pressure of the blood flowing through the brachial artery are transferred to the recording pen by the column of air in a rubber tube; individual pulses show up as more rapid fluctuations superposed on the blood-pressure curve. The rate and depth of breathing are sensed by an accordion-like pneumatic device fastened around the chest. Skin resistance, variously referred to as galvanic skin response (GSR), psychogalvanic response (PGR) and electrodermal response (EDR), is detected by two electrodes placed on the fingers or other parts of the hand. A small electric current, made to flow through the electrodes and through an arbitrary resistance and a galvanometer, varies with changes in the resistance of the skin. The skin response is associated with the sweating of the palms that comes with tension but is not due simply to increased activity of the sweat glands. Its exact nature is still under investigation, but it apparently involves a number of electrical changes in the skin, including polarization of the sweat gland membranes.

Although a few practitioners still call the commercial polygraph the "lie detector," it is generally agreed that the instrument itself records not lies but physiological changes. Any detecting of lies is done by the examiner, the person who conducts the interrogation. A great deal depends, therefore, on the technique of examination, and this varies widely with different examiners and different "systems." The examining session is conducted in an atmosphere that is inevitably at least somewhat tense, so that the examiner's first effort is to get the subject to relax and to explain to him in some detail the procedure that will be

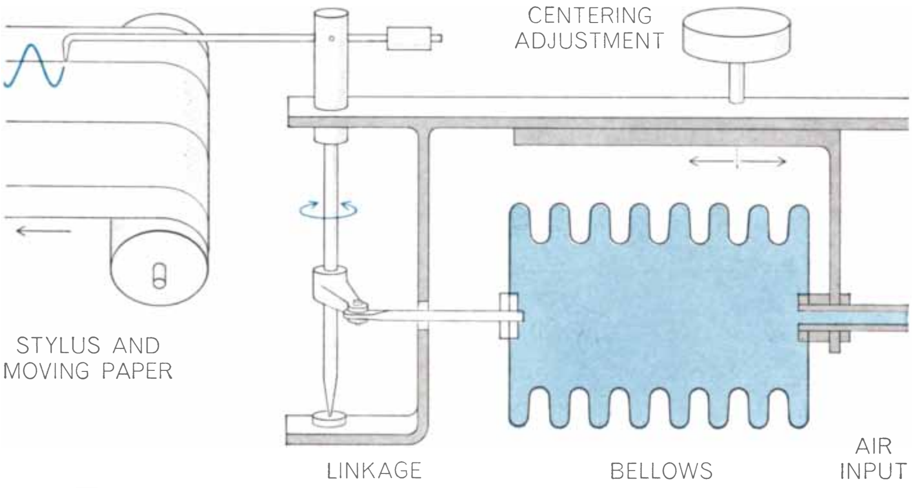


PORTABLE POLYGRAPH is shown with its attachments. The corrugated tube at the top left is placed around the chest to measure respiration. The cloth cuff (*top right*) senses blood pressure and pulse. The cable and finger electrodes (*right*) are for the instrument that measures the galvanic skin response. The three pens record (*top to bottom*) respiratory, skin and cardiac responses.

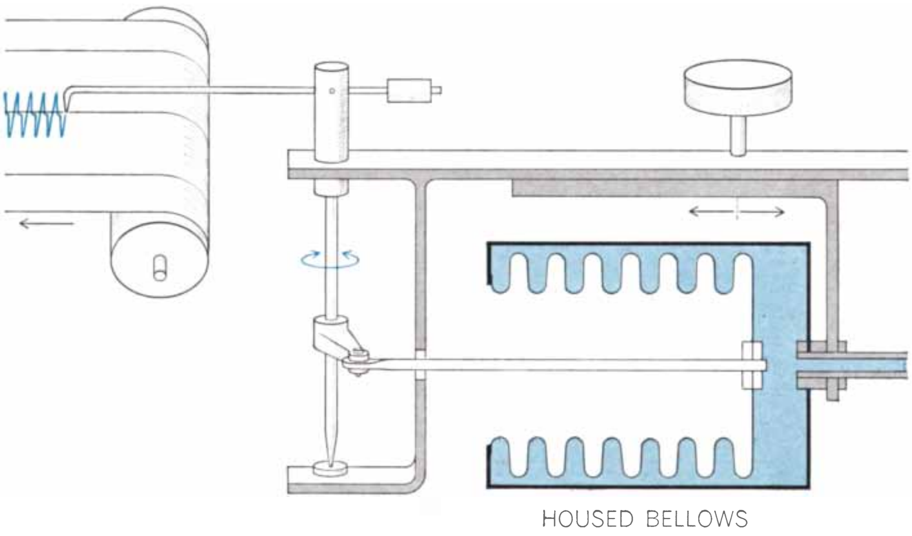
followed. Many practitioners conduct a rather full preexamination interview during which material is gathered for neutral "control" questions. Usually all the questions that will be asked during the examination proper are gone over in advance; among other things, this makes it possible for the subject to "clear" himself with regard to the critical questions. For example, it is desirable that he first admit to having once taken money from his little brother or a former employer so that he can later give an unequivocal answer to a question such as: "Apart from what you told me before, have you been stealing money?" Throughout the period before the examination it is common practice to impress the subject implicitly or explicitly with the idea that "the machine cannot be beaten."

Finally the subject is seated in a special chair and the various sensors are attached to him. The polygraph is turned on and the recording pens are adjusted to a normal base line. Then the series of carefully worded questions, each answerable by "Yes" or "No," is read to the subject; a marker is placed on the record for each question and the answer is jotted down. In most techniques "critical" questions are interspersed among "neutral" ones, the assumption being that the machine will record greater fluctuations from normal when the subject answers critical questions untruthfully. A substantial interval—up to a minute or so—is allowed between questions so that the traces can return to the base line. Often the entire examination is repeated after a period during which the examiner may try to clarify any ambiguous points. New questions can be added to achieve special objectives. For instance, in a "peak of tension" test the examiner can try to determine the location of a crime by suggesting various sites or progressively narrowing circles and watching for signs of increasing and decreasing tension in the subject.

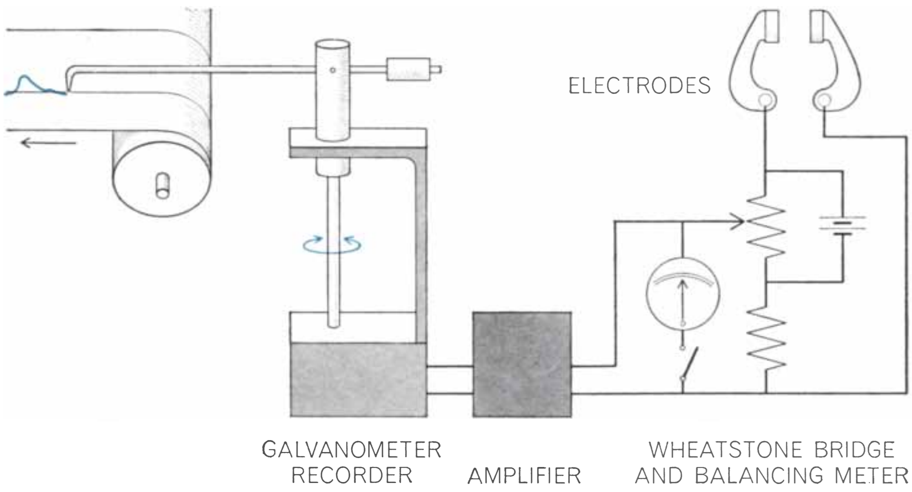
Once the record is obtained there are several things that can be done with it. One practice, which is certainly not rare, is simply to show the subject some oscillations on the tape, accuse him of a lie and thereby elicit a confession. The genuine interpretation of a record requires a good deal of technique. It is seldom that a lie is clearly indicated by distinct changes in the cardiac, respiratory and galvanic-skin-response traces; the variations are usually small, and often they are mutually contradictory. There are various systems for interpreting records, all relying on visual scanning of the traces and each taught by a different polygraph school or institute. There is considerable



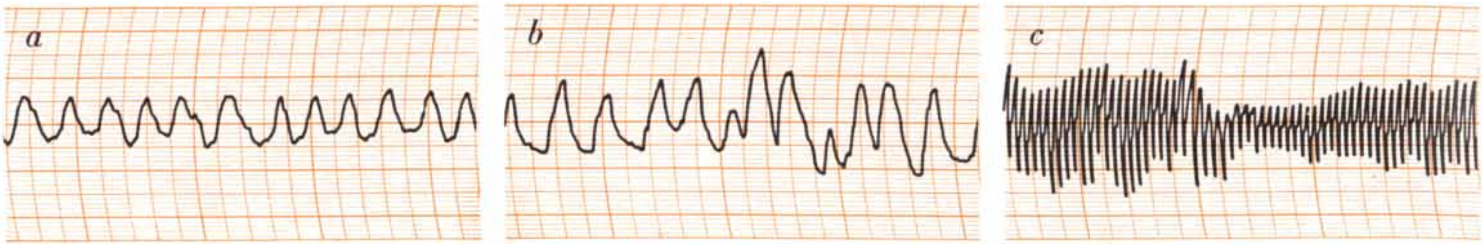
RESPIRATION recorder operates by dead-air displacement. An accordion-like tube fitted to the subject's chest is connected to the thin-walled metal bellows. As the subject inhales or exhales, air (*color*) is withdrawn from or returned to the bellows, rotating the vertical shaft that carries the pen. The pen is centered by moving the bellows assembly manually.



BLOOD PRESSURE can be recorded by a similar system but requires a "housed bellows" to withstand the air pressure in the measuring cuff around the subject's arm. When the cuff has been inflated (with the rubber bulb seen in the photograph on the opposite page), the pen is centered. Changes in blood pressure affect the volume of the cuff and thus the pressure in the bellows. The pen therefore records the pulse rate and relative blood pressure.



SKIN RESPONSE is recorded by a unit that includes a Wheatstone bridge and a galvanometer. The bridge is balanced by adjusting a variable resistance to match that of the subject's skin. Any subsequent changes in current across the electrodes are amplified and recorded.



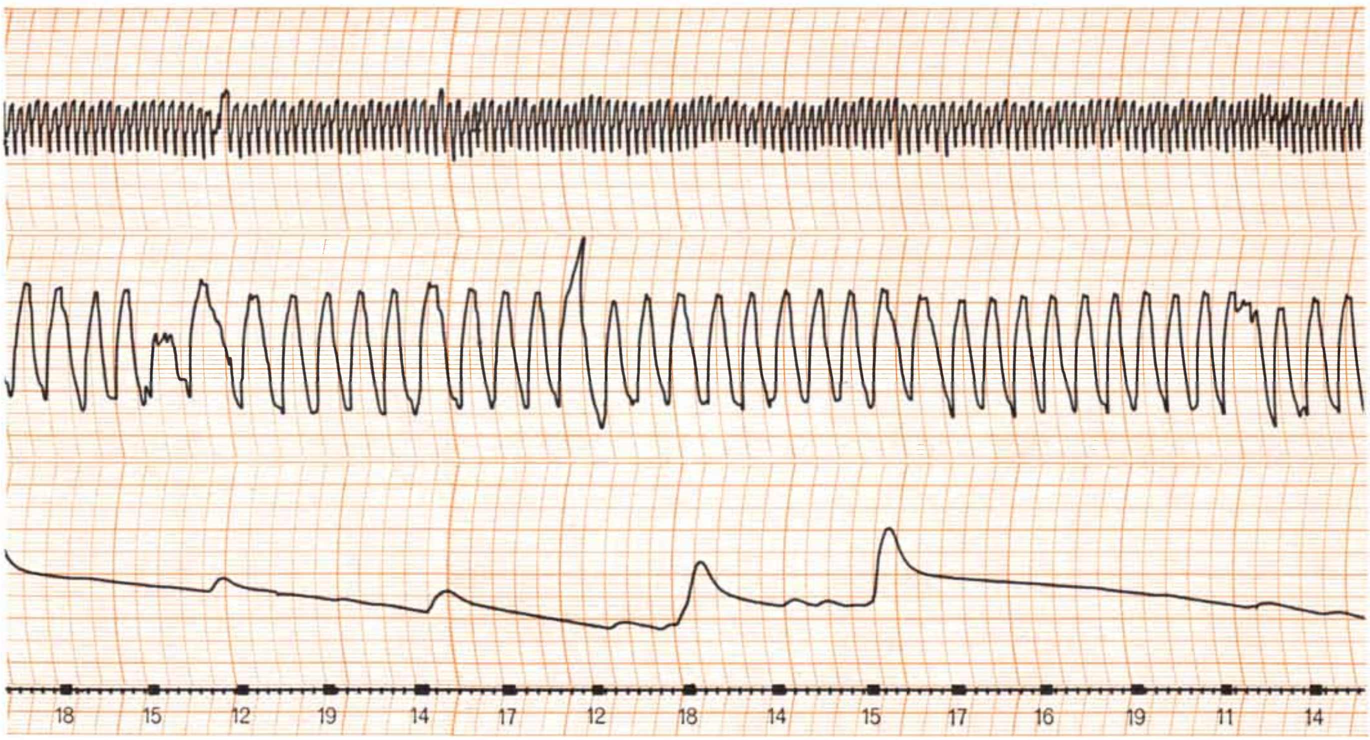
SAMPLES from polygraph records illustrate the variability in traces from different subjects and some possible indications of emotional responses. A respiratory trace may show variations in period (*a*) or magnitude (*b*). Blood-pressure curves (made in this case by a plethysmograph, which measures blood volume in a fingertip, instead of by an upper-arm cuff) can vary widely. An

intuition involved; as one examiner puts it, the analysis is "a Gestalt process." Most polygraphers come to prefer one index and may ignore the others; some work with instruments that measure only two or three of the four usual indexes.

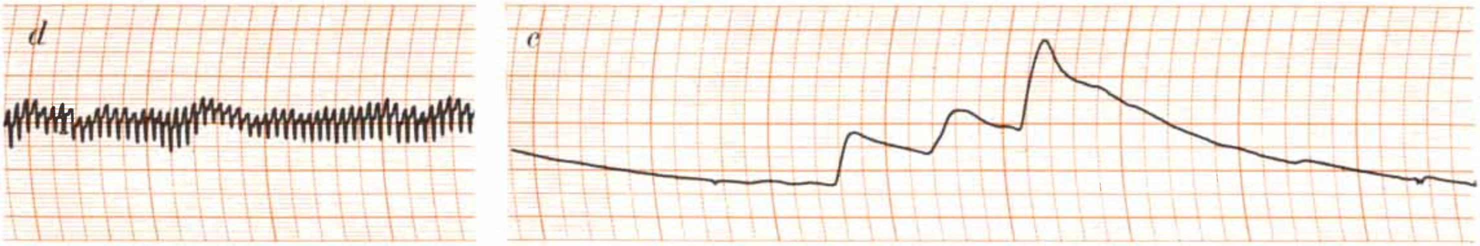
Polygraph operators, of whom there are an estimated 2,000 to 3,000 in the U.S., vary widely in their general educational background and training in polygraphy. Some are college graduates and a few are lawyers or have other advanced degrees; most are high school graduates with no academic background in psychology or physiology. For the most part they are trained at commercial or Government-run polygraph schools for between four and seven weeks. It is possible, however, to take a correspondence course instead. There is no general agreement among polygraphers on what constitutes adequate educational and on-the-job preparation, but many believe a six-month training course should be a minimum requirement.

Although the polygraph was developed as an aid in police work, enterprising practitioners have long since discovered new applications for the device and since about 1950 the polygraph has become firmly established in industry and government. There are some 500 commercial polygraph firms. Many companies retain polygraph examiners not only to investigate specific losses but also to conduct routine preemployment interviews in an attempt to identify applicants with a criminal record, alcoholics, homosexuals or people who are likely to be disloyal to the company. Some companies give a polygraph test before promoting an employee. Many companies, particularly those whose employees regularly handle money, administer periodic polygraph tests "to keep them honest."

In 1964 and 1965 a Congressional subcommittee headed by Representative John E. Moss of California investigated the use of polygraphs in the Federal Government. The committee found that 19 agencies had a total of at least 512 polygraphs and 639 authorized operators who had conducted some 20,000 examinations in 1963. (These figures do not include the Central Intelligence Agency or the National Security Agency, presumably the biggest users.) Some of the tests were administered in the course of criminal investigations; others were for security purposes or simply for personnel screening. The report charged that most Federal polygraph operators lacked proper qualifications, that administrative controls were weak and that employees' rights were frequently violated. The committee concluded: "Polygraph testing is extensive and growing in the Federal Government. All too often



RESPIRATION AND SKIN responses are of interest in this record from an experiment in which subjects picked a number and then tried to conceal its identity from the examiner. In this case the number was 15. The skin-resistance trace (*bottom*) peaks at 15. Breathing (*middle*) is cut short and then slowed (*left*) or merely slowed (*right*). Anomalous respiration peaks may indicate movement.



emotional response may be indicated by a constriction (*c*), which indicates a decrease in systolic and increase in diastolic pressure, or by a general rise in pressure (*d*). The galvanic skin response, which is not superposed like the others on a cyclical curve, may be easier to read, as in the "peak of tension" test the result of which is illustrated (*e*). This response is not dependably present, however.

it is used on trivial matters." It recommended, among other things, that use of the polygraph be prohibited "in all but the most serious national security and criminal cases." Four months later the Department of Defense did issue a directive sharply reducing the use of the polygraph, regulating the conduct of examinations and setting higher standards for polygraph examiners.

Outside the Federal Government the polygraph remains largely uncontrolled. Evidence from the polygraph record is not admitted in any court, but the device can be used freely for investigations in most jurisdictions. In 1959 Massachusetts adopted a law forbidding employers to require job applicants to take a polygraph test as a condition of employment; since then Oregon, California and Alaska have passed similar laws. So far only Illinois, Kentucky and New Mexico have adopted legislation requiring polygraph operators to be licensed. Some of the training schools come under the supervision of state regulatory boards, but standards vary widely.

The complaints against investigative polygraphy fall into two broad categories: scientific and ethical. Polygraphy is sometimes called "scientific lie detection"; its critics often suggest that this is a misnomer. A scientific technique, they maintain, must rest on a theory and be developed through experimentation and findings expressed in statistics. It should utilize the best tools available and be refined through continuing research. None of this is true of polygraphy. There is, to be sure, a related scientific discipline: psychophysiology. Whereas the standard polygraph has not basically changed since the 1920's, polygraphs designed for research have become much more sophisticated. Some of them can record data on 20 or more physiological processes at once. Varied and more precise sensors have been developed to detect physiological changes; electronic circuitry has been introduced to transmit the changes through several stages of amplification to the recorder; in some cases the data can be immediately processed and analyzed by computer. A broad range of additional physiological responses has been investigated: changes in brain waves, skin temperature, muscle potentials, hand and finger tremors, eye movements, pupil diameter, salivation and even stomach motions.

As research instruments polygraphs have produced valuable data on the reactions of people to various kinds of stress, including the effects of drugs as well as of emotional stimulation. One of the interesting findings is that there are large individual differences in responsiveness to identical stresses. People

CARDIAC AND SKIN responses are the most pronounced ones on this record made, like the others on these two pages, by Joseph F. Kubis of Fordham University. In this test the subject was lying as to number 26. The skin response peaks each time the number is called; the blood-pressure change (*top*) is fairly clear the first time. The cardiac change at 22 is probably from an arm movement.

tend to exhibit repeatable patterns of response: for one person the cardiovascular system may quite regularly mirror emotion most sensitively, whereas another person may be primarily a "pulmonary reactor." Moreover, some organ systems "adapt"—become less responsive—after a number of stimulations. In any individual, therefore, certain autonomic responses are better indexes of emotion than others. This and other findings should be of interest to polygraph practitioners, but there has apparently been little or no crossover from scientific to investigative polygraphy. And the scientists, perhaps not surprisingly, have done little research bearing directly on the detection of deception.

The lack of research gives rise to the major question about investigative polygraphy: How well does it work? To be effective an instrument or a test must be valid and it must be reliable. Validity is the extent to which something measures what it is supposed to measure: the Rorschach test, for example, can be considered a valid test of personality only insofar as its results show positive correlations with the results of other personality tests and with experience. Since the polygraph as an instrument measures not lies but physiological changes, the question is how well the results of the total polygraph examination—the interrogation, the record and the interpretation of the record—correlate with objective, independent measures of deception.

Good evidence on this question can come only from a comparison of examination findings with the results of thorough, independent investigations. There are no such statistics. In the few cases in which effectiveness has been evaluated, confessions of guilt or of attempts to deceive have been commonly taken as criteria for determining validity. The trouble with this is that in many cases the confession may have come before or during the examination, or even after an inconclusive examination, which is thereupon said to have been conclusive! Moreover, it is well known that confessions are not always reliable.

One such case, which I investigated with H. B. Dearman, then of the University of Virginia School of Medicine, involved a young bank manager who was subjected to a "routine" polygraph examination. He showed a violent response to the question: "Have you ever stolen any money from the bank or its customers?" On a peak-of-tension test to specify the amount of money stolen, he showed strong reactions at the mention of the sums $800 and $1,100. He could not remember taking any such sum but, confused and convinced of the machine's infallibility, he confessed to having stolen $1,000 and told how he must have done it. The bank's auditors could find no such shortage or manipulation, and so the manager was referred for psychiatric examination. Dearman found that the patient had strongly ambivalent feelings about his mother and wife and felt guilty about personal financial dealings with them involving the sums of $800 and $1,100. Both the mother and the wife were customers of the bank. Dearman therefore concluded that it was the phrase "or its customers" in the critical polygraph question that had elicited the violent reaction.

To test this hypothesis we had a different polygraph examiner administer a second test with the same questions that were used on the first, and also new questions in which the words "bank" and "customers of the bank" were separated. Once again the examiner decided the manager was lying and was guilty of theft. Careful study of the polygraph record showed, however, that consistent emotional reactivity was displayed only to questions in which the word "customers" appeared.

Clearly the original polygraph results were not valid. It was not deception but an autonomic response to unconscious attitudes that had caused the strong polygraph reactions. The same effect was shown on a trivial question included as a control: "Do you drink coffee?" The manager answered, quickly and truthfully, "Yes," but the polygraph showed a strong emotional reaction. The young man could not explain this, but psychotherapy revealed that coffee-drinking had been absolutely forbidden during his childhood; the memory of that prohibition had been lost or suppressed but remained potent. In much the same way a confirmed smoker who thinks he should stop smoking might respond emotionally to the question "Do you smoke?" In fact, any word that happens to have strong emotional connotations for an individual and that is included in a critical question may elicit a response that is erroneously attributed to an attempt at deception.

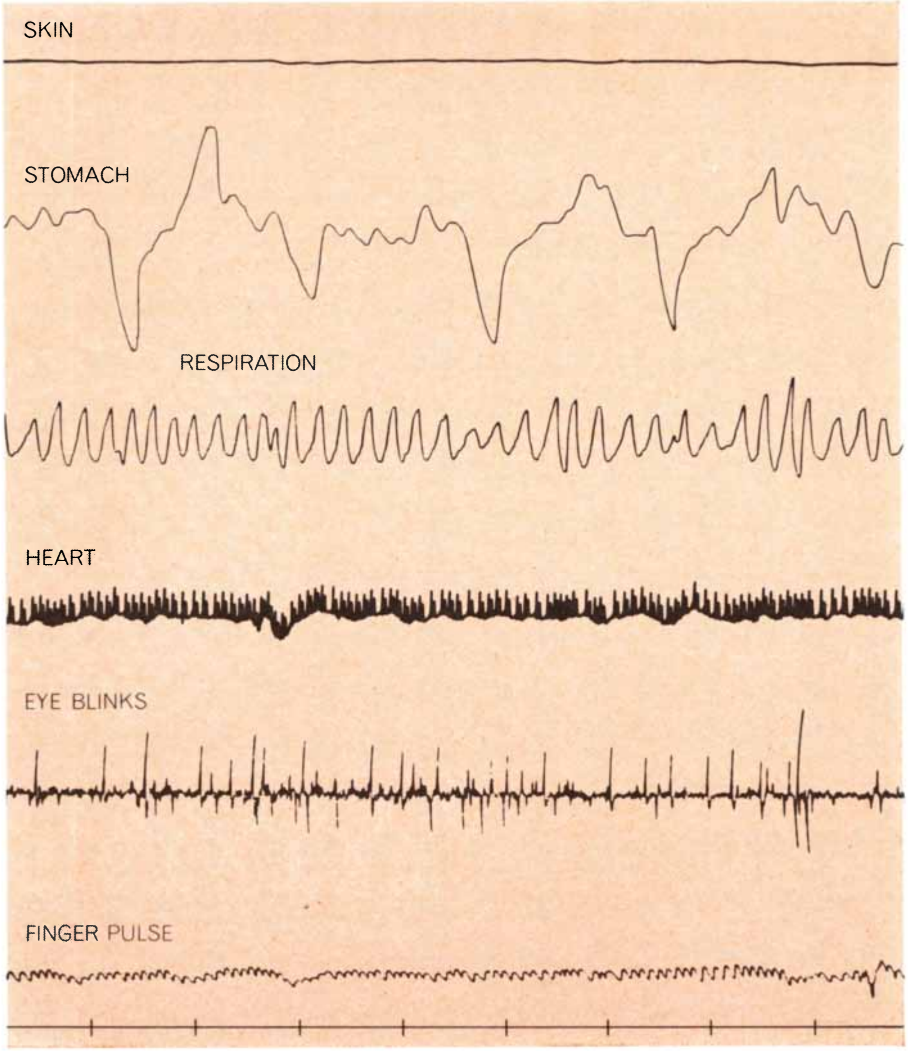
There are other pitfalls that can lead to "false positive" or "false negative" interpretations of a record. Some people are emotionally highly sensitive even to supposedly neutral stimuli; others are unresponsive. A person who believes what he says is true may show no emotional response even when he says what is objectively untrue. A person who is ashamed of his name may show emotion when he quite truthfully answers "Yes" to "Is your name Adolf Schicklgruber?"

To be effective a test must be not only fundamentally valid but also reliable,

COUNTERMEASURE is illustrated by a record from Kubis' series. The subject lied about number 27. He simulated lying about number 22 by tensing his toes. The respiratory trace (*top*) shows that he held his breath as he undertook the first countermeasure. He was able to produce sizable reactions in the cardiac (*middle*) and skin-resistance (*bottom*) traces.

that is, it must be capable of being repeated by different people and under different circumstances and yield about the same results. It is difficult to assess reliability in polygraphy because there are no absolute measures or even any hard numbers; there are only ups and downs, visually scanned, so that it is impossible to compare two sets of results with any precision. There are certainly a number of potential sources of inaccuracy. The instrumentation is relatively crude. It is known that reactivity varies with the "initial value" of a physiological process, but the polygrapher does not know that value. Room temperature and humidity and the subject's physical condition affect the record but are seldom taken into account. A badly phrased question may complicate an answer (as in the case of the "bank or its customers" question put to the bank manager). Even the tone of the examiner's voice or his manner as he asks a question can influence the nature of the response; few investigative polygraphers have the training, skill, interest or time required to recognize and rectify such sources of error. Finally, there is the possibility of countermeasures. The machine can be "beaten" by a subject who either tenses some muscles or concentrates on some exciting image or thought and thereby creates a false-positive response to obscure his critical responses.

In spite of all these problems, a polygraph interrogation by an experienced examiner certainly has a better-than-chance probability of arriving at a correct determination of truth or deception. The question is: How much better? Polygraphers claim anywhere from 95 to 100 percent accuracy but, as I have indicated, they have no valid statistics to support their claims and few scientists have sought to investigate the matter. Joseph F. Kubis of Fordham University did conduct a study of the methods of polygraphy in 1962. His major experiment involved a sham theft situation: the examiners had to distinguish a volunteer "thief" from a "lookout" and an "innocent bystander" on the basis of polygraph interrogations. Kubis found that the examiners correctly identified the volunteers' roles in 73 to 92 percent of the cases; in 112 sessions only two "innocent bystanders" were incorrectly called "thieves." The galvanic skin response provided the highest accuracy (about 90 percent); the respiratory and cardiac indicators yielded figures of 60 to 70 percent. In another experiment, in which parolees were told to lie twice about their criminal records, examiners were able to detect both lies in 40 percent of the cases, one lie in 48 percent and neither lie in 12 percent. In a countermeasure experiment the subjects were able to reduce the examiners' accuracy scores from 75 percent in a control test to 25 percent by thinking of something exciting or upsetting and to 10 percent by tensing their toe muscles.



MULTICHANNEL RECORDING is illustrated by this record made by Richard A. Sternbach of the University of Wisconsin Medical School, who was measuring autonomic responses of children watching a movie. In addition to skin resistance, respiration and finger pulse, he recorded stomach movements with a magnetometer that followed the motions of a tiny magnet the children swallowed, heart rate with an electrocardiograph and eye blinks with an electroencephalographic lead that sensed eye-muscle impulses.

Beyond the scientific questions about polygraph interrogation there are the ethical considerations. First of all, to say or imply that the machine is infallible is to use a lie to detect a lie. To elicit admissions through fear of the machine or misrepresentation of its record is to force a confession. (Incidentally, although evidence based on polygraph results is inadmissible in court, a confession obtained in the course of a polygraph examination may be admissible.)

A person undergoing even a routine polygraph test may inadvertently reveal, particularly in the preexamination interview, information about himself that he would not voluntarily have revealed. The polygraph operator is not a physician or a lawyer or a priest; he is anxious to pass on whatever details he can find to his superior or to the man who has hired him. If his findings cast doubt (rightly or wrongly) on the integrity or reliability of his subject or reveal idiosyncrasies or weaknesses, the subject's welfare or entire career may be harmed. Can such invasions of privacy be justified? It is said that taking a polygraph test is voluntary. Is it really voluntary, however, if a refusal can be interpreted as evidence of guilt or seems likely to jeopardize a job? These and similar questions cannot be answered by scientific investigation; they are questions for all citizens—including scientists—to consider.

CHEMICAL FOSSILS

Certain rocks as much as three billion years old have been found to contain organic compounds. What these compounds are and how they may have originated in living matter is under active study

by Geoffrey Eglinton and Melvin Calvin

If you ask a child to draw a dinosaur, the chances are that he will produce a recognizable picture of such a creature. His familiarity with an animal that lived 150 million years ago can of course be traced to the intensive studies of paleontologists, who have been able to reconstruct the skeletons of extinct animals from fossilized bones preserved in ancient sediments. Recent chemical research now shows that minute quantities of organic compounds—remnants of the original carbon-containing chemical constituents of the soft parts of the animal—are still present in some fossils and in ancient sediments of all ages, including some measured in billions of years. As a result of this finding organic chemists and geologists have joined in a search for "chemical fossils": organic molecules that have survived unchanged or little altered from their original structure, when they were part of organisms long since vanished.

This kind of search does not require the presence of the usual kind of fossil—a shape or an actual hard form in the rock. The fossil molecules can be extracted and identified even when the organism has completely disintegrated and the organic molecules have diffused into the surrounding material. In fact, the term "biological marker" is now being applied to organic substances that show pronounced resistance to chemical change and whose molecular structure gives a strong indication that they could have been created in significant amounts only by biological processes.

One might liken such resistant compounds to the hard parts of organisms that ordinarily persist after the soft parts have decayed. For example, hydrocarbons, the compounds consisting only of carbon and hydrogen, are comparatively resistant to chemical and biological attack. Unfortunately many other biologically important molecules such as nucleic acids, proteins and polysaccharides contain many bonds that hydrolyze, or cleave, readily; hence these molecules rapidly decompose after an organism dies. Nevertheless, several groups of workers have reported finding constituents of proteins (amino acids and peptide chains) and even proteins themselves in special well-protected sites, such as between the thin sheets of crystal in fossil shells and bones [see "Paleobiochemistry," by Philip H. Abelson; SCIENTIFIC AMERICAN, July, 1956].

Where complete destruction of the organism has taken place one cannot, of course, visualize its original shape from the nature of the chemical fossils it has left behind. One may, however, be able to infer the biological class, or perhaps even the species, of organism that gave rise to them. At present such deductions must be extremely tentative because they involve considerable uncertainty. Although the chemistry of living organisms is known in broad outline, biochemists even today have identified the principal constituents of only a few small groups of living things. Studies in comparative biochemistry or chemotaxonomy are thus an essential parallel to organic geochemistry. A second uncertainty involves the question of whether or not the biochemistry of ancient organisms was generally the same as the biochemistry of present-day organisms. Finally, little is known of the chemical changes wrought in organic substances when they are entombed for long periods of time in rock or a fossil matrix.

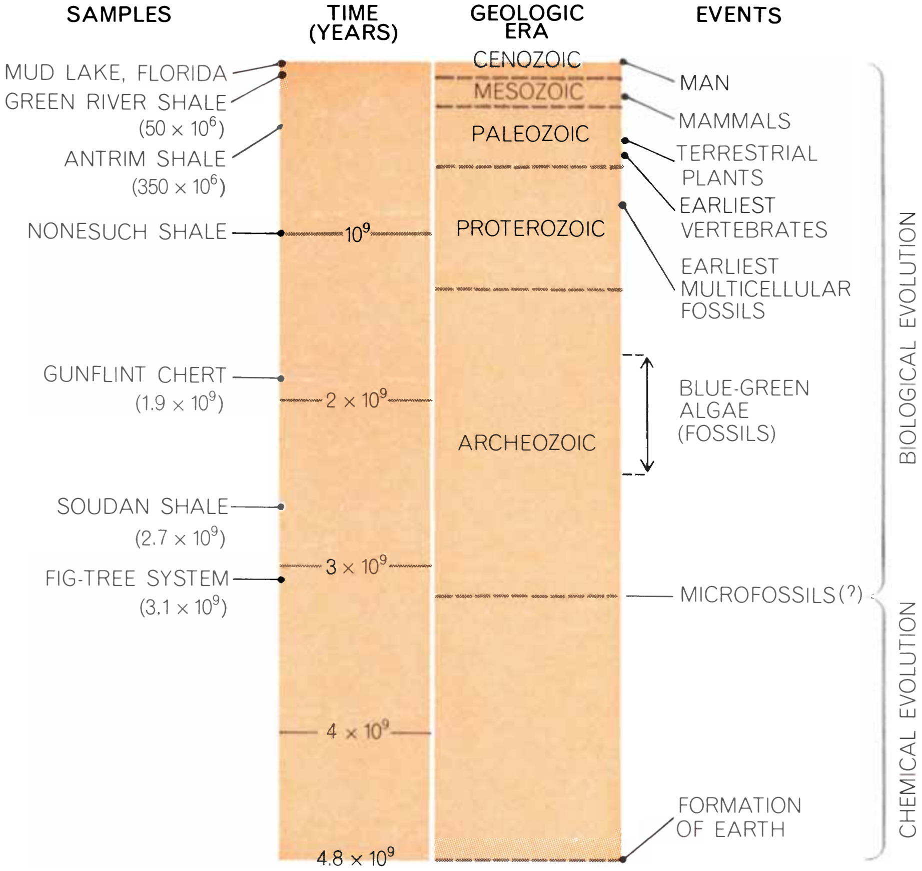
In our work at the University of California at Berkeley and at the University of Glasgow we have gone on the assumption that the best approach to the study of chemical fossils is to analyze geological materials that have had a relatively simple biological and geological history. The search for suitable sediments requires a close collaboration between the geologist and the chemist. The results obtained so far augur well for the future.

Organic chemistry made its first major impact on the earth sciences in 1936, when the German chemist Alfred Treibs isolated metal-containing porphyrins from numerous crude oils and shales. Certain porphyrins are important biological pigments; two of the best-known are chlorophyll, the green pigment of plants, and heme, the red pigment of the blood. Treibs deduced that the oils were biological in origin and could not have been subjected to high temperatures, since that would have decomposed some of the porphyrins in them. It is only during the past decade, however, that techniques have been available for the rapid isolation and identification of organic substances present in small amounts in oils and ancient sediments. Further refinements and new methods will be required for detailed study of the tiny amounts of organic substances found in some rocks. The effort should be worthwhile, because such techniques for the detection and definition of the specific architecture of organic molecules should not only tell us much more about the origin of life on the earth but also help us to establish whether or not life has developed on other planets. Furthermore, chemical fossils present the organic chemist with a new range of organic compounds to study and may offer the geologist a new tool for determining the environment of the earth in various geological epochs and the conditions subsequently experienced by the sediments laid down in those epochs.

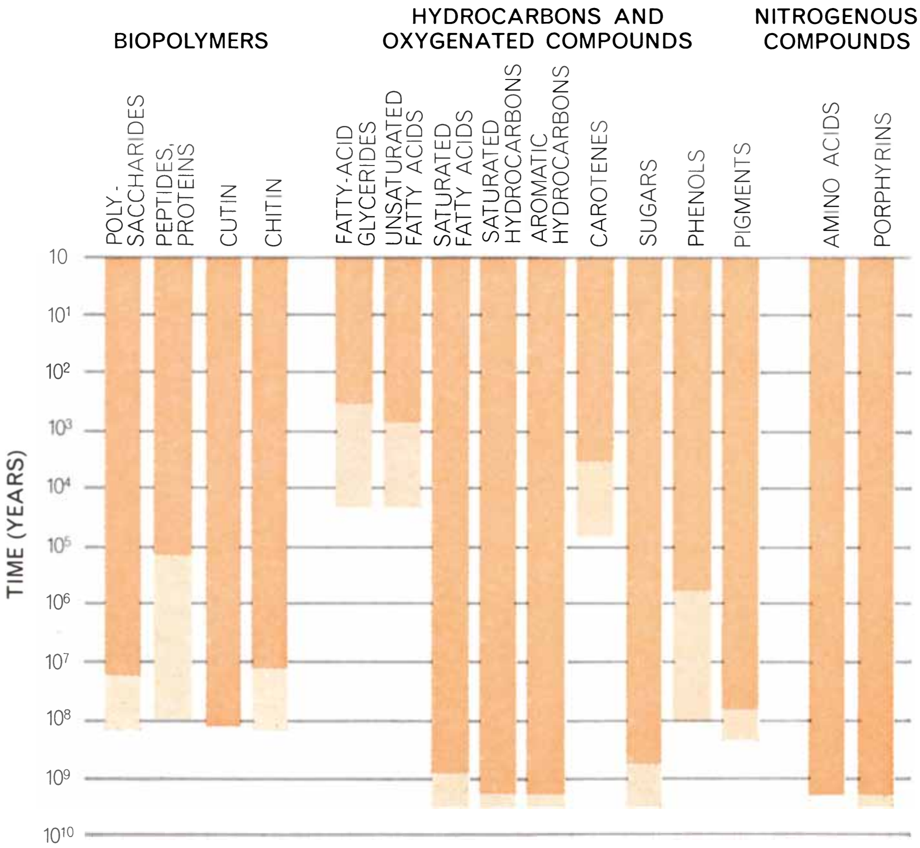
If one could obtain the fossil molecules from a single species of organism, one would be able to make a direct correlation between present-day biochemistry and organic geochemistry. For example, one could directly compare the lipids, or fatty compounds, isolated from a living organism with the lipids of its fossil ancestor. Unfortunately the fossil lipids and other fossil compounds found in sediments almost always represent the chemical debris from many organisms.

The deposition of a compressible fine-grained sediment containing mineral particles and disseminated organic matter takes place in an aquatic environment in which the organic content can be partially preserved; an example would be the bottom of a lake or a delta. The organic matter makes up something less than 1 percent of many ancient sediments. The small portion of this carbon-containing material that is soluble in organic solvents represents a part of the original lipid content, more or less modified, of the organisms that lived and died while the sediment was being deposited.

The organic content presumably consists of varying proportions of the components of organisms—terrestrial as well as aquatic—that have undergone chemical transformation while the sediment was being laid down and compressed. Typical transformations are reduction, which has the effect of removing oxygen from molecules and adding hydrogen, and decarboxylation, which removes the carboxyl radical (COOH). In addition, it appears that a variety of reactive unsaturated compounds (compounds having available chemical bonds) combine to form an insoluble amorphous material known as kerogen. Other chemical changes that occur with the passage of time are related to the temperature to which the rock is heated by geologic processes. Thus many petroleum chemists and geologists believe petroleum is created by progressive degradation, brought about by heat, of the organic matter that is finely disseminated throughout the original sediment. The organic matter that comes closest in structure to the chains and rings of carbon atoms found in the hydrocarbons of petroleum is the matter present in the lipid fraction of organisms. Another potential source of petroleum hydrocarbons is kerogen itself, presumably formed from a wide variety of organic molecules; it gives off a range of straight-chain, branched-chain and ring-containing hydrocarbons when it is strongly heated in the laboratory. One would also like to know more about the role of bacteria in the early steps of sediment formation. In the upper layers of most newly formed sediments there is strong bacterial activity, which must surely re-



GEOLOGICAL TIME SCALE shows the age of some intensively studied sedimentary rocks (*left*) and the sequence of major steps in the evolution of life (*right*). The stage for biological evolution was set by chemical evolution, but the period of transition is not known.



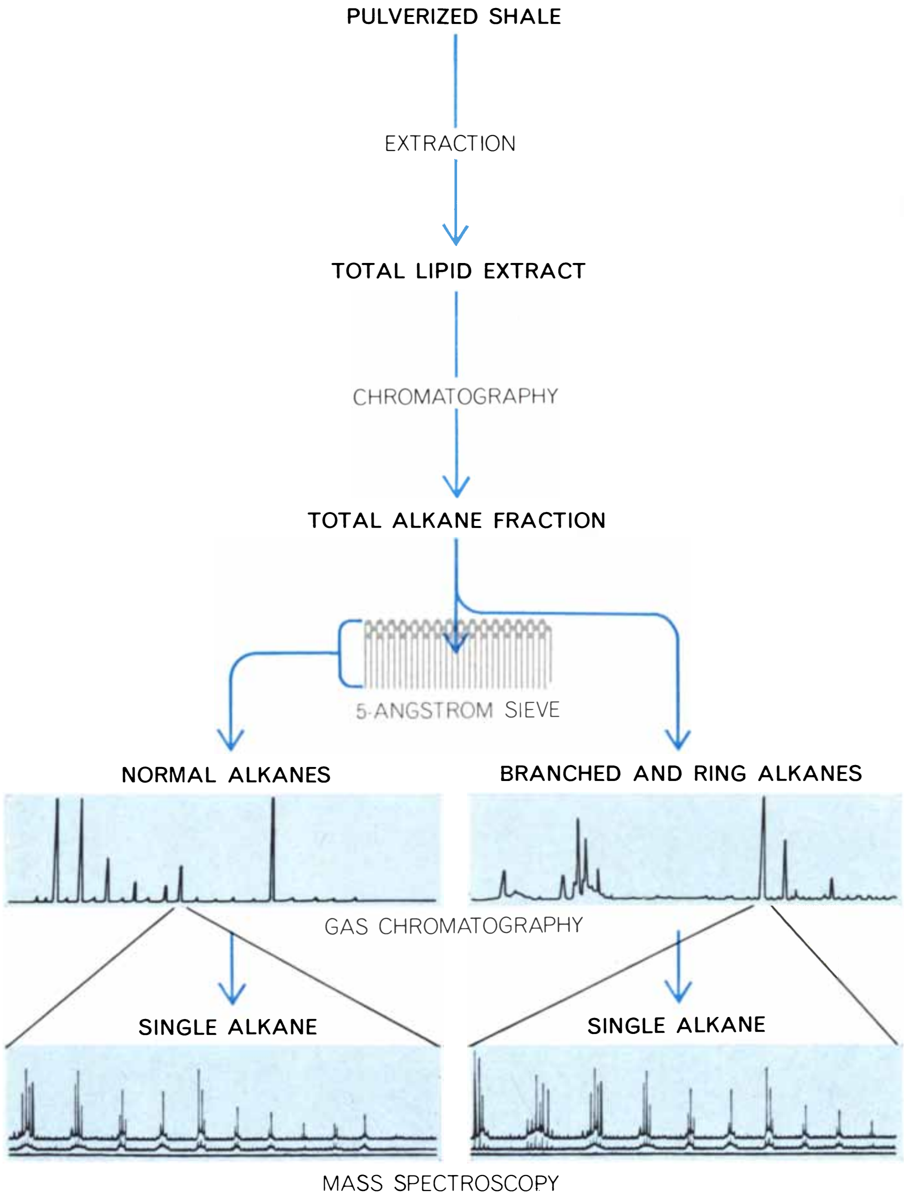
ORGANIC COMPOUNDS originally synthesized by living organisms and more or less modified have now been found in many ancient rocks that began as sediments. The dark bars indicate reasonably reliable identification; the light bars, unconfirmed reports. Cutin and chitin are substances present respectively in the outer structures of plants and of insects.

sult in extensive alteration of the initially deposited organic matter.

In this article we shall concentrate on the isolation of fossil hydrocarbons. The methods must be capable of dealing with the tiny quantity of material available in most rocks. Our general procedure is as follows.

After cutting off the outer surface of a rock specimen to remove gross contaminants, we clean the remaining block with solvents and pulverize it. We then place the powder in solvents such as benzene and methanol to extract the organic material. Before this step we sometimes dissolve the silicate and carbonate minerals of the rock with hydrofluoric and hydrochloric acids. We separate the organic extract so obtained into acidic, basic and neutral fractions. The compounds in these fractions are converted, when necessary, into derivatives that make them suitable for separation by the technique of chromatography. For the initial separations we use column chromatography, in which a sample in solution is passed through a column packed with alumina or silica. Depending on their nature, compounds in the sample pass through the column at different speeds and can be collected in fractions as they emerge.

In subsequent stages of the analysis finer fractionations are achieved by means of gas-liquid chromatography. In this variation of the technique, the sample is vaporized into a stream of light gas, usually helium, and brought in contact with a liquid that tends to trap the compounds in the sample in varying degree. The liquid can be supported on an inorganic powder, such as diatomaceous earth, or coated on the inside of a capillary tube. Since the compounds are alternately trapped in the liquid medium and released by the passing stream of gas they progress through the column at varying speeds, with the result that they are separated into distinct fractions as they emerge from the tube. The temperature of the column is raised steadily as the separation proceeds, in order to drive off the more strongly trapped compounds.



ANALYTICAL PROCEDURE for identifying chemical fossils begins with the extraction of alkane hydrocarbons from a sample of pulverized shale. In normal alkanes the carbon atoms are arranged in a straight chain. (Typical alkanes are illustrated on page 36.) Molecular sieves are used to separate straight-chain alkanes from alkanes with branched chains and rings. The two broad classes are then further fractionated. Compounds responsible for individual peaks in the chromatogram are identified by mass spectrometry and other methods.

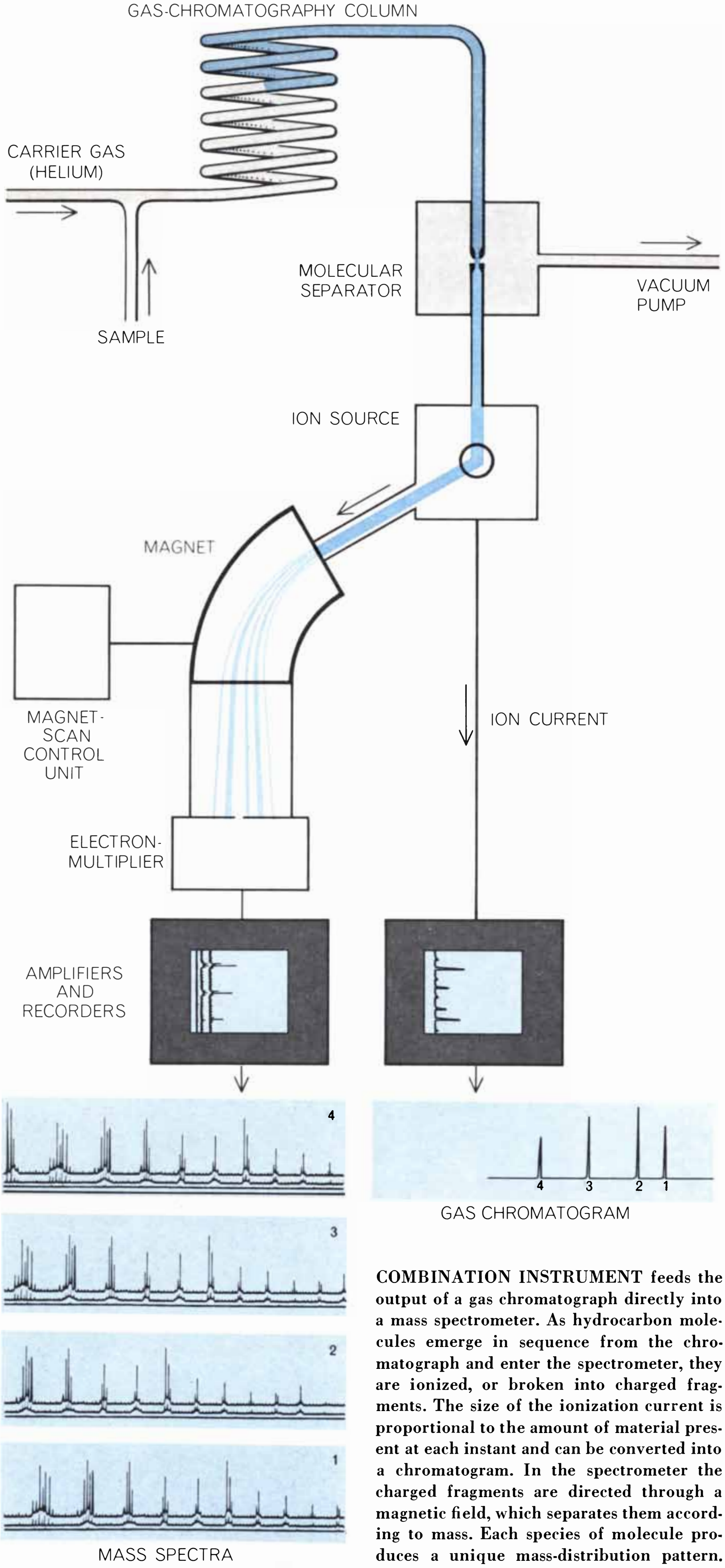
The initial chromatographic separation is adjusted to produce fractions that consist of a single class of compound, for example the class of saturated hydrocarbons known as alkanes. Alkane molecules may consist either of straight chains of carbon atoms or of chains that include branches and rings. These subclasses can be separated with the help of molecular sieves: inorganic substances, commonly alumino-silicates, that have a fine honeycomb structure. We use a sieve whose mesh is about five angstrom units, or about a thousandth of the wavelength of green light. Straight-chain alkanes, which resemble smooth flexible rods about 4.5 angstroms in diameter, can enter the sieve and are trapped. Chains with branches and rings are too big to enter and so are held back. The straight-chain alkanes can be liberated from the sieve for further analysis by dissolving the sieve in hydrofluoric acid. Other families of molecules can be trapped in special crystalline forms of urea and thiourea, whose crystal lattices provide cavities with diameters of five angstroms and seven angstroms respectively.

The families of molecules isolated in this way are again passed through gas chromatographic columns that separate the molecular species within the family. For example, a typical chromatogram of straight-chain alkanes will show that molecules of increasing chain length emerge from the column in a regularly spaced sequence that parallels their increasing boiling points, thus producing a series of evenly spaced peaks. Although the species of molecule in a particular peak can often be identified tentatively on the basis of the peak's position, a more precise identification is usually desired. To obtain it one must collect the tiny amount of substance that produced the peak—often measured in micrograms—and examine it by one or more analytical methods such as ultraviolet and infrared spectroscopy, mass spectrometry or nuclear magnetic resonance. In one case X-ray crystallography is being used to arrive at the structure of a fossil molecule.

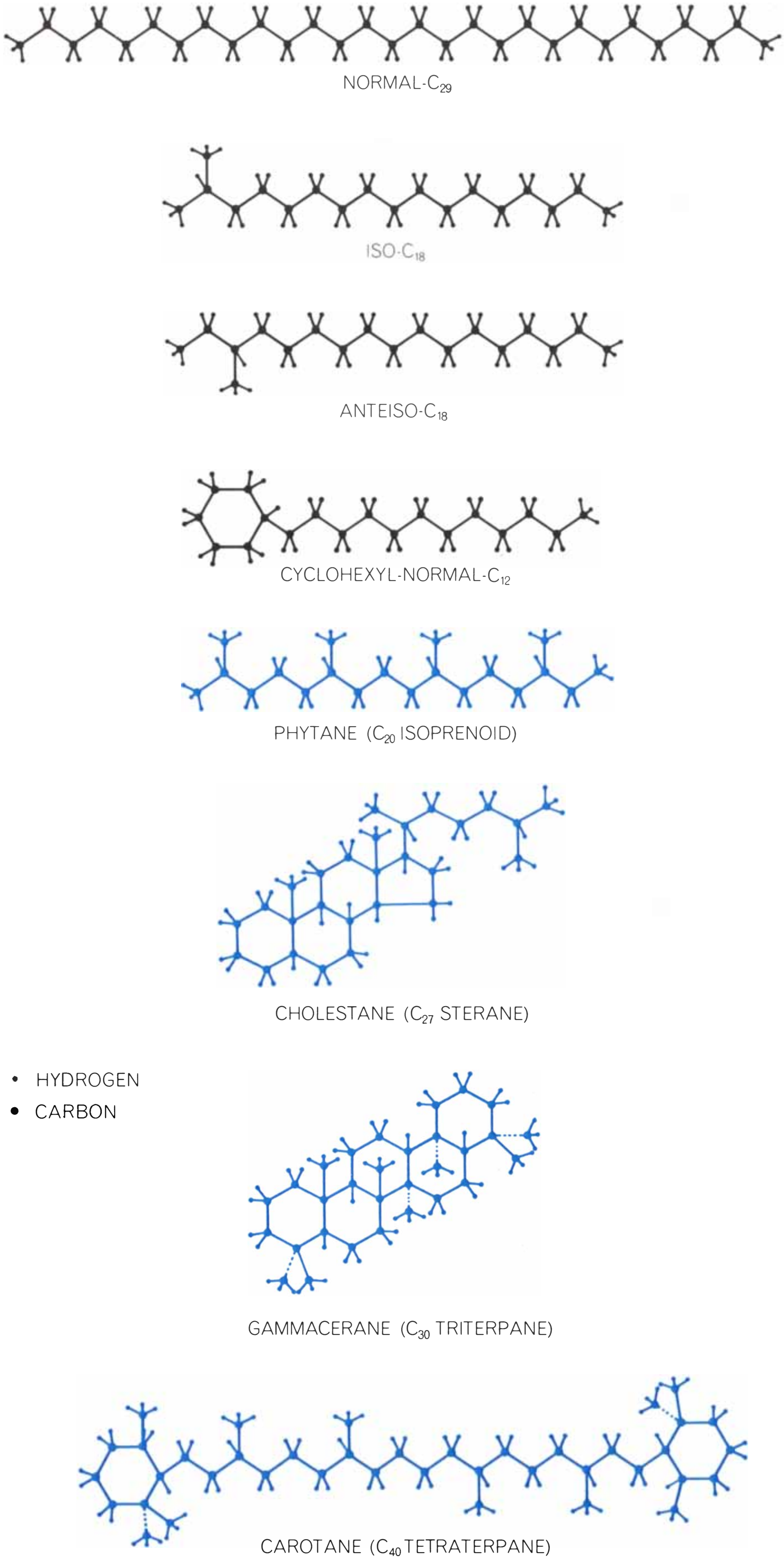
A new and useful apparatus is one that combines gas chromatography and mass spectrometry [*see illustration at right*]. The separated components emerge from the chromatograph and pass directly into the ionizing chamber of the mass spectrometer, where they are broken into submolecular fragments whose abundance distribution with respect to mass is unique for each component. These various analytical procedures enable us to establish a precise structure and relative concentration for each organic compound that can be extracted from a sample of rock.

How is it that such comparatively simple substances as the alkanes should be worthy of geochemical study? There are several good reasons. Alkanes are generally prominent components of the soluble lipid fraction of sediments. They survive geologic time and geologic conditions well because the carbon-hydrogen and carbon-carbon bonds are strong and resist reaction with water. In addition, alkane molecules can provide more information than the simplicity of their constitution might suggest; even a relatively small number of carbon and hydrogen atoms can be joined in a large number of ways. For example, a saturated hydrocarbon consisting of 19 carbon atoms and 40 hydrogen atoms could exist in some 100,000 different structural forms that are not readily interconvertible. Analysis of ancient sediments has already shown that in some cases they contain alkanes clearly related to the long-chain carbon compounds of the lipids in present-day organisms [*see illustration on next page*]. Generally one finds a series of compounds of similar structure, such as the normal, or straight-chain, alkanes (called *n*-alkanes); the compounds extracted from sediments usually contain up to 35 carbon atoms. Alkanes isolated from sediments may have been buried as such or formed by the reduction of substances containing oxygen.

The more complicated the structure of the molecule, the more valuable it is likely to be for geochemical purposes: its information content is greater. Good examples are the alkanes with branches and rings, such as phytane and cholestane. It is unlikely that these complex alkanes could be built up from small subunits by processes other than biological ones, at least in the proportions found. Hence we are encouraged to look



COMBINATION INSTRUMENT feeds the output of a gas chromatograph directly into a mass spectrometer. As hydrocarbon molecules emerge in sequence from the chromatograph and enter the spectrometer, they are ionized, or broken into charged fragments. The size of the ionization current is proportional to the amount of material present at each instant and can be converted into a chromatogram. In the spectrometer the charged fragments are directed through a magnetic field, which separates them according to mass. Each species of molecule produces a unique mass-distribution pattern.



ALKANE HYDROCARBON MOLECULES can take various forms: straight chains (which are actually zigzag chains), branched chains and ring structures. Those depicted here have been found in crude oils and shales. The molecules shown in color are so closely related to well-known biological molecules that they are particularly useful in bespeaking the existence of ancient life. The broken lines indicate side chains that are directed into the page.

for biological precursors with appropriate preexisting carbon skeletons.

In conducting this kind of search one makes the assumption, at least at the outset, that the overall biochemistry of past organisms was similar to that of present-day organisms. When lipid fractions are isolated directly from modern biological sources, they are generally found to contain a range of hydrocarbons, fatty acids, alcohols, esters and so on. The mixture is diverse but by no means random. The molecules present in such fractions have structures that reflect the chemical reaction pathways systematically followed in biological organisms. There are only a few types of biological molecule wherein long chains of carbon atoms are linked together; two examples are the straight-chain lipids, the end groups of which may include oxygen atoms, and the lipids known as isoprenoids.

The straight-chain lipids are produced by what is called the polyacetate pathway [*see illustration on opposite page*]. This pathway leads to a series of fatty acids with an even number of carbon atoms; the odd-numbered molecules are missing. One also finds in nature straight-chain alcohols (*n*-alkanols) that likewise have an even number of carbon atoms, which is to be expected if they are formed by simple reduction of the corresponding fatty acids. In contrast, the straight-chain hydrocarbons (*n*-alkanes) contain an *odd* number of carbon atoms. Such a series would be produced by the decarboxylation of the fatty acids.

The second type of lipid, the isoprenoids, have branched chains consisting of five-carbon units assembled in a regular order [*see illustration on page 38*]. Because these units are assembled in head-to-tail fashion the side-chain methyl groups (CH_3) are attached to every fifth carbon atom. (Tail-to-tail addition occurs less frequently but accounts for several important natural compounds, for example beta-carotene.) When the isoprenoid skeleton is found in a naturally occurring molecule, it is reasonable to assume that the compound has been formed by this particular biological pathway.

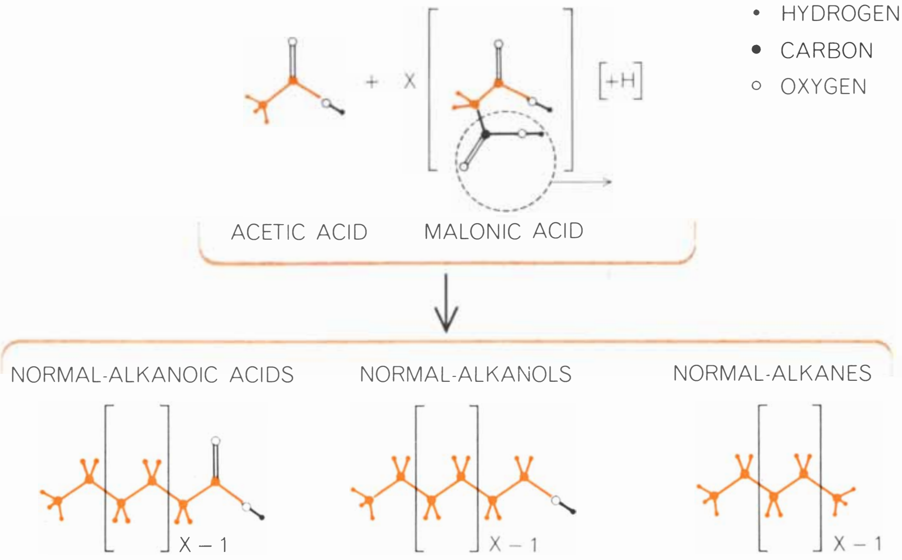
Chlorophyll is possibly the most widely distributed molecule with an isoprenoid chain; therefore it must make some contribution to the organic matter in sediments. Its fate under conditions of geological sedimentation is not known, but it may decompose into only two or three large fragments [*see illustration on page 39*]. The molecule of chlorophyll *a* consists of a system of interconnected rings and a phytyl side chain, which is an isoprenoid. When chlorophyll is decomposed, it seems likely that the phytyl chain is split off and converted to phytane (which has the same number of carbon atoms) and pristane (which is shorter by one carbon atom). When both of these branched alkanes are found in a sediment, one has reasonable presumptive evidence that chlorophyll was once present. The chlorophyll ring system very likely gives rise to the metal-containing porphyrins that are found in many crude oils and sediments.

Phytane and pristane may actually enter the sediments directly. Max Blumer of the Woods Hole Oceanographic Institution showed in 1965 that certain species of animal plankton that eat the plant plankton containing chlorophyll store quite large quantities of pristane and related hydrocarbons. The animal plankton act in turn as a food supply for bigger marine animals, thereby accounting for the large quantities of pristane in the liver of the shark and other fishes.

An indirect source for the isoprenoid alkanes could be the lipids found in the outer membrane of certain bacteria that live only in strong salt solutions, an environment that might be found where ancient seas were evaporating. Morris Kates of the National Research Council of Canada has shown that a phytyl-containing lipid (diphytyl phospholipid) is common to bacteria with the highest salt requirement but not to the other bacteria examined so far.

This last example brings out the point that in spite of the overall oneness of present-day biochemistry, organisms do differ in the compounds they make. They also synthesize the same compounds in different proportions. These differences are making it possible to classify living species on a chemotaxonomic, or chemical, basis rather than on a morphological, or shape, basis. Eventually it may be possible to extend chemical classification to ancient organisms, creating a discipline that could be called paleochemotaxonomy.

Our study of chemical fossils began in 1961, when we decided to probe the sedimentary rocks of the Precambrian period in a search for the earliest signs of life. This vast period of time, some four billion years, encompasses the beginnings of life on this planet and its early development to the stage of organisms consisting of more than one cell [*see illustrations on page 33*]. We hoped that our study would complement the efforts being made by a number of workers, including one of us (Calvin), to imitate in the laboratory the chemical evolution that must have preceded the appearance of life on earth. We also saw the possibility that our work could be adapted to the study of meteorites and of rocks obtained from the moon or nearby planets. Thus it even includes the possibility of uncovering exotic and alien biochemistries. The exploration of the ancient rocks of the earth provides a testing ground for the method and the concepts involved.



STRAIGHT-CHAIN LIPIDS are created in living organisms from simple two-carbon and three-carbon compounds: acetate and malonate, shown here as their acids. The complex biological process, which involves coenzyme *A*, is depicted schematically. The fatty acids (*n*-alkanoic acids) and fatty alcohols (*n*-alkanols) produced in this way have an even number of carbon atoms. The removal of carbon dioxide from the fatty acids, the net effect of decarboxylation, would give rise to a series of *n*-alkanes with an odd number of carbon atoms.

We chose the alkanes because one might expect them to resist fairly high temperatures and chemical attack for long periods of time. Moreover, J. G. Bendoraitis of the Socony Oil Company, Warren G. Meinschein of the Esso Research Laboratory and others had already identified individual long-chain alkanes, including a range of isoprenoid types, in certain crude oils. Even more encouraging, J. J. Cummins and W. E. Robinson of the U.S. Bureau of Mines had just made a preliminary announcement of their isolation of phytane, pristane and other isoprenoids from a relatively young sedimentary rock: the Green River shale of Colorado, Utah and Wyoming. Thus the alkanes seemed to offer the biological markers we were seeking. Robinson generously provided our laboratory with samples of the Green River shale, which was deposited some 50 million years ago and constitutes the major oil-shale reserve of the U.S.

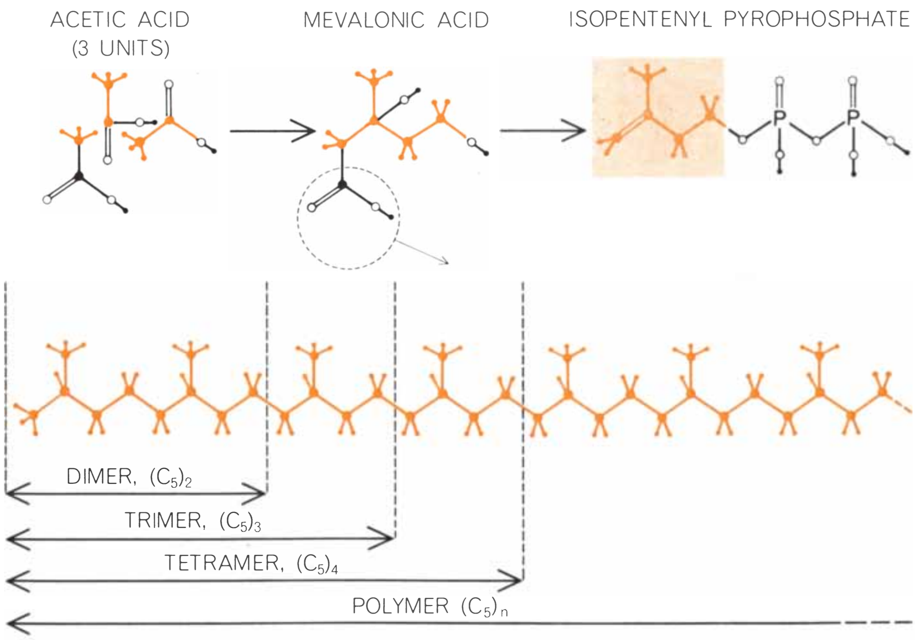
The Green River shale, which is the remains of large Eocene lakes in a rather stable environment, contains a considerable fraction (.6 percent) of alkanes. Using the molecular-sieve technique, we split the total alkane fraction into alkanes with straight chains and those with branched chains and rings and ran the resulting fractions through the gas chromatograph [*see illustration at top left on page 40*]. The straight-chain alkanes exhibit a marked dominance of molecules containing an odd number of carbon atoms, which is to be expected for straight-chain hydrocarbons from a biological source. The other fraction shows a series of prominent sharp peaks; we conclusively identified them as isoprenoids, confirming the results of Cummins and Robinson. The large proportion of phytane, the hydrocarbon corresponding to the entire side chain of chlorophyll, is particularly noteworthy. The oxygenated counterparts of the steranes and triterpanes (27 to 30 carbon atoms) and the high-molecular-weight *n*-alkanes (29 to 31 carbons) are typical constituents of the waxy covering of the leaves and pollen of land plants, leading to the inference that such plants made major contributions to the organic matter deposited in the Green River sediments.

Although the gross chemical structure (number of rings and side chains) of the steranes and triterpanes was established in this work, it was only recently that the precise structure of one of these hydrocarbons was conclusively established. E. V. Whitehead and his associates in the British Petroleum Company and Robinson and his collaborators in the Bureau of Mines have shown that one of the triterpanes extracted from the Green River shale is identical in all respects with gammacerane [*see illustration on page 36*]. Conceivably it is produced by the reduction of a compound known as gammaceran-3-beta-ol, which was recently isolated from the common protozoon *Tetrahymena pyriformis*. Other derivatives of gammacerane are rather widely distributed in the plant kingdom.

At our laboratory in Glasgow, Sister Mary T. J. Murphy and Andrew McCormick recently identified several steranes and triterpanes and also the tetraterpane called perhydro-beta-carotene, or carotane [*see top illustration on page 43*]. Presumably carotane is derived by reduction from beta-carotene, an important red pigment of plants. A similar reduction process could convert the familiar biological compound cholesterol into cholestane, one of the steranes found in the Green River shale [*see same illustration on page 43*]. The mechanism and sedimentary site of such geochemical reduction processes is an important problem awaiting attack.

W. H. Bradley of the U.S. Geological Survey has sought a contemporary counterpart of the richly organic ooze that presumably gave rise to the Green River shale. So far he has located only four lakes, two in the U.S. and two in Africa, that seem to be reasonable candidates. One of them, Mud Lake in Florida, is now being studied closely. A dense belt of vegetation surrounding the lake filters out all the sand and silt that might otherwise be washed into it from the land. As a result the main source of sedimentary material is the prolific growth of microscopic algae. The lake bottom uniformly consists of a grayish-green ooze about three feet deep. The bottom of the ooze was deposited about 2,300 years ago, according to dating by the carbon-14 technique.

Microscopic examination of the ooze shows that it consists mainly of minute fecal pellets, made up almost exclusively of the cell walls of blue-green algae. Some pollen grains are also present. Decay is surprisingly slow in spite of the ooze's high content of bound oxygen and the temperatures characteristic of Florida. Chemical analyses in several laboratories, reported this past November at a meeting of the Geological Society of America, indicate that there is indeed considerable correspondence between the lipids of the Mud Lake ooze and those of the Green River shale. Eugene McCarthy of the University of California at Berkeley has also found beta-carotene in samples of Mud Lake ooze that are about 1,100 years old. The high oxygen content of the Mud Lake ooze seems inconsistent, however, with the d minance of oxygen-poor compounds in the Green River shale. The long-term geological mechanisms that account for the loss of oxygen may have to be sought in sediments older than those in Mud Lake.



BRANCHED-CHAIN LIPIDS are produced in living organisms by an enzymatically controlled process, also depicted schematically. In this process three acetate units link up to form a six-carbon compound (mevalonic acid), which subsequently loses a carbon atom and is combined with a high-energy phosphate. "Head to tail" assembly of the five-carbon subunits produces branched-chain molecules that are referred to as isoprenoid structures.

Sediments much older than the Green River shale have now been examined by our groups in Berkeley and Glasgow, and by workers in other universities and in oil-industry laboratories. We find that the hydrocarbon fractions in these more ancient samples are usually more complex than those of the Green River shale; the gas chromatograms of the older samples tend to show a number of partially resolved peaks centered around a single maximum. One of the older sediments we have studied is the Antrim shale of Michigan. A black shale probably 350 million years old, it resembles other shales of the Chattanooga type that underlie many thousands of square miles of the eastern U.S. Unlike the Green River shale, the straight-chain alkane fraction of the Antrim shale shows little or no predominance of an odd number of carbon atoms over an even number [*see middle illustration of three at top of pages 40 and 41*]. The alkanes with branched chains and rings, however, continue to be rich in isoprenoids.

The fact that alkanes with an odd number of carbon atoms are not predominant in the Antrim shale and sediments of comparable antiquity may be owing to the slow cracking by heat of carbon chains both in the alkane component and in the kerogen component. The effect can be partially reproduced in the laboratory by heating a sample of the Green River shale for many hours above 300 degrees centigrade. After such treatment the straight-chain alkanes show a reduced dominance of odd-carbon molecules and the branched-chain-and-ring fraction is more complex.

The billion-year-old shale from the Nonesuch formation at White Pine, Mich., exemplifies how geological, geochemical and micropaleontological techniques can be brought to bear on the problem of detecting ancient life. With the aid of the electron microscope Elso S. Barghoorn and J. William Schopf of Harvard University have detected in the Nonesuch shale "disaggregated particles of condensed spheroidal organic matter." In collaboration with Meinschein the Harvard workers have also found evidence that the Nonesuch shale contains isoprenoid alkanes, steranes and porphyrins. Independently we have analyzed the Nonesuch shale and found that it contains pristane and phytane, in addition to iso-alkanes, anteiso-alkanes and cyclohexyl alkanes.

Barghoorn and S. A. Tyler have also detected microfossils in the Gunflint chert of Ontario, which is 1.9 billion years old, almost twice the age of the

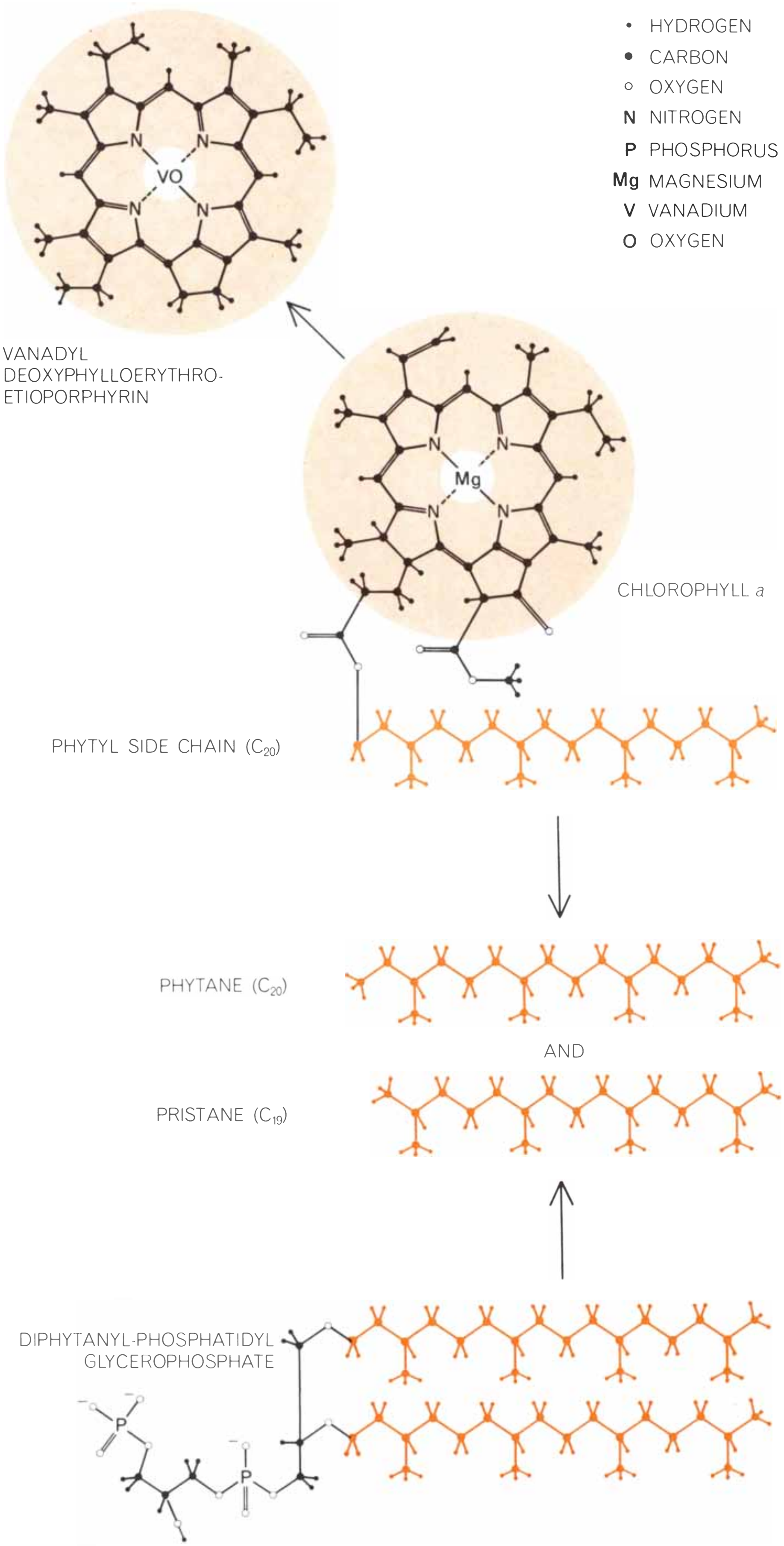
Nonesuch shale. They have reported that the morphology of the Gunflint microfossils "is similar to that of the existing primitive filamentous blue-green algae."

One of the oldest Precambrian sediments yet analyzed is the Soudan shale of Minnesota, which was formed about 2.7 billion years ago. Although its total hydrocarbon content is only .05 percent, we have found that it contains a mixture of straight-chain alkanes and branched-chain-and-ring alkanes not unlike those present in the much younger Antrim shale [*see third illustration of three at top of next two pages*]. In the branched-chain-and-ring fraction we have identified pristane and phytane. Steranes and triterpanes also seem to be present, but we have not yet established their precise three-dimensional structure. Preston E. Cloud of the University of California at Los Angeles has reported that the Soudan shale contains microstructures resembling bacteria or blue-green algae, but he is not satisfied that the evidence is conclusive.

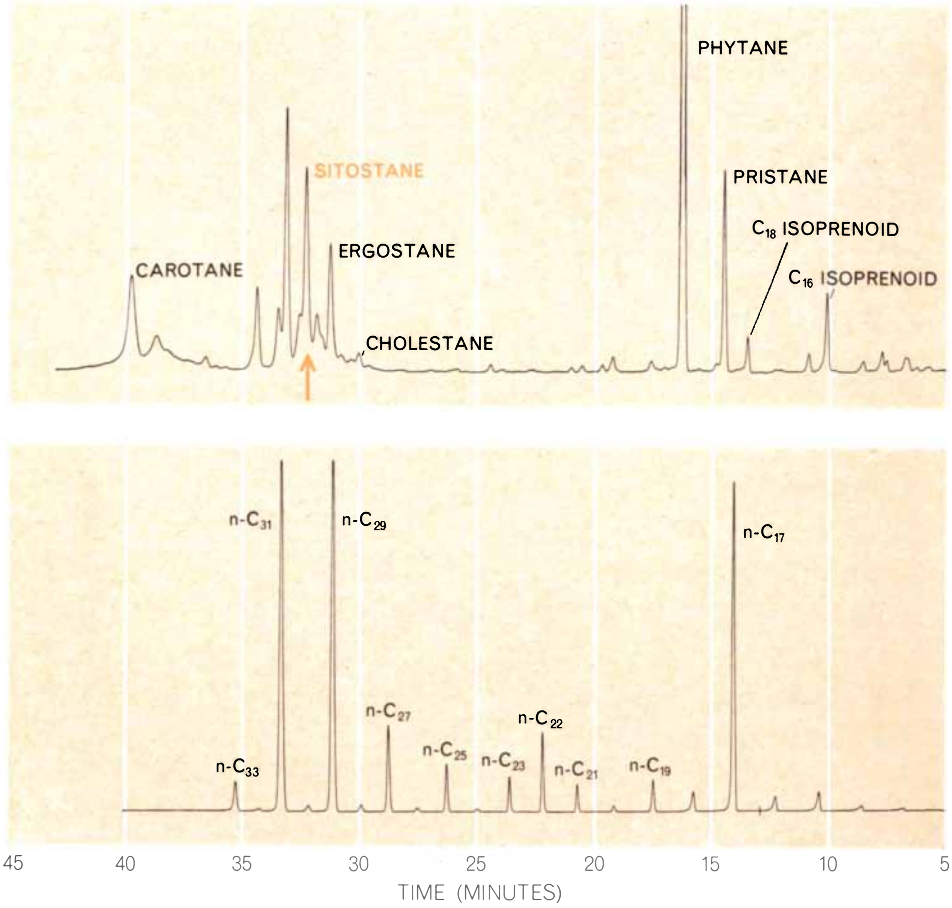
A few reports are now available on the most ancient rocks yet examined: sediments from the Fig Tree system of Swaziland in Africa, some 3.1 billion years old. An appreciable fraction of the alkane component of these rocks consists of isoprenoid molecules. If one assumes that isoprenoids are chemical vestiges of chlorophyll, one is obliged to conclude that living organisms appeared on the earth only about 1.7 billion years after the earth was formed (an estimated 4.8 billion years ago).

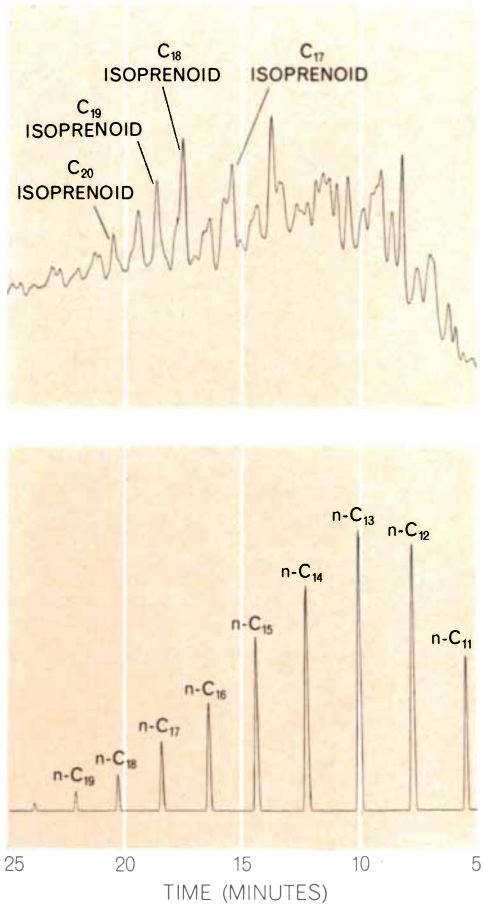
Before reaching this conclusion, however, one would like to be sure that the isoprenoids found in ancient sediments have the precise carbon skeleton of the biological molecules from which they are presumed to be derived. So far no sample of pristane or phytane—the isoprenoids that may be derived from the phytyl side chain of chlorophyll—has been shown to duplicate the precise three-dimensional structure of a pure reference sample. Vigorous efforts are being made to clinch the identification.

Assuming that one can firmly establish the presence of biologically structured isoprenoid alkanes in a sediment, further questions remain. The most serious one is: Were the hydrocarbons or their precursors deposited when the sediment was formed or did they seep in later? This question is not easily answered. A sample can be contaminated at any point up to—and after—the time it reaches the laboratory bench. Fossil fuels, lubricants and waxes are omnipresent, and laboratory solvents contain



DEGRADATION OF CHLOROPHYLL *A*, the green pigment in plants, may give rise to two kinds of isoprenoid molecules, phytane and pristane, that have been identified in many ancient sediments. It also seems likely that phytane and pristane can be derived from the isoprenoid side chains of a phosphate-containing lipid (*bottom structure*) that is a major constituent of salt-loving bacteria. The porphyrin ring of chlorophyll *a* is the probable source of vanadyl porphyrin (*upper left*) that is widely found in crude oils and shales.



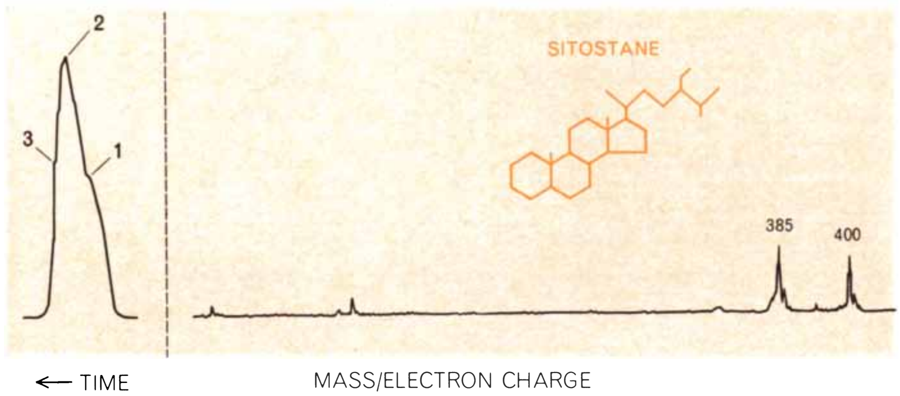


HYDROCARBONS IN YOUNG SEDIMENT, the 50-million-year-old Green River shale, produced these chromatograms. Alkanes with branched chains and rings appear in the top curve, normal alkanes in the bottom curve. The alkanes in individual peaks were identified by mass spectrometry and other methods. Such alkanes as phytane and pristane and the predominance of normal alkanes with an odd number of carbon atoms affirm that the hydrocarbons are biological in origin. The bimodal distribution of the curves is also significant.

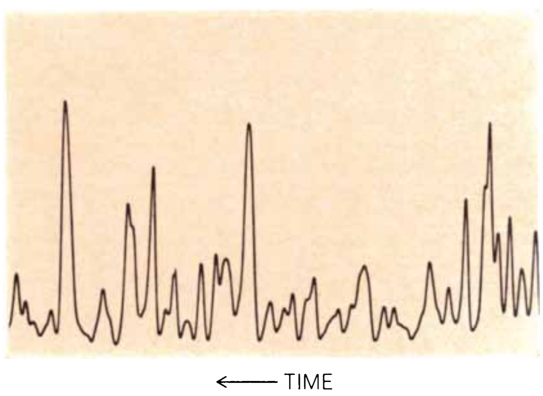
OLDER SEDIMENTS are represented by the Antrim shale (*left*), which is 350 million years old, and by the Soudan shale (*right*), which is 2.7 billion years old. Alkanes with branched chains and rings again are shown in the top curves, normal alkanes

tiny amounts of pristane and phytane unless they are specially purified.

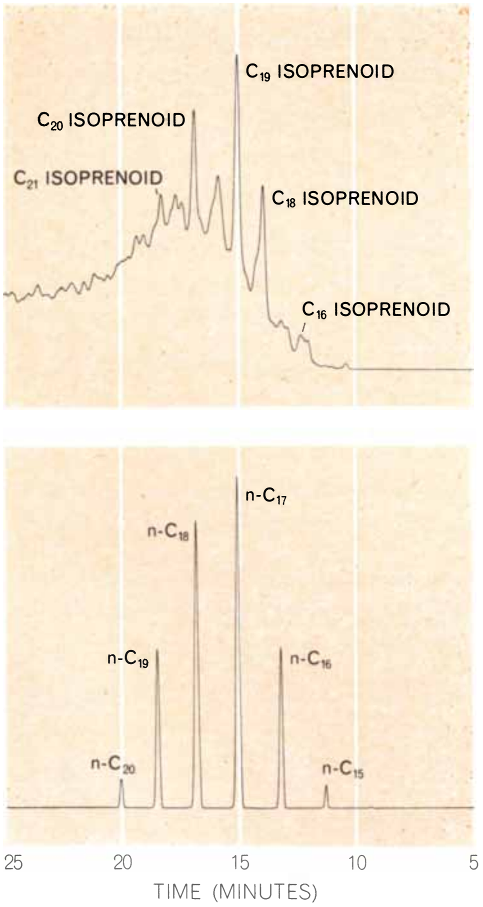
One way to determine whether or not rock hydrocarbons are indigenous is to measure the ratio of the isotopes carbon 13 and carbon 12 in the sample. (The ratio is expressed as the excess of carbon 13 in parts per thousand compared with the isotope ratio in a standard: a sample of a fossil animal known as a belemnite.) The principle behind the test is that photosynthetic organisms discriminate against carbon 13 in preference to carbon 12. Although we have few clues to the abundance of the two isotopes throughout the earth's history, we can at least test various hydrocarbon fractions in a given sample to see if they have the same isotope ratio. As a simple assumption, one would expect to find the same ratio in the soluble organic fraction as in the insoluble kerogen fraction, which could not have seeped into the rock as kerogen.



IDENTIFICATION OF SITOSTANE in the Green River shale was accomplished by "trapping" the alkanes that produced a major peak in the chromatogram (*colored arrow at top left on this page*) and passing them through the chromatograph-mass spectrometer. As the chromatograph drew the curve at the left, three scans were made with the spectrometer. Scan 1 (*partially shown at right*) is identical with the scan produced by pure sitostane.

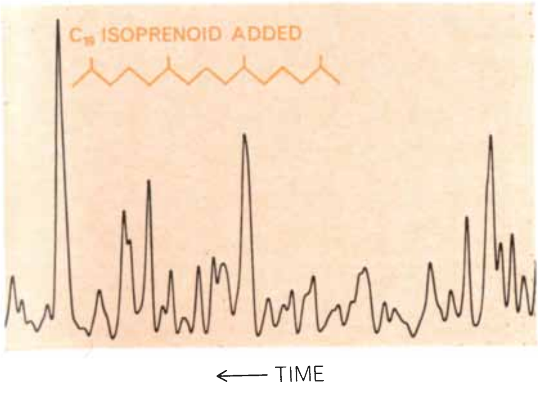


NINETEEN-CARBON ISOPRENOID was identified in the Antrim shale by using a co-injection technique together with a high-resolution gas chromatograph. These two high-resolution curves, each taken from a



in the bottom curves. These chromatograms lack a pronounced bimodal distribution and the normal alkanes do not show a predominance of molecules with an odd number of carbon atoms. Nevertheless, the prevalence of isoprenoids argues for a biological origin.

Philip H. Abelson and Thomas C. Hoering of the Carnegie Institution of Washington have made such measurements on sediments of various geological ages and have found that the isotope ratios for soluble and insoluble fractions in most samples agree reasonably well. In some of the oldest samples, however,



much longer trace, show the change in height of a specific peak when a small amount of pure 19-carbon isoprenoid was coinjected with the sample. Other peaks can be similarly identified by coinjecting known alkanes.

there are inconsistencies. In the Soudan shale, for example, the soluble hydrocarbons have an isotope ratio expressed as −25 parts per thousand compared with −34 parts per thousand for the kerogen. (In younger sediments and in present-day marine organisms the ratio is about midway between these two values: −29 parts per thousand.) The isotope divergence shown by hydrocarbons in the Soudan shale may indicate that the soluble hydrocarbons and the kerogen originated at different times. But since nothing is known of the mechanism of kerogen formation or of the alterations that take place in organic matter generally, the divergence cannot be regarded as unequivocal evidence of separate origin.

On the other hand, there is some reason to suspect that the isoprenoids did indeed seep into the Soudan shale sometime after the sediments had been laid down. The Soudan formation shows evidence of having been subjected to temperatures as high as 400 degrees C. The isoprenoid hydrocarbons pristane and phytane would not survive such conditions for very long. But since the exact date, extent and duration of the heating of the Soudan shale are not known, one can only speculate about whether the isoprenoids were indigenous and survived or seeped in later. In any event, they could not have seeped in much later because the sediment became compacted and relatively impervious within a few tens of millions of years.

A still more fundamental issue is whether or not isoprenoid molecules and others whose architecture follows that of known biological substances could have been formed by nonbiological processes. We and others are studying the kinds and concentrations of hydrocarbons produced by both biological and nonbiological sources. Isoprene itself, the hydrocarbon whose polymer constitutes natural rubber, is easily prepared in the laboratory, but no one has been able to demonstrate that isoprenoids can be formed nonbiologically under geologically plausible conditions. Using a computer approach, Margaret O. Dayhoff of the National Biomedical Research Foundation and Edward Anders of the University of Chicago and their colleagues have concluded that under certain restricted conditions isoprene should be one of the products of their hypothetical reactions. But this remains to be demonstrated in the laboratory.

It is well known, of course, that complex mixtures of straight-chain, branched-chain and even ring hydrocarbons can readily be synthesized in the laboratory from simple starting materials. For example, the Fischer-Tropsch process, used by the Germans as a source of synthetic fuel in World War II, produces a mixture of saturated hydrocarbons from carbon monoxide and water. The reaction requires a catalyst (usually nickel, cobalt or iron), a pressure of about 100 atmospheres and a temperature of from 200 to 350 degrees C. The hydrocarbons formed by this process, and several others that have been studied, generally show a smooth distribution of saturated hydrocarbons. Many of them have straight chains but lack the special characteristics (such as the predominance of chains with an odd number of carbons) found in the similar hydrocarbons present in many sediments. Isoprenoid alkanes, if they are formed at all, cannot be detected.

Paul C. Marx of the Aerospace Corporation has made the ingenious suggestion that isoprenoids may be produced by the hydrogenation of graphite. In the layered structure of graphite the carbon atoms are held in hexagonal arrays by carbon-carbon bonds. Marx has pointed out that if the bonds were broken in certain ways during hydrogenation, an isoprenoid structure might result. Again a laboratory demonstration is needed to support the hypothesis. What seems certain, however, is that nonbiological syntheses are extremely unlikely to produce those specific isoprenoid patterns found in the products of living cells.

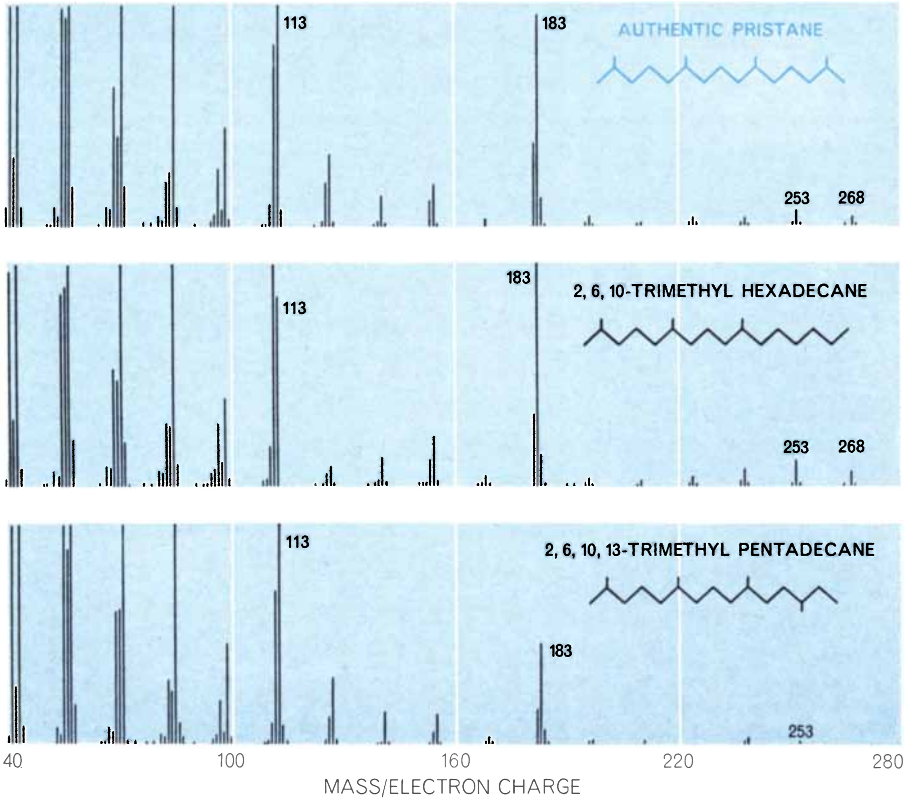
Another dimension is added to this discussion by the proposal, made from time to time by geologists, that certain hydrocarbon deposits are nonbiological in origin. Two alleged examples of such a deposit are a mineral oil found enclosed in a quartz mineral at the Abbott mercury mine in California and a bitumen-like material called thucolite found in an ancient nonsedimentary rock in Ontario. Samples of both materials have been analyzed in our laboratory at Berkeley. The Abbott oil contains a significant isoprenoid fraction and probably constitutes an oil extracted and brought up from somewhat older sediments of normal biological origin. The thucolite consists chiefly of carbon from which only a tiny hydrocarbon fraction can be extracted. Our analysis shows, however, that the fraction contains trace amounts of pristane and phytane. Recognizing the hazards of contamination, we are repeating the analysis, but on the basis of our preliminary findings we suspect that the thucolite sample represents an oil of biological origin that has been almost completely carbonized. We are aware, of course, that one runs the risk of invoking circular arguments in such discussions. Do isoprenoids demonstrate biological origin (as we and others are suggesting) or does the presence of isoprenoids in such unlikely substances indicate that they were formed nonbiologically? The debate may not be quickly settled.

There is little doubt, in any case, that organic compounds of considerable variety and complexity must have accumulated on the primitive earth during the prolonged period of nonbiological chemical development—the period of chemical evolution. With the appearance of the first living organisms biological evolution took command and presumably the "food stock" of nonbiological compounds was rapidly altered. If the changeover was abrupt on a geological time scale, one would expect to find evidence of it in the chemical composition of sediments whose age happens to bracket the period of transition. Such a discontinuity would make an intensely exciting find for organic geochemistry. The transition from chemical to biological evolution must have occurred earlier than three billion years ago. As yet, however, no criteria have been established for distinguishing between the two types of evolutionary process.

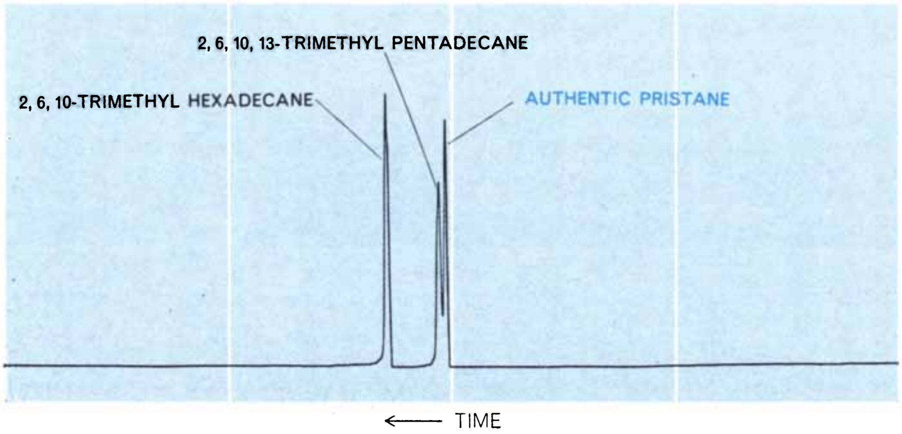
We suggest that an important distinction should exist between the kinds of molecules formed by the two processes. In the period of chemical evolution autocatalysis must have been one of the dominant mechanisms for creating large molecules. An autocatalytic system is one in which a particular substance promotes the formation of more of itself. In biological evolution, on the other hand, two different molecular systems are involved: an information-bearing system based on nucleic acids and a catalytic system based on proteins. The former directs the synthesis of the latter. A major problem, subject to laboratory experiment, is visualizing how the two systems originated and were linked.

The role of lipids in the transition may have been important. Today lipids form an important part of the membranes of all living cells. A. I. Oparin, the Russian investigator who was among the first to discuss in detail the chemical origin of life, has suggested that an essential step in the transition from chemical to biological evolution may have been the formation of membranes around droplets, which could then serve as "reaction vessels." Such self-assembling membranes might well have required lipid constituents for their function, which would be to allow some compounds to enter and leave the "cell" more readily than others. These membranes might have been formed nonbiologically by the polymerization of simple two-carbon and three-carbon units. According to this line of reasoning, the compounds that are now prominent constituents of living things are prominent precisely because they were prominent products of chemical evolution. We scarcely need add that this is a controversial and therefore stimulating hypothesis.

What one can say with some confidence is that autocatalysis alone seems unlikely to have been capable of producing the distribution pattern of hydrocarbons observed in ancient Precambrian rocks, even when some allowance is made for subsequent reactions over the course of geologic time. That it could have produced compounds of the observed type is undoubtedly possible, but



SIMILARITY OF MASS SPECTRA makes it difficult to distinguish the 19-carbon isoprenoid pristane from two of its many isomers (molecules with the same number of carbon and hydrogen atoms). The three records shown here are replotted from the actual tracings produced by pure compounds. When the sample contains impurities, as is normally the case, the difficulty of identifying authentic pristane by mass spectrometry is even greater.



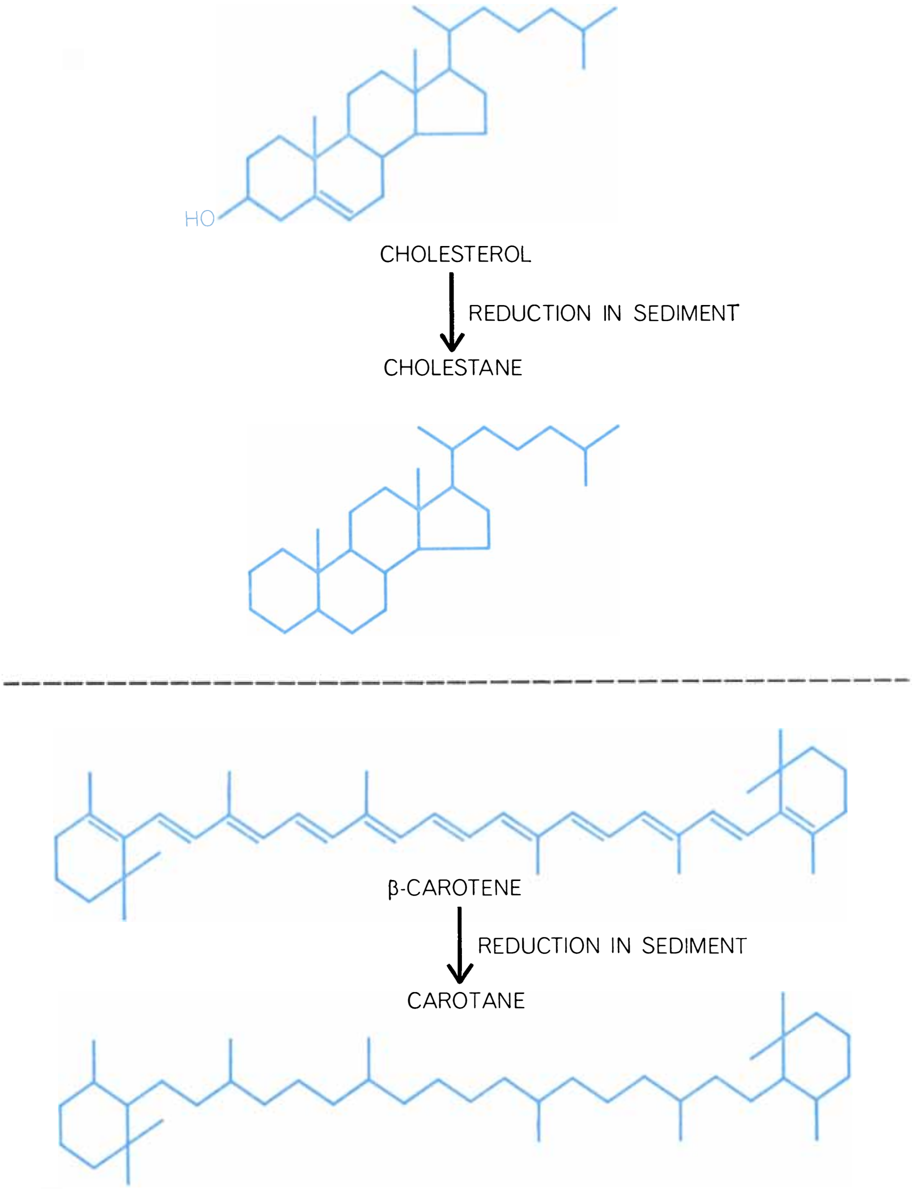
IDENTIFICATION OF PRISTANE can be done more successfully with the aid of a high-resolution gas chromatograph. When pure pristane and the isomers shown in the illustration above are fed into such an instrument, they produce three distinct peaks. This curve and the mass spectra were made by Eugene McCarthy of the University of California at Berkeley. He also made the isoprenoid study shown at the bottom of preceding two pages.

it seems to us that the observed pattern could not have arisen without the operation of those molecular systems we now recognize as the basis of living things. Eventually it should be possible to find in the geological record certain molecular fossils that will mark the boundary between chemical and biological evolution.

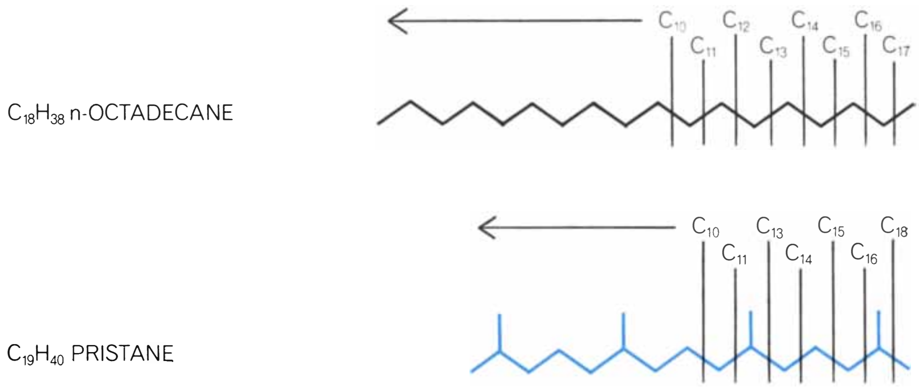
Another and more immediate goal for the organic geochemist is to attempt to trace on the molecular level the direction of biological evolution. For such a study one would like to have access to the actual nucleic acids and proteins synthesized by ancient organisms, but these are as yet unavailable (except perhaps in rare instances). We must therefore turn to the geochemically stable compounds, such as the hydrocarbons and oxygenated compounds that must have derived from the operation of the more perishable molecular systems. These "secondary metabolites," as we have referred to them, can be regarded as the signatures of the molecular systems that synthesized them or their close relatives.

It follows that the carbon skeletons found in the secondary metabolites of present-day organisms are the outcome of evolutionary selection. Thus it should be possible for the organic geochemist to arrange in a rough order of evolutionary sequence the carbon skeletons found in various sediments. There are some indications that this may be feasible. G. A. D. Haslewood of Guy's Hospital Medical School in London has proposed that the bile alcohols and bile acids found in present-day vertebrates can be arranged in an evolutionary sequence: the bile acids of the most primitive organisms contain molecules nearest chemically to cholesterol, their supposed biosynthetic precursor.

Within a few years the organic geochemist will be presented with a piece of the moon and asked to describe its organic contents. The results of this analysis will be awaited with immense curiosity. Will we find that the moon is a barren rock or will we discover traces of organic compounds—some perhaps resembling the complex carbon skeletons we had thought could be produced only by living systems? During the 1970's and 1980's we can expect to receive reports from robot sampling and analytical instruments landed on Mars, Venus and perhaps Jupiter. Whatever the results and their possible indications of alien forms of life, we shall be very eager to learn what carbon compounds are present elsewhere in the solar system.



TWO ALKANES IN GREEN RIVER SHALE, cholestane and carotane, probably have been derived from two well-known biological substances: cholesterol and beta-carotene. The former is closely related to the steroid hormones; the latter is a red pigment widely distributed in plants. These two natural substances can be converted to their alkane form by reduction: a process that adds hydrogen at the site of double bonds and removes oxygen.



EFFECT OF HEATING ALKANES is to produce a smoothly descending series of products (normal alkenes) if the starting material is a straight-chain molecule such as *n*-octadecane. (The term "alkene" denotes a hydrocarbon with one carbon-carbon double bond.) If, however, the starting material is an isoprenoid such as pristane, heating it to 600 degrees centigrade for .6 second produces an irregular series of alkenes because of the branched chain. Such degradation processes may take place in deeply buried sediments. These findings were made by R. T. Holman and his co-workers at the Hormel Institute in Minneapolis, Minn.

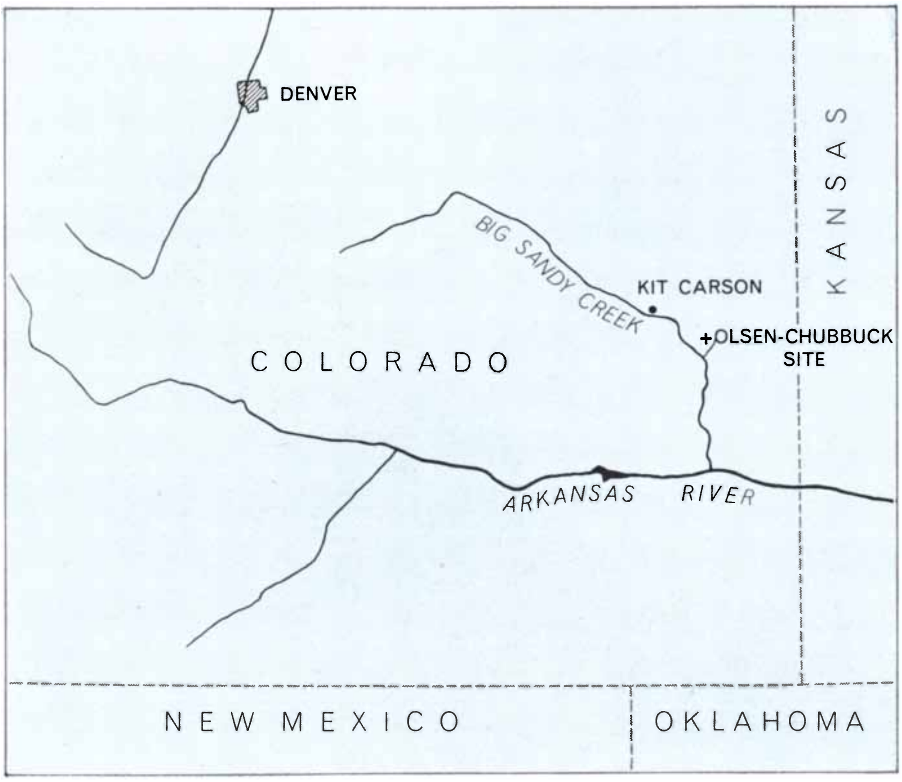
A Paleo-Indian Bison Kill

Some 8,500 years ago a group of hunters on the Great Plains stampeded a herd of buffaloes into a gulch and butchered them. The bones of the animals reveal the event in remarkable detail

by Joe Ben Wheat

When one thinks of American Indians hunting buffaloes, one usually visualizes the hunters pursuing a herd of the animals on horseback and killing them with bow and arrow. Did the Indians hunt buffaloes before the introduction of the horse (by the Spanish conquistadors in the 16th century) and the much earlier introduction of the bow? Indeed they did. As early as 10,000 years ago Paleo-Indians hunted species of bison that are now extinct on foot and with spears. My colleagues and I at the University of Colorado Museum have recently excavated the site of one such Paleo-Indian bison kill dating back to about 6500 B.C. The site so remarkably preserves a moment in time that we know with reasonable certainty not only the month of the year the hunt took place but also such details as the way the wind blew on the day of the kill, the direction of the hunters' drive, the highly organized manner in which they butchered their quarry, their choice of cuts to be eaten on the spot and the probable number of hunters involved.

The bison was the most important game animal in North America for millenniums before its near extermination in the 19th century. When Europeans arrived on the continent, they found herds of bison ranging over vast areas, but the animals were first and foremost inhabitants of the Great Plains, the high, semiarid grassland extending eastward from the foothills of the Rocky Mountains and all the way from Canada to Mexico. Both in historic and in late prehistoric times the bison was the principal economic resource of the Indian tribes that occupied the Great Plains. Its meat, fat and bone marrow provided them with food; its hide furnished them with shelter and clothing; its brain was used to tan the hide; its horns were fashioned into containers. There was scarcely a part of the animal that was not utilized in some way.



SITE OF THE KILL is 140 miles southeast of Denver. It is named the Olsen-Chubbuck site after its discoverers, the amateur archaeologists Sigurd Olsen and Gerald Chubbuck.

This dependence on big-game hunting probably stretches back to the very beginning of human prehistory in the New World. We do not know when man first arrived in the Americas, nor do we know in detail what cultural baggage he brought with him. The evidence for the presence of man in the New World much before 12,000 years ago is scattered and controversial. It is quite clear, however, that from then on Paleo-Indian hunting groups, using distinctive kinds of stone projectile point, ranged widely throughout the New World. On the Great Plains the principal game animal of this early period was the Columbian mammoth [see "Elephant-hunting in North America," by C. Vance Haynes, Jr.; SCIENTIFIC AMERICAN, June, 1966]. Mammoth remains have been found in association with projectile points that are usually large and leaf-shaped and have short, broad grooves on both sides of the base. These points are typical of the complex

BONES OF BISON unearthed at the Olsen-Chubbuck site lie in a long row down the center of the ancient arroyo the Paleo-Indian hunters utilized as a pitfall for the stampeding herd. The bones proved to be the remains of bulls, cows and calves of the extinct species *Bison occidentalis.* Separate piles made up of the same types of bones (for example sets of limb bones, pelvic girdles or skulls) showed that the hunters had butchered several bison at a time and had systematically dumped the bones into the arroyo in the same order in which they were removed from the carcasses. In the foreground is a pile of skulls that was built up in this way.

PROJECTILE POINTS found at the site show a surprising divergence of form in view of the fact that all of them were used simultaneously by a single group. In the center is a point of the Scottsbluff type. At top left is another Scottsbluff point that shows some of the characteristics of a point of the Eden type at top right. At bottom left is a third Scottsbluff point; it has characteristics in common with a point of the Milnesand type at bottom right. Regardless of form, all the points are equally excellent in flaking.

of cultural traits named the Clovis complex; the tool kit of this complex also included stone scrapers and knives and some artifacts made of ivory and bone.

The elephant may have been hunted out by 8000 B.C. In any case, its place as a game animal was taken by a large, straight-horned bison known as *Bison antiquus*. The first of the bison-hunters used projectile points of the Folsom culture complex; these are similar to Clovis points but are generally smaller and better made. Various stone scrapers and knives, bone needles and engraved bone ornaments have also been found in Folsom sites.

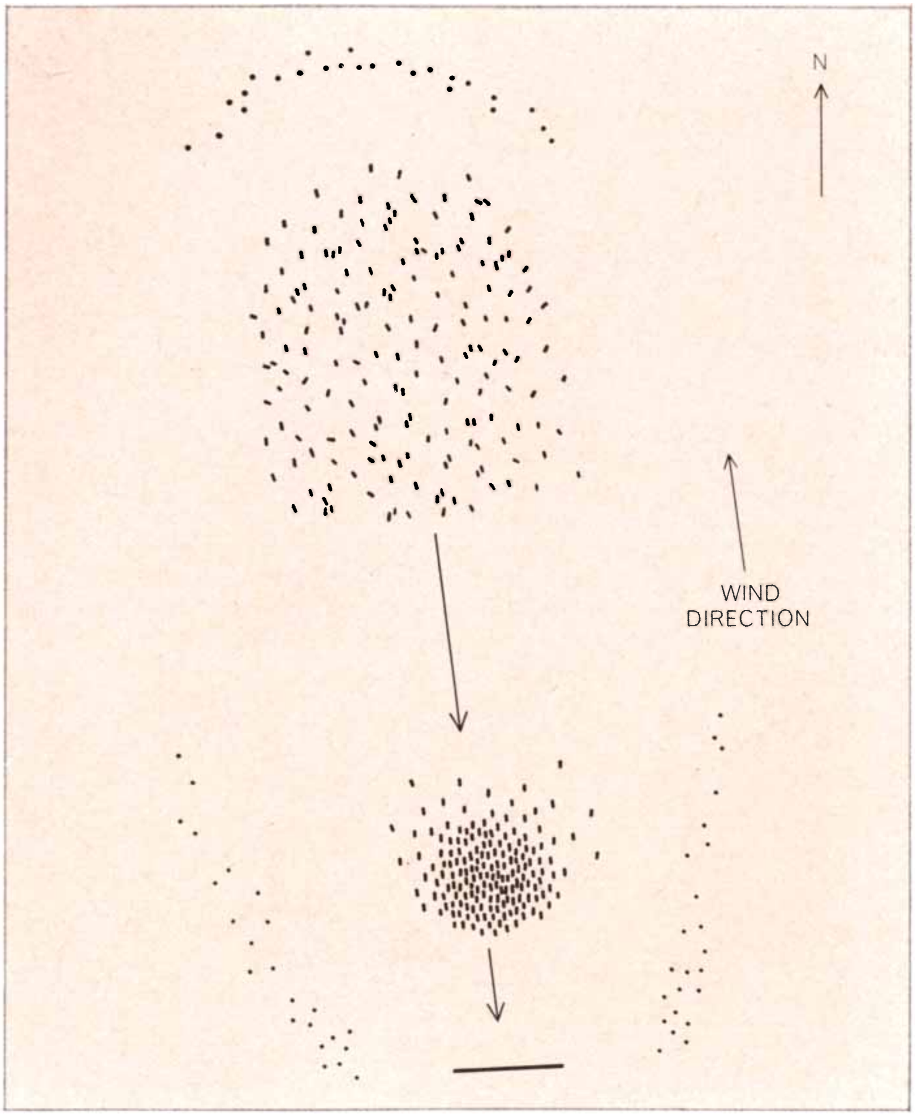
A millennium later, about 7000 B.C., *Bison antiquus* was supplanted on the Great Plains by the somewhat smaller *Bison occidentalis*. The projectile points found in association with this animal's remains are of several kinds. They differ in shape, size and details of flaking, but they have some characteristics in common. Chief among them is the technical excellence of the flaking. The flake scars meet at the center of the blade to form a ridge; sometimes they give the impression that a single flake has been detached across the entire width of the blade [*see illustration on opposite page*]. Some of the projectile points that belong to this tradition, which take their names from the sites where they were first found, are called Milnesand, Scottsbluff and Eden points. The last two kinds of point form part of what is called the Cody complex, for which there is a fairly reliable carbon-14 date of about 6500 B.C.

Paleo-Indian archaeological sites fall into two categories: habitations and kill sites. Much of our knowledge of the early inhabitants of the Great Plains comes from the kill sites, where are found not only the bones of the animals but also the projectile points used to kill them and the knives, scrapers and other tools used to butcher and otherwise process them. Such sites have yielded much information about the categories of projectile points and how these categories are related in time. Heretofore, however, they have contributed little to our understanding of how the early hunters actually lived. The kill site I shall describe is one of those rare archaeological sites where the evidence is so complete that the people who left it seem almost to come to life.

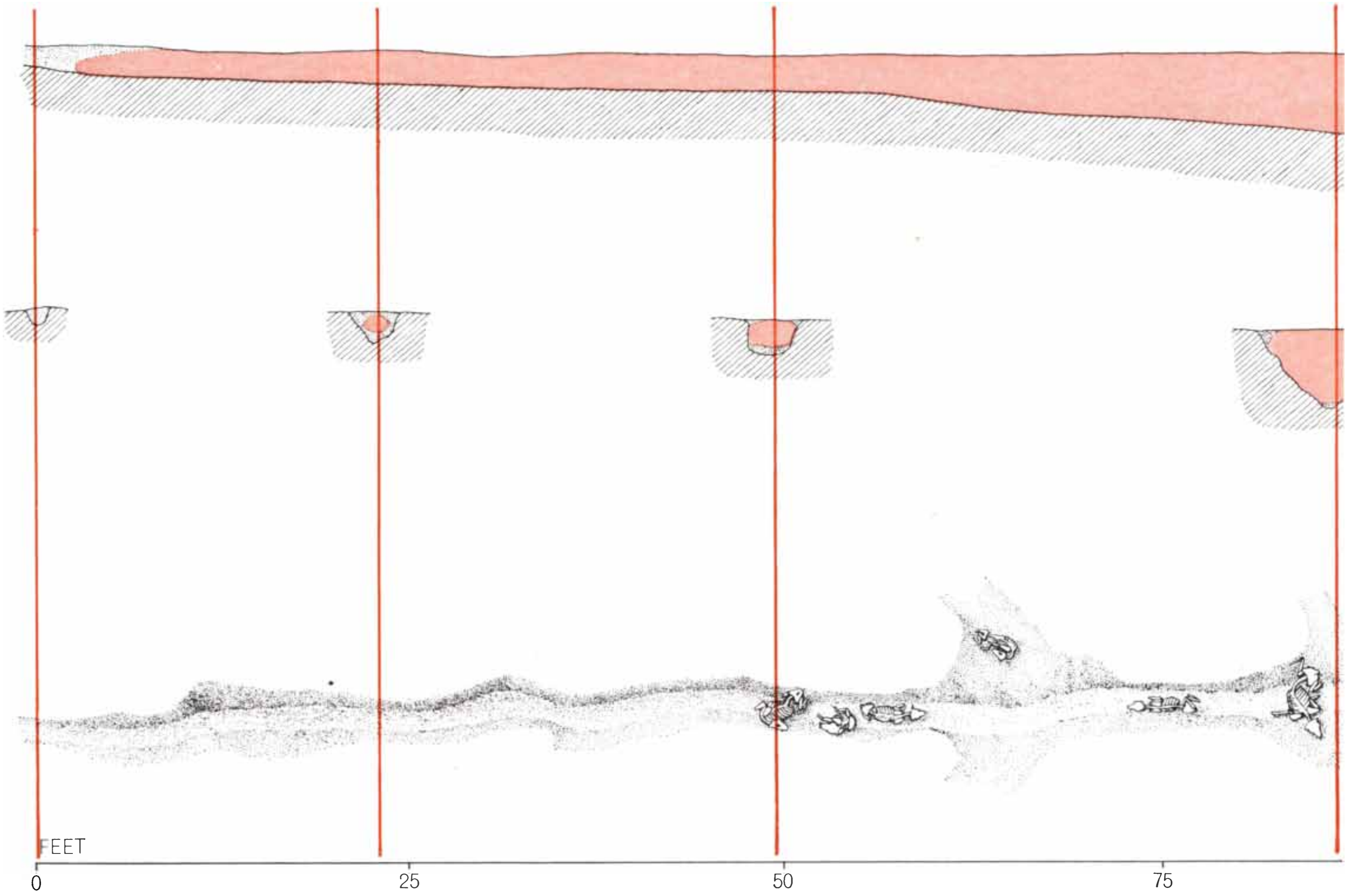
Sixteen miles southeast of the town of Kit Carson in southeastern Colorado, just below the northern edge of the broad valley of the Arkansas River, lies a small valley near the crest of a low divide. The climate here is semiarid; short bunchgrass is the main vegetation and drought conditions have prevailed since the mid-1950's. In late 1957 wind erosion exposed what appeared to be five separate piles of bones, aligned in an east-west direction. Gerald Chubbuck, a keen amateur archaeologist, came on the bones in December, 1957; among them he found several projectile points of the Scottsbluff type. Chubbuck notified the University of Colorado Museum of his find, and we made plans to visit the site at the first opportunity.

Meanwhile Chubbuck and another amateur archaeologist, Sigurd Olsen, continued to collect at the site and ultimately excavated nearly a third of it. In the late spring of 1958 the museum secured permission from the two discoverers and from Paul Forward, the owner of the land, to complete the excavation. We carried out this work on summer expeditions in 1958 and 1960.

The Olsen-Chubbuck site consists of a continuous bed of bones lying within the confines of a small arroyo, or dry gulch. The arroyo, which had long since been buried, originally rose near the southern end of the valley and followed a gently undulating course eastward through a ridge that forms the valley's eastern edge. The section of the arroyo that we excavated was some 200 feet long. Its narrow western end was only about a foot and a half in depth and the same in width, but it grew progressively deeper and wider to the east. Halfway down the arroyo its width was five feet and its depth six; at the point to the east where our excavation stopped it was some 12 feet wide and seven feet deep. At the bottom of the



BISON STAMPEDE was probably set off by the Paleo-Indian hunters' close approach to the grazing herd from downwind. Projectile points found among the bones of the animals at the eastern end of the arroyo (*bottom*) suggest that some hunters kept the bison from veering eastward to escape. Other hunters probably did the same at the western end of the arroyo.



SECTION AND PLAN **of the Olsen-Chubbuck site show how the remains of the dead and butchered bison formed a deposit of bones that lined the center of the arroyo for a distance of 170 feet (*color at top*). One part of the site had been excavated by its discoverers**

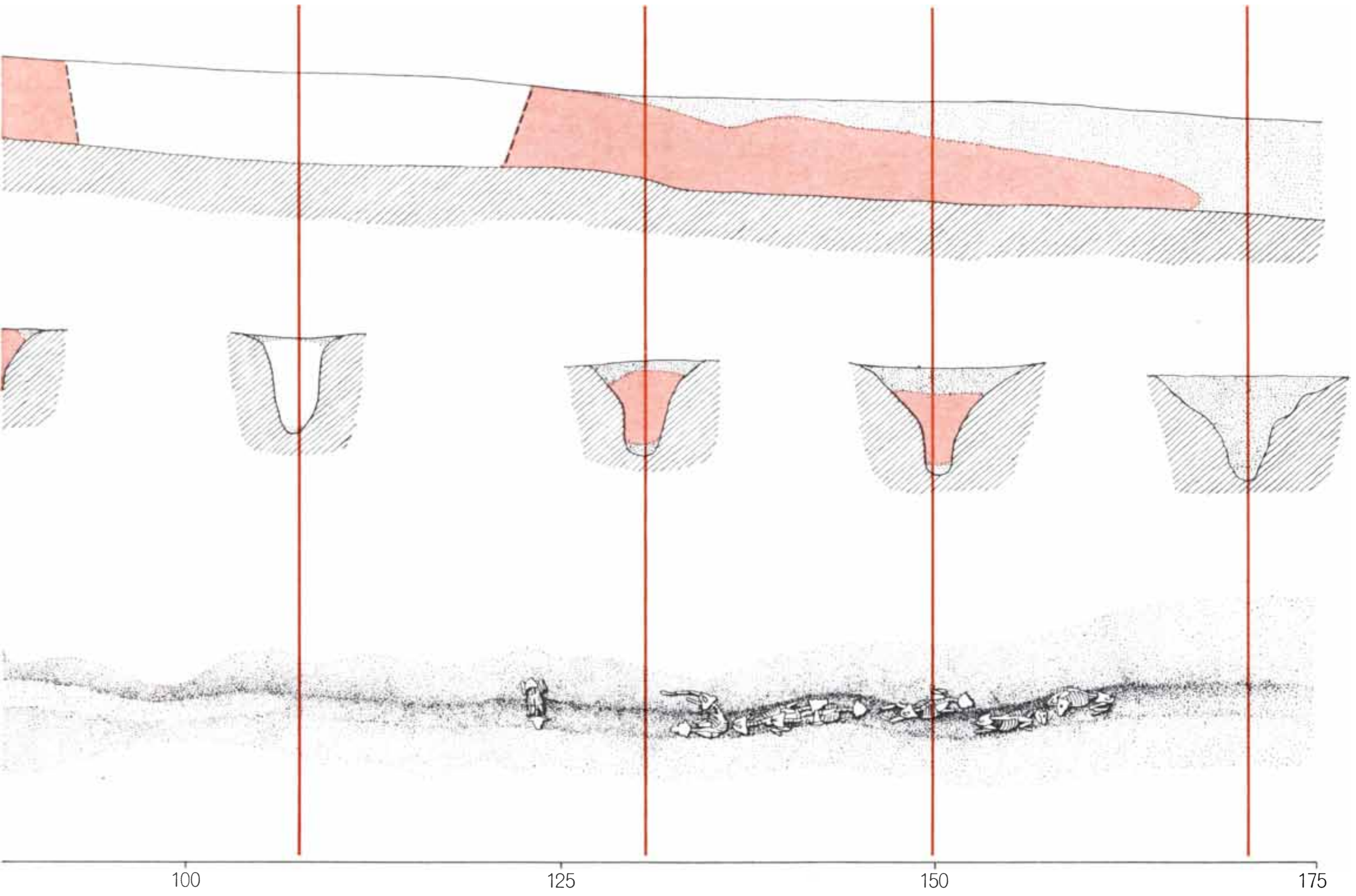
arroyo for its entire length was a channel about a foot wide; above the channel the walls of the arroyo had a V-shaped cross section [*see top illustration on page 50*].

Today the drainage pattern of the site runs from north to south. This was probably the case when the arroyo was formed, and since it runs east and west it seems certain that it was not formed by stream action. Early frontiersmen on the Great Plains observed that many buffalo trails led away from watering places at right angles to the drainage pattern. Where such trails crossed ridges they were frequently quite deep; moreover, when they were abandoned they were often further deepened by erosion. The similarity of the Olsen-Chubbuck arroyo to such historical buffalo trails strongly suggests an identical origin.

The deposit of bison bones that filled the bottom of the arroyo was a little more than 170 feet long. It consisted of the remains of nearly 200 buffaloes of the species *Bison occidentalis*. Chubbuck and Olsen unearthed the bones of an estimated 50 of the animals; the museum's excavations uncovered the bones of 143 more. The bones were found in three distinct layers. The bottom layer contained some 13 complete skeletons; the hunters had not touched these animals. Above this layer were several essentially complete skeletons from which a leg or two, some ribs or the skull were missing; these bison had been only partly butchered. In the top layer were numerous single bones and also nearly 500 articulated segments of buffalo skeleton. The way in which these segments and the single bones were distributed provides a number of clues to the hunters' butchering techniques.

As the contents of the arroyo—particularly the complete skeletons at the bottom—make clear, it had been a trap into which the hunters had stampeded the bison. Bison are gregarious animals. They move in herds in search of forage; the usual grazing herd is between 50 and 300 animals. Bison have a keen sense of smell but relatively poor vision. Hunters can thus get very close to a herd as long as they stay downwind and largely out of sight. When the bison are frightened, the herd has a tendency to close ranks and stampede in a single mass. If the herd encounters an abrupt declivity such as the Olsen-Chubbuck arroyo, the animals in front cannot stop because they are pushed by those behind. They can only plunge into the arroyo, where they are immobilized, disabled or killed by the animals that fall on top of them.

The orientation of the skeletons in the middle and lower layers of the Olsen-Chubbuck site is evidence that the Paleo-Indian hunters had initiated such a stampede. Almost without exception the complete or nearly complete skeletons overlie or are overlain by the skeletons of one, two or even three other whole or nearly whole animals; the bones are massed and the skeletons are contorted. The first animals that fell into the arroyo had no chance to escape; those behind them wedged them tighter into the arroyo with their struggles. Many of the skeletons are sharply twisted around the axis of the spinal column. Three spanned the arroyo, deformed into



before the author and his associates began work in 1958; this area is represented by the 20-foot gap in the deposit. The shallow inner channel at the bottom of the arroyo can be seen in the plan view (*bottom*); outlines show the locations of 13 intact bison skeletons.

an unnatural U shape. Ten bison were pinned in position with their heads down and their hindquarters up; an equal number had landed with hindquarters down and heads up. At the bottom of the arroyo two skeletons lie on their backs.

The stampeding bison were almost certainly running in a north-south direction, at right angles to the arroyo. Of the 39 whole or nearly whole skeletons, which may be assumed to lie in the positions in which the animals died, not one faces north, northeast or northwest. A few skeletons, confined in the arroyo's narrow inner channel, face due east or west, but all 21 animals whose position at the time of death was not affected in this manner faced southeast, south or southwest. The direction in which the bison stampeded provides a strong clue to the way the wind was blowing on the day of the hunt. The hunters would surely have approached their quarry from downwind; thus the wind must have been from the south.

We have only meager evidence of the extent to which the stampede, once started, was directed and controlled by the hunters. The projectile points found with the bison skeletons in the deepest, most easterly part of the arroyo suggest that a flanking party of hunters was stationed there. It also seems a reasonable inference that, if no hunters had covered the stampede's western flank, the herd could have escaped unscathed around the head of the arroyo. If other hunters pursued the herd from the rear, there is no evidence of it.

Even if the hunters merely started the stampede and did not control it thereafter, it sufficed to kill almost 200 animals in a matter of minutes. The total was 46 adult bulls and 27 immature ones, 63 adult and 38 immature cows and 16 calves. From the fact that the bones include those of calves only a few days old, and from what we know about the breeding season of bison, we can confidently place the date of the kill as being late in May or early in June.

As we excavated the bone deposit we first uncovered the upper layer containing the single bones and articulated segments of skeleton. It was soon apparent that these bones were the end result of a standardized Paleo-Indian butchering procedure. We came to recognize certain "butchering units" such as forelegs, pelvic girdles, hind legs, spinal columns and skulls. Units of the same kind were usually found together in groups numbering from two or three to as many as 27. Similar units also formed distinct vertical sequences. As the hunters had removed the meat from the various units they had discarded the bones in separate piles, each of which contained the remains of a number of individual animals. In all we excavated nine such piles.

Where the order of deposition was clear, the bones at the bottom of each pile were foreleg units. Above these bones were those of pelvic-girdle units. Sometimes one or both hind legs were attached to the pelvic girdle, but by and large the hind-leg units lay separately among or above the pelvic units. The next level was usually composed of spinal-column units. The ribs had been removed from many of the chest vertebrae, but ribs were still attached to some of the other vertebrae. At the top

EXCAVATION at the eastern end of the arroyo reveals its V-shaped cross section and the layers of sand and silt that later filled it. The bone deposit ended at this point; a single bison shoulder blade remains in place at the level where it was unearthed (*lower center*).

BISON SKULL AND STONE POINT lie in close association at one level in the site. The projectile point (*lower left*) is of the Scottsbluff type. The bison skull, labeled *4-F* to record its position among the other bones, rests upside down where the hunters threw it.

of nearly every pile were skulls. The jawbones had been removed from most of them, but some still retained a few of the neck vertebrae. In some instances these vertebrae had been pulled forward over the top and down the front of the skull. When the skull still had its jawbone, the hyoid bone of the tongue was missing.

Like the various butchering units, the single bones were found in clusters of the same skeletal part: shoulder blades, upper-foreleg bones, upper-hind-leg bones or jawbones (all broken in two at the front). Nearly all the jawbones were found near the top of the bone deposit. The tongue bones, on the other hand, were distributed throughout the bed. About 75 percent of the single foreleg bones were found in the upper part of the deposit, as were nearly 70 percent of the single vertebrae. Only 60 percent of the shoulder blades and scarcely half of the single ribs were in the upper level.

The hunters' first task had evidently been to get the bison carcasses into a position where they could be cut up. This meant that the animals had to be lifted, pulled, rolled or otherwise moved out of the arroyo to some flat area. It seems to have been impossible to remove the bison that lay at the bottom of the arroyo; perhaps they were too tightly wedged together. Some of them had been left untouched and others had had only a few accessible parts removed. The way in which the butchering units were grouped suggests that several bison were moved into position and cut up simultaneously. Since foreleg units, sometimes in pairs, were found at the bottom of each pile of bones it seems reasonable to assume that the Paleo-Indians followed the same initial steps in butchering that the Plains Indians did in recent times. The first step was to arrange the legs of the animal so that it could be rolled onto its belly. The skin was then cut down the back and pulled down on both sides of the carcass to form a kind of mat on which the meat could be placed. Directly under the skin of the back was a layer of tender meat, the "blanket of flesh"; when this was stripped away, the bison's forelegs and shoulder blades could be cut free, exposing the highly prized "hump" meat, the rib cage and the body cavity.

Having stripped the front legs of meat, the hunters threw the still-articulated bones into the arroyo. If they followed the practice of later Indians, they would next have indulged themselves by cutting into the body cavity, removing some of the internal organs and eating them raw. This, of course, would have left no evidence among the bones. What is certain is that the hunters did remove and eat the tongues of a few bison at this stage of the butchering, presumably in the same way the Plains Indians did: by slitting the throat, pulling the tongue out through the slit and cutting it off. Our evidence for their having eaten the tongues as they went along is that the tongue bones are found throughout the deposit instead of in one layer or another.

The bison's rib cages were attacked as soon as they were exposed by the removal of the overlying meat. Many of the ribs were broken off near the spine. The Plains Indians used as a hammer for this purpose a bison leg bone with the hoof still attached; perhaps the Paleo-Indians did the same. In any case, the next step was to sever the spine at a point behind the rib cage and remove the hindquarters. The meat was cut away from the pelvis (and in some instances simultaneously from the hind legs) and the pelvic girdle was discarded. If the hind legs had been separated from the pelvis, it was now their turn to be stripped of meat and discarded.

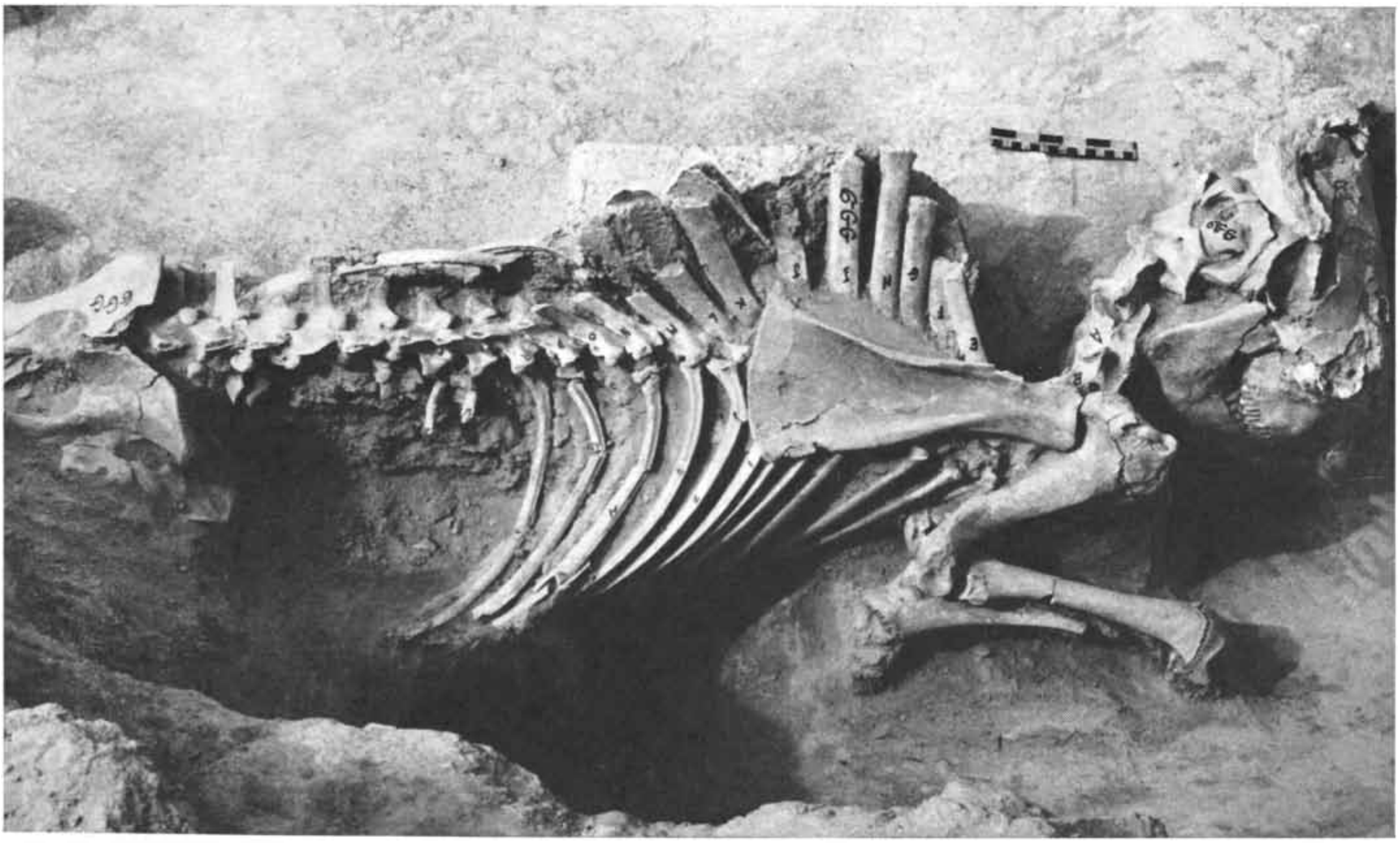
After the bison's hindquarters had been butchered, the neck and skull were cut off as a unit—usually at a point just in front of the rib cage—and set aside. Then the spine was discarded, presumably after it had been completely stripped of meat and sinew. Next the hunters turned to the neck and skull and cut the neck meat away. This is evident from the skulls that had vertebrae draped over the front; this would not have been possible if the neck meat had been in place. The Plains Indians found bison neck meat too tough to eat in its original state. They dried it and made the dried strips into pemmican by pounding them to a powder. The fact that the Paleo-Indians cut off the neck meat strongly suggests that they too preserved some of their kill.

If the tongue had not already been removed, the jawbone was now cut away, broken at the front and the tongue cut out. The horns were broken from a few skulls, but there is little evidence that the Paleo-Indians broke open the skull as the Plains Indians did to take out the brain. Perhaps the most striking difference between the butchering practices of these earlier Indians and those of later ones, however, lies in the high degree of organization displayed by the Paleo-Indians. Historical accounts of butchering by Plains Indians indicate no such efficient system.

In all, 47 artifacts were found in association with the bones at the Olsen-Chubbuck site. Spherical hammerstones and knives give us some idea of what constituted the hunter's tool kit; stone scrapers suggest that the bison's skins were processed at the site. A bone pin and a piece of the brown rock limonite that shows signs of having been rubbed tell something about Paleo-Indian ornamentation.

The bulk of the artifacts at the site are projectile points. There are 27 of them, and they are particularly significant. Most of them are of the Scottsbluff type. When their range of variation is considered, however, they merge gradually at one end of the curve of variation into Eden points and at the other end into Milnesand points. Moreover, among the projectile points found at the site are one Eden point and a number of Milnesand points. The diversity of the points clearly demonstrates the range of variation that was possible among the weapons of a single hunting group. Their occurrence together at the site is conclusive proof that such divergent forms of weapon could exist contemporaneously.

How many Paleo-Indians were pres-



INTACT SKELETON of an immature bison cow, uncovered in the lowest level of the arroyo, is one of 13 animals the Paleo-Indian hunters left untouched. The direction in which many bison faced suggests that the stampede traveled from north to south.

ent at the kill? The answer to this question need not be completely conjectural. We can start with what we know about the consumption of bison meat by Plains Indians. During a feast a man could consume from 10 to 20 pounds of fresh meat a day; women and children obviously ate less. The Plains Indians also preserved bison meat by drying it; 100 pounds of fresh meat would provide 20 pounds of dried meat. A bison bull of today yields about 550 pounds of edible meat; cows average 400 pounds. For an immature bull one can allow 165 pounds of edible meat, for an immature cow 110 pounds and for a calf 50 pounds. About 75 percent of the bison killed at the Olsen-Chubbuck site were completely butchered; on this basis the total weight of bison meat would have been 45,300 pounds. The *Bison occidentalis* killed by the Paleo-Indian hunters, however, was considerably larger than the *Bison bison* of modern times. To compensate for the difference it seems reasonable to add 25 percent to the weight estimate, bringing it to a total of 56,640 pounds. To this total should be added some 4,000 pounds of edible internal organs and 5,400 pounds of fat.

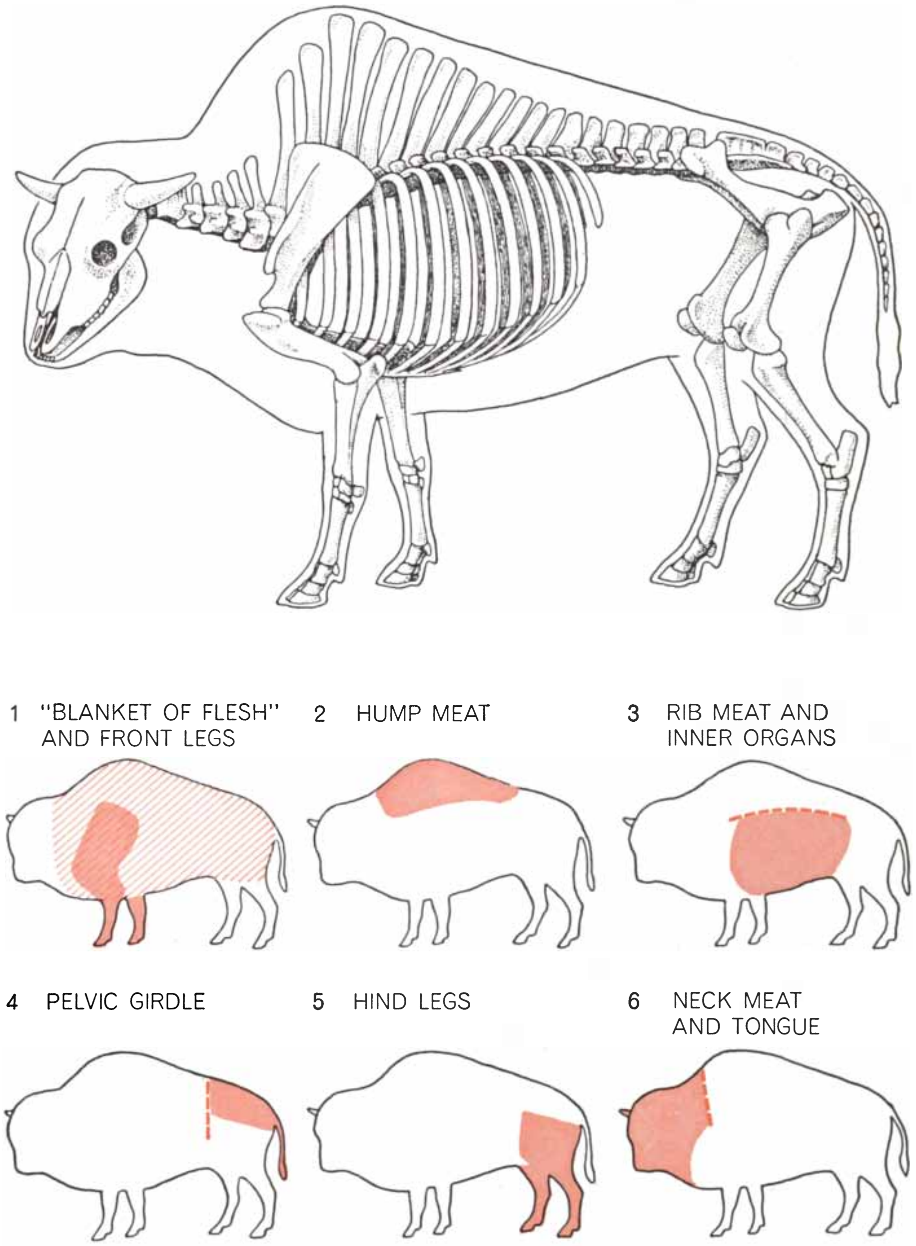
A Plains Indian could completely butcher a bison in about an hour. If we allow one and a half hours for the dissection of the larger species, the butchering at the Olsen-Chubbuck site would have occupied about 210 man-hours. In other words, 100 people could easily have done the job in half a day.

To carry the analysis further additional assumptions are needed. How long does fresh buffalo meat last? The experience of the Plains Indians (depending, of course, on weather conditions) was that it could be eaten for about a month. Let us now assume that half of the total weight of the Olsen-Chubbuck kill was eaten fresh at an average rate of 10 pounds per person per day, and that the other half was preserved. Such a division would provide enough fresh meat and fat to feed 150 people for 23 days. It seems reasonable to assume that the Paleo-Indian band was about this size. One way to test this assumption is to calculate the load each person would have to carry when camp was broken.

The preserved meat and fat, together with the hides, would have weighed about 7,350 pounds, which represents a burden of 49 pounds for each man, woman and child in the group (in addition to the weight of whatever other necessities they carried). Plains Indians are known to have borne loads as great as 100 pounds. Taking into account the likelihood that small children and active hunters would have carried smaller loads, a 49-pound average appears to be just within the range of possibility.

A band of 150 people could, however, have eaten two-thirds of the kill fresh and preserved only one-third. In that case the fresh meat would have fed them for somewhat more than a month. At the end the meat would have been rather gamy, but the load of preserved meat per person would have been reduced to the more reasonable average of 31 pounds.

One possibility I have left out is that the Paleo-Indians had dogs. If there were dogs available to eat their share of fresh meat and to carry loads of preserved meat, the number of people in the group may have been somewhat less. In the absence of dogs, however, it seems improbable that any fewer than 150 people could have made use of the bison killed at the Olsen-Chubbuck site to the degree that has been revealed by our excavations. Whether or not the group had dogs, the remains of its stay at the site are unmistakable evidence that hunting bands of considerable size and impressive social organization were supporting themselves on the Great Plains some 8,500 years ago.



BUTCHERING METHODS used by the Paleo-Indians have been reconstructed on the dual basis of bone stratification at the Olsen-Chubbuck site and the practices of the Plains Indians in recent times. Once the carcass of the bison (*skeleton at top*) had been propped up and skinned down the back, a series of "butchering units" probably were removed in the order shown on the numbered outline figures. The hunters ate as they worked.

The hope of doing each other some good prompts these advertisements

Disclosure

If there weren't so many pretty girls around wearing pretty, bright-colored things, we wouldn't have done as well as we have with KODACHROME Film. The dyes in the film have to get themselves synthesized *in situ* after the shutter has operated, but some of the dyes in the clothes, which the dyes in the film try to ape, we synthesize in large reaction kettles in competition with other textile dyemakers, who also know a thing or two. The pressure from them to keep our dyestuff quality and reproducibility high and our costs low makes us think hard whether we want to give away any tricks. We have decided that our shareowners have more to gain than to lose by the following disclosure ▶

Thin-layer chromatography has now become so straightforward that an operator can be taught to use this supersensitive technique of separations chemistry to mind the progress of his chlorination and cut it off after every bit of his p-nitroaniline has reacted and before any tetrachloroquinone has formed. He does it with EASTMAN CHROMAGRAM Sheet and that little EASTMAN CHROMAGRAM Developing Apparatus at the left, both of which can be purchased by one and all from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company).

Microfilm outfit

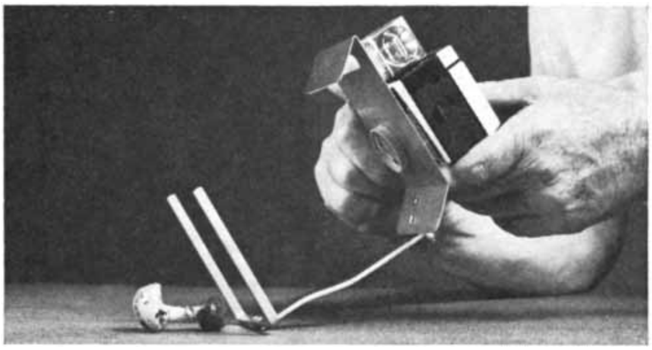
We are modern marketers. We are in "systems" right up to our receding hairlines. We have organized a Business Systems Markets Division and have assigned it to sit down with any respectable organizational management to recommend whether and how microfilming can most effectively and economically simplify its information-handling problems. "Don't just peddle the merchandise," we warn the men. One of the last stands of the old ways, then, is represented by the following advertising approach. We here assume that why you want a portable microfilmer, a portable microfilm reader, and/or a little microfilm processing machine for a corner of the office is none of our business. The very same Business Systems Markets Division, Eastman Kodak Company, Rochester, N. Y. 14650, is ready to supply literature on the equipment and to accept orders.

◀The case contains a RECORDAK Portable Microfilmer weighing 24 pounds. The device accepts documents up to 12 inches wide and of any length. It can microfilm 60 letter-size documents in one minute—on two rolls of 16mm film simultaneously if you like. Gets its juice from a regular AC outlet.

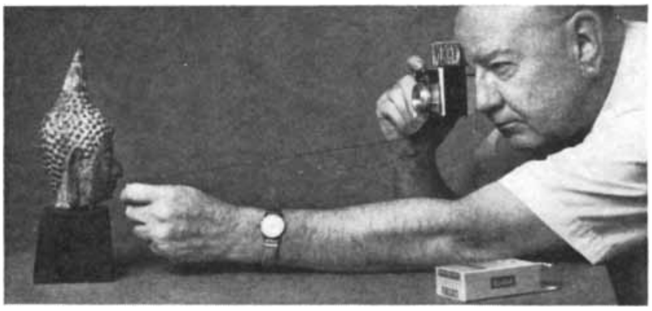
◀This RECORDAK PROSTAR Film Processor needs no darkroom. Just 1¾ minutes after you put exposed film in, out it comes at 5 or 10 feet per minute, dry and processed to archival standards. It takes 16mm or 35-mm film, 2 feet to 100 feet, two separate 16mm rolls at a time if you like.

◀This case contains a RECORDAK Portable Film Reader and 18,000 documents on microfilm. The reader takes less than 20 seconds to set up. It weighs 20 pounds and enlarges 16mm microfilm 20 times on a bright 9″ x 12″ screen. It runs on its own internal battery. It runs on AC house current. It also runs when plugged into the lighter socket in an automobile. Press the button and race the film until an index mark reaches the right number on the edge of the screen.

INSTATECH Camera Outfit



Place any work of nature or of man within this frame and press the button.



If it won't fit in the frame, hold the camera this chain's length away and press the button.

No lighting to arrange. No exposures to calculate. No focusing. No fumbling to load film—just drop in a 126 film cartridge, basis of the incredibly popular system that makes photography cheap by cutting out mistakes. Even less chance for mistakes here than when snapshooting places and people.*

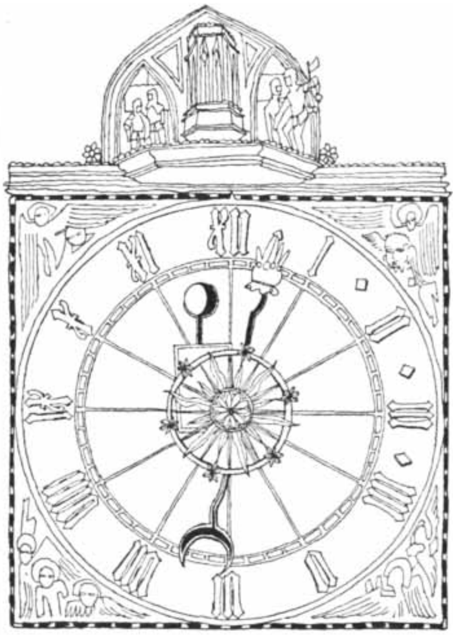
You may be less than pleased to learn about this. You may feel that vivid slides and prints that capture fine details of interesting objects are becoming too easy to make, too common.

The new KODAK INSTATECH *Camera, the above equipment that fits it for its two working distances, 5 flashcubes good for the 20 shots in a* KODAK EKTACHROME-X *Film cartridge, such a cartridge, and a pair of batteries are offered as an outfit for $49.75 by Lester A. Dine, Inc., 2080 Jericho Turnpike, New Hyde Park, N.Y. 11041.*

*Dentists, surgeons, and other professionals whose profession is not photography actually do use this equipment on people—in their own professional way. In fact, it was designed for them.

Price does not include local taxes and is subject to change without notice.

Kodak



The Space Treaty

With the approval by the UN General Assembly of an international treaty on the peaceful uses of "outer space, including the moon and other celestial bodies," the first rules have been established governing man's activities beyond his own planet. The treaty provides that no signatory shall place nuclear weapons in orbit around the earth or in space and prohibits all military activities on the moon and other celestial bodies. It affirms that the exploration of space is "the province of all mankind," provides for "freedom of scientific investigation" in space and establishes principles of cooperation and mutual assistance.

The treaty has its roots in two UN resolutions passed in the fall of 1963 after the signing of the partial-test-ban treaty. One resolution called on the nations not to place nuclear weapons in orbit and the other put forward a set of "legal principles" applying to space exploration. Last spring the U.S. and the U.S.S.R. submitted proposals for a treaty to the 28-nation UN Committee on the Peaceful Uses of Outer Space. The treaty was drafted by a legal subcommittee in Geneva during the summer; the final language was negotiated in a series of meetings between American and Russian representatives in New York. It is open for ratification by all countries, whether or not they are members of the UN. President Johnson, who called the treaty "the most important arms control development" since the test-ban agreement, said he would submit it to the Senate for early ratification.

SCIENCE AND

The text begins by asserting that space should be explored "in the interests of all countries" on a basis of equality and in accordance with international law, including the UN Charter. It asserts that space, the moon and other bodies are "not subject to national appropriation by claim of sovereignty." In addition to banning weapons of mass destruction in orbit, it forbids the "establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military maneuvers on celestial bodies," but does not bar peaceful activities conducted by military personnel. Signatory states are to regard astronauts of all nations as "envoys of mankind" and to render assistance to them in the case of any accident, distress or emergency landing; astronauts of various countries are specifically called on to help one another. The principle is established of national responsibility and liability for both governmental and nongovernmental activities in space. These activities are to avoid "harmful contamination" of the moon and other bodies and adverse changes in the environment of the earth.

The Ascendant Atom

The year just ended may be recorded as the one in which nuclear fuels came to play a larger role than fossil fuels in the plans of U.S. power companies. In the first nine months of 1966, 51 percent of the new electric generating capacity ordered by U.S. utilities, both public and private, was nuclear. It is possible, of course, that the atom's unexpected ascendancy reflects a temporary surge of orders, and does not mean that fossil fuels have been permanently relegated to second place.

The 20 nuclear power plants ordered in the first nine months of 1966 will have a total capacity of nearly 16 million kilowatts. This is 38 percent more than the capacity of all U.S. nuclear power plants built or announced before 1966. (As of October 1, 1966, the total installed capacity of all U.S. utility power plants, nuclear and fossil fuel combined, was 244 million kilowatts—about 15 times the capacity of the nuclear plants ordered in the first nine months of 1966.) The investment in the new nuclear power plants will come to $1.7 billion. The largest of the 20 has been ordered by the Tennessee Valley Authority for installation at Browns Ferry, Ala. It will have a capacity of 2.2 million kilowatts and will cost $247 million.

Grants across the Board

Government support of science and higher scientific education in the U.S. is sometimes criticized on the ground that too many grants are awarded to an individual and his project and not enough are given directly to the educational institution for which he works. The National Science Foundation has now begun two new programs of direct aid to colleges and universities and has changed an existing program, to help improve science instruction and research in institutions "that are not now at the forefront but that have potential and aspirations to rise." The three programs complement one another in providing assistance to institutions differing in size, type and function.

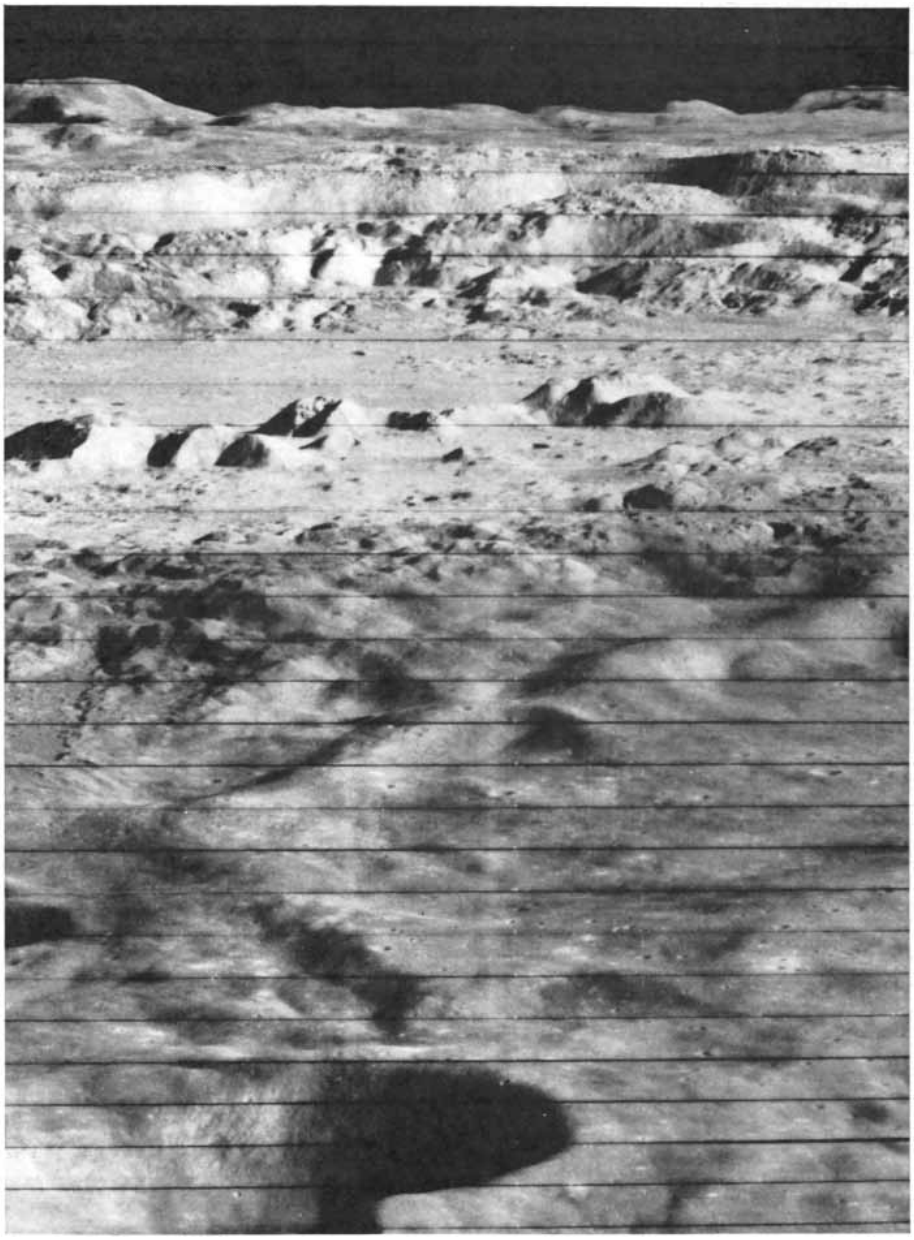
The new College Science Improvement Program will support comprehensive plans to upgrade the preparation of students in predominantly undergraduate institutions for careers in science. The emphasis will be on improved instruction. Grants of up to $100,000 a year will be available, with the amounts related to the number of science baccalaureate degrees awarded. A new Departmental Science Development Program is intended for institutions that have graduate programs in science but are not recognized as having "outstanding strength" in the field. Grants of up to $600,000 for three years will be made for the support of specific areas in which the institution seems to be capable of reaching a high level. The existing Science Development Program, now renamed the University Science Development Program, will be restricted to institutions with doctoral programs. It is designed for universities that are "below the highest level" but have the potential to rise to the level of the leading institutions.

Close-up of Copernicus

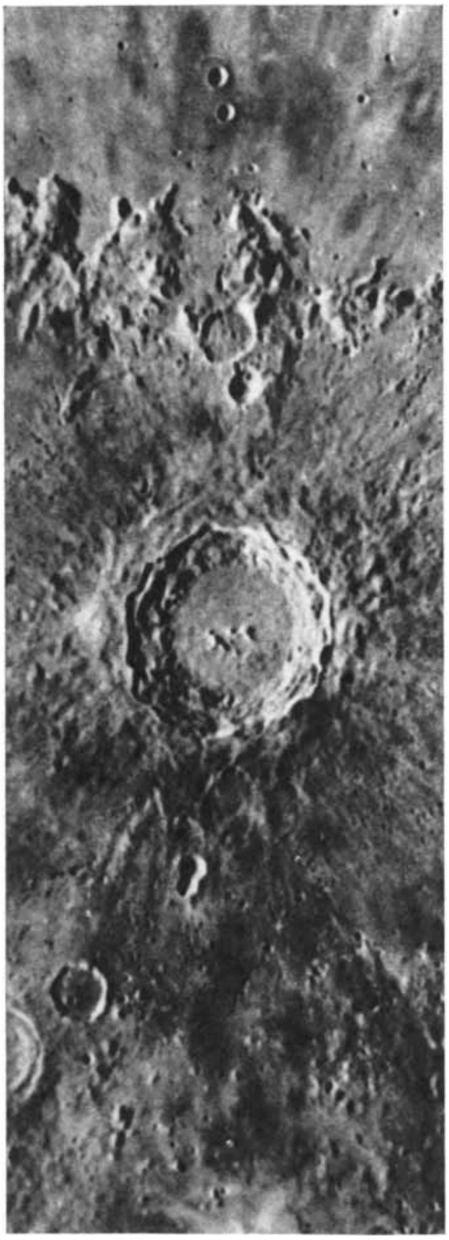
The extraordinarily detailed photographs of the moon's surface obtained on the recent flights of the Lunar Orbiter spacecraft owe their high quality to a number of technological feats, not the least of which was putting a complete photographic laboratory into a package weighing only 150 pounds. Included in each package were two cameras (one for high-resolution photography and the other for medium-resolution photography), a 200-foot roll of 70-millimeter film, equipment for chemically developing and heat-drying the exposed film and an electronic "readout" system for scanning the developed image and transmitting it back to the earth.

Thus the image-recording system of the Lunar Orbiters differed essentially from the television systems employed on the previous Ranger and Surveyor missions. Because of the high orbital speed of the spacecraft (up to 4,500 miles per hour) and the comparatively slow exposure times of the photographic film (between 1/25 and 1/100 of a second), the Lunar Orbiter cameras were provided with a special device to reduce blurring of the image. The device, called a "velocity/height sensor," electronically scanned a circular portion of each image formed by the high-resolution lens and compared successive scans. A signal from the sensor then advanced the film slightly during the exposure to compensate for the motion of the spacecraft.

Lunar Orbiter II, which made the high-resolution photograph of the crater Copernicus below, was launched from Cape Kennedy on November 6. After two mid-course maneuvers had been executed, a retro-rocket on the spacecraft was fired on November 10, slowing the craft enough for it to be captured by the moon's gravitational field. The initial orbit had an apolune (highest point) of 1,150 miles and a perilune (lowest point) of 125 miles. This orbit was precisely tracked for five days before the retro-rocket was fired again on November 15, lowering the perilune to about 28 miles. Most of the photographs were made at or near the perilune as it shifted westward along the lunar equator on successive orbits.



SIDE VIEW of a 17-mile-wide section of the lunar crater Copernicus (*top*) was photographed on November 23 by *Lunar Orbiter II* while the spacecraft was 28.4 miles above the surface of the moon and 120 miles south of the crater's near rim (*dark edge across center*). The floor of the crater is about two miles deep; the peaks rising from the floor are roughly 1,000 feet high. A portion of the smaller Fauth crater is visible in the foreground. The horizontal lines result from the scanning process used in transmitting the photograph to earth.



TELESCOPIC VIEW of Copernicus was made with the 120-inch reflecting telescope at the Lick Observatory in California. Keyhole-shaped double crater to the south of Copernicus is the Fauth crater. Copernicus is approximately 60 miles in diameter.

The primary assignment of *Lunar Orbiter II* was to provide detailed topographic and geologic information about specific areas in the vicinity of the moon's equator to help in the selection of landing sites for the Project Apollo manned vehicle, scheduled to be launched before 1970. In all, 184 of the 211 dual-exposure frames in the photographic package were devoted to this task. The remaining 27 frames represent film that had to be moved through the camera system at intervals of four to eight hours in order to prevent the film from developing a permanent set or sticking to the processing rollers. The photograph of Copernicus was made on one of these 27 frames.

Bones, Arteries and Fluorides

The consumption of fluorides has an important effect on the fragility of the bones of older people and may also affect the course of atherosclerosis, or degeneration of the arteries. Investigators from the Harvard School of Public Health have found that people who regularly drink water with a high fluoride content have less osteoporosis, a disease characterized by a reduction in bone mass, and less calcification of the aorta, which is evidence of severe atherosclerosis in the major artery of the body.

These conclusions were drawn on the basis of X-ray studies of two population groups in North Dakota: 300 men and women, ranging in age from 45 to over 65, from a region in the southwestern part of the state where the water supply is rich in fluorides (from 4 to 5.8 parts per million) and 1,015 people in the same age group from an area in the northeastern part of the state where the water has a low fluoride content (.15 to .3 part per million). About twice as many women had decreased bone density and two to six times as many had collapsed vertebrae in the low-fluoride area as in the high-fluoride area. A similar but less marked tendency was noted in the men. Calcification of the aorta was less prevalent in the high-fluoride area, with the difference in this case appreciably more significant in men. Differences in the amounts of cheese and milk (good sources of calcium) consumed in the two areas did not appear to affect the incidence of either disease.

The Harvard group included Daniel S. Bernstein, Norman Sadowsky, D. Mark Hegsted, Charles D. Guri and Fredrick J. Stare. They point out that fluoride is known to enhance the growth and architectural integrity of crystalline material in the enamel of teeth and in bone. "The enlarged and more nearly perfect bone crystal may be less susceptible to resorption, accounting for our observations." An editorial in the issue of the *Journal of the American Medical Association* in which their report is published comments: "It appears as though the fluoride ion helps to keep calcium deposited in the hard tissues of the body."

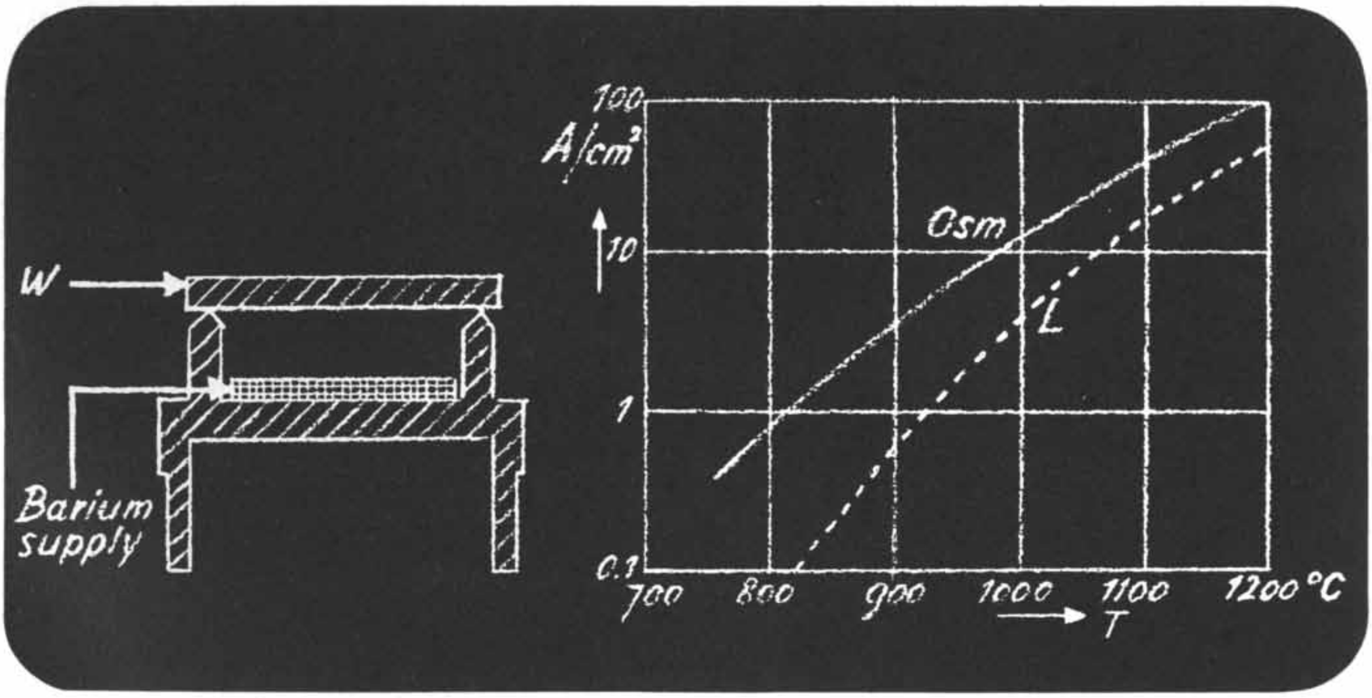
Garbage In, Merchandise Out

An automatic plant that converts garbage and trash into marketable compost and metal scrap has gone into operation in St. Petersburg, Fla. Its designers say it marks the first application of modern materials-handling techniques to the problem of processing refuse at reasonable cost. The plant can process up to 105 tons of refuse a day, which is adequate to serve about a quarter of the city's population of 210,000. A plant of such design does not generate smoke or unpleasant odors, according to the designers, and so can be operated in densely populated areas. The St. Petersburg plant is in a park surrounded by residential neighborhoods.

The plant was designed and built by the Westinghouse Electric Corporation and is owned and operated by the International Disposal Corporation. Its major components are magnetic separators, a pulverizer, two grinders and five large cells in which material is digested by bacteria. A load of refuse first goes through the magnetic separators, which remove metal objects for processing into scrap. The remaining material is wetted and mixed in the pulverizer and then put through the first grinder. After it has passed through two of the digestion cells, it is sent to the second grinder and through three more cells. At the end of five days it is screened. The material that passes through the screen is sold for compost. Of the remaining material, some is carried off for dumping and the rest is recycled to make more compost. The city pays the disposal company about $3 for each ton of refuse delivered to the plant, and the corporation receives the proceeds from the sale of scrap and compost. The compost is a soil conditioner, not a fertilizer; it improves the structure of soil and its ability to hold water. An official of the disposal firm said the market for compost from the St. Petersburg plant had proved to be good.

Undersea Elephants

Over the years a substantial number of bones of mammoths, mastodons and other extinct mammals have been brought up from the ocean floor off the



Electrons available from stock; evolution in cathodes

Condensed from a paper by dr. P. Zalm

The development of electron tubes for higher frequencies and energy output creates an ever increasing demand for better cathodes. Today's magnetrons and other microwave tubes could never have been developed, had not the spectacular evolution of thermionic cathodes led to impressive possibilities. Of particular importance in this connection are the dispenser-type cathodes, on the subject of which we here set down a few stray thoughts.

It is to the credit of the late H. J. Lemmens, of the Philips Research Laboratories, a creative investigator with exceptional intuition, that he proceeded from a fundamental separation of functions in cathodes. Whereas for a long time the functions of "heating" and "emission" in oxide-coated cathodes had been separated, he applied separation of the "electron-emission" and "barium-supply" functions as well. He thus indicated ways of solving the problem of the limited current density of oxide-coated cathodes. In the normal oxide-coated cathode the average current density must not exceed 0.5 to 1 A per cm^2, since otherwise, owing to the layer's resistance, so much heat would be generated in it that damage would occur. One of the factors determining the resistance in the layer and with which the life of the cathode is also linked, is its thickness (approx. 80 microns). If the layer is made very thin (say 5 to 20 microns), then, for the same current density the cathode's life will be short.
In the case of normal barium-strontium oxide-cathodes the emitting layer consists of small (Ba, Sr)O crystals. These owe their low work function (and thus good emission at not too high temperatures) to the adsorption of barium. Barium evaporates, however, and has to be replenished. This occurs through reaction of the BaO with the reducing agent added to the nickel of the cathode: Al, Mg or Si etc.
In L-cathodes (L for Lemmens) and other dispenser-type cathodes the necessary barium is replenished not from the layer, but from a separate, small supply chamber shut off by a "lid" of porous tungsten; this results in a good separation of functions between emitting layer and barium supply. Hence the emitting surface consists of the porous tungsten on which a film of barium of atomic thickness has been adsorbed; the series resistance is then extremely low. A pleasing aspect of this development is that the substratum (the metal "lid" on the supply chamber) can be varied at will. Frequent use is now made of this degree of freedom.

More recent developments in these cathodes disclosed an interesting paradox. When a study is made of the question as to how the work function of metals is influenced by adsorption of electropositive elements such as barium, it is found that at tungsten-barium interface a change in potential occurs, due to formation of a dipole layer as a result of polarization of barium atoms. This dipole layer reduces the work function. It is possible to calculate that for a higher work function of the base material the number of barium atoms which can be adsorbed in such a state of polarization is greater. This increase is so sharp that the paradoxical effect is obtained that the higher work function of the base metal is more than compensated.

This calculation has been confirmed in practice. So we looked for the base material among metals with high work functions. These are to be found especially in the platinum group. For a number of applications osmium was chosen from this group. The Os-cathode, as every other normal dispenser-type cathode, can withstand temperatures of up to 1,100 °C.
For professional purposes, particularly in communications engineering, it excels on account of high current densities (up to 40 A/cm^2) and long life (10^5 hours at 1 A/cm^2).
Therefore it can truly be said that here many electrons are available from stock, and will be for a very long time.

The Philips Research Laboratories carry out research in many fields of fundamental science. Among these: Acoustics, Chemistry, Cryogenics, Perception, Plasma, Material testing, Nuclear physics, Solid state physics, Telecommunications, Television.

The laboratories are an integral adjunct to the International Concern whose simple slogan is:

trust in **PHILIPS** is world-wide

East Coast of the U.S. This is a vivid reminder that at the height of the Pleistocene glaciation the Atlantic was a smaller ocean. The dragnets of commercial fishermen often bring up fossils, most frequently the teeth of mammoths and mastodons that between 25,000 and 11,000 years ago roamed 300,000 square miles of what is now submerged continental shelf from Maine to Virginia. The fishermen do not consistently save the fossils, nor until recently did they often bring any of them to the attention of interested scholars. Since the beginning of a five-year study of the continental shelf undertaken jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution in 1962, the project's staff has acquired 35 teeth of the two species of early elephant and also the remains of other land animals. The tooth found farthest from the present Atlantic coast came from 80 miles offshore; the deepest one found was at a depth of 270 feet. Other mammals that inhabited the tundra of the continental shelf at the height of the Pleistocene glaciation were the musk ox, the moose, the bison and a species of giant sloth.

Asphalt Agriculture

Petroleum products are being used in two ingenious efforts to upgrade submarginal land. In Libya the Esso Research and Engineering Company undertook in 1961 to stabilize 125 acres of shifting sand dunes by spraying them with a low-grade oil. Such dunes usually cannot support even vegetation that will grow in the desert, but recently the company announced that 80 percent of the eucalyptus and acacia seedlings it had planted on the dunes had survived and are now trees averaging 25 feet in height. The Libyan government has contracted for the stabilization of 3,000 additional acres, an action that could eventually lead to the creation of a national forest in the treeless desert kingdom.

At Michigan State University asphalt is being used to attack the problem of sandy soils that are infertile because they cannot hold water. A plowlike blade lifts the soil by being pulled along two feet below the surface and the asphalt is sprayed into the bottom of the cut. Clarence M. Hansen and A. Earl Erickson, who devised the method, are able to undercoat sandy soils with an eighth of an inch of asphalt at a cost of about $225 per acre. The yield of such crops as potatoes, cabbages and cucumbers, which benefit from the asphalt's retention of rainfall, is usually doubled, so that the undercoating can pay for itself in a year.

PIPELINES

A vast and rapidly growing network transports oil and gas in many parts of the world. A recent trend is the use of pipelines to move solids both in slurries and in capsules containing solid products

by E. J. Jensen and H. S. Ellis

When Edwin L. Drake brought in his historic oil well at Titusville, Pa., in 1859, setting off an oil rush that was to become fully as colorful as the gold rush 10 years earlier in California, he triggered other developments besides the petroleum industry. Among them one of the most useful is the technology of pipelines. Today North America alone is traversed by more than a million miles of pipelines—four times the distance to the moon—and networks of pipelines are being rapidly extended on a worldwide scale. The North American system, already representing an investment of $15 billion, is growing at the rate of almost $1 billion a year. Moreover, the functions of pipelines are proliferating into many fields beyond the original purpose of moving oil and kindred products. As a means of transportation pipelines have proved to be so efficient and economical that they are being adapted to transport not only liquids and gases but also solids such as coal, minerals, sand, gravel and even steel.

A brief review of the economic history of pipelines will help to explain their importance as a technological innovation. In the early years after Drake's strike the crude oil from the wells along Oil Creek was hauled to railheads in wooden barrels on horse-drawn wagons. The haulage charge was sometimes as high as $5 per 42-gallon barrel, and about two gallons leaked out of the barrel along the road. In 1863 one J. L. Hutchinson, who had invented a rotary pump, decided to build a pipeline to the nearest railroad. He began to lay down two-inch cast-iron pipe, caulked with lead at the joints, along a two-mile route. Teamsters in the oil-hauling business tore up his pipe, and it turned out that Hutchinson's pipeline would not work anyway because it leaked badly at the joints. Two years later, however, another entrepreneur, Samuel Van Syckel, succeeded in building a five-mile pipeline to a railroad with the protection of armed guards. Although his two-inch cast-iron pipe also leaked at the joints, it served well enough to enable him to transport oil to the railhead at a cost of perhaps five cents a barrel. He charged the well owners 50 cents to $2 a barrel—about half of what teamsters needed to stay in business.

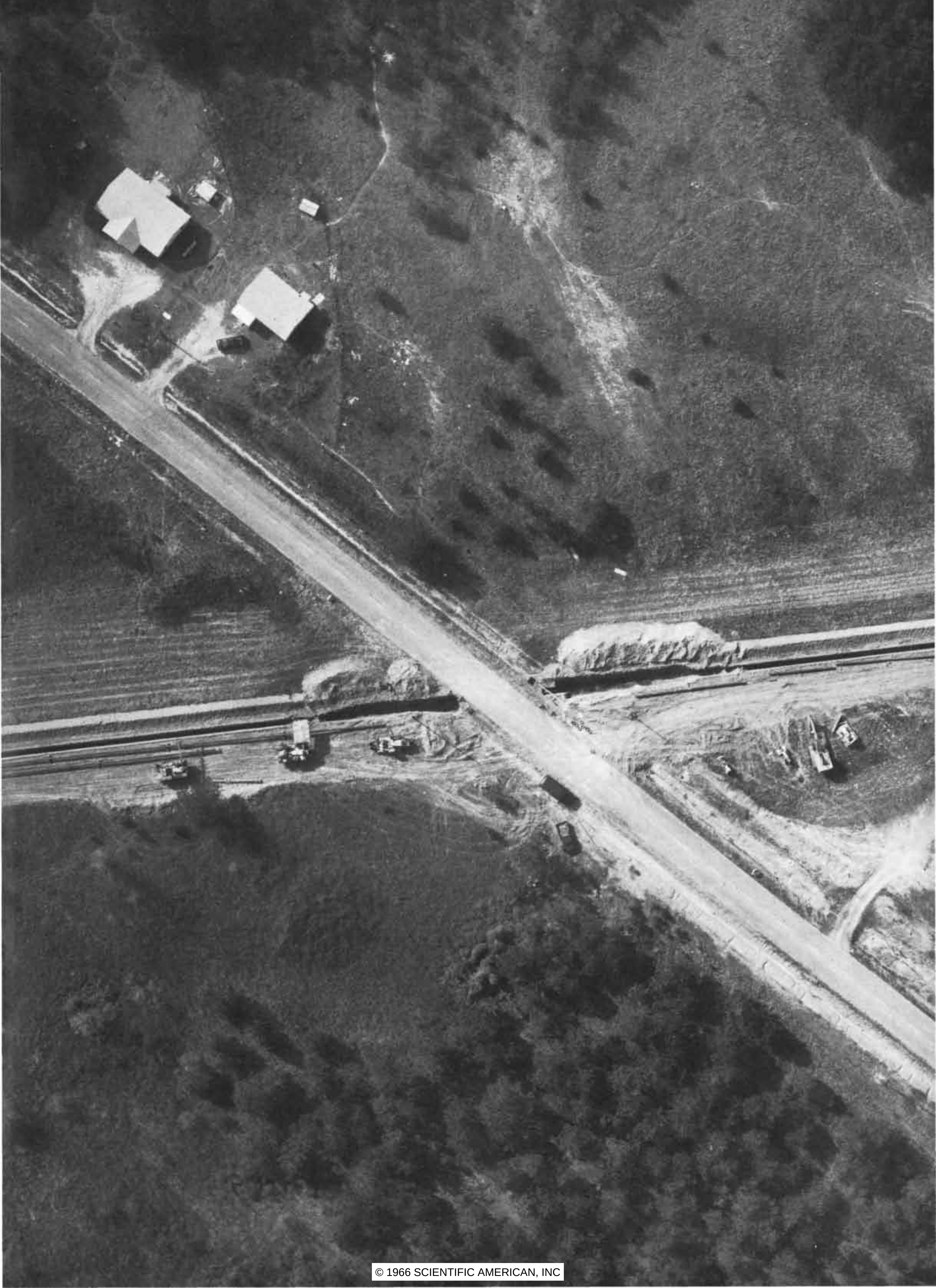
Van Syckel's pipeline is recognized as the first successful oil line. Other short lines soon followed. Petroleum was a rich new cargo in great demand for lighting the newly invented kerosene lamps, and sulfur-free Pennsylvania oil provided a profitable incentive for pipeline construction on an extensive scale. In 1879 an enterprise called the Tidewater Pipe Line Company built the first long-distance pipeline—a 110-mile line six inches in diameter from Bradford in the Pennsylvania oil field to a connection with the Reading Railroad at Williamsport. Labeled "Benson's Folly" (after the president of the Tidewater company), the line was laid across the Allegheny Mountains in midwinter. It became a great success and aroused alarm among the railroads. The rail companies did not attack the Tidewater line itself, because they had helped to finance it as a connecting link to their roads, but they took an aggressive stand against the construction of other pipelines and succeeded in delaying the building of several proposed lines. Battles over rights-of-way sought by pipeline builders were fought in a number of legislatures. Nevertheless, economic advantage and John D. Rockefeller's Standard Oil Company, which controlled most of the pipeline projects, won the day. By 1907 some 45,000 miles of pipeline had been built in the U.S.

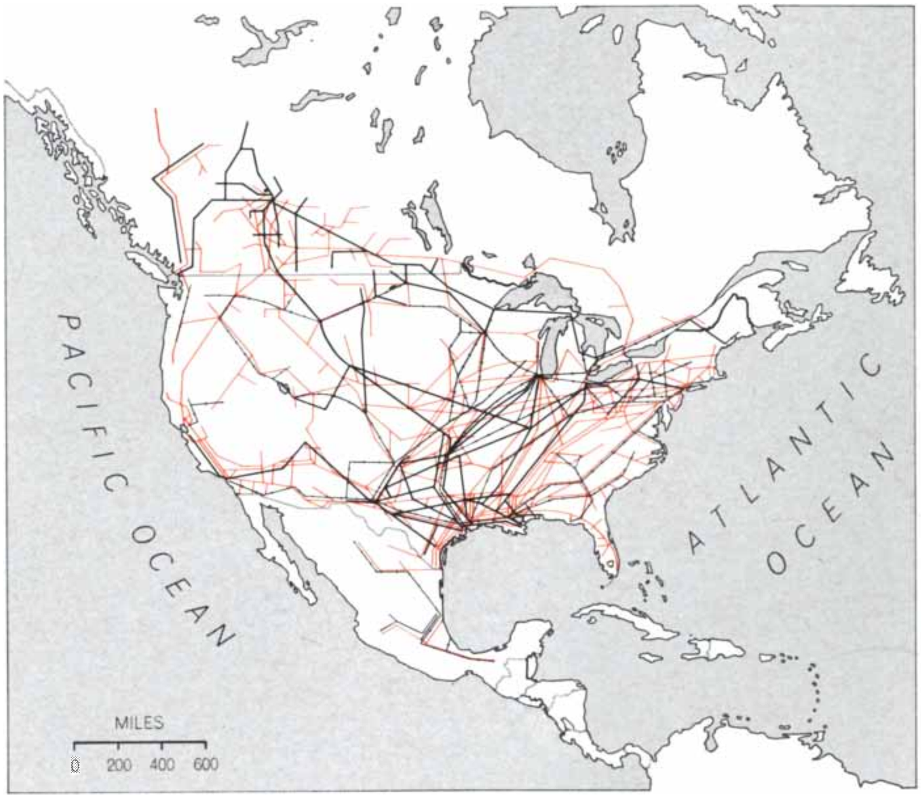
Up to about 1890 the market for oil had been based almost entirely on the use of kerosene for lamps; in the refining of crude oil the gasoline fraction was burned off as useless. The arrival of Thomas Edison's electric light bulb drastically reduced the consumption of kerosene in the 1880's and 1890's, and the price of crude oil, which had started at $20 a barrel when Drake drilled his first well, fell at times as low as 10 cents a barrel. At the turn of the century, however, the automobile, the diesel engine and the burgeoning use of fuel oil in industry created an entirely new status for oil in the economy. A worldwide search for oil began; large new fields were opened up in the U.S. Southwest, the West and in other parts of the world.

The Advance of Pipelines

At first the new interest in oil had comparatively little impact on pipelining. With pipeline technology still in too primitive a state to produce efficient long-distance lines, it was cheaper to transport oil and its products by tanker ship than by pipeline from Texas to the cities and industrial centers of the U.S. Northeast. In the 1920's and 1930's technical advances and the increasing use of natural gas began to change this situation. Pipelines were undertaken on a continental scale; the first was a 24-inch line more than 1,000 miles long

GAS PIPELINE under construction in Georgia will be laid under the highway in the aerial photograph on the opposite page. At left the 14-inch steel line is nearly ready to be put in the trench; at right sections of pipe have been strung alongside the trench in preparation for welding. The Latex Construction Company is installing the pipeline for the Southern Natural Gas Company.





PIPELINE NETWORK in North and Central America is more concentrated than in any other part of the world. Map shows major pipelines carrying oil (*solid black*), gas (*color*) and products (*broken black*). There are many shorter lines, some used for other materials.

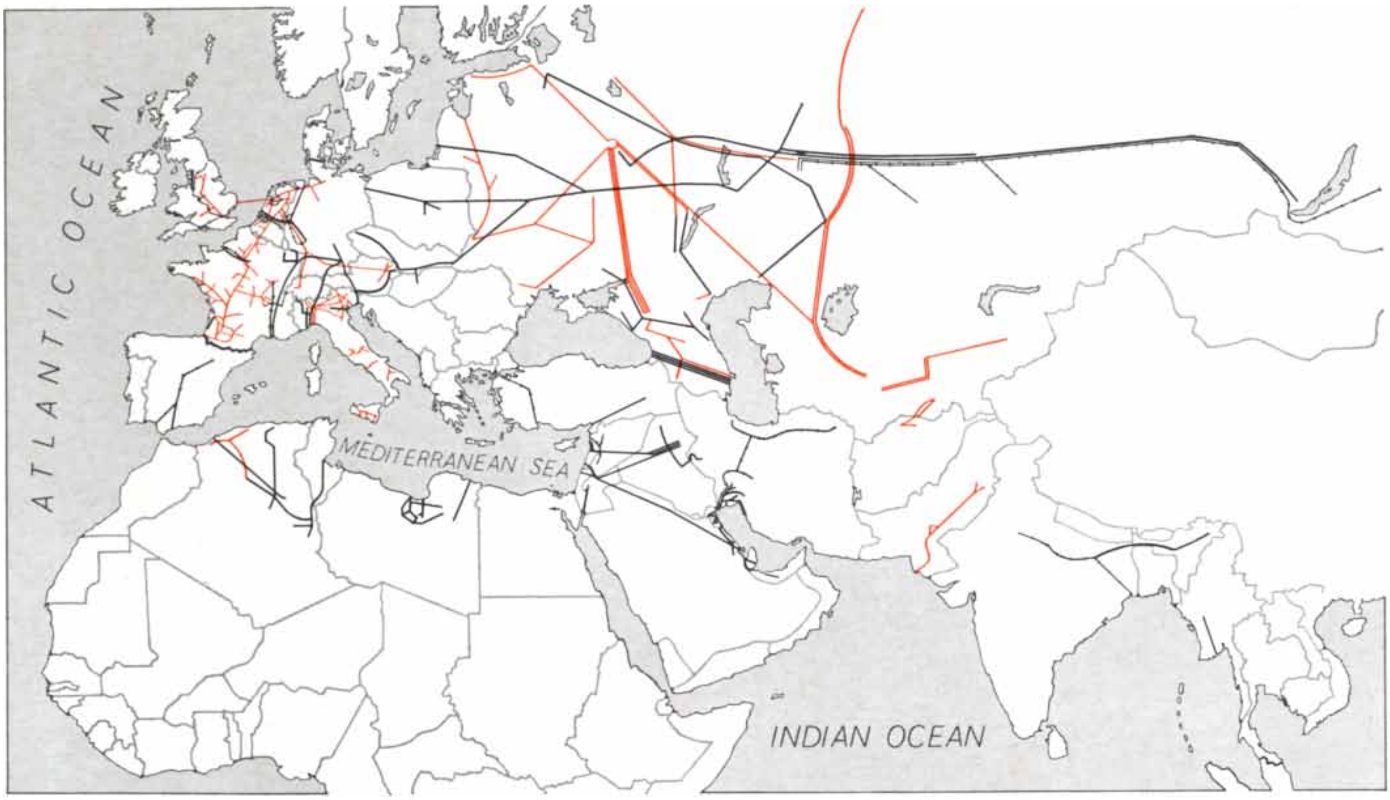
SOUTH AMERICA has a network of pipelines that is characteristic of most areas outside the U.S. and Canada; there are relatively few lines and they tend to be concentrated in certain areas. An era of rapid expansion of the South American network is in prospect.

built in 1931 to carry natural gas from the Texas Panhandle to Chicago.

It was not until World War II, however, that pipelining became a major industry. The specific stimulus was the German submarine threat to shipping. At the beginning of the war tankers carried 95 percent of the oil delivered to the U.S. Eastern Seaboard. To assure the supply after the U-boat raids began, the U.S. Government financed the building of two pipelines from Texas to New Jersey: the 24-inch "Big Inch" line, 1,341 miles long, and the 20-inch "Little Big Inch," 1,475 miles long. These lines, the first to operate at high pressure, carried crude oil during the war; afterward they were converted to natural gas, but in 1957 the Little Big Inch resumed the transport of crude oil over part of its route.

The Allied armies resorted to pipelines in battle areas to supply water and gasoline to the advancing motorized troops. These lines were made up of portable units, each pipe section 20 feet long and four inches in diameter, and they employed portable gasoline pumps spaced at about 10-mile intervals. All together some 11,000 miles of this type of pipe was used during the war. The longest line, 1,400 miles, was laid from Calcutta to South China, crossing the mountains en route. Britain performed a spectacular crossing of the English Channel with pipelines—a project called Pluto (for pipelines under the ocean). Using three-inch piping of flexible steel or lead alloy that could be paid out from drums like an electric cable, the British laid 20 lines (varying in length from 29 to 66 miles) across the channel bottom. The lines transported a total of a million gallons of gasoline per day at pressures of up to 1,200 pounds per square inch.

Since the war almost every oil-producing and oil-using country in the world has built elaborate pipeline systems [*see illustrations on these two pages*]. The lines are laid underground and over desert sands, across seas and on ocean bottoms—in some cases even under the sea floor. The U.S. has the most extensive system, but there are spectacular pipelines in many other parts of the world. Canada has built the world's longest line for the transport of natural gas—a 36-inch line called the Trans-Canada that runs 2,300 miles from Alberta to Montreal; Canada also has the longest trunk line for moving crude oil—the Interprovincial, which consists of 3,500 miles of pipe up to 34 inches in diameter, holds 40 million gal-



UNEVEN DISTRIBUTION of pipelines appears in Europe, Africa and Asia. Many of the lines lead from oil fields to shipping points. In many of these countries, however, extensive programs of pipeline construction are under way. The data for this map and those on the opposite page have been obtained from a number of sources. Some of the pipelines shown are still under construction.

lons of oil when it is fully loaded and extends 2,000 miles from the Alberta oil fields in western Canada to its terminus in Ontario. The world's largest crude-oil line in diameter—42 inches—was recently completed in the Middle East fields. It runs from the Persian Gulf to the Mediterranean, is 1,060 miles long, eliminates 3,500 miles of tanker haul and obviates the need of conveying Middle East oil via the Suez Canal.

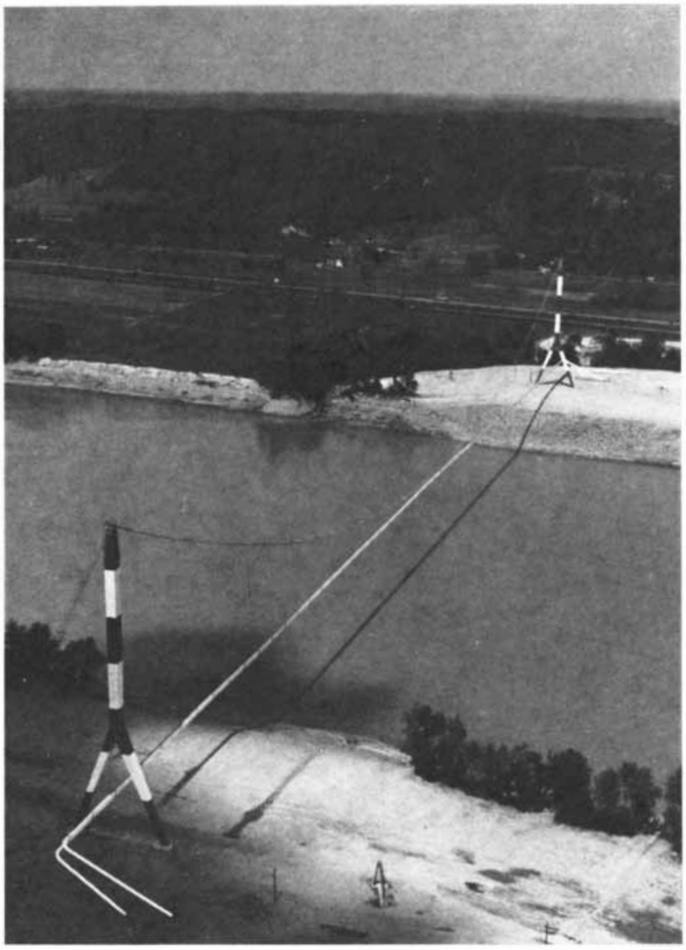
The U.S.S.R., which built its first pipeline in 1908 (in the Baku oil fields on the Caspian Sea), is engaged in several large projects at present, among them a network that will link the Baku gas fields to Moscow and one that will connect the country's large industrial centers with the gas fields of Siberia. Britain and Germany are building pipelines to tap the gas fields under the North Sea, and France and Germany collaborated on a trunk line that transports oil from Marseilles across France and into Germany. A crude-oil pipeline is even being built across the Alps; one of the most difficult pipeline projects ever undertaken, this 40-inch line will run from Trieste in Italy to Ingolstadt in Germany and will require the boring of tunnels through the Alps.

Pipelines represent a very large investment in those countries where extensive systems have been installed. A 36-inch line may cost $100,000 to $150,000 per mile for construction, even when exceptional difficulties are not encountered. Notwithstanding this high initial expense, pipelines have proved to be by far the most economical method of overland transportation. A pipeline can move a ton of oil 1,000 miles for about $2; by railroad the cheapest rate is roughly $4. The advantage of pipeline transportation is so impressive that in North America today pipelines carry 20 percent (in terms of ton-miles) of all the land freight moved on the continent.

The Technology of Pipelines

The technology that makes the high efficiency of pipelines possible has developed gradually over the course of more than half a century. In part it has been dependent on advances in the design of pumps, piping and associated techniques. By the turn of the century the original cast-iron pipes had been replaced by steel piping, made less leaky by flanged joints, which made possible pumping at considerable pressure through lines up to 12 inches in diameter. In the 1920's the development of steel pipe with high tensile strength and of new welding methods (acetylene and electric arc) further improved the strength and tightness of piping systems, so that it became possible to construct lines over long distances and pump gas through them at high pressures. Piping technology has advanced greatly in recent years, and it now produces very thin-walled pipe (only a quarter of an inch thick) that is 42 inches in diameter and can withstand stresses of 100,000 pounds per square inch. Automatic welding machines are available for the joining of the pipe lengths. The most recent development is a mobile pipe mill that moves along with the pipelayers and manufactures sections of pipe up to 10 inches in diameter as the line advances.

After the formation of the American Petroleum Institute in 1919 pipelining developed a sophisticated technology soundly based on scientific principles and systematic research. Much of this research, of course, has been in the field of fluid dynamics, and its approach is founded on the basic studies of three 19th-century investigators: Julius Weisbach of Germany, Henri Philibert Gaspard Darcy of France and Osborne Reynolds of England. Weisbach and Darcy, working independently, developed a formula that relates the pressure required to drive a fluid through a pipe



SUSPENSION BRIDGE carries two pipelines over the Ohio River. Bridging is an alternative to the more customary technique of laying pipe across rivers and railroads by going under them.

TRANSALPINE CONSTRUCTION of a 40-inch oil pipeline entailed special construction problems. Here the line descends into an Austrian valley north of a tunnel that is line's highest point.

at a given rate to the diameter and length of the pipe (and a friction factor, which depends on the characteristics of the pipe and the flow).

Reynolds, who is well known for his studies of fluid flow, showed that the character of flow through a tube depends on the viscosity of the fluid, its density, its velocity and the diameter of the tube. From his experiments he derived the formula (tube diameter times flow velocity times fluid density divided by the fluid's viscosity) that yields the "Reynolds number." If the Reynolds number is less than 2,000, the flow is likely to be laminar, or stratified; at higher numbers it tends to become turbulent. When the flow through a pipe is laminar, the velocity is greatest at the center and diminishes parabolically toward the walls; if the flow is turbulent, the eddies tend to make the velocity distribution almost uniform across the pipe. Application of the Reynolds number makes it possible to calculate the friction factor in the Darcy-Weisbach formula under given flow conditions.

The understanding of fluid flow in pipes was significantly advanced in the 1930's by the two outstanding theoreticians of fluid dynamics in this century, Theodor von Kármán of Hungary, Germany and the U.S. and Ludwig Prandtl of Germany, and by experimenters studying flow in smooth and roughened pipes. From these investigations Lewis F. Moody of Princeton University in 1944 derived a diagram that is now widely used to determine the friction factor in various situations. Thus the designers of pipelines have an accurate basis for deciding what pipe diameters and pump pressures they must select to provide the specified rate of flow through their lines. The design problem is still complicated, of course, because a pipeline is not a straightaway affair; allowances must be made for bends, junctions, valves, other fittings and variations of diameter along the line—all of which generally produce extra pressure losses.

The Building of Pipelines

Once the design has been adopted and the cost calculated, the building of a pipeline begins with obtaining a permit from the responsible government agencies and acquiring a right-of-way, generally a strip 50 to 200 feet wide. This can be a tedious matter; the company that built the recently completed Colonial pipeline from Houston, Tex., to Linden, N.J., had to negotiate with 17,000 owners of land along the route.

Bulldozers and other earth-moving machines then move in to clear and level the right-of-way. Next come trucks or "cats" (Caterpillar tractors) bearing the sections of pipe, 40 to 80 feet long, which they "string" evenly along the route. The delivery of the pipe lengths is followed by the arrival of the ditch-digging machine, which excavates a trench from four to seven feet deep. Where the contour of the land requires curving the pipe, a huge bending machine is called in to bend the lengths of pipe. After the ditchdigger moves on, the pipe lengths are laid on "skids" and butted end to end; they are then welded together by the electric-arc method. To ensure that the joints are firm and leakproof, the welders make at least three passes over each weld, and the welds are then examined by X-ray methods.

The next step is the highly important

operation of applying protection against corrosion of the pipe. Before the line is lowered into the trench the outside of the pipe is painted with asphalt and wrapped with a blanket of protective material. Defense against corrosion is a major problem in pipelining, and improved methods are continually being sought by research. One of the new techniques is the use of a plastic-tape coating instead of asphalt. In some recent installations the inside of the pipe is coated with a paint or a plastic, which not only serves to prevent inner corrosion but also provides a smooth surface that minimizes friction. Sometimes chemicals are added to the crude-oil cargo to inhibit corrosive substances in the oil. Increasing use is now being made of corrosion-resistant aluminum pipe; plastic pipe, available in diameters of up to 10 inches, is also coming into favor.

Finally the long sections of welded pipe are placed in the ditch by mobile cranes and "tied in," or welded together. The line is then tested for strength under hydraulic pressure, and after it is covered by backfilling a further test is applied to determine the exposure to corrosive effects from the surrounding ground. In spite of protective coating, pipe can be corroded as a result of small electric currents between the pipe and the ground. The intensity of these currents is therefore measured with the line in place, and cathodic protection is then installed to divert or counter the damaging currents [*see top illustration on next page*].

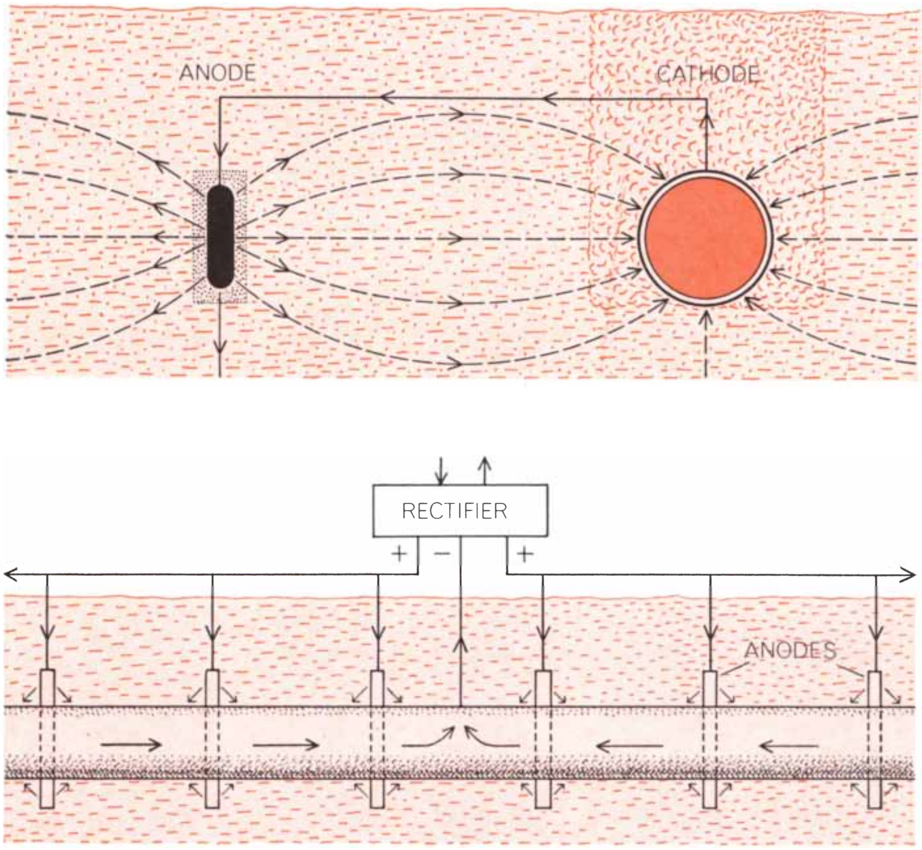
Special Problems

Across wide rivers pipelines are lowered to the river bottom from barges and weighted with concrete or steel anchors to counteract their buoyancy. Where the river water is particularly corrosive because of pollution, the pipe is buried under the bottom. Over narrow, swift streams the pipeline crosses on trestles; under highways it is bored under the roadbed and is enclosed in a larger pipe that can withstand the load of traffic. In mountainous areas of California inaccessible to tractors pipe has been strung on the ground from helicopters, equipped with a television camera in the tail so that the pilot can see precisely where he is placing the pipe lengths. In the Libyan Desert pipe was strung by a specially built vehicle that had 16 wheels with seven-foot tires partly filled with water; it hauled 250-ton loads over the desert sand. In the muskeg regions of northern Canada pipe is laid during the winter, when the bogs, swamps and lakes are frozen hard enough to bear heavy equipment. To lay the pipe across lakes the digging machines cut "ditches" through up to four feet of lake ice so that the pipe can be lowered to the lake bottom. In the marine waters of the Gulf of Mexico, the North Sea, the Mediterranean and the Alaska coast pipelines are given a special protective coating, and they are assembled on barges before being lowered to the sea bottom.

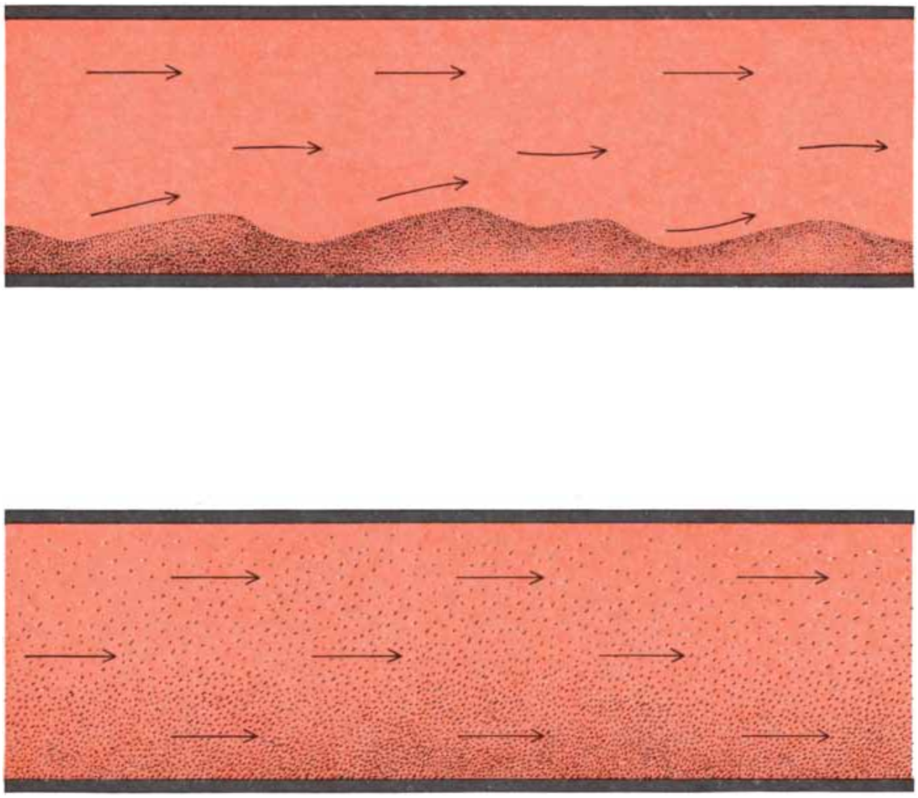
Pipeline systems today are highly mechanized and automated. Equipped with motorized valves, they can be operated by remote control. The continu-

DESERT PIPELINE in Libya awaits coating and wrapping before being lowered into the trench. Desert construction requires special measures to keep the trench from collapsing.

SUBMERGED CROSSING of a river is one of 77 being made for a 738-mile oil pipeline in India. The Bechtel Corporation, a U.S. engineering firm, is supervising the construction.



CATHODIC DEVICES protect buried pipelines from corrosive electrolytic effects. In the "sacrificial" method (*top*) the pipeline is the cathode; a wire leads to a zinc or magnesium anode. The natural flow of current is reversed, so that corrosion affects the anode instead of the pipe. Similarly, in the rectifier method (*bottom*) anodes carry current from an outside source into the pipe; current returns to the rectifier by cable. The anodes corrode.



SLURRY LINE carries solids as particles swept along in a liquid. If the particles settle (*top*), they tend to form a bed on the bottom of the pipe. As the bed deepens, the velocity of the liquid increases because of the smaller free area, so that blockage is retarded. At a critical velocity (*bottom*) particles are swept off the bottom and carried along in the liquid.

ous stream flowing through a line may consist of successive batches of different liquid products with negligible mixing between one batch and the next. The shipments can be measured accurately and tracked as they move through the system. The trend is toward operating the systems entirely by computer programs, with the computer directing the quantities of shipments and their routing to destinations. At Kennedy International Airport in New York, for example, a computer monitors the gasoline storage tanks and pipelines, and in South America a large natural-gas distribution system, containing 68 booster stations and 524 compressors, has been turned over to computer control. Within a few years "precision pipelining" by computer will undoubtedly be adopted by most pipeline systems around the world.

One of the technical problems in pipelining to which much effort is being devoted at present is that of reducing the cost of transporting natural gas. Because of its high volume-to-weight ratio, gas is expensive to move in terms of weight: ton for ton, it costs about four times more to transport gas than it does to transport crude oil by pipeline. Studies are therefore being made of the feasibility of carrying natural gas in the liquefied state. This would require cooling the gas to below −115 degrees Fahrenheit and compressing it to a pressure of 673 pounds per square inch—well below the pressure natural-gas pipelines are designed to withstand.

A recent study strongly indicates that the transportation of natural gas in the liquid state, with the use of refrigeration, would be economical and practicable if the pipe were jacketed with vacuum insulation, like a Thermos bottle. Insulated pipe is, in fact, already employed on a small scale in a seven-mile pipeline that carries molten sulfur ashore from where it is mined in the Gulf of Mexico off Grande Isle, La. The sulfur is obtained from beds 2,000 feet below the sea surface by melting it with hot water and driving it up to the surface with compressed air. From there it is conveyed to shore via a six-inch pipeline that is heated by circulating water at 320 degrees F. in a surrounding larger pipe, which in turn is enclosed within a still larger pipe containing insulation [*see top illustration on page* 72]. The molten sulfur enters the pipeline at 320 degrees and reaches the end of the seven-mile trip at not less than 280 degrees—a minimum chosen to maintain an easy flow of sulfur.

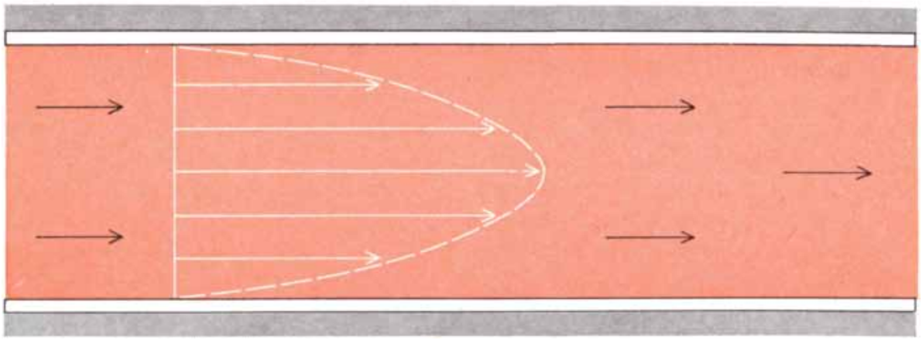
Helium, a much lighter gas than methane (the main constituent of natural gas), is of course more expensive to transport. Because helium is required for nuclear reactors, rockets and missiles, the U.S. Government is spending large sums to subsidize the conservation and storage of this gas, and special pipelines have been built to move helium from the plants where it is produced (by separation from natural gas) to the storage places. These pipelines, which vary between 2⅜ inches and 8⅝ inches in outside diameter, are made of extra-heavy seamless pipe. They can withstand pressures of up to 2,800 pounds per square inch and must be tested very carefully for leaks, because helium escapes through tiny holes much more easily than natural gas does.

The Transmission of Solids

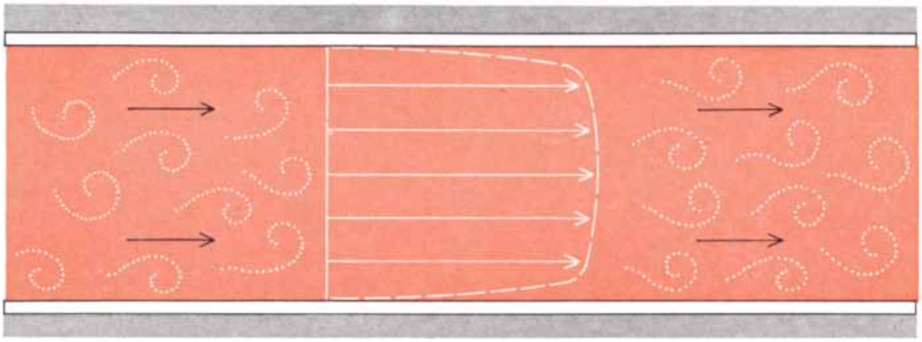
The demonstration by the petroleum industry that pipelines could transport its products overland at unprecedentedly low cost naturally attracted the interest of many other industries. Transportation is a major cost in the marketing of most commodities; this applies particularly to raw or semiprocessed materials, but it is also true of many finished products. On looking into the matter, a number of industries found to their surprise that it is entirely feasible to move solid materials through pipelines. Exploration of this possibility, which includes the transportation of finished products, is only in its early stages, but already a substantial tonnage of solid products is being transported by pipeline in both the U.S. and Canada.

Every schoolboy is acquainted with Archimedes' classic demonstrations of the buoyant properties of water. Also familiar is the fact that a moving stream will carry solids that would fall to the bottom in still water. A rushing river bearing soil particles and debris is in effect a slurry: a mixture of liquid and solids. The ability of a stream to carry solid material without letting it settle to the bottom depends on the size and specific gravity of the particles and the velocity of the stream. Given enough turbulence-generating power, a stream will sweep along even large and heavy objects.

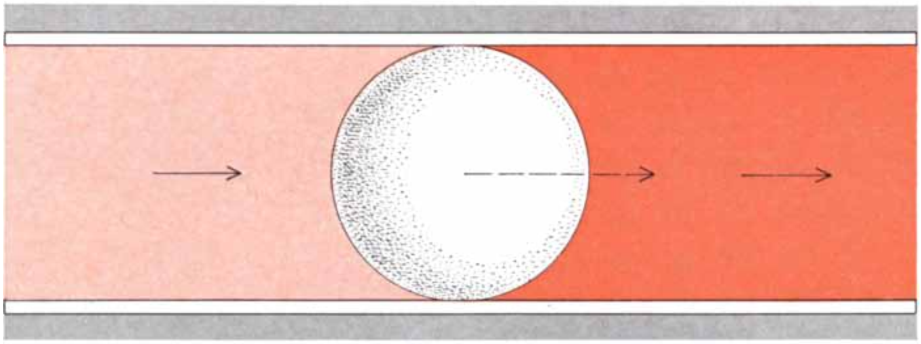
A patent for a system to pump slurries through pipes was issued in the U.S. as early as 1891. The idea was first put into commercial practice in England in 1914, when an eight-inch pipeline was built to carry coal in the form of dust and lumps from barges on the Thames to a power station. Short lines of this kind were later constructed in the U.S. to move ores from mines to



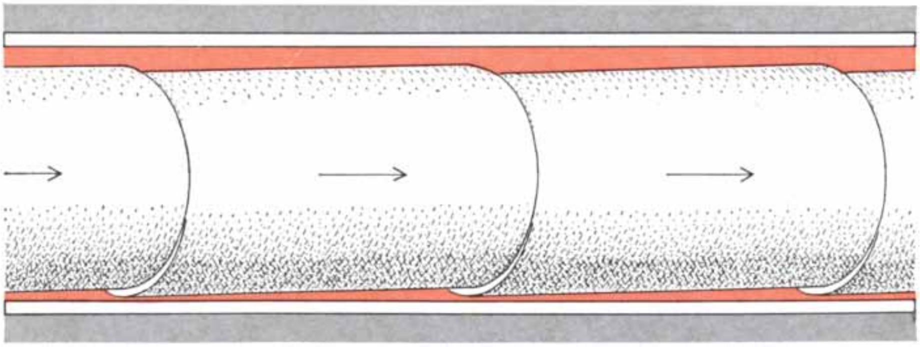
LAMINAR FLOW in a pipeline produces a streamlined effect; the velocity is distributed parabolically across the diameter of the pipe and the fluid moves in laminae, or layers.



TURBULENT FLOW produces a more uniform distribution of velocity than laminar flow. When the flow through a pipeline is turbulent, the fluid moves in random, highly irregular paths, so that there is an exchange of momentum between different parts of the fluid.



BATCHING TECHNIQUES enable different kinds of material to flow through the same pipeline. In some cases it is desirable to separate two different products, such as gasoline and fuel oil, with an inflatable sphere. The sphere is overinflated to provide a good seal. Often two products need no separating object; they commingle only slightly as they move.



TRAIN OF CAPSULES, a concept tested only experimentally, would provide a means of transporting large quantities of solids in a pipeline. Liquid moves the capsules and partly or wholly supports them. Speed in commercial operation would be about three miles an hour.

nearby concentrating plants and to carry off mine tailings to dumps. Not until 1957, however, was the method applied to long-distance transportation. The Consolidation Coal Company built a 108-mile line from a coal mine at Cadiz, Ohio, to a power plant in Cleveland, and for several years this 10-inch line transported more than a million tons of coal a year in the form of a slurry made up of equal weights of coal and water. (The company discontinued operation of the line in 1963 when a railroad offered it attractive rates for distribution of its coal over a wider area.)

Another line, which has operated without interruption since 1957, is a 72-mile line built to carry Gilsonite, a kind of asphalt, from a mine at Bonanza, Utah, to a refinery at Grand Junction, Colo. Traversing a 3,000-foot mountain, this line delivers 700 tons of the mineral per day as a 40 percent slurry. Other products that are being pipelined successfully in slurry form elsewhere include anthracite sludge, phosphate rock (with lumps six to nine inches across), nickel-copper and copper concentrates, borax, limestone, clay, sand and gravel. The Pulp and Paper Institute of Canada is designing a pipeline to carry wood chips. More than 100 slurry pipelines, transporting various products and ranging up to 100 miles in length, are now in operation in North America. Many hundreds more serve a great variety of local industrial purposes.

Obviously the moving of slurries through pipes raises certain technical questions and problems. Solids have occasionally piled up and blocked the passage, but this can be prevented by applying enough pumping power to keep the slurry moving at the necessary rate of speed. Another factor that was expected to be troublesome is the wear and tear on the pumps and pipes caused by the abrasive action of the solid particles. In some cases the scouring effect is serious enough to require rather frequent replacement of pump parts and periodic rotation of the pipes so that the bottom is shifted and wear is distributed evenly over the entire area of the pipe wall. On the whole, however, slurry-pipeline operators have been pleasantly surprised by how little wear actually occurs in most cases. It appears that the flow pattern often tends to maintain a layer of clear liquid between the solid material and the wall. The economics of a slurry line will depend on many factors, including the availability of alternative transport.

COATING AND WRAPPING of a pipeline is typically done automatically by machines such as this after the line has been welded but before it is lowered into the trench and tested.

Transmission by Capsule

Are there any limits to the kind of material that could be transported by pipeline? At first thought it would seem that the method is unsuited to carrying cargoes that must be kept dry or uncontaminated by the transporting fluid. Suppose, however, that the cargo were packaged in sealed capsules. It might then be possible to use pipelines to move agricultural products, canned goods, pure chemicals, machine parts or any other fine products capable of being capsulated. Ten years ago the Research Council of the Province of Alberta undertook a program of theoretical and experimental studies to test this idea.

The experiments have been made with capsules of various weights or densities and with water or oil as the conveying liquid. When the package is of the same density as the carrier liquid, it rides along easily in the stream with little more application of power than would be needed to drive the liquid itself. Moreover, even for heavier packages the pressures ordinarily used in oil pipelining suffice to keep the capsules moving with the stream. The faster the capsule travels, the more it is lifted off the bottom of the pipe and the less extra power is needed to move it (beyond what would be needed for the liquid only). Indeed, friction with the pipe bottom can be eliminated altogether. A cylindrical capsule planes along in a slightly nose-up attitude like that of a speedboat moving over water; a spherical capsule, if it is denser than the liquid, rolls along the bottom almost without friction, and less pressure is needed to move packages of this shape.

Experiments showed that the most favorable cylindrical or spherical capsules were those large enough to fill 90 to 95 percent of the pipe diameter and that such capsules could readily be driven along a pipe as a continuous train at the economical speed of three or four miles per hour. Projecting the experimental results, it can be calculated that even a small pipeline only six inches in diameter, carrying capsuled material with about the density of aluminum, could deliver more than a million tons a year. A successful field test in a large oil pipeline—a section of the 20-inch line of the Interprovincial Pipe Line Company—was made about a year ago. The cylindrical capsule, 16 inches in diameter and about 50 inches long, weighed 514 pounds. With oil as the carrier fluid this

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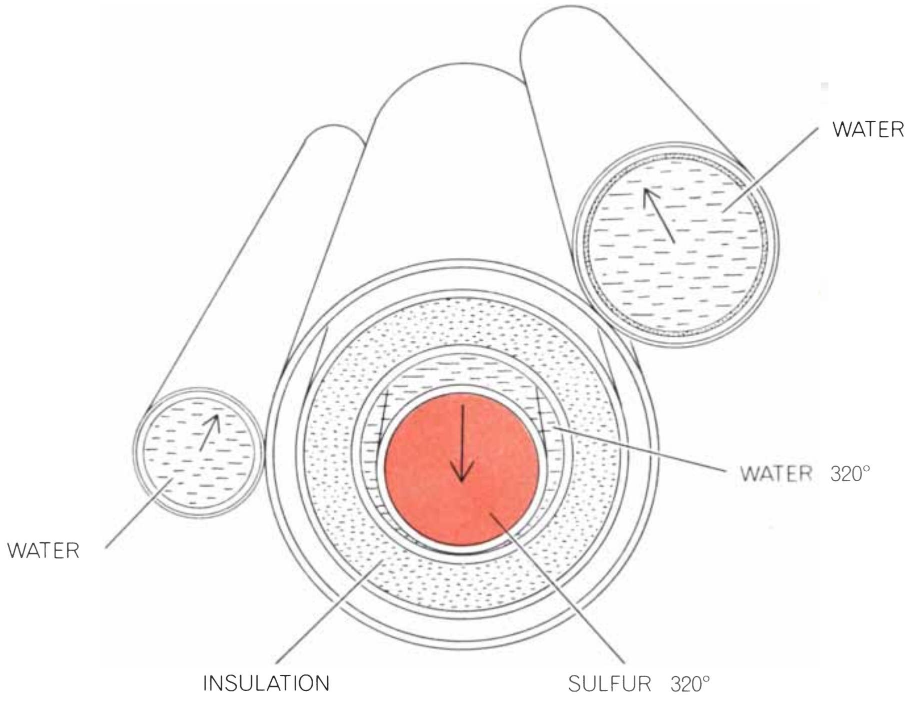
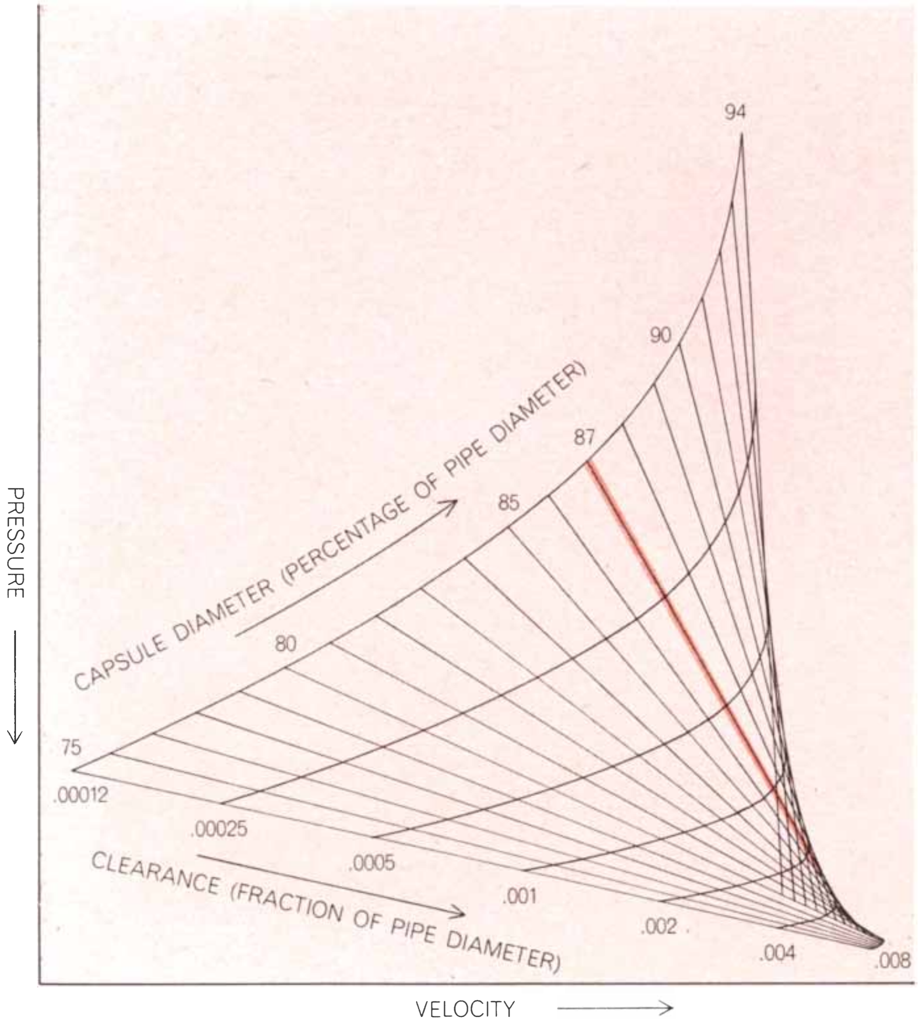


SPECIALIZED PIPELINE carries molten sulfur ashore from the Gulf of Mexico. The pipe has insulated jacketing to keep the sulfur at a high temperature. Vacuum-jacketed pipes may be developed for transporting natural gas in the liquid (low-temperature) state.



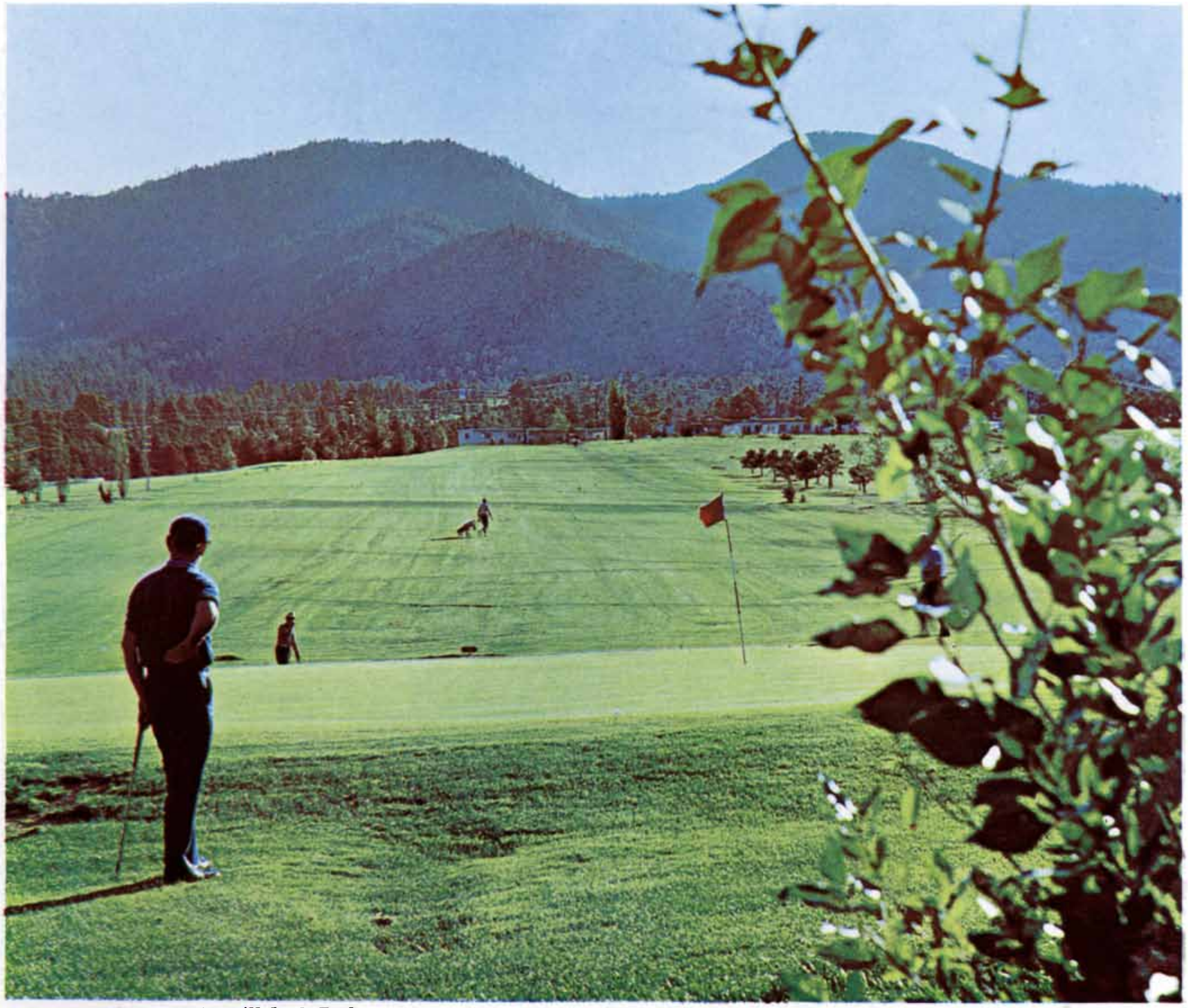
PERFORMANCE OF CAPSULES can be predicted by means of computer-plotted diagrams such as this one, which is for a long capsule with laminar flow of the surrounding liquid. The colored line represents a capsule with a diameter 87 percent of that of the pipeline.

heavy object was transported in the line for a distance of 109 miles over undulating country, including a steep rise where the line ascends from a riverbed. With the conveying oil driven at an average velocity of 2.78 miles per hour, the capsule traveled at an average speed of 1.95 miles per hour for the trip. It showed very little wear.

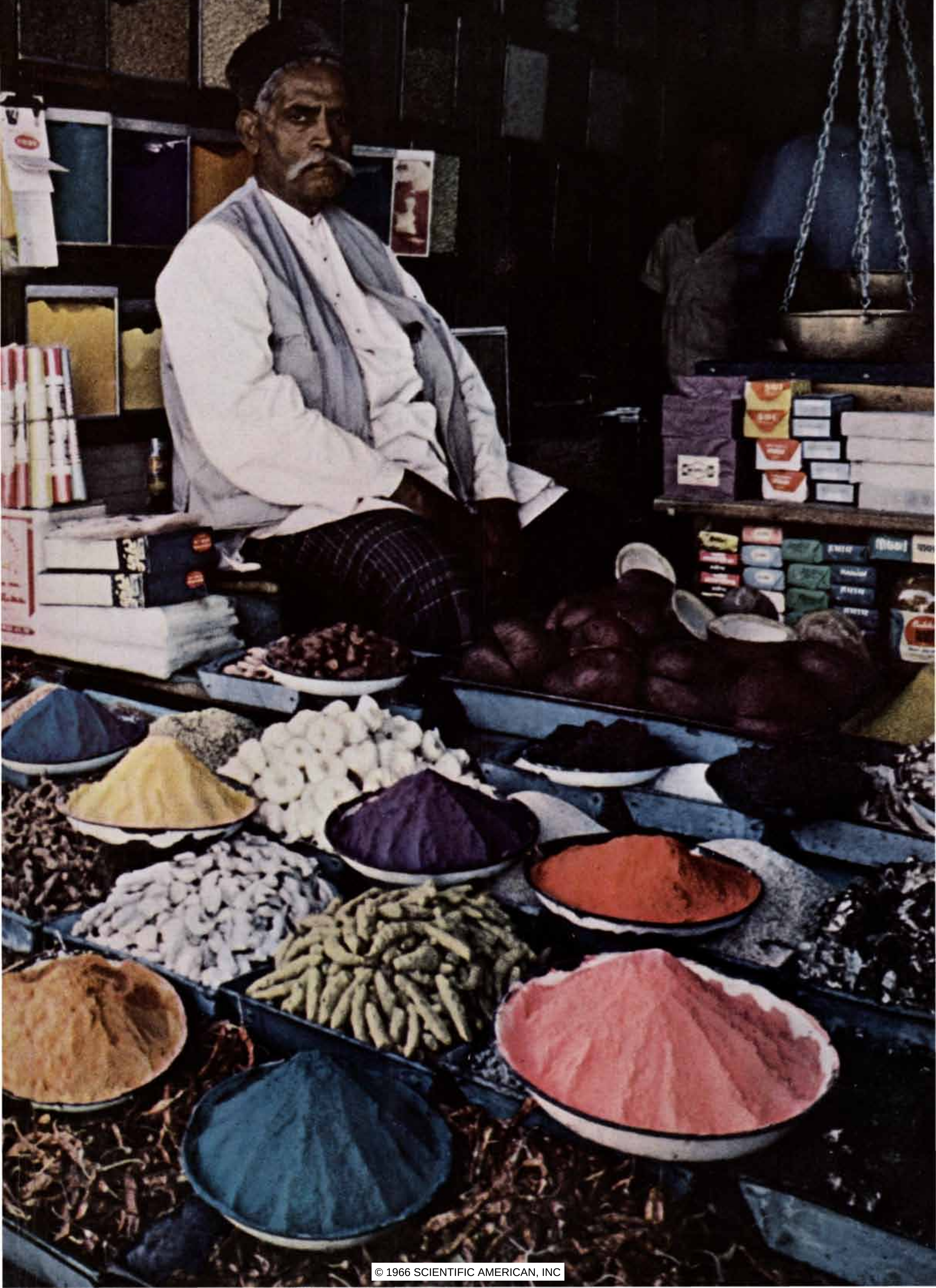
The foregoing findings of course apply not only to goods packaged in an enclosing capsule but also to any cylindrical or spherical mass of material—a ball of aluminum, a bar of iron or whatever. It has been suggested that sulfur, beneficiated ores, potash, steel, aluminum, plastics and many other materials could be extruded, cast, sintered or otherwise formed into cylindrical slugs or balls for transportation in pipelines. Moreover, it has been demonstrated that cylindrical slugs made of a paste of coal and water are strong and resilient enough to be conveyed in an oil line. It also appears that heavy materials such as iron, nickel and copper concentrates could be transported more efficiently in ball form than in slurries. The driving of a slurry calls for a greater consumption of pumping power, because the stream velocity must be raised to the level of turbulence to keep the particles suspended. To move capsules, which are supported by a thin layer of liquid below, all that is needed is enough power to keep the system moving.

In the case of a slurry the cargo material has to be separated from the fluid at the end of the journey. Capsules, on the other hand, can be collected intact at the delivery point simply by depositing them on rollers or a conveyor belt. Engineers engaged in the design of capsule-transporting systems have also developed working models of equipment for putting the capsules into the pipeline at the starting point and for shunting them past the booster pumps along the line.

Pipelining, in short, has entered a most exciting period; it is steadily advancing new ideas and opportunities for imaginative innovation. Most of the present pipelines are operating at full capacity in the transportation of the materials for which they were originally built—oil, petroleum products or natural gas—but it seems altogether likely that we shall soon see this method of transportation extended to other applications on a large scale. One strong possibility is that pipelines will be built as "common carriers," transporting a great variety of products, liquid and solid, with both the liquid and the solids as payloads.



LASL photograph by Bill Jack Rodgers



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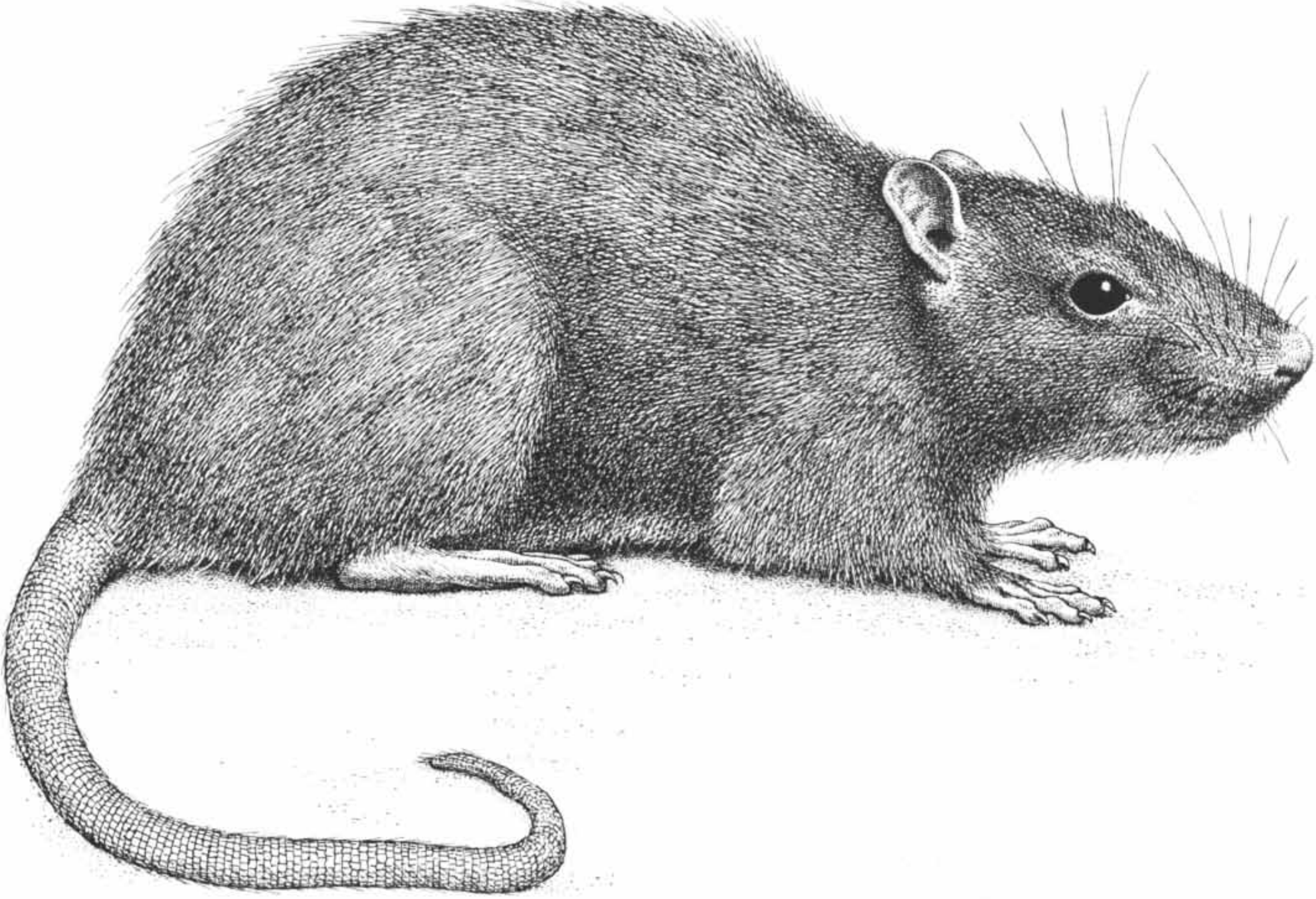


BROWN RAT, *Rattus norvegicus*, is the larger of the two species of rats that are most closely associated with man. A well-fed male may weigh one pound and attain a body length of nine inches; its ears are small and its thick tail is shorter than its body. The species varies in color: some individuals are black and the laboratory white rat is an albino variety. Brown rats are burrowers.

BLACK RAT, *Rattus rattus*, is the smaller species. It rarely weighs more than 11 ounces or exceeds seven inches in body length. Its ears are large and its tail is long and slender. Its color varies even more than the brown rat's; city-dwelling individuals are usually black but those that live in the open often have tawny coats. Unlike brown rats, black rats seek heights and even nest in trees.

RATS

These ubiquitous companions of man are detested as dangerous pests, but they are worth studying for their own sake. Their social behavior is subtly adapted to maintain the integrity of the group

by S. A. Barnett

"The Common or Brown Rat is probably the most injurious and universal pest of the human race.... It does not appear to have a single redeeming feature." This forceful judgment, delivered by the English zoologists G. E. H. Barrett-Hamilton and M. A. C. Hinton half a century ago, reflects a widespread and partly justified horror of wild rats. Nevertheless, these animals are worth study for their own sake and not only as pests.

The species to which Barrett-Hamilton and Hinton referred is *Rattus norvegicus*, often called for no good reason the Norway rat. As a result of its emigrations during the past few centuries this animal is now present in most of the cold, temperate and subtropical regions of the world occupied by man; its range includes almost all of North America and much of Central and South America. In the Tropics, however, it is evidently at a disadvantage compared with other rats, notably *Rattus rattus*, commonly known as the black rat.

R. norvegicus is heavily built and often looks clumsy; it has small ears and a thick tail shorter than its head and body combined. A well-fed male may weigh a pound and attain a body length of nine inches. *R. rattus* is more delicately built and rarely reaches two-thirds of a pound. It has large ears and a long, slender tail [*see bottom illustration on opposite page*]. The two species cannot reliably be distinguished by color. *Norvegicus*, the "brown" rat, is sometimes black. *Rattus*, the "black" rat, has several color varieties. In warm countries, where it lives in the open, it is most often tawny; the black variety is common only where most of the rats live in buildings. Although *rattus* is more attractive in appearance than *norvegicus*, it is regarded with equal hostility by man, since it is commonly thought of as the principal carrier of plague.

Both species depend almost entirely on human communities for food and shelter, but they differ markedly in detail. *Rattus* thrives in a warm environment; it remains lively at temperatures that prostrate *norvegicus*, and in cold climates it lives only in buildings. *Norvegicus* is a burrowing animal and lives readily in hedgerows, earth banks, haystacks and the ground near sewers and streams. (It is a good swimmer.) *Rattus* is a climber. It has not been observed to burrow or swim; it can nest in trees. In ports such as London both species sometimes live in the same building—*norvegicus* in the basement and *rattus* in the attic. *Rattus* is often called the roof rat.

In temperate regions, including most of Europe, *rattus* is now found almost wholly in ports; in hot countries such as India the same is true of *norvegicus*. But *rattus* was widespread in Europe before *norvegicus* arrived there.

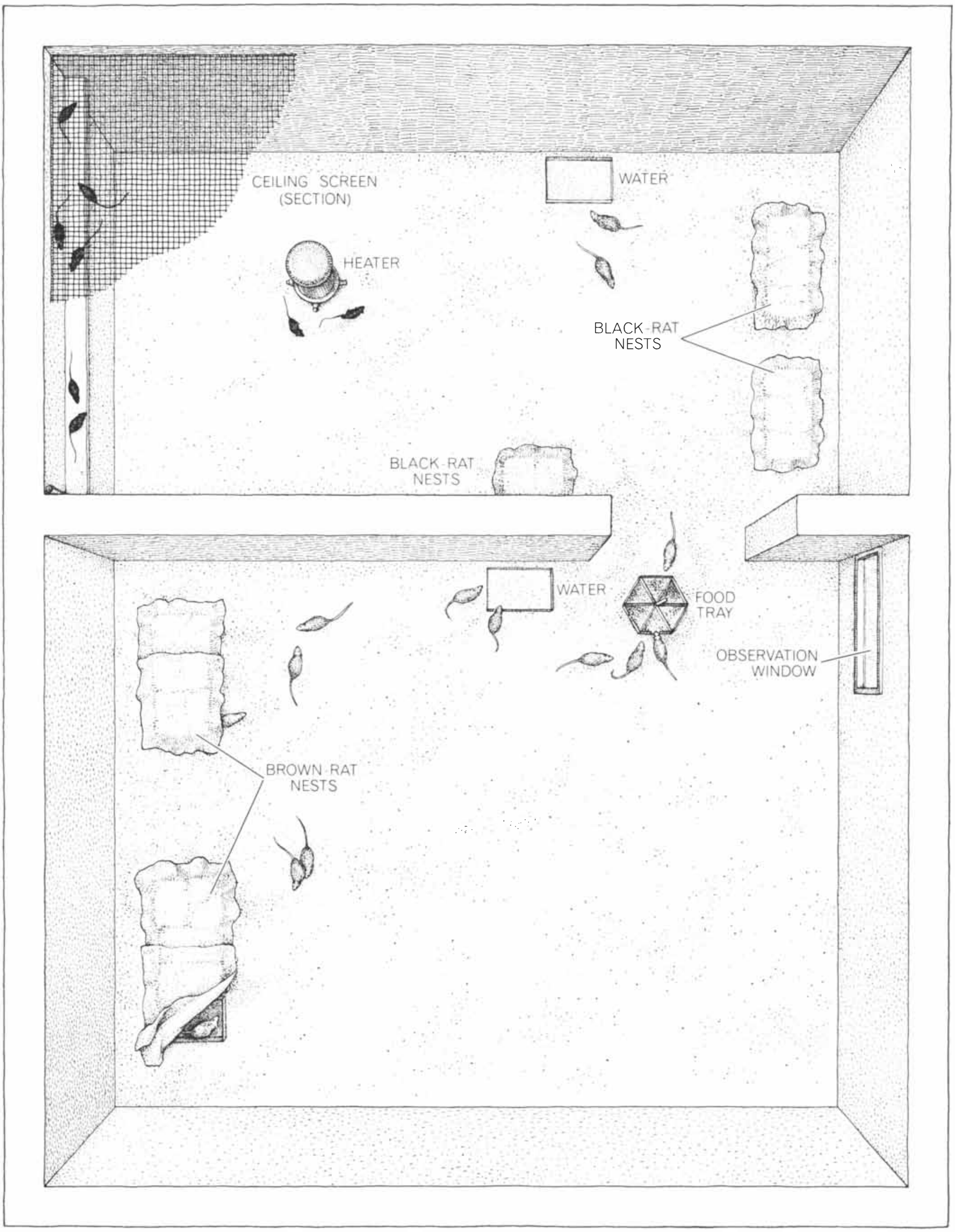
There are many tales, usually mythical, of large-scale movements by *norvegicus*. According to one that is often told, a massive invasion of Europe began in 1727; a German naturalist, Peter Simon Pallas, is said to have seen an army of these animals swimming the Volga at Astrakhan. But Pallas was not born until 1741, and the rats he described were crossing the Volga not toward Europe but in the opposite direction. At any rate, although rats sometimes emigrate in substantial numbers over short distances, the spread of *norvegicus* over Europe and other parts of the world must have been a fairly slow process.

It is commonly assumed that, when the two species meet, the larger *norvegicus* tears *rattus* to pieces, but this is unlikely. The only relevant experiment I know of was carried out in the winter of 1949–1950. My colleagues and I set up colonies of the two species in adjoining compartments of a converted stable near London. For the purposes of the experiment a door between the compartments was removed and a single source of food was put at the opening. Almost at once the largest *norvegicus* entered the other room and drove the *rattus* that lived in it from their nests. Thirteen of the *rattus* soon died, but six exceptionally belligerent individuals remained [*see illustration on next page*]. The deaths were not due to wounding, nor was there any evidence of starvation. As we shall see, the direct cause of death in such circumstances remains quite mysterious.

The rest of this account is devoted mainly to *norvegicus*, the "common" rat. What has made this species so successful in human environments? Among its assets are, first, its ability to live hugger-mugger in crowded underground colonies and, second, its readiness to eat anything man does.

Since rats are usually active only at night and live under cover, intimate knowledge of their social life depends on observing them in artificial colonies. From a single pair in a spacious cage or enclosure a large and thriving family can develop. How quickly a given population is attained can be calculated from the following approximations. A female rears six young per litter; the young are sexually mature after four months (later than laboratory rats); the gestation period is three weeks; a female can easily rear four litters in a year, even allowing for a period of infertility that may occur in winter.

Alternatively, a colony can be started with a group of young rats. They must be juveniles, because if adult males and



COMPETITION BETWEEN RAT SPECIES was induced experimentally by the author and his colleagues in 1949. They put colonies of brown and black rats in adjoining rooms and opened a connecting door when the brown colony totaled 29 and the black colony 19. A single feeding tray was placed by the open door. The largest of the brown rats almost immediately explored the black rats' nests (*top*). The black rats retreated to a high ledge (*top left*) or to the ceiling netting, which they left only to eat or drink. In a few days 13 of the black rats were dead, although none had been wounded. Only the six most "aggressive" of the black rats survived.

females are put together the males come into conflict.

What happens if a strange rat is introduced into a peaceful family group? If the newcomer is a juvenile, it is ignored; if it is an adult female, it is ignored unless it is in estrus, when the males will attempt coitus (and probably succeed). If, however, it is an adult male, it is vigorously attacked. The attacks are not concerted; there is no "pack" behavior. Individual males act independently.

This intolerance of strangers is common among vertebrates. A region is defended, by a pair or by a larger group, against others of the same species. Among rats the defended region, or "territory," is held by a group in spite of the lack of cooperation among its members.

A prime effect of territorial behavior is to disperse the members of a population. Unfortunately we know little about the density of rat populations, although many guesses have been published. The most reliable census method is one devised by Dennis Chitty and Monica Shorten of the University of Oxford. Piles of wheat grain are put down at many points near the burrows of rats and on their runways, and the amount eaten is recorded. When daily consumption levels off, this quantity in grams is divided by 24 to give the minimum number of rats present. (The mean daily consumption of grain by the common rat is about 24 grams.)

Censuses by this method were taken in two English farming villages in 1948 and 1949. One village had 364 people, 55 cats, 25 dogs and at least 330 rats; the other had 266 people, 43 cats, 14 dogs and at least 180 rats. The rat populations—about as many rats as people—were probably unusually high. Good hygiene and efficient control by poison baiting could have kept numbers down.

Each village had about 15 distinct rat colonies, which were associated with sources of food such as farm buildings. The creation of a source of food, such as a new chicken run, quickly attracted rats where there had been none before. Rats are highly exploratory; hence they soon find new food supplies or other favorable features in their living area. The same kind of effect may be seen if a rat population is largely wiped out. The destruction by poisoning of most of the rats in a system of sewers, for instance, has often been followed by a rapid inflow of other rats, presumably from colonies in the surrounding earth or in the buildings above.

What controls the growth of a rat colony? When a few rats begin to breed in an area with plenty of food and cover, their rate of increase is slow at first, but it becomes rapid when there are plenty of fecund females; later it slows again. As density increases, several hostile forces can be expected to act progressively against still further increase. Predation by dogs, hawks and man may become more intense; nest sites for rearing young will be less easily found; infectious disease may increase. Any of these (or a shortage of food) could put a ceiling on further growth.

It is possible, however, that none will do so, and that social interactions will limit density before food and shelter fail, and before predators or parasites do more than kill the old and the weak. D. E. Davis, then at Johns Hopkins University, reduced a rat population by half by a strenuous trapping operation. The pregnancy rate of the survivors doubled in two months. Crowding evidently interferes with breeding, but we do not know just how. Females with litters may be pestered by males, although ordinarily a parturient female can drive away intruders from her nest merely by making sounds and perhaps a snapping movement of her head.

It is possible that the regulating process is far more complex, and involves several factors acting together. Hunger, for instance, increases aggressiveness in rats (as it does in man). Perhaps social interactions in a colony change when food becomes more difficult to get. If so, an increasing tendency among the colony members to attack other rats could reduce the fertility of the females and enhance centrifugal movement. The position of food and nests may also interact with territorial attacks. John B. Calhoun of the National Institute of Mental Health set up a large artificial colony of wild rats in Baltimore with a single, central source of food. Rats living at the periphery were at a considerable disadvantage, since they were subjected to attack by rats living in an inner circle nearer the food.

At the University of Glasgow we have made detailed studies of social behavior in colonies of wild rats. Rather surprisingly, if adult males were put together in a strange cage, they settled down without strife, grew well and survived (if left to do so) to old age. But if females were included, the result was a high death rate among the males; sometimes after a few weeks only one male remained, usually the largest. Yet the males did not fight for the females. Conflict flares when males are aroused by a female not yet in estrus and are frustrated in their attempts at coitus. Evidently sexual excitement without consummation lowers the threshold for territorial fighting among males. Recent experiments (as yet unpublished) have confirmed this. Resident males attack newcomers more vigorously if females are present than if they are absent.

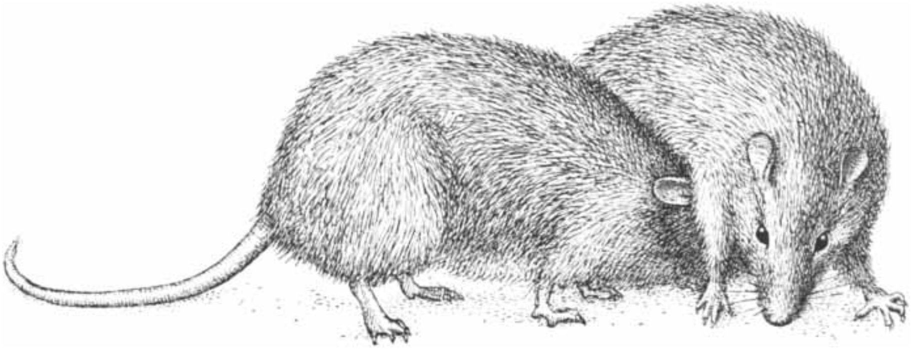
Since male rats are combative animals, there must be something that makes them peaceable within the colony. Some species achieve this by a status system: each member of a herd or colony has a social status, or position in a peck order, that determines its behavior—dominant or submissive—toward other members. It is easy to assume that there is a regular "dominance hierarchy" among rats, but there is no good evidence for anything so elaborate. In artificial colonies all females are equal, but males of three types are observed.

The "alphas" move about without regard to other rats. Their movements are brisk; their skin is sleek; they grow well. There may be several alphas, in this sense, in one colony. "Betas" too look healthy and grow well, but they retreat at the approach of an alpha. The status of beta is reached (as in formal peck orders) through the experience of clashes; the beta has adapted itself to a "subordinate" role. Again, there may be several betas in a colony. Betas also behave subserviently toward strange males (which would ordinarily be attacked). They even greet strange males of a different species, *R. rattus,* in this way. Evidently the adoption of the beta status entails almost total inhibition of aggressive behavior.

The third kind of male is the "omega." It does not belong in a stable rat colony; this status soon ends in death. Most newcomers to an established colony rapidly fall into the omega position. Their fur is staring or bedraggled; they move about listlessly; they lose weight; they withdraw at the approach of another male. Perhaps in a large natural colony these distinctions would not be so clear. Omegas would hardly be found, but there might be "gammas," less flourishing than the sleek betas of laboratory experiments but not in a state of rapid decline.

None of this accounts for the difference between the pacific attitude toward fellow colony members and the attacks on strangers. Probably the distinction is made principally or wholly by odor. When strangers are present in

SUBMISSIVE POSTURE is assumed by a male brown rat *(left)* when confronted by another male. He lies on his side with eyes half-closed. This is one of several social signals that appear to prevent attack. Female rats sometimes adopt this submissive posture.



UNDERCRAWL is another action that a subordinate male (a "beta") may perform on meeting another male. Both black rats and brown rats have been observed acting in this way.

GROOMING is another social gesture that involves bodily contact both between male rats and between males and females. "Amicable" actions of this sort probably prevent attacks.

ONE-SIDED FIGHT takes place when a resident male *(right)* confronts a stranger. The stranger, shown in a defensive posture, may squeal or run away but does not fight. The resident may never draw blood, but a stranger that is persistently attacked dies in a few hours.

a colony, there is a marked increase in "recognition sniffing" among the residents. Evidently the members possess a specific scent that inhibits attack. Moreover, rats leave odor trails as they move about. The passage of rats over a white surface such as a whitewashed wall leaves a dark smear containing odorous secretions; these apparently attract other rats.

Other social signals that seem to inhibit aggression involve posture or bodily contact. A beta male, deficient in aggression, may greet another male with a "submissive" posture: he lies on his side with eyes half-closed. Or he may crawl under the newcomer, a quite specific act performed by *rattus* as well as by *norvegicus*. A third harmless and seemingly "amicable" act is grooming another rat. All of these acts can be seen among males of a stable colony, and the "submissive" posture is sometimes adopted by females also.

It is all too easy to guess at the function of these performances, but to interpret them with certainty is difficult. For instance, some people regard the grooming of one male by another as not amicable but as a muted form of aggression. This illustrates the hazardous subjectivity that is likely to influence our accounts of such behavior. What do we mean by "amicable behavior"? Crawling under another rat is a harmless action performed in situations in which conflict might occur; the word "amicable" is used in this article to name such behavior. These actions probably help to prevent attack by their effect on the animal to which they are directed (although this is not included in the definition). The extent to which they do have this effect is a matter for further experiment. Certainly some fierce males on their own ground are persistently belligerent toward strangers, whatever the latter do.

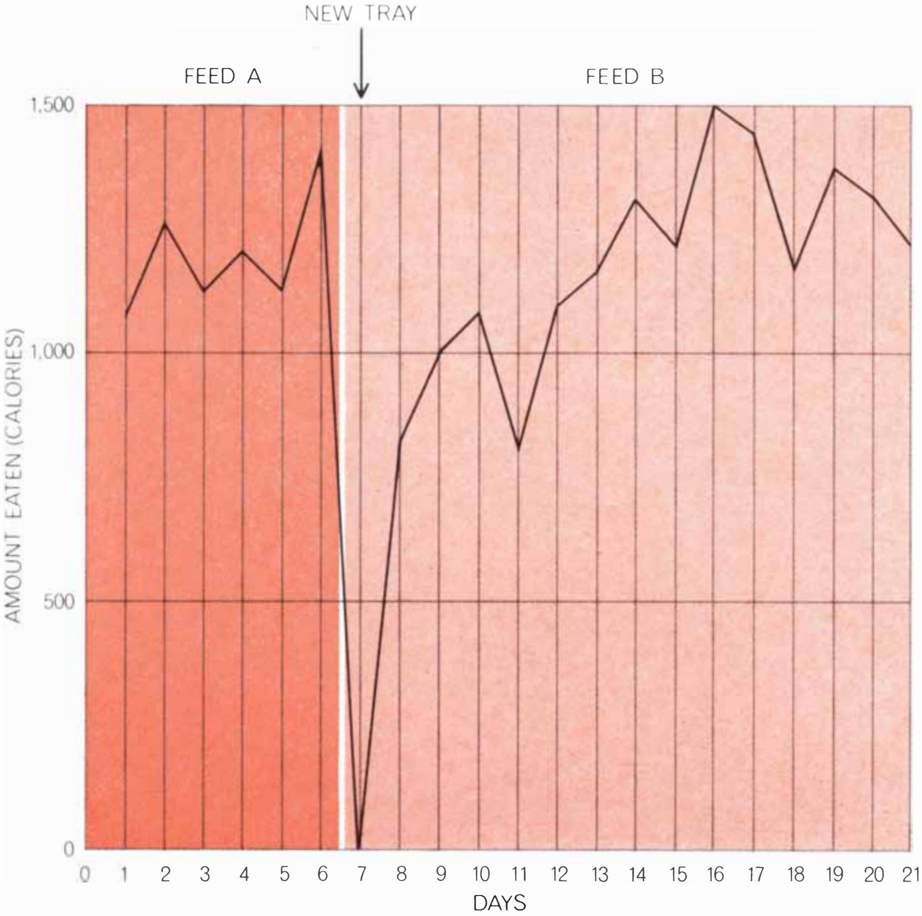
Although strangers are attacked, rats do not fight in the human sense: the attacked rat never retaliates. A typical assault begins when a large, ferocious male in his own territory approaches a strange male. His teeth chatter and his hair is raised; as he approaches he defecates and urinates. He now sniffs the intruder, turns his flank and adopts a highly characteristic "threat posture": the legs are extended, the back is arched and the rat moves around his opponent with mincing steps. Sometimes this formality is omitted; the resident leaps straight at the intruder with rapid movements of his forelimbs (which can be seen clearly only in slow-motion pictures). At the same time he may briefly nip a limb, an ear or the tail of the defender. After a few seconds of wild leaping the bout ends, but others follow rapidly.

At the end of a series of bouts the attacker withdraws for a time, but he is by no means exhausted. He can readily turn to another activity, such as coitus. His victim, on the other hand, is often left stretched out limply, breathing rapidly and irregularly.

Persistent persecution usually ends with the death of the victim in a few days. In an extreme case death has occurred in 90 minutes. The cause of these deaths is enigmatic. They often occur in the entire absence of wounding. (The bites are usually ineffectual, since a rat's hair and skin are thick.) No internal bleeding or other such pathological signs are found. The animals, initially healthy and vigorous, drop dead. To talk of "shock" is futile. "Vagal syncope" (a phrase hardly more precise than "heart failure") is little better. (The vagus is a nerve whose action slows the heartbeat.) It does, however, indicate where we should seek the source of disorder, namely in the brain.

Unfortunately we cannot yet describe what goes on in the nervous system of a rat under attack, but we know something of other changes. There are, for example, marked effects on the adrenals. During a brief, severe attack these glands greatly increase their output of hormones, and when a rat is persistently persecuted for days or weeks the adrenals enlarge. Increased activity and enlargement of the adrenals occur in a variety of adverse conditions, such as wounding, infection and exposure to cold. Adrenal hormones help an animal to resist stressful conditions. Their secretion is itself regulated by the nervous system. Hence in the adrenal changes of attacked rats we have a physiological effect of "social stress" that parallels what happens when the body is near the limits of endurance from other causes.

The existence of "betas" presents a further problem. They show that some males can withstand the stress of being attacked and can adapt themselves to it, but we do not know what enables a rat to become a beta. We do know that experience as an alpha does not armor a male against the ill effects of being attacked. A large, fierce, healthy male, accustomed to victory over newcomers in his own territory, succumbs when subjected to attack as an intruder in another's territory.



AVOIDANCE OF THE NEW is the normal behavior of wild rats in a familiar environment. Here a change from whole wheat to white flour as one item in the diet was sufficient to halt feeding. Such withdrawal from anything novel has a high survival value for the wild rat.

Nevertheless, it is doubtful that attack by a resident much smaller than the intruder would be severely traumatic. We have begun in Glasgow to study the effects of size systematically. The larger the intruder in relation to the attacker, the more time the attacker spends in the threat posture instead of in leaping and biting. This suggests that one function of the posture is to act as a harmless substitute for true attack. There is no clear evidence that it induces withdrawal in a newcomer. Perhaps its principal function is to limit conflict *within* colonies. Alphas in a stable group do posture at one another and then move away without further excitement, as if the impulse to fight had spent itself in harmless prancing.

The sexual, parental and filial behavior of rats, as well as their patterns of attack and submission, are regulated by signals typical of the species. When an adult male rat encounters a mature female, he approaches and sniffs, particularly at her genitalia. If she is not in estrus and he attempts coitus, she kicks him off with a thrust of a hind leg. If the female is receptive, she may herself approach the male and gently touch his flank with her nose. In all of this odors are evidently crucial signs of the physiological state of the performers.

Signals similarly guide a female with young. (The males have no parental role after insemination.) A pregnant female makes a nest of any material at hand. When the young are born, they are licked and assembled in a group in the nest. If the young are not licked, they do not develop the reflexes of elimination and soon die.

When the young fall or wander from the nest, they are retrieved. The young themselves make high-pitched squeaks when they need food or when they are cold. Charles Evans has recorded the noises of infant wild rats in our laboratory. They consist of a tone of about 3.1 kilocycles per second with a harmonic at 6.2 kilocycles; each squeak lasts about half a second and the squeaks are emitted at a high rate. They are readily localized by the female and no doubt guide her to strayed nestlings. A female employs several other senses in retrieving her young. Their appearance plays a part, including their size: larger nestlings are less reliably carried back to the nest than smaller ones. Their odor too is important. Experiment on laboratory rats has shown that no one of these features is indispensable.

The social behavior of even such simple mammals as rats clearly raises many questions. That it should do so sometimes surprises those who know only the laboratory varieties of rat. These useful creatures, a product of several decades of unnatural selection, have been much changed by domesticity. They are all members of the species *R. norvegicus,* as can easily be proved by crossing them with the wild form. Their tameness and high fertility as laboratory animals or as pets obviously set them apart from their wild cousins. They are also adapted to life in cages by having lost all the more violent forms of territorial behavior. "Attacks" on other rats mostly take the form of play, if they occur at all. The threat posture (and also amicable signals such as crawling under another rat) is usually absent. Accordingly a strange male can often be put in an occupied cage without harm.

Nevertheless, there remains much to be learned about wildness and tameness. Wild rats can be tamed if they are handled regularly from infancy. Conversely, laboratory rats left alone for long periods become fierce; this also happens if they are allowed to run free. In Glasgow we have bred wild rats for 10 generations in the laboratory, and the later generations are less likely than their forebears to attack other rats. We do not know whether this is owing to selection of inherited differences or to the environment.

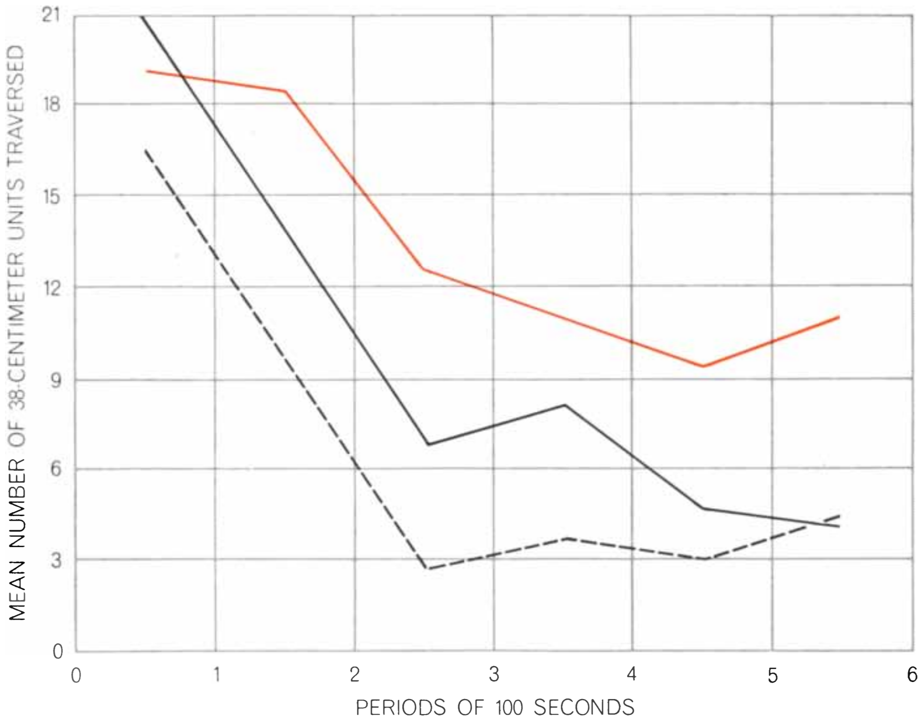
Laboratory rats have not only lost the capacity to give (and presumably to respond to) many social signals. They are also less resistant to cold than wild rats. Among other differences, they apparently lack the capacity to grow a thicker coat of hair in cold weather. Their adrenal glands are lighter than those of wild rats. Since the adrenals are particularly concerned with the immediate bodily response to stressful conditions, this appears to represent an inherited change allowed by the luxurious conditions of the laboratory.

In spite of the many differences between tame rats and wild ones, experiments on laboratory rats have given us much information about rats as animals that can survive in a natural environment. Concerning feeding behavior it is possible to combine information from the wild and the domestic forms. Wild or tame, they sample anything edible or potable they can reach. This insatiable "curiosity" and sampling would lead wild rats in man-made environments into danger but for an opposite kind of behavior. In a familiar environment any new food, or any other new object, is initially avoided. If piles of poison bait or a number of bait boxes or traps are put in an area, the rats may completely disappear from their usual runways for a night or two. This is the main foundation of their reputation for cleverness. In human beings an automatic neophobia, or fear of anything new, is considered neurotic or stupid. For rats it has a high survival value. Probably it is strongly developed in them as a result of thousands of years of natural selection in human communities.

A further protection against man is provided by a simple learning process. A strange food, avoided at first, is later sampled in small amounts. If it is toxic, there is time for the ill effects of a small dose to develop. Feeding then ceases; when it is resumed, the rat refuses the bait (and anything that tastes like it) and may continue to do so for many months.

This "poison shyness" has an obverse characteristic in the ability to choose nutritionally favorable foods. "Dietary self-selection," first rigorously described some 30 years ago by L. J. Harris and his colleagues at the University of Cambridge, enables laboratory rats to select a mixture containing vitamin B_1 in preference to one without; rats can also adjust their intake of sodium chloride and other salts according to need. Since rats are omnivorous, in the wild state this ability no doubt helps them to achieve a balanced diet.

Avoiding dangerous foods and choosing nutritious ones depends on a kind of learning, or adapting behavior to experience. Work on the learning abilities, or intelligence, of rats has, however, been mainly directed toward the discovery of the "laws of learning" and their physiological basis; it has not been much motivated by interest in rats themselves. Nonetheless, the vast amount of work in this area has revealed something about rats as animals. Barrett-Hamilton and Hinton say they are "diabolically intelligent animals," but this notion is not borne out by their actual behavior. Laboratory rats readily learn to find their way to food or some other incentive through a system of branching passages—a maze. This ability is particularly appropriate in a burrowing animal, but it is probably widespread in the animal kingdom. The rats also display a more subtle form of learning that occurs in the *absence* of need: laboratory rats that have had the opportunity to wander about a maze when they were not hungry, and without finding food (or some other reward), can later learn, with a suitable incen-



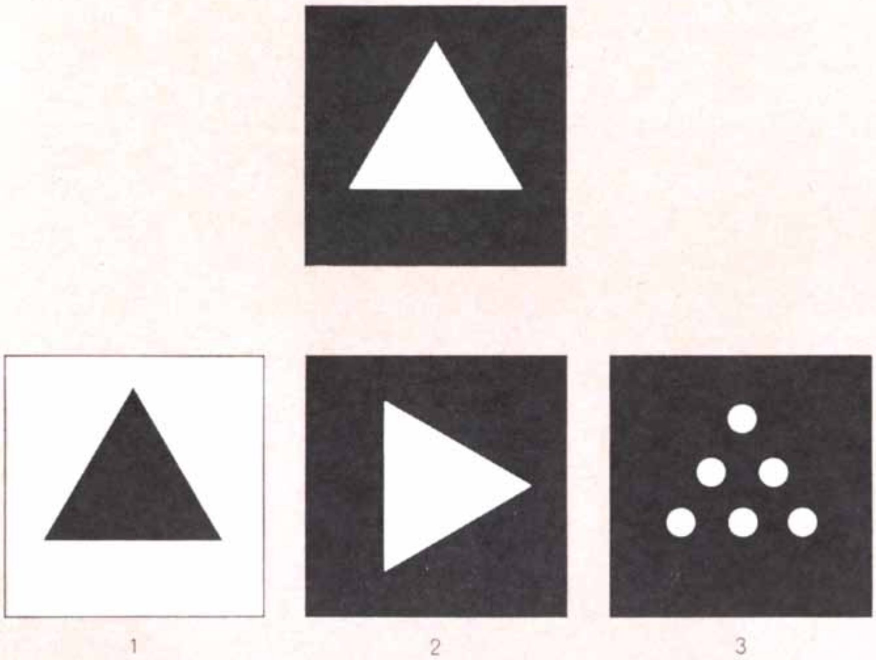
INTENSITY OF EXPLORATION by laboratory rats increases in response to greater environmental complexity. Rats put in a T-maze were more active (*colored line*) than rats put in an L-maze (*solid line*) and much more active than rats in an I-maze (*broken line*).

tive, to run through the maze correctly more quickly than rats that have never been in it. Like men, rats can pick up topographical information during casual exploration. The underlying process is called latent or exploratory learning. The cues employed may involve any of the senses; they may be the texture of a surface, the echo of footfalls, odors and even the slope of a passage.

Rats are adaptable in other ways. They use their forefeet when feeding and when building nests. They are manipulating animals and hence can readily learn to press a lever or pull a string for a reward. They have therefore been much used in the study of learning processes in problem boxes. They can also be induced to jump from a platform toward a door that falls open with the impact. The late K. S. Lashley of the Yerkes Laboratories for Primate Biology used an arrangement that had two doors marked with different patterns; rats could be trained to discriminate between these visual stimuli. Rats distinguish simple, bold patterns readily. Unlike monkeys, they cannot be trained to respond, say, to triangles in general—only to triangles of a fairly narrowly defined size, shape and orientation [*see illustration at right*].

Another intellectual limitation is revealed by the "oddity problem." A monkey, given three boxes, can easily learn always to open the one bearing a pattern *different* from that of the other two. Rats can do this, if at all, only with special preliminary training. A more general deficiency is social as well as intellectual. In spite of many legends, rats do not cooperate—to get food, for instance. They carry or drag food under cover, and a chunk of meat as heavy as a large rat may be dragged away by two or three rats at once, but the rats are as likely as not to be pulling in different directions.

The function of eating (as of sleeping) under cover is obvious. So, at first sight, is the hoarding of food in burrows. Yet much else may be carried away or piled in a corner by wild rats: coins, cakes of soap, small toys—anything that can be carried. This behavior, like miscellaneous gnawing, resembles play; it is performed in addition to activities such as feeding that are immediately essential for life. Indeed, one of the most conspicuous features of rat behavior is restlessness. The propensity for exploration is more easily studied in laboratory rats than in wild ones, since the tame rats are not neophobic. In the laboratory, exploration can be reduced to a minimum by putting a rat in (or on) a maze with a single "choice point": a T- or Y-shaped maze that allows a rat to turn either left or right. If the rat finds no reward in the first arm entered, it usually chooses the alternative arm on a second run; if there is again no reward, it continues to alternate thereafter.



RAT REACTION to visual patterns shows little ability to recognize general likenesses. A rat trained to respond to the upright white triangle (*top*) makes only random responses when presented with any of the other three triangles (*bottom*). A similarly trained chimpanzee recognizes both solid triangles, and a two-year-old child recognizes all three.

What makes a rat behave in this way? Experiment has shown that novelty is the crucial feature: a rat usually chooses the less familiar kind of stimulation. Indeed, the opportunity to explore a complex area can be used instead of food or water as a reward to induce a rat to choose one passage rather than another. This well-developed neophilia has led some writers to use the term "curiosity drive" to refer to it; one might also say that rats often behave *as if* they wished to avoid boredom.

For wild rats the obvious function of exploratory behavior and food sampling, with the accompanying learning, is to keep them regularly informed on the amenities of their environment—food, water, shelter and other rats. Their neophobia prevents their "curiosity" from being lethal in man-made conditions. Moreover, exploratory behavior (and probably play) also has an important role in the development of intelligence. D. O. Hebb of McGill University compared laboratory rats reared in the impoverished environment of a small cage with others that had spent their youth in larger enclosures containing diverse objects. The latter learned mazes more readily. Similarly, the learning of visual discriminations is aided by the rats' experience of a variety of visible patterns in early life.

This "learning to learn" is an immensely important feature of mammalian behavior. It is not confined to early life. A rat that has learned to solve one problem is usually quicker to solve a similar problem; for instance, the more experience it has in learning to find its way about, the more proficient it becomes at doing so (up to a point). This may involve unlearning some habits and replacing them with new ones. Rats, even if they are not diabolically clever, are in this respect also highly adaptable. These abilities have no doubt made possible the success of wild rats in the great variety of environments created by man, and have enabled rats to become the universal pest most people think they are.

Electric Currents in Organic Crystals

A new technique for measuring the energy levels of certain organic crystals may provide the key to an understanding of the mechanisms of electron transfer in living plants

by Martin Pope

The sun, as everyone knows, is the ultimate source of energy for all life on earth. The most familiar manifestation of the sun's influence on life processes is the hydrologic cycle: Radiation from the sun causes water to evaporate from the oceans, forming the clouds that yield the rain that nourishes the plant life that sustains the animal life. In terms of energy transfer, the movement of the water upward represents a conversion of heat energy to mechanical potential energy, and the movement of the water downward over the land back to the sea represents a degradation of the mechanical potential energy.

A subtler but no less important cycle that is also powered by the sun is that of photosynthesis, which can be understood as an analogue of the hydrologic cycle. In the process of photosynthesis energy from the sun is absorbed by the green, chlorophyll-rich tissue of plants, causing the "evaporation" of electrons to form "clouds" in the higher energy levels of the molecules. The electrons soon "fall" from the clouds like rain and eventually find their way back to their ground level. Nature has so adapted the plants, however, that the electrons are forced to move downward in a devious path that traverses many different molecules, doing the chemical work of synthesizing carbohydrate and protein on which all other life on earth depends.

Many investigators are engaged in studying the electronic pathways from higher energy levels to the ground level in organic molecules, notably in chlorophyll. An important step toward understanding the mechanisms of electron transfer in living plants is the study of energy levels in organic crystals, an undertaking that corresponds roughly to charting the contours of a watercourse. In our laboratory at New York University my colleagues and I have developed a new technique for evaluating energy levels in certain of these crystals. One somewhat unusual aspect of our approach is that it is almost entirely based on the Nobel-prize-winning work of two giants of modern physics: the photoelectric equation put forward by Albert Einstein in 1905 and the electron-charge experiment performed by Robert A. Millikan in 1913.

The organic crystals with which we have been working belong to the family called conjugated aromatic hydrocarbons. The best-known solid member of the family is naphthalene ($C_{10}H_8$), commonly used in mothballs. Other members are benzene (C_6H_6), anthracene ($C_{14}H_{10}$) and tetracene ($C_{18}H_{12}$). From the structural diagrams of these compounds [*see top illustration on page 88*] it is evident that the more complex ones can be regarded as derivatives of benzene. Some of the earliest-known benzene derivatives were fragrant substances extracted from balsams, resins and essential oils. Because of their smell, these substances were differentiated from other organic compounds by the designation "aromatic." The term "conjugated" refers to the regular alternation of single and double chemical bonds in the molecules.

Each bond in the structural diagrams represents a pair of electrons. The double bond thus represents two pairs of electrons, one pair being contributed by each carbon atom. Normally the distance between two atoms connected by a double bond is appreciably shorter than the distance between two identical atoms connected by a single bond. In the aromatic compounds, however, the separation of all the carbon atoms is practically the same. This fact and other considerations have led workers in the field to visualize a somewhat more complex distribution of electrons in aromatic molecules than their structural diagrams would indicate. In addition to the strictly localized bonding electrons, each molecule contains delocalized, or "pi," electrons that spend most of their time in cloudlike regions above and below the central plane of the molecule [*see bottom illustration on page 88*]. The pi electrons appear to circulate rapidly around the benzene rings that form the aromatic molecules; as a consequence any disturbance of the electron density at one corner of a molecule is quickly "felt" at the farthest corner from the point of excitation. The conduction of an electric current from one molecule to another involves only the pi electrons; the localized electrons play a negligible role in the phenomena we are studying.

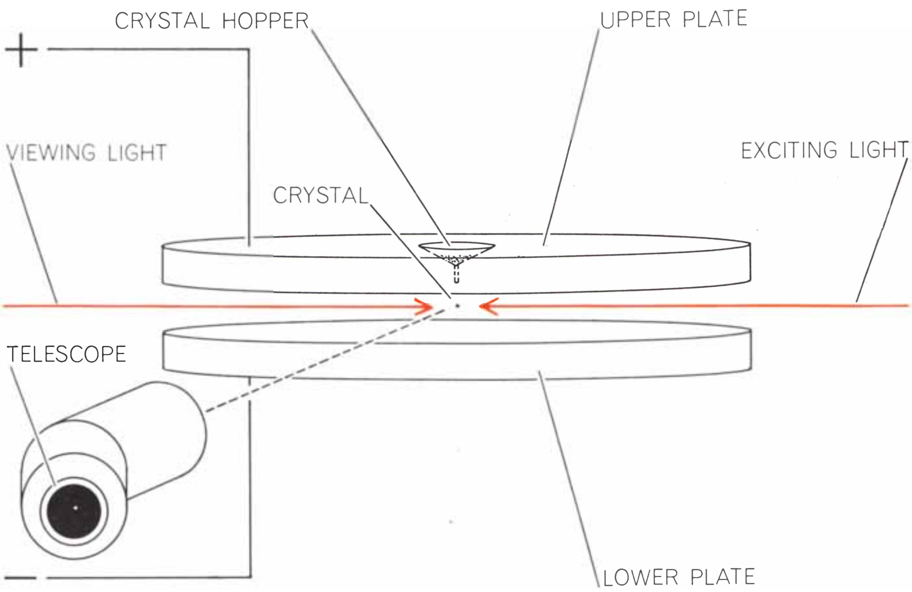
Like electrons in atoms, the pi electrons in the aromatic molecules can occupy various energy levels. There is first of all a ground state representing the least energetic or most stable configuration of electrons in the molecule. As energy is added to the molecule the electrons can be excited to higher energy levels; for example, the electrons can become more distant from the central plane of the molecule. The excited electron then falls back to the ground state, emitting its excess potential energy in the form of heat or light. By increasing the exciting energy it is possible to lift an electron to a higher energy level and eventually to remove it from the molecule entirely. This last process is called ionization, and it is basic to the process of electrical conduction in both semiconductors and insulators.

So far I have been discussing only isolated molecules, whereas our real interest is in the properties of crystals. The most intensively studied aromatic crystal is that of anthracene. Inside the anthracene crystal the molecules are packed in a repeating pattern of unit cells, each of which contains two complete molecules [*see illustration on page 89*]. The unit cell is monoclinic, that is, two of its axes (a and b) are at right angles to each other, but the third axis (c) is at an angle other than a right angle to the other two. The crystals we use in our experiments are oriented so that the ab plane is the largest area and the thickness of the crystal is measured in the direction perpendicular to the ab plane.

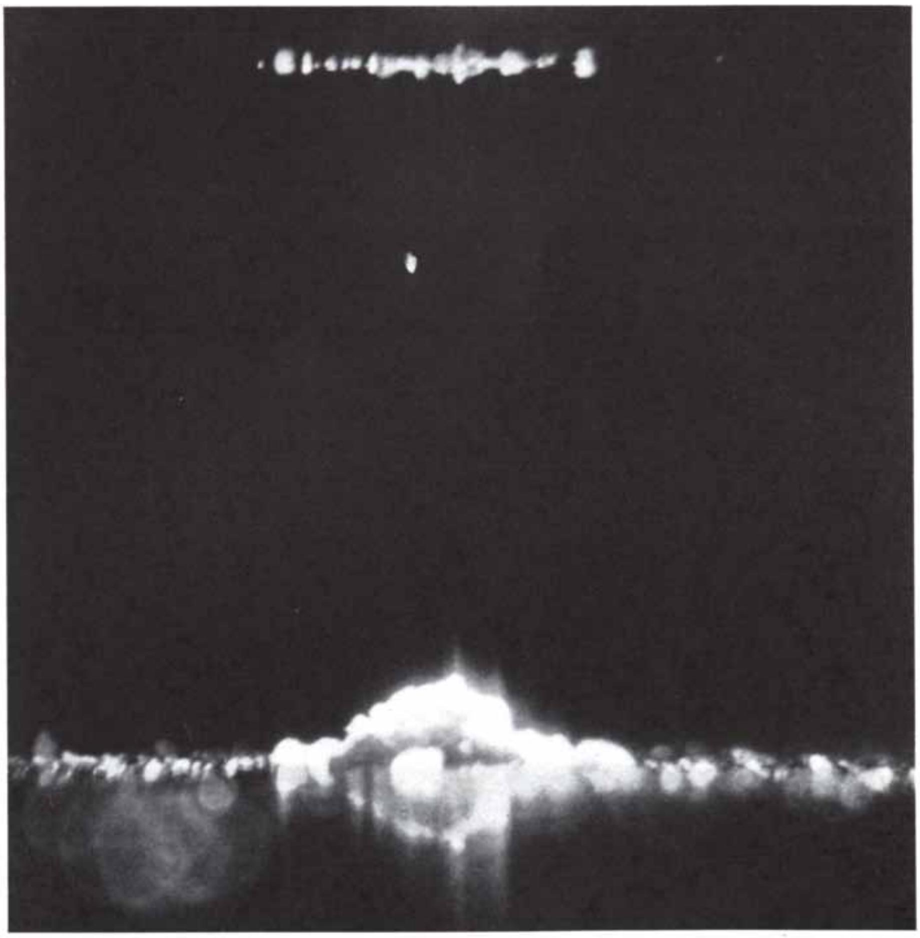
Electrical conductivity in a solid requires the existence of moving carriers of charge. The specific conductivity of a substance is expressed in units of reciprocal ohm-centimeters (ohm-centimeters to the power of -1) and depends on the concentration of charge carriers and their mobility. The mobility of a charge carrier is defined as the velocity of the carrier when one volt of electromotive force is applied across opposite faces of a cube of the substance one centimeter on an edge.

The difference in conductivity between substances can be enormous. For example, in copper the specific conductivity is about 10^6 reciprocal ohm-centimeters, whereas in the plastic polyethylene the specific conductivity is only 10^{-16} reciprocal ohm-centimeter. The aromatic compounds are classified as insulators, some being as good as polyethylene in this respect. The remarkable thing about an insulator such as anthracene is that its conductivity can be increased by a factor of 10^8 simply by exposing it to intense ultraviolet radiation; this does not occur in polyethylene. Moreover, the conductivity can be increased as much as a million times in total darkness by using special electrodes.

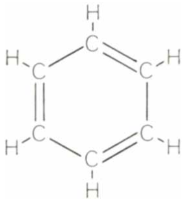
There are two basic problems in any study of electrical conduction that involves insulators: How much energy is required to ionize the molecules in the solid, thereby producing the charge carriers, and how do the carriers move through the solid from one electrode to the other? In considering the first problem it is useful to imagine a highly schematic model of a crystal lattice of anthracene in the presence of an external electric field [*see top part of illustration on page 90*]. When a large jolt of energy is given to one molecule, it ejects an electron; the electron can land on another molecule distant enough from the first so that the effective restoring force



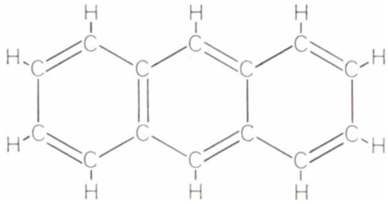
EXPERIMENTAL SETUP used by the author and his colleagues at New York University to determine the energy levels of organic crystals is based on a technique devised more than 50 years ago by Robert A. Millikan to measure the charge of the electron. A negatively charged crystal is dropped through a hole in the center of the top plate and is suspended in space by adjusting the voltage between the two plates. After the crystal is balanced an electron-exciting light is focused on the crystal and the energy, or frequency, of the light is gradually increased. At a certain energy the crystal begins to fall, indicating that it has lost some negative charge. This loss is caused by the emission of electrons, and the energy level at which the emission occurs is termed the photoelectric threshold of the substance.



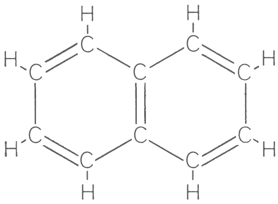
PHOTOGRAPH made through the telescope of the apparatus depicted above shows a crystal of anthracene suspended between the two charged plates. The crystals are typically about five ten-thousandths of a centimeter in diameter, or about the size of red blood corpuscles. The plates are a centimeter apart. A pile of fallen crystals is visible at bottom.



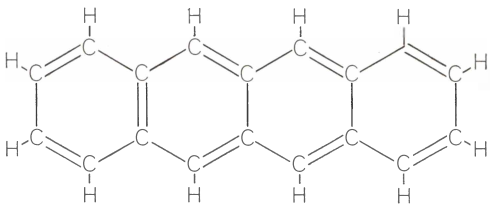
BENZENE



ANTHRACENE

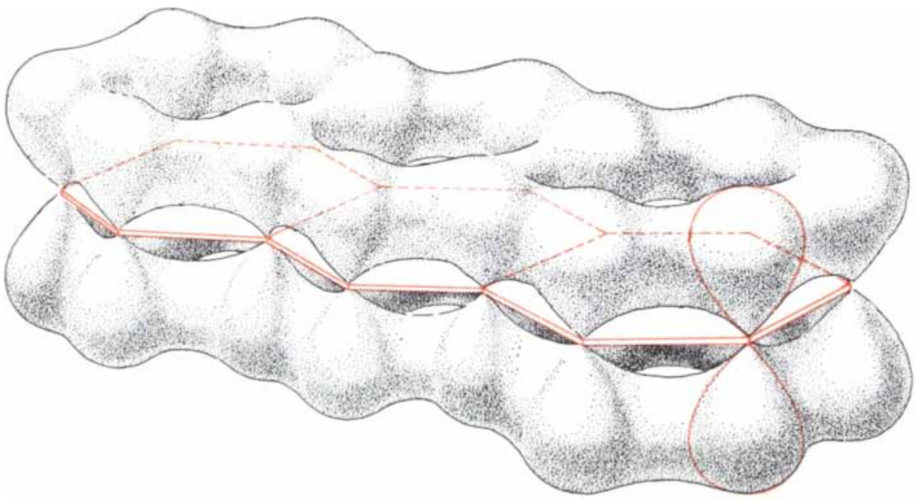


NAPHTHALENE



TETRACENE

MOLECULAR DIAGRAMS of four conjugated aromatic hydrocarbons show clearly why the more complex members of this family can be regarded as derivatives of benzene. The term "conjugated" refers to the regular alternation of single and double chemical bonds in the molecules. Each single bond represents a pair of electrons; each double bond, two pairs.



DISTRIBUTION OF ELECTRONS in a molecule of anthracene consists in part of delocalized "pi" electrons that spend most of their time in cloudlike regions above and below the central plane of the molecule. In the aromatic compounds only the pi electrons are involved in the conduction of an electric current from one molecule to another.

acting on the electron is almost zero. The first molecule is now positively charged, since it was electrically neutral before losing the electron; the molecule is said to have an electron deficiency—more simply, a "hole." The second molecule is of course negatively charged, since it has gained an extra electron.

In the presence of the electric field the excess electron will naturally move toward the positive electrode. Not so obvious is the fact that an electron on a third molecule adjoining the first can "hop" into the original site, transferring the hole to a site on the third molecule. Because of the electric field the holes move predominantly in the direction of the negative electrode. The hole motion gives rise to the same electrical effects that would be produced by a positively charged particle. Thus in the aromatic compounds, as in semiconductors, one can observe conductivity as the result of the motion of either electrons or holes, or of some combination of the two. This contrasts with the situation in metals, where conductivity involves only the motion of electrons.

The generation of charge carriers in anthracene can also be represented graphically in terms of the energy involved [*see bottom part of illustration on page 90*]. This mode of carrier generation is called intrinsic because it is a property of the pure crystal lattice. The energy provided to free the electron from the molecule in the crystal is plotted vertically, and distance into the crystal is plotted horizontally. When an electron has been given enough energy, it is no longer bound to its parent molecule and begins to move toward the positive electrode. The hole that is left behind is also free to move toward the negative electrode. The range of free-electron energies is called the conduction band; it is helpful to think of the conduction band not as a physical entity such as a channel in the crystal but rather as a pathway in energy space. As long as the electron has an energy within the conduction band, it can move from one molecule to another through the crystal lattice.

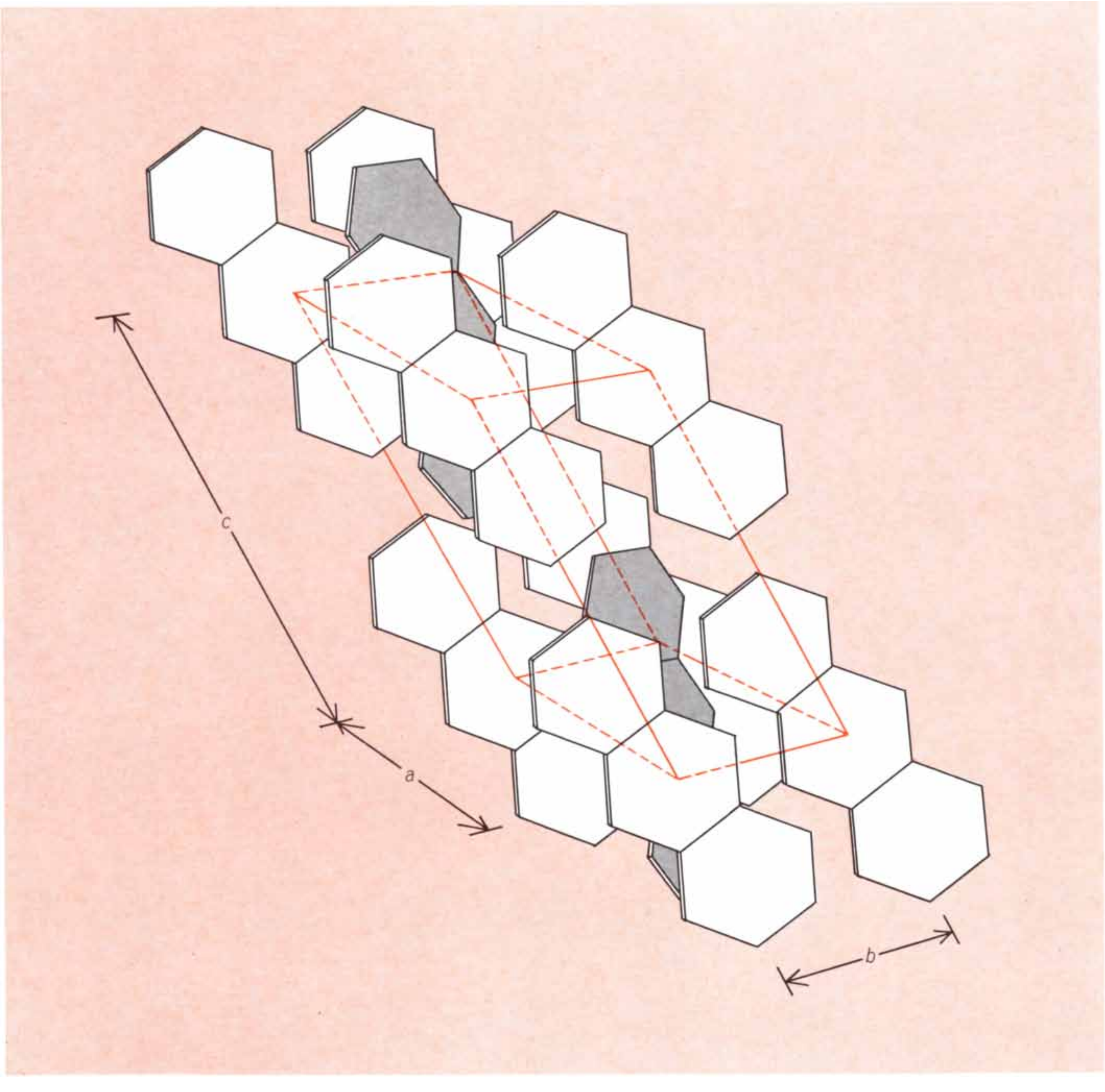
Strange as it may seem, the evaluation of the intrinsic conduction threshold (the bottom edge of the conduction band) for anthracene has resisted the efforts of experimenters for more than 10 years. The main difficulty is the large energy required for intrinsic conduction to occur. In germanium (a semiconductor) the intrinsic conduction threshold is about .8 electron volt (eV), whereas in anthracene (an insulator) it is more than 3 eV. This means that whereas at room temperature in metals there is about one free electron per atom and in semiconductors about one free electron in 10^{12} atoms, in a good insulator there is only about one free electron in 10^{25} molecules.

The conduction band for an aromatic compound is narrow compared with that of a semiconductor. The narrow band indicates that it is comparatively difficult for a free electron to move through an anthracene crystal; in other words, such an electron has a lower mobility than a free electron in, say, germanium. This lower mobility is a consequence of the fact that the clouds of pi electrons in anthracene are almost entirely restricted to individual molecules, and only a small portion of the cloud extends across the space between one molecule and its neighbor to link the individual clouds. In general the ease with which a free electron travels from one molecule to another in a substance depends on the extent to which the pi-electron clouds are linked.

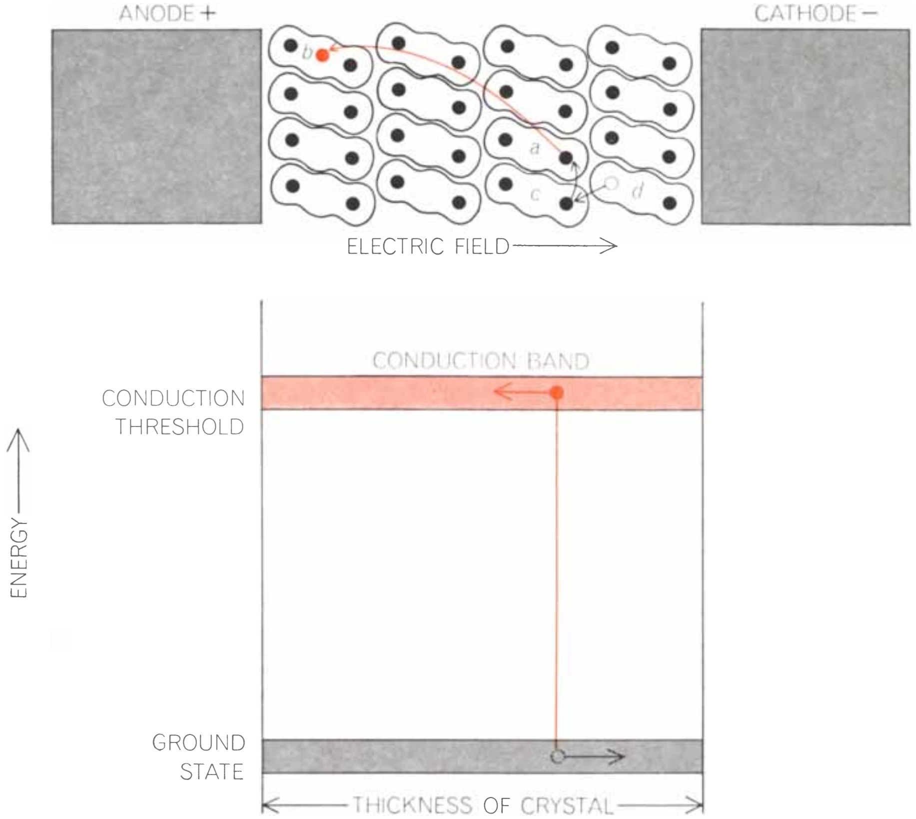
Intrinsic ionization is seldom encountered in insulators at room temperature in the absence of light. More often the production of carriers inside the insulator is caused by the electrodes themselves. It is well known that a glowing metal filament can emit electrons. Such a filament provides the free electrons in the vacuum tubes that were the mainstay of the electronics industry up to the time of the introduction of the transistor. To obtain appreciable electric current the filament must be heated to a high temperature so that the electrons can literally boil away into the vacuum. The ability of the electrons to leave the metal does not disappear as the temperature is lowered, but the rate decreases enormously. When one places a metal electrode in contact with an insulator at room temperature, it certainly is not easy for an electron to leave the metal and enter the insulator, but it is much less difficult for the electron to leave the metal under these circumstances than if there were no contact at all.

The reason for this is that the electron does not have to jump all the way from the ground level of the electrode to the energy level of the vacuum but merely has to jump part of the way—into the conduction band of the insulator [*see illustration on page 91*]. The number of electrons that can perform this feat is small, but in an insulator the normal density of free electrons in the conduction band is so low that even this inefficient mechanism can dominate the charge-carrier generation process. Such electrode effects have been an important factor in preventing the use of conventional techniques for the evaluation of energy levels in insulators. Not only can electrons jump from the electrode into the insulator if their initial energy is close to the conduction band of the insulator, but also it is possible for an electron to jump from the insulator into the electrode if the electrode's ground state is close to the insulator's ground state. The former process is called electron injection; the latter, hole injection.

With special electrodes, such as an



CRYSTAL STRUCTURE OF ANTHRACENE consists of a repeating pattern of unit cells, one of which is shown here. Each unit cell is monoclinic, that is, two of the axes (*a*, *b*) are at right angles to each other, but the third axis (*c*) is at an angle other than a right angle to the other two. In the author's experiments thickness of a crystal is measured in the direction perpendicular to the *ab* plane.



SCHEMATIC MODEL of a crystal of anthracene placed between two metal electrodes (*top*) is helpful in considering how charge carriers are generated in an organic crystal. The black dots represent the two electrons in each unexcited molecule that have the highest energy. An electron has been ejected from molecule *a* and has landed on molecule *b*. Another electron can now jump from molecule *c* to the original site, or "hole," in *a*, transferring the hole to *c*. The same process is repeated for an electron going from *d* to *c*. The motion of the hole toward the negative electrode produces the same electrical effects that would be produced by a positively charged particle. The graph at bottom shows the process in terms of the energy involved. The original electron is shown going from the ground state to the conduction band, where it is free to move toward the positive electrode. One of the author's principal aims was to determine the intrinsic conduction threshold for anthracene.

electrolytic solution containing a strong oxidizing agent, the ground state of the electrode is so low that it becomes easy for an electron in the ground state of the insulator to jump into the electrode, freeing a hole that can carry a current. In this way currents that are more than a million times stronger than the normal "dark" current can be produced in anthracene. Workers at the National Research Council in Canada have prepared nonaqueous electrolytic electrodes in which the ground state of the electrode is very close to the conduction band of the insulator, and they have been able to inject comparatively large electron currents into anthracene. By simultaneously using a hole-injecting electrode at the opposite end of the insulator, they have brought about the recombination of the electrons and the holes inside the crystal, producing a faint blue light.

Before going any further in the discussion of charge-generation mechanisms, I should like to introduce a conceptual entity known as the exciton. Imagine a ray of light striking an anthracene molecule inside the crystal. If the energy of the light is high enough (in the ultraviolet region of the electromagnetic spectrum or higher), an electron will be excited to one of the upper energy levels of the molecule, specifically to the first excited "singlet" state 3.15 eV above the ground level [*see illustration on page 92*]. The vacancy in the ground level of the molecule left by the excited electron can be regarded as a hole. On the average the electron will remain in the excited state for a hundred-millionth of a second before recombining with the hole in the ground state. It has been found that during this interval the excitation (a hole-electron pair) can be transferred as a unit, somewhat like a hot potato, from one molecule to its neighbor (in some cases to more distant molecules in the crystal); as many as 10,000 transfers can take place before the excitation disappears. This excitation, or hole-electron pair on the same molecule, is called a singlet exciton, and it diffuses through the crystal like a particle, with the exception that it represents a transfer of energy, not matter.

In the course of its diffusion the exciton can strike the inner surface of the crystal. This is made even more likely by the fact that the exciting light is so highly absorbed that practically all the excitons are created very close to the illuminated surface. When the exciton strikes the surface, several things can happen. If there is an electrode at the surface, the exciton can react with the electrode [*see top illustration on page 93*]. This reaction consists of a dissociation of the exciton, in which the electron leaves the crystal to enter the electrode and the hole in the molecule diffuses away from the surface under the influence of the external electric field. Charge-carrier generation that is effected by light is called photoconductivity; in the case of anthracene and many other substances, both organic and inorganic, the exciton plays an important role in this process.

The exciton can create charge carriers even if no electrode is in contact with the crystal. When an exciton strikes an impurity such as oxygen at the surface of the crystal, the electron is taken up by the oxygen molecule and the hole is once more free to move [*see bottom illustration on page 93*]. Another example of carrier generation does not involve the surface of the crystal; in this process two excitons chance on the same molecule at the same time and annihilate each other [*see illustration on page 94*]. The energy given off is the sum of the energies of the two excitons, and it is so large that the molecule at the site of the collision is ionized, the electron going off in one direction and the hole in the other.

The ability of the exciton to produce charge carriers was originally attributed to the existence of a conductivity level that was lower than the exciton energy level. In view of the variety of ways in which the exciton can produce charge carriers, either by utilizing the additional potential energy of an electrode or an impurity or by the mutual annihilation of two excitons, this hypothesis could not be justified.

Because both the dark-conductivity and the photoconductivity measurements in substances such as anthracene are so sensitive to the electrode and to impurities, and because of the peculiarities of carrier generation when excitons are involved, the values of the threshold for conductivity derived from these studies were held to be inconclusive.

From our point of view it was important to look for a method of measurement that avoided electrode contacts altogether.

One important energy level to know is the one at which an electron will leave the crystal entirely, if it happens to be traveling in the direction of the surface (external ionization). This energy is certain to be larger than the one required to produce an electron and a hole inside the solid (internal ionization) and therefore sets an upper limit to the conduction threshold. To obtain this information, and at the same time to avoid the use of electrodes, we resurrected the technique used by Millikan more than 50 years ago to determine the charge of the electron. Millikan began by producing a mist of oil droplets between two charged metal plates; he next created ions in the air between the plates by means of X rays. The oil droplets picked up the charged ions on a random basis, and Millikan then measured the charge on the droplets. He found that it was always a multiple of a fundamental unit of charge, and he identified this unit as the charge of the electron.

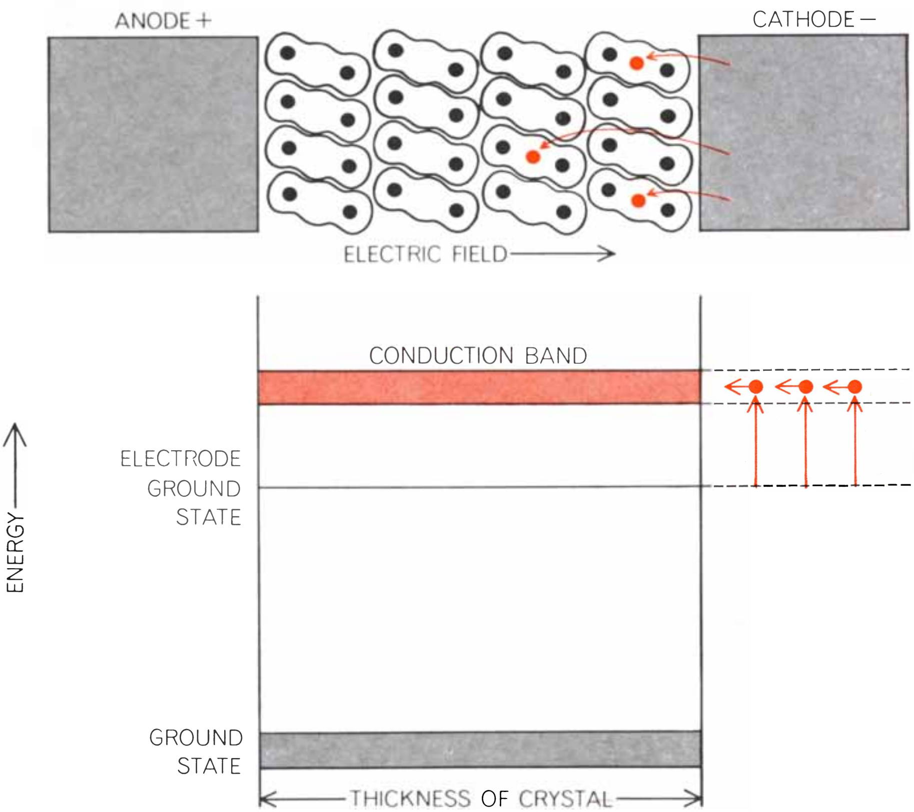
In our variation of Millikan's experiment we introduced negatively charged organic crystals between the charged plates in an atmosphere of argon [*see top illustration on page* 87]. By adjusting the voltage between the plates we could suspend the particle in space by compensating for the downward force of gravity by the upward force of the electric field. The crystals were about five ten-thousandths of a centimeter in diameter, or about the size of red blood corpuscles. On the average each crystal had about 200 excess electrons at the start of the experiment. The crystals pick up an excess negative (or positive) charge in rubbing against each other as they are tapped through the hole in the top plate of the Millikan apparatus.

We then directed the electron-exciting light at the particle, gradually increasing the energy of the light until we observed that the particle had begun to fall. This meant that the electric field was no longer capable of supporting the particle, which in turn indicated a decrease in negative charge on the particle. In other words, the light had begun to knock electrons from the surface of the crystal, and the energy of the light that was just capable of doing this was the threshold of the crystal's ionization. (It should be borne in mind that the energy of light is determined only by its wavelength, or color, and not by its intensity, or brightness.) The sensitivity of this technique is such that we could easily measure the emission of as few as 10 electrons per minute, which is a current of 10^{-20} ampere. No other known electronic instrument can accurately measure a current of this size.

There is an aspect of the experiment that bears on the way in which we understand unfamiliar physical phenomena. In the usual kind of experiment the stimulus is given and the response is noted. The response is often detected by an electronic device that translates it into an electrical signal, which must then be interpreted. In a sense one looks at the footprint left by the phenomenon and not at the phenomenon itself. A different situation prevails in our ionization experiment. The sight of the tiny starlike crystal suddenly dropping in response to a change in the color of the light brings directly to the mind of the observer a vision of molecules being struck hammer blows by quanta of light and of electrons shooting out of the crystal into space. One has a strong feeling here that one genuinely understands the process.

Our next experiment involved testing a hypothesis that had been put forward to explain one type of photoconductivity in anthracene. This theory stated that the conduction threshold of anthracene is really quite high and that the normal singlet exciton does not have sufficient energy to ionize a molecule. It went on to state that if any ionization is observed, it must be produced by the collision of two normal excitons; in that case the energy of two excitons would be available on one molecule to produce ionization. Collisions between excitons are possible because of the ability of the exciton to move about like a particle during its lifetime. Some experimental support had been given the theory by traditional techniques of measuring photoconductivity. We reasoned that since the energy of two normal excitons in anthracene is larger than the ionization energy of the crystal, it should be possible to observe the emission of electrons from the surface of a crystal that had been subjected to light with an energy just a little higher than the first excited singlet state.

Since the lifetime of a normal singlet exciton is about 10^{-8} second, one cannot expect to find a high concentration of singlet excitons at any one place and time. In fact, in our experiments the concentration of excitons is about the same as would be obtained by putting a tea-



ELECTRODES can generate more charge carriers than the anthracene crystal does if the difference between the ground state of the free electrons in the electrode and either the conduction band of the crystal or the ground state of the crystal is less than the difference in energy between the conduction band of the crystal and the ground state of the crystal.

spoonful of sugar in a million gallons of water.

Because the exciton moves rapidly, however, it can visit some 10,000 molecules before it disappears. We did find that electrons were ejected from the surface of the crystal when we used an intense beam of low-energy light. Furthermore, we found that the rate of emission of electrons varied as the square of the light intensity, instead of the usual first power. This meant that two quanta of light were somehow cooperating in the ejection of the same electron. The observation of exciton-exciton annihilation to produce external electron emission was one of the first of its kind ever made and distinctly the first in any organic crystal.

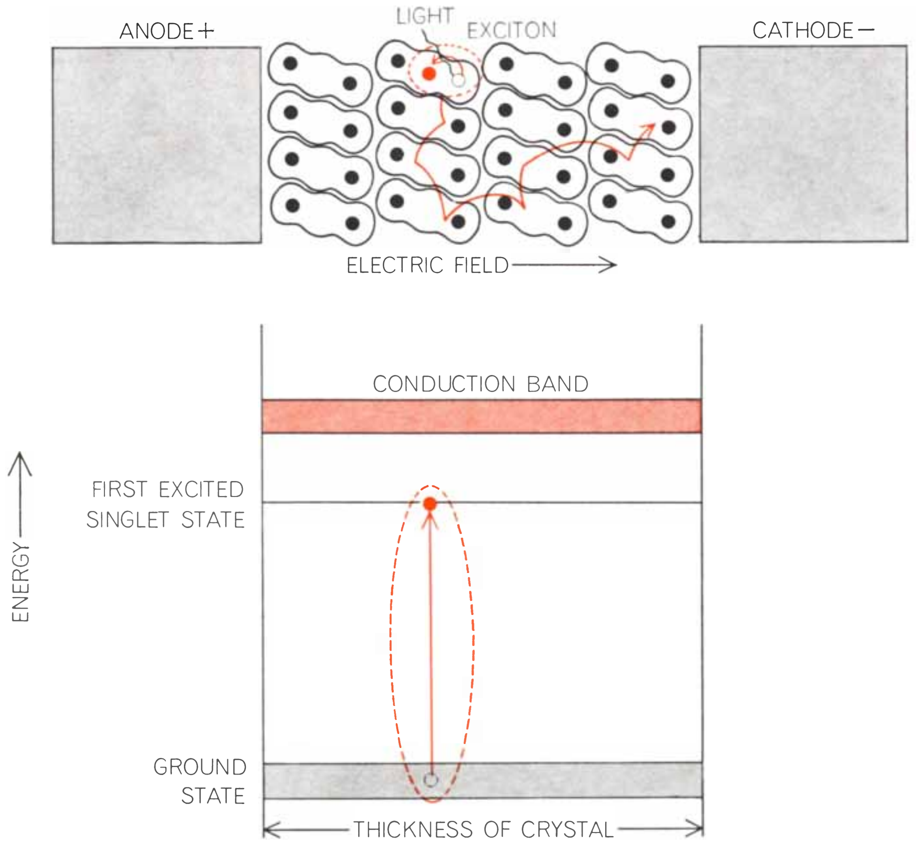
The next step was to determine how two absorbed quanta could eject one electron. This was done by using Einstein's photoelectric equation, which states that the energy of the incoming light (E) equals the photoelectric-emission threshold for the substance (I_c) plus the kinetic energy of the emitted electron ($K.E.$). In symbols, $E = I_c + K.E.$ In other words, if a light quantum with an energy higher than the photoelectric threshold is absorbed by a molecule in the solid, then an electron in the molecule can not only be moved to a region outside the crystal but also will be given additional kinetic energy, or energy of motion.

The maximum kinetic energy the electron possesses is the difference between the energy of the incoming light and the energy required to remove the electron to a point just outside the surface of the crystal. The kinetic energy of an electron can be measured by arranging for the electron to move in a region that can be subjected to an electric field. Thus by forcing the electron to run into an opposing electric field, it can be made to stop and reverse its path. The voltage required to barely prevent the electron from leaving the surface of the crystal is called the stopping potential, and it measures the maximum kinetic energy of the electron.

In our technique we do not use an externally applied electric field; we use the field generated by the particle itself as follows: Instead of choosing a negatively charged crystal for study, we choose a positively charged crystal. This is done by making the top plate of the Millikan apparatus negative; we can then suspend a positive particle for study. By shining energetic light on this particle, we can cause the ejection of electrons. In the experiment described earlier we caused the emission of electrons from a negatively charged crystal and the crystal was never allowed to acquire a net positive charge. There is an important difference in this experiment. With the emission of each electron the tiny crystal becomes more and more positively charged. This means that it is more difficult to remove each additional electron, and that eventually, if we continue to use light of constant energy, the emission of electrons will cease.

At this point the crystal has become positively charged to such an extent that any electron that leaves the interior of the crystal will be returned to the crystal as soon as it crosses the outer surface [*see illustration at left on page 95*]. The excess positive charge on the crystal generates a stopping potential at the surface that is equal to the maximum kinetic energy that an emitted electron could have. In other words, if light quanta are absorbed in a material, and the energy of the quanta is not known but the photoelectric threshold of the material is known, then by measuring the maximum positive charge the light can produce in the crystal we can get the maximum kinetic energy of the emitted electrons. The sum of this energy and the photoelectric threshold for anthracene equals the energy of the incoming light that is being utilized by the crystal for the electron-ejection process.

Where the energy of the light quantum is sufficient to directly ionize the molecule in the crystal, the energy delivered to the ejected electron is the same as the energy of the light quantum (as long as the energy of the quantum is not too much higher than the photoelectric threshold). Under these conditions Einstein's equation is obeyed. The reason for the equivalence of the energy of the light quantum and the energy delivered to the electron is that the ionization process takes place in a span that is short compared with that of any other energy-degrading process in the crystal. On the other hand, if for any reason an electron can be ejected from the crystal as a result of the cooperative effort of more than one light quantum, one cannot assume that the energy utilized by the crystal is the sum of the energies of the quanta striking the crystal. One must



SINGLET EXCITON is a conceptual entity produced when a photon of light striking an anthracene molecule is energetic enough to excite an electron to one of the upper energy levels of the molecule (in this case to the first excited "singlet" state). In the brief interval before the electron recombines with the "hole" it left in the ground state, the hole-electron pair (the singlet exciton) can travel as a unit through the crystal from one molecule to another. As many as 10,000 such transfers can take place before the exciton disappears.

prove that the energy of the light quantum is not degraded in any way between the time of absorption and the time of utilization.

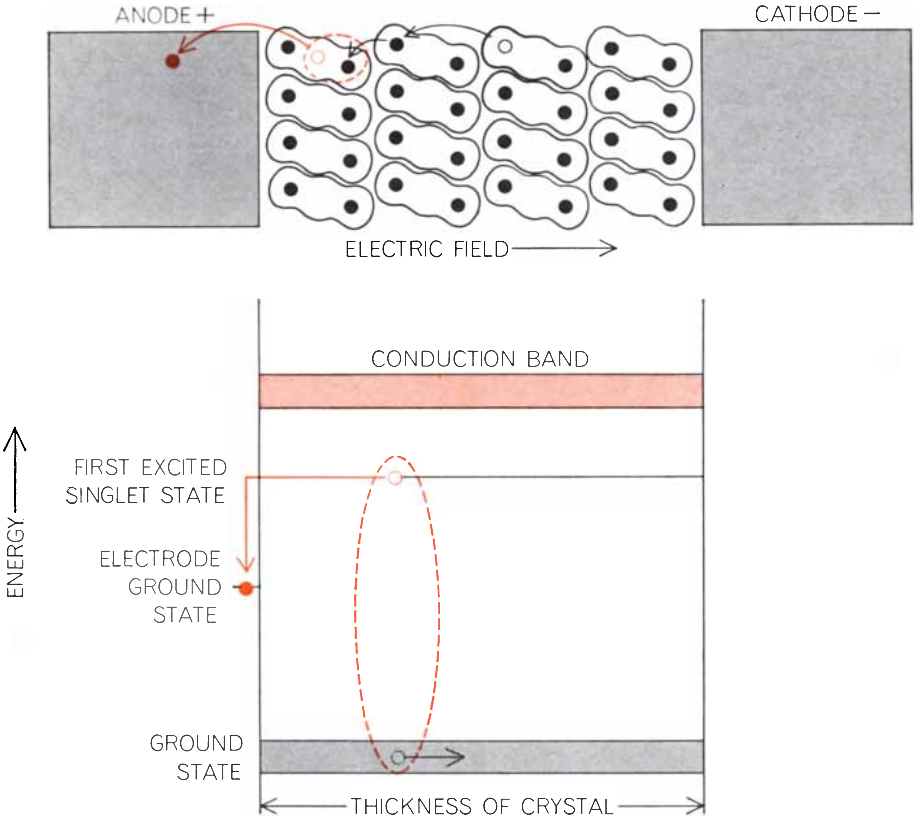
It is, however, quite normal for the energy delivered to the crystal by the light quantum to be degraded, if this energy is less than the ionization energy of the molecule in the crystal. In the case of anthracene there is a mobile singlet exciton that has an energy of 3.15 eV. The crystal can absorb light of energy 3.6 eV, for example, but the mobile exciton that is created still has an energy of only 3.15 eV. The difference of .45 eV is dissipated as heat.

The net result of all these considerations is that if more than one light quantum is involved in the ejection of an electron, special techniques must be used to determine the energies of the states that are actually contributing to the emission process. The determination of the quantity of charge in a crystal, and hence the stopping potential, is fortunately independent of the nature of the exciting process, and it is this fact that enables us to determine the energy utilized by the crystal from the absorbed light to produce the electron emission.

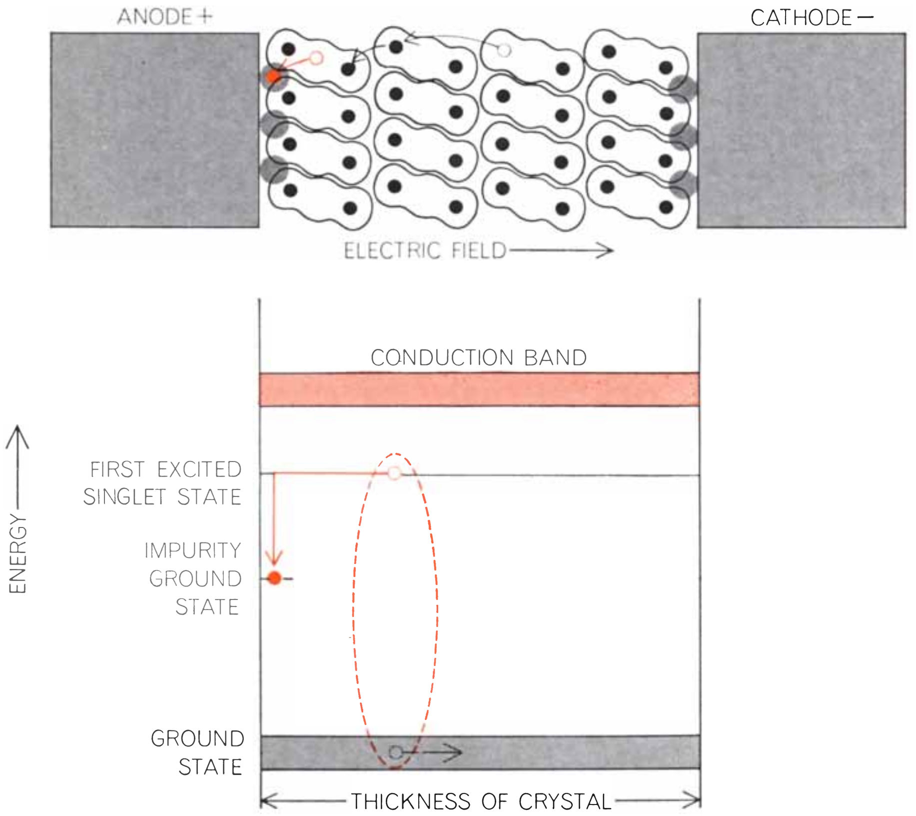
In practice it would be quite difficult to measure the stopping potential of the particle, because the shape as well as the excess positive charge of the particle is important, and the crystals do not have a regular geometric shape. It is quite easy to circumvent this difficulty, however, by making all measurements on the same particle. In this way only the charge on the particle is important, and that is much easier to determine.

It can be shown that Einstein's photoelectric equation can be rewritten to state that the energy of the incoming light is equal to the photoelectric threshold for anthracene plus a reciprocal of the voltage applied to the plates in order to balance the crystal ($1/V$). The graph of this equation is a straight line, and the point at which this line crosses the energy axis gives the value of the photoelectric threshold [*see illustration at right on page* 95].

In order to use this rewritten version of Einstein's equation to determine the photoelectric threshold of anthracene, we suspend a positively charged particle between the plates of the Millikan condenser and then subject it to light of fixed energy (E_1), which causes electron emission. The particle begins to rise (since it becomes more positively charged and is therefore attracted more strongly to the negative upper plate) and



EXCITON CAN CREATE CHARGE CARRIERS in an anthracene crystal by several different mechanisms. In this case the exciton strikes the inside surface of the crystal where the crystal is in contact with the anode. The exciton ejects its excited electron into the anode, leaving behind the positive hole, which can move through the crystal toward the cathode.



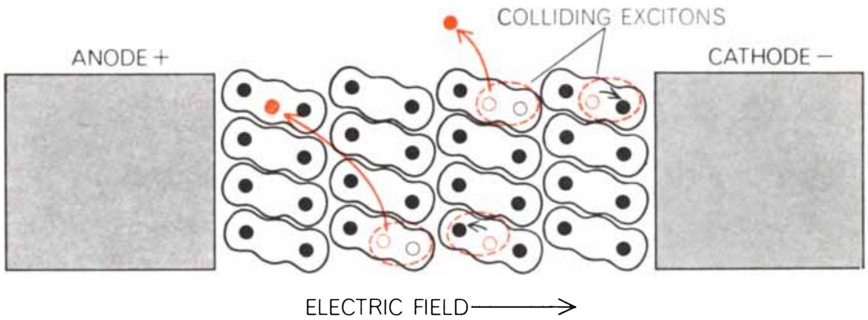
ANOTHER MECHANISM by which an exciton can generate charge carriers in anthracene comes into play when the crystal is separated from the electrodes by a layer of some impurity such as oxygen. When the exciton strikes the inside surface of the crystal, it gives up its electron to a molecule of oxygen, again freeing the hole to travel toward the cathode.

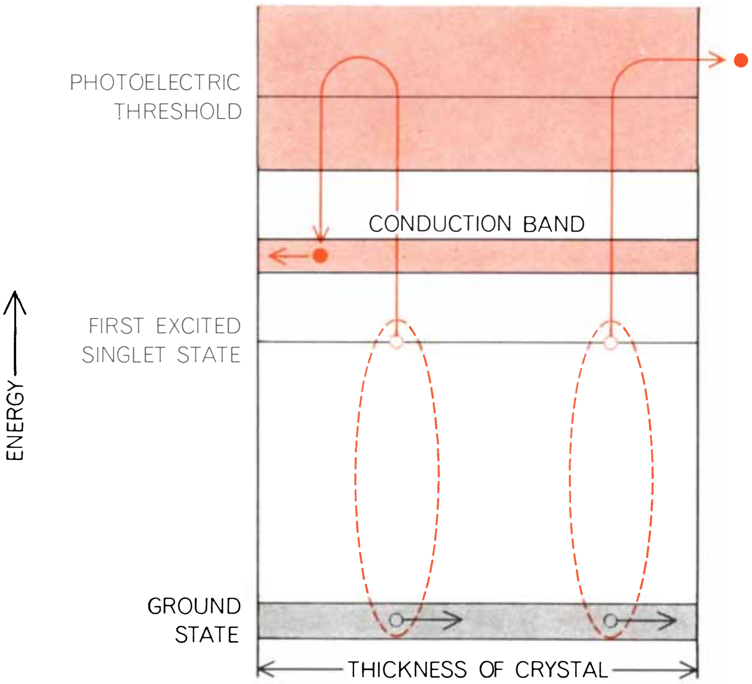
the voltage on the plates is accordingly decreased by the experimenter so that the particle remains in the field of view of the telescope. Eventually the particle ceases to move; at this point the balancing voltage (V_1) is measured. The wavelength of the light is then decreased, increasing the energy of the light to E_2. Electron emission starts afresh and the balancing operation is repeated, resulting in a new balancing potential (V_2). The entire procedure can be repeated and the information plotted on a graph. The result is a straight line that crosses the energy axis at the same point as the photoelectric threshold.

In the preceding experiment the light was high-energy light and each absorbed light quantum was capable of directly ejecting an electron. We now turn to the problem of measuring the energy liberated in the process that takes place inside the crystal when two light quanta cooperate in ejecting one electron. Our strategy is to sandwich the double-quantum process between two single-quantum processes. In this way we should be able to interpolate to obtain the information we want. We start once more with a positively charged crystal and expose it to low-intensity, high-energy light, whereupon electrons are ejected from the particle until the remaining positive charge becomes large enough to prevent electrons from leaving. This positive charge is measured by the balancing voltage on the plates of the Millikan apparatus. We then expose the particle to *high*-intensity, *low*-energy light. Electron emission is observed to resume, caused now by a double-quantum process, and continues until the increased positive charge on the particle results in the cessation of the electron emission. The new balancing potential is recorded. Here, however, we do not know the corresponding energy, because we do not know beforehand how much of the energy of the incident light has been utilized in the crystal.

The same particle is now exposed once more to low-intensity, high-energy light, and electron emission resumes until a new balance is attained. The process is repeated for a still higher energy, yielding another balancing voltage. The results of the experiment are then plotted on a graph. Since the energies plotted against the reciprocals of the balancing voltages fall on a straight line, the balancing voltage for the high-intensity, low-energy light must have been produced by an amount of absorbed energy equal to that represented by the double-quantum effect.

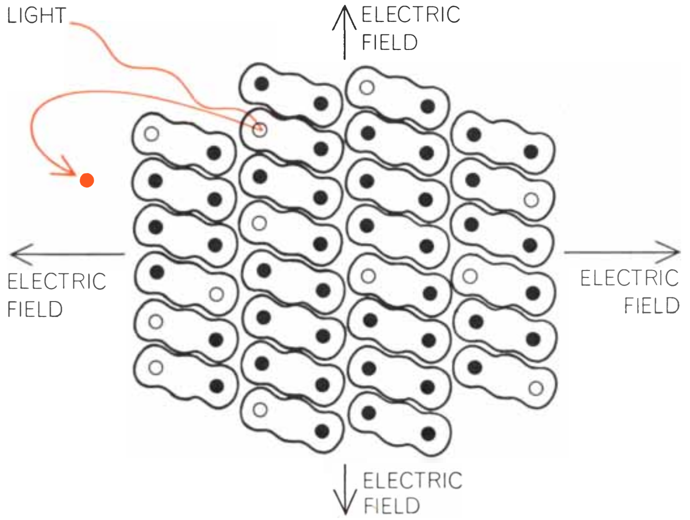
In anthracene, using light with an energy of less than 4 eV, the energy delivered by the double-quantum process is 6.3 eV. It can further be shown that the two units of energy that combine to add to 6.3 eV are equal in magnitude and therefore are 3.15 eV each. This, of course, is the value of the energy of the normal singlet exciton, proving that two singlet excitons have indeed annihilated themselves near the surface, the released energy being delivered to one molecule and causing electron emission. Furthermore, the energy for the double-quantum effect is 6.3 eV regardless of the energy of the incident light as long as the energy of the light is more than 3.15 eV and less than 4 eV, showing that the absorbed energy is always degraded to the same state, namely the singlet exciton.

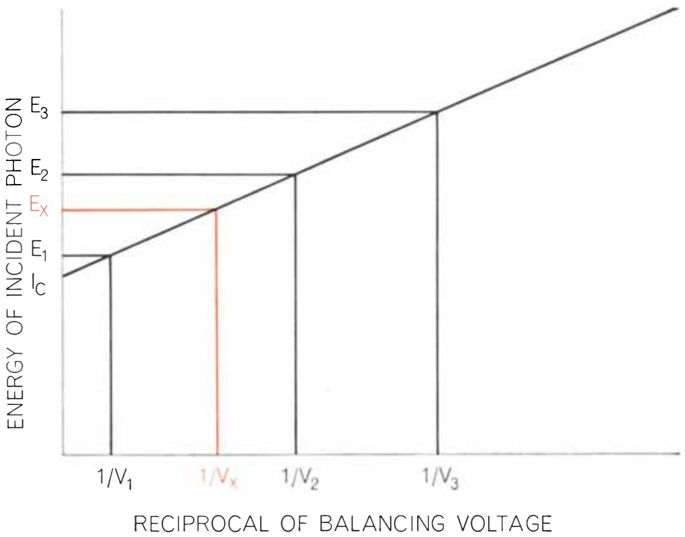




THIRD MECHANISM for generating charge carriers by means of excitons does not involve actual contact with the surface of the crystal. Two excitons can collide and annihilate each other, giving off enough energy to ionize the molecule at the site of the collision. If the collision takes place far inside the crystal (*left*), the electron will rise to an energy level high above the conduction band of the crystal before falling back into the conduction band, where it can begin to move toward the anode; this process is called internal ionization. If the collision takes place close to the surface of the crystal (*right*), the electron will leave the crystal entirely; this process is called external ionization. In both cases the holes remaining in the ground state of the molecules are free to move in the direction of the cathode.

The same experiment was repeated for tetracene, and as before electron emission caused by a double-quantum process was observed. This might have been expected, except for one detail. The energy of two singlet excitons in the tetracene crystal add up to a total of 4.8 eV, whereas electron emission requires 5.25 eV; thus two singlet excitons cannot produce electron emission by themselves. In other words, the electron emission must have been caused by a different double-quantum process.





POSITIVELY CHARGED CRYSTAL can be suspended in space by making the top plate of the Millikan apparatus negative. By shining energetic light at the particle one can cause the ejection of electrons, making the crystal more and more positively charged. Eventually any electron that leaves the interior of the crystal will be returned to the crystal as soon as it crosses the outer surface. The stopping potential of the crystal is then equal to the maximum kinetic energy (energy of motion) of the emitted electron.

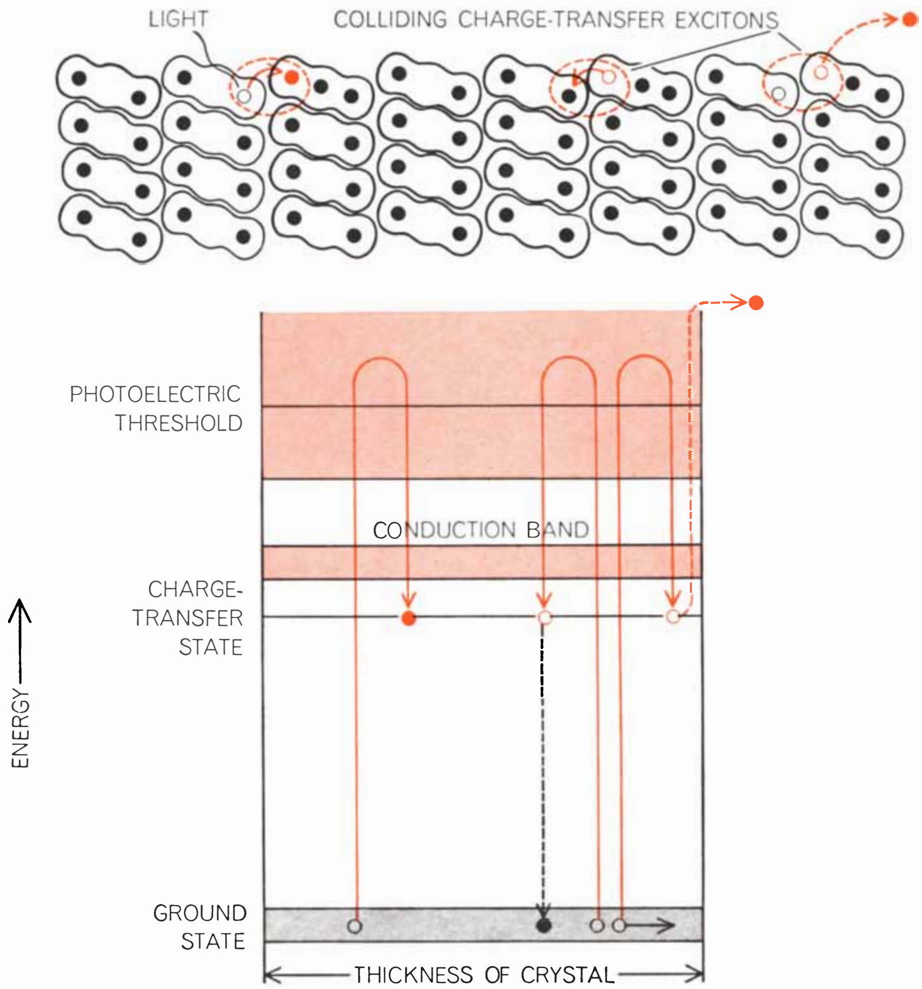
GRAPH illustrates Einstein's photoelectric equation, which can be rewritten to state that the energy of the incoming light is equal to the photoelectric threshold for anthracene plus a constant multiple of the reciprocal of the voltage that must be applied to the plates in order to balance the crystal against gravity. (This voltage is related to the stopping potential of the crystal.) The graph of this equation is a straight line, and the point at which it crosses the energy axis gives the value of photoelectric threshold for anthracene.

With the same techniques it was shown that the two excitons that were annihilated each had an energy of 2.9 eV. This was a strange value, and an examination of the optical absorption spectrum of tetracene, which shows the degree to which the tetracene crystal absorbs light of different energies, showed no peculiarities at this energy value. Furthermore, it was found that it was almost impossible to cause electron emission in tetracene by using incident light with an energy of 2.9 eV. This was not the case with anthracene, in which it was just as easy to cause electron emission at 3.15 eV as at 4 eV as long as the number of quanta absorbed was the same. The difficulty in causing electron ejection in tetracene by a double-quantum process persisted until light with an energy of 3.5 eV was used; at this energy, and above it up to 4.9 eV, electrons emerged from the illuminated tetracene crystal all with the same kinetic energy.

We interpreted this result as follows: The 2.9 eV state in tetracene represents a different type of exciton, called a charge-transfer exciton, never before observed in organic crystals. In this exciton the electron and hole are not on the same molecule but on different molecules. In our work these oppositely charged molecules are adjacent to each other, although larger separations are possible. The lifetime of this hole-electron pair is not yet known, although it is probably longer than the lifetime of the singlet exciton. During its lifetime the charge-transfer exciton too can move about, probably more slowly than the singlet exciton; it represents a less neutral electrical entity than the singlet exciton and therefore encounters more resistance to its motion through the crystal. The annihilation of two charge-transfer excitons near the surface of the crystal liberates the energy that causes electron emission [*see top illustration on next page*].

The following explanation was put forward for the fact that the charge-transfer exciton at 2.9 eV could not be efficiently generated unless light of at least 3.5 eV was used. In tetracene the normal singlet exciton, in which the hole and the electron are on the same molecule, has an energy of 2.4 eV. This energy is too low to form the charge-transfer exciton at 2.9 eV. There is an excited singlet exciton at 2.9 eV, but its lifetime is very short compared with that of the 2.4 eV state. The lifetime of the excited singlet exciton is so short that the crystal does not have time to make the necessary adjustments in its structure to accept the charge-transfer exciton before the excited singlet exciton has decayed to the 2.4 eV level. Therefore the efficiency of generating the charge-transfer exciton with light of energy 2.9 eV is poor. On the other hand, it is known that some internal ionization processes are extremely rapid, so that a molecule inside the crystal, once excited to its ionization energy, dissociates into a separated hole and electron with comparatively high efficiency. Here both electron and hole remain inside the crystal. Holes and electrons that are produced in the small crystals in our apparatus have nowhere to go because there are no electrodes in contact with the crystal. The holes and electrons have only one choice: they must eventually recombine. The free holes and electrons are drawn to each other by their electrostatic fields; at one point in their travels before they annihilate themselves they find themselves on neighboring molecules, forming a charge-transfer exciton. In other words, the energy 3.5 eV is the *internal* ionization energy of the tetracene molecule in the tetracene crystal.

The fact that an energy of 3.5 eV was enough to cause internal ionization does not necessarily mean that this is the least energy required to produce a separated hole and electron. The latter energy is what we have called the conduction threshold. Moreover, since the charge-transfer state represents a hole and an electron on neighboring molecules, and the normal ionized state represents a hole and an electron on widely separated molecules, clearly more energy is required for normal ionization than for the creation of a charge-transfer exciton. Therefore we know that the conduction threshold is higher than the



CHARGE-TRANSFER EXCITON, in which the electron and hole are on different (in this case adjacent) molecules, can be produced when light strikes a molecule in the ground state and excites an electron to an energy level above the conduction band (*left*). In the absence of an electric field the electron will fall back toward the ground state, but it will stop at the charge-transfer level for a short time. During this interval the electron and hole are bound together by their electrical attraction and move through the crystal as a pair. Two such charge-transfer excitons can collide and annihilate each other, adding their energies to promote an electron to a level high enough to send it completely out of the crystal (*right*).

IONIZED STATES	ENERGY LEVELS (ELECTRON VOLTS) ANTHRACENE	TETRACENE
IONIZATION ENERGY OF MOLECULE IN GAS PHASE	7.5	6.9
IONIZATION ENERGY OF MOLECULE IN SOLID PHASE	5.65*	5.25*
CONDUCTION THRESHOLD (UPPER BAND)	4.1*	3.5**
CONDUCTION THRESHOLD (LOWER BAND)	3.7**	3.1**
CHARGE-TRANSFER EXCITON	3.45**	2.9**
SINGLET EXCITON	3.15*	2.4
TRIPLET EXCITON	1.8	1.4

ENERGY LEVELS for anthracene and tetracene are given in this table. Single asterisks refer to values that have been measured by the author's technique and also by other methods. Double asterisks refer to values that were identified by the author and his colleagues.

charge-transfer exciton energy. In tetracene, if our conclusions are correct, the latter energy is 2.9 eV. If we go no further than to say that in tetracene the conduction threshold is higher than 2.9 eV, this already represents a bold statement, since the value is much higher than any that had been previously measured or anticipated. As a result of other considerations, such as measurements of electrical conductivity as a function of wavelength, we have been drawn to the conclusion that the conduction threshold for tetracene is roughly 3.1 eV. The energy 3.5 eV, in our opinion, represents an upper conductivity state that is normally not used by charge carriers in the presence of small electric fields.

Having found the charge-transfer exciton in tetracene, we returned to anthracene; the existence of the charge-transfer exciton should be a general phenomenon, if it is true at all. We had previously found that as long as the energy of the incident light was more than 3.15 eV and less than 4 eV, an electron was emitted from the anthracene crystal by a double-quantum process that provided 6.3 eV of energy to a molecule in the crystal. By raising the energy of the incident light we found that at energies from 4.1 eV to 4.9 eV the electron was emitted by a double-quantum process that provided 6.9 eV to the crystal. In other words, regardless of the incident photon energy in the region from 4.1 to 4.9 eV, only 6.9 eV was utilized to eject an electron. We were again able to show that the energy states involved were of equal magnitude, namely 3.45 eV. This state was identified as the charge-transfer exciton state for anthracene, and the threshold energy 4.1 eV was associated with that of an upper conductivity level. As in tetracene, since the conduction threshold is higher than the charge-transfer state, the conduction threshold is higher than 3.45 eV, a higher minimum value than had been measured by conventional conductivity techniques. Our calculation at present is that the conduction threshold for anthracene is roughly 3.7 eV. The complete energy-level scheme for anthracene and tetracene is given in the bottom illustration at the left.

The energy levels for these two aromatic crystals probably represent the most complete set of ionized-state energies determined for any organic insulator. One can see at a glance what the minimum energy requirements are for intrinsic dark conductivity. It happens that in anthracene and tetracene, and probably in many other organic crystals, this energy is much larger than the ones that have been measured by conventional conductivity techniques, indicating that earlier conductivity measurements have been confounded by impurity or electrode effects. One can conclude out of hand that any steady-state photoconductivity observed below 2.9 eV in tetracene or below 3.45 eV in anthracene must involve either a surface effect, an electrode effect or exciton-exciton annihilation.

I mentioned earlier the connection between our work with aromatic crystals and the study of energy levels in chlorophyll. We recently observed electron-emission caused by double-exciton annihilation in crystals of chlorophyll *a*, a form of chlorophyll present in all higher plants. The implication of this observation is either that the ionization energy of chlorophyll *a* is much lower than anyone has measured or that there is a charge-transfer-exciton state in chlorophyll *a* with an energy higher than the 1.8 eV excited singlet state. The discovery of a comparatively long-lived, mobile energy state above the singlet state in chlorophyll would have great biological significance. We are in the process of determining whether such a state exists in chlorophyll *a*.

Our work is also relevant to a recent report by workers at the Bell Telephone Laboratories announcing the observation in crystals of silicon of what they called "excitonic molecules." These would correspond to comparatively stable, mobile pairs of charge-transfer excitons. We have also observed such pairs in anthracene and have described them as "exciton dimers." We believe they may play a role in prolonging the emission of light from organic scintillators, commonly used as high-energy radiation detectors. The exciton dimer, or excitonic molecule, should be much more stable and easier to study in organic crystals than in inorganic ones.

Finally, it should be mentioned that holes and electrons are ideal chemical reagents, since they are oxidants and reductants without mass. Some workers have been tempted to explain chemical oxidation and reduction inside living tissue at relatively distant sites from each other by the migration of these charges. Tetracene and anthracene may provide the key to unlock the energy-level scheme of those molecules that are of more direct biological interest. By measuring the energy levels of the molecules in the solid state it should be possible to resolve these problems.

CAN TIME GO BACKWARD?

It seems intuitively plausible that it can, but the concept creates a variety of paradoxes. For example, a time-reversed galaxy would be invisible to us because light would flow into it instead of out

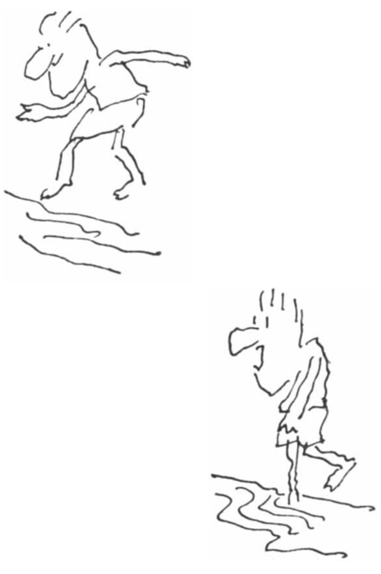
by Martin Gardner

"...time, dark time, secret time, forever flowing like a river...."

—THOMAS WOLFE, *The Web and the Rock*

Time has been described by many metaphors, but none is older or more persistent than the image of time as a river. You cannot step twice in the same river, said Heraclitus, the Greek philosopher who stressed the temporal impermanence of all things, because new waters forever flow around you. You cannot even step into it once, added his pupil Cratylus, because while you step both you and the river are changing into something different. As Ogden Nash put it in his poem "Time Marches On,"

While ladies draw their stockings on,
The ladies they were are up and gone.



RIVER IMAGE appealed to ancient Greek philosophers. You cannot step twice into the same river, said Heraclitus. Indeed, added Cratylus, you cannot do it even once.

In James Joyce's *Finnegans Wake* the great symbol of time is the river Liffey flowing through Dublin, its "hither-and-thithering waters" reaching the sea in the final lines, then returning to "riverrun," the book's first word, to begin again the endless cycle of change.

It is a powerful symbol, but also a confusing one. It is not time that flows but the world. "In what units is the rate of time's flow to be measured?" asked the Australian philosopher J. J. C. Smart. "Seconds per ——?" To say "time moves" is like saying "length extends." As Austin Dobson observed in his poem "The Paradox of Time,"

Time goes, you say? Ah no!
Alas, time stays, we *go.*

Moreover, whereas a fish can swim upriver against the current, we are powerless to move into the past. The changing world seems more like the magic green carpet that carried Ozma across the Deadly Desert (the void of nothingness?), unrolling only at the front, coiling up only at the back, while she journeyed from Oz to Ev, walking always in one direction on the carpet's tiny green region of "now." Why does the magic carpet never roll backward? What is the physical basis for time's strange, undeviating asymmetry?

There has been as little agreement among physicists on this matter as there has been among philosophers. Now, as the result of recent experiments, the confusion is greater than ever. Before 1964 all the fundamental laws of physics, including relativity and quantum laws, were "time-reversible." That is to say, one could substitute $-t$ for t in any basic law and the law would remain as applicable to the world as before; regardless of the sign in front of t the law described something that could occur in nature. Yet there are many events that are possible in theory but that never or almost never actually take place. It was toward those events that physicists turned their attention in the hope of finding an ultimate physical basis for distinguishing the front from the back of "time's arrow."

A star's radiation, for example, travels outward in all directions. The reverse is never observed: radiation coming from all directions and converging on a star with backward-running nuclear reactions that make it an energy sink instead of an energy source. There is nothing in the basic laws to make such a situation impossible in principle; there is only the difficulty of imagining how it could get started. One would have to assume that God or the gods, in some higher continuum, started the waves at the rim of the universe. The emergence of particles from a disintegrating radioactive nucleus and the production of ripples when a stone is dropped into a quiet lake are similar instances of one-way events. They never occur in reverse because of the enormous improbability that "boundary conditions"—conditions at the "rim" of things—would be such as to produce the required kind of converging energy. The reverse of beta decay, for instance, would require that an electron, a proton and an antineutrino be shot from the "rim" with such deadly accuracy of aim that all three particles would strike the same nucleus and create a neutron.

The steady expansion of the entire cosmos is another example. Here again there is no reason why this could not, in principle, go the other way. If the directions of all the receding galaxies were reversed, the red shift would become a blue shift, and the total picture would violate no known physical laws. All these expanding and radiative processes, although always one-way as far as our experience goes, fail to provide a fundamental distinction between the two ends of time's arrow.

It has been suggested by many philosophers, and even by some physicists, that it is only in human consciousness, in the one-way operation of our minds, that a basis for time's arrow can be found. Their arguments have not been convincing. After all, the earth had a long history before any life existed on it, and there is every reason to believe that earthly events were just as unidirectional along the time axis then as they are now. Most physicists came finally to the conclusion that all natural events are time-reversible in principle (this became known technically as "time invariance") except for events involving the statistical behavior of large numbers of interacting objects.

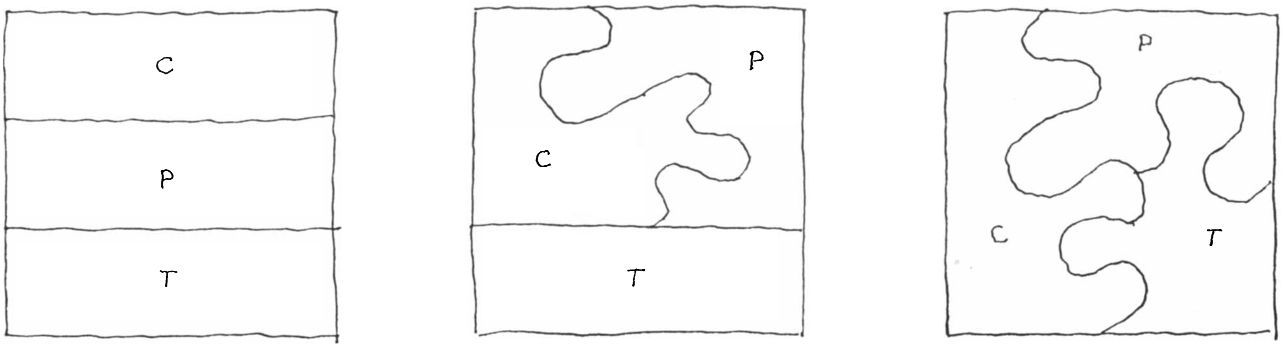
Consider what happens when a cue ball breaks a triangle of 15 balls on a pool table. The balls scatter hither and thither and the 8 ball, say, drops into a side pocket. Suppose immediately after this event the motions of all the entities involved are reversed in direction while keeping the same velocities. At the spot where the 8 ball came to rest the molecules that carried off the heat and shock of impact would all converge on the same spot to create a small explosion that would start the ball back up the incline. Along the way the molecules that carried off the heat of friction would move toward the ball and boost it along its upward path. The other balls would be set in motion in a similar fashion. The 8 ball would be propelled out of the side pocket and the balls would move around the table until they finally converged to form a triangle. There would be no sound of impact because all the molecules that had been involved in the shock waves produced by the initial break of the triangle would be converging on the balls and combining with their momentum in such a way that the impact would freeze the triangle and shoot the cue ball back toward the tip of the cue. A motion picture of any individual molecule in this event would show absolutely nothing unusual. No basic mechanical law would seem to be violated. But when the billions of "hither-and-thithering" molecules involved in the total picture are considered, the probability that they would all move in the way required for the time-reversed event is so low that no one can conceive of its happening.

Because gravity is a one-way force, always attracting and never repelling, it might be supposed that the motions of bodies under the influence of gravity could not be time-reversed without violating basic laws. Such is not the case. Reverse the directions of the planets and they would swing around the sun in the same orbits. What about the collisions of objects drawn together by gravity—the fall of a meteorite, for example? Surely *this* event is not time-reversible. But it is! When a large meteorite strikes the earth, there is an explosion. Billions of molecules scatter hither and thither. Reverse the directions of all those molecules and their impact at one spot would provide just the right amount of energy to send the meteorite back into orbit. No basic laws would be violated, only statistical laws.

It was here, in the laws of probability, that most 19th-century physicists found an ultimate basis for time's arrow. Probability explains such irreversible processes as the mixing of coffee and cream, the breaking of a window by a stone and all the other familiar one-way-only events in which large numbers of molecules are involved. It explains the second law of thermodynamics, which says that heat always moves from hotter to cooler regions, increasing the entropy (a measure of a certain kind of disorder) of the system. It explains why shuffling randomizes a deck of ordered cards.

"Without any mystic appeal to consciousness," declared Sir Arthur Edding-

LIVING BACKWARD in a time-forward world leads to all kinds of difficulties. It is possible, however, to imagine galaxies in which time's arrow is reversed or to consider, at the level of quantum theory, that some particles may move "the wrong way" in time.



THREE SYMMETRIES, charge (*C*), parity (*P*) and time (*T*), are likened to pieces that fit into a pattern. Before 1957 they were all assumed to be symmetrical; any experiment (the pattern) involving the three could be duplicated with any one piece, any two or all three reversed (*left*). Then experiments were found that violate *P*-symmetry, suggesting that if overall (*CPT*) symmetry holds, some piece other than *P* must also be asymmetrical. *C* was found to be such a piece; an experiment remains the same if *C* and *P* are reversed together (*middle*). In 1964 experiments that violate this *CP*-symmetry were reported. It follows that *T* must be asymmetrical in these cases, since a pattern violating *CP*-symmetry can be duplicated only by reversing all three pieces simultaneously (*right*).

ton (in a lecture in which he first introduced the phrase "time's arrow"), "it is possible to find a direction of time.... Let us draw an arrow arbitrarily. If as we follow the arrow we find more and more of the random element in the state of the world, then the arrow is pointing towards the future; if the random element decreases the arrow points towards the past. That is the only distinction known to physics."

Eddington knew, of course, that there are radiative processes, such as beta decay and the light from suns, that never go the other way, but he did not consider them sufficiently fundamental to provide a basis for time's direction. Given the initial and boundary conditions necessary for starting the reverse of a radiative process, the reverse event is certain to take place. Begin with a deck of disordered cards, however, and the probability is never high that a random shuffle will separate them into spades, hearts, clubs and diamonds. Events involving shuffling processes seem to be irreversible in a stronger sense than radiative events. That is why Eddington and other physicists and philosophers argued that statistical laws provide the most fundamental way to define the direction of time.

It now appears that there is a basis for time's arrow that is even more fundamental than statistical laws. In 1964 a group of Princeton University physicists discovered that certain weak interactions of particles are apparently not time-reversible [see "Violations of Symmetry in Physics," by Eugene P. Wigner; Scientific American, December, 1965]. One says "apparently" because the evidence is both indirect and controversial. Although it is possible to run certain particle interactions backward to make a direct test of time symmetry, such experiments have not as yet shown any violations of time-reversibility. The Princeton tests were of an indirect kind. They imply, if certain premises are granted, that time symmetry is violated.

The most important premise is known as the *CPT* theorem. *C* stands for electric charge (plus or minus), *P* for parity (left or right mirror images) and *T* for time (forward or backward). Until a decade ago physicists believed each of these three basic symmetries held throughout nature. If you reversed the charges on the particles in a stone, so that plus charges became minus and minus charges became plus, you would still have a stone. To be sure, the stone would be made of antimatter, but there is no reason why antimatter cannot exist. An antistone on the earth would instantly explode (matter and antimatter annihilate each other when they come in contact), but physicists could imagine a galaxy of antimatter that would behave exactly like our own galaxy; indeed, it could be in all respects exactly like our own except for its *C* (charge) reversal.

The same universal symmetry was believed to hold with respect to *P* (parity). If you reversed the parity of a stone or a galaxy—that is, mirror-reflected its entire structure down to the last wave and particle—the result would be a perfectly normal stone or galaxy. Then in 1957 C. N. Yang and T. D. Lee received the Nobel prize in physics for theoretical work that led to the discovery that parity is *not* conserved [see "The Overthrow of Parity," by Philip Morrison; Scientific American, April, 1957]. There are events on the particle level, involving weak interactions, that cannot occur in mirror-reflected form.

It was an unexpected and disturbing blow, but physicists quickly regained their balance. Experimental evidence was found that if these asymmetrical, parity-violating events were reflected in a special kind of imaginary mirror called the *CP* mirror, symmetry was restored. If in addition to ordinary mirror reflection there is also a charge reversal, the result is something nature can "do." Perhaps there are galaxies of antimatter that are also mirror-reflected matter. In such galaxies, physicists speculated, scientists could duplicate every particle experiment that can be performed here. If we were in communication with scientists in such a *CP*-reversed galaxy, there would be no way to discover whether they were in a world like ours or in one that was *CP*-reflected. (Of course, if we went there and our spaceship exploded on arrival, we would know we had entered a region of antimatter.)

No sooner had physicists relaxed a bit with this newly restored symmetry than the Princeton physicists found some weak interactions in which *CP* symmetry appears to be violated. In different words, they found some events that, when *CP*-reversed, are (in addition to their *C* and *P* differences) not at all duplicates of each other. It is at this point that time indirectly enters the picture, because the only remaining "magic mirror" by which symmetry can be restored is the combined *CPT* mirror in which all three symmetries—charge, parity and time—are reversed. This *CPT* mirror is not just something physicists want to preserve because they love symmetry. It is built into the foundations of relativity theory in such a way that, if it turned out not to be true, relativity theory would be in serious trouble. There are therefore strong grounds for believing the *CPT* theorem holds. *On the assumption that it does,* a violation of *CP* symmetry would imply that time symmetry is also violated [*see illustration above*]. There are a few ways to preserve the *CP* mirror without combining it with *T*, but none has met with any success. The best way is to suppose there is a "fifth force" (in addition to the four known forces: gravity, the weak-interaction force, electromagnetism and the nuclear force) that is causing the newly discovered anomalies. Experiments have cast strong doubt on the fifth-force hypothesis, however.

Early this year Paolo Franzini and his wife, working with the alternating-gradient synchrotron at the Brookhaven National Laboratory, found even stronger evidence of *CP* violations—this time in events involving electromagnetic reactions. The Franzini work was controverted, however, by a group of physicists at the European Organization for Nuclear Research (CERN) in Geneva, who announced their results in September. At the moment the cause of this discrepancy in results is not clear.

Although the evidence is still indirect and in part controversial, many physicists are now convinced that there are events at the particle level that go in only one time direction. If this holds throughout the universe, there is now a way to tell, while communicating with scientists in a distant galaxy, whether they are in a world of matter or of antimatter. We simply ask them to perform one of the *CP*-violating experiments. If their description of such a test coincides exactly with our own description of the same test when done here, we shall not explode when we visit them. It may well be that the universe contains no galaxies of antimatter. But physicists like to balance things, and if there is as much antimatter as there is matter in the universe, there may be regions of the cosmos in which all three symmetries are reversed. Events in our world that are lopsided with respect to *CPT* would all go the other way in a *CPT*-reversed galaxy. Its matter would be mirror-reflected, reversed in charge and moving backward in time.

What does it mean to say that events in a galaxy are moving backward in time? At this point no one really knows. The new experiments indicate that there is a preferred time direction for certain particle interactions. Does this arrow have any connection with other time arrows such as those that are defined by radiative processes, entropy laws and the psychological time of living organisms? Do all these arrows have to point the same way or can they vary independently in their directions?

Before the recent discoveries of the violation of *T* invariance the most popular way to give an operational meaning to "backward time" was by imagining a world in which shuffling processes went backward, from disorder to order. Ludwig Boltzmann, the 19th-century Austrian physicist who was one of the founders of statistical thermodynamics, realized that after the molecules of a gas in a closed, isolated container have reached a state of thermal equilibrium—that is, are moving in complete disorder with maximum entropy—there will always be little pockets forming here and there where entropy is momentarily decreasing. These would be balanced by other regions where entropy is increasing; the overall entropy remains relatively stable, with only minor up-and-down fluctuations.

Boltzmann imagined a cosmos of vast size, perhaps infinite in space and time, the overall entropy of which is at a maximum but which contains pockets where for the moment entropy is decreasing. (A "pocket" could include billions of galaxies and the "moment" could be billions of years.) Perhaps our fly-speck portion of the infinite sea of space-time is one in which such a fluctuation has occurred. At some time in the past, perhaps at the time of the "big bang," entropy happened to decrease; now it is increasing. In the eternal and infinite flux a bit of order happened to put in its appearance; now that order is disappearing again, and so our arrow of time runs in the familiar direction of increasing entropy. Are there other regions of space-time, Boltzmann asked, in which the arrow of entropy points the other way? If so, would it be correct to say that time in such a region was moving backward, or should one simply say that entropy was decreasing as the region continued to move forward in time?

It seems evident today that one cannot speak of backward time without meaning considerably more than just a reversal of the entropy arrow. One has

TIME IS RELATIONAL, not absolute. Observers in galaxies with opposite time directions each suppose the other to be moving backward in time. The man in *A* sees a diner in *B* eating backward; the diner in *B*, whose time is reversed, sees the man in *A* eating backward.

SHUFFLING ordinarily randomizes a pack of cards; it would be surprising to find it working the other way. Statistical laws therefore provide a way to define the direction of time.

to include all the other one-way processes with which we are familiar, such as the radiative processes and the newly discovered *CP*-violating interactions. In a world that was completely time-reversed *all* these processes would go the other way. Now, however, we must guard against an amusing verbal trap. If we imagine a cosmos running backward while we stand off somewhere in space to observe the scene, then we must be observing the cosmos moving backward in a direction opposite to our own psychological time, which still runs forward. What does it mean to say that the *entire* cosmos, including all possible observers, is running backward?

In the first book of Plato's *Statesman* a stranger explains to Socrates his theory that the world goes through vast oscillating cycles of time. At the end of each cycle time stops, reverses and then goes the other way. This is how the stranger describes one of the backward cycles:

"The life of all animals first came to a standstill, and the mortal nature ceased to be or look older, and was then reversed and grew young and delicate; the white locks of the aged darkened again, and the cheeks of the bearded man became smooth, and recovered their former bloom; the bodies of youths in their prime grew softer and smaller, continually by day and night returning and becoming assimilated to the nature of a newly born child in mind as well as body; in the succeeding stage they wasted away and wholly disappeared."

Plato's stranger is obviously caught in the trap. If things come to a standstill in time and "then" reverse, what does the word "then" mean? It has meaning only if we assume a more fundamental kind of time that continues to move forward, altogether independent of how things in the universe move. Relative to this meta-time—the time of the hypothetical observer who has slipped unnoticed into the picture—the cosmos is indeed running backward. But if there *is* no meta-time—no observer who can stand outside the entire cosmos and watch it reverse—it is hard to understand what sense can be given to the statement that the cosmos "stops" and "then" starts moving backward.

There is less difficulty—indeed, no logical difficulty at all—in imagining two portions of the universe, say two galaxies, in which time goes one way in one galaxy and the opposite way in the other. The philosopher Hans Reichenbach, in his book *The Direction of Time,* suggests that this could be the case, and that intelligent beings in each galaxy would regard their own time as "forward" and time in the other galaxy as "backward." The two galaxies would be like two mirror images: each would seem reversed to inhabitants of the other [*see illustration on preceding page*]. From this point of view time is a relational concept like up and down, left and right or big and small. It would be just as meaningless to say that the *entire* cosmos reversed its time direction as it would be to say that it turned upside down or suddenly became its own mirror image. It would be meaningless because there is no absolute or fixed time arrow outside the cosmos by which such a reversal could be measured. It is only when *part* of the cosmos is time-reversed in relation to another part that such a reversal acquires meaning.

Now, however, we come up against a significant difference between mirror reflection and time reversal. It is easy to observe a reversed world—one has only to look into a mirror. But how could an observer in one galaxy "see" another galaxy that was time-reversed? Light, instead of radiating from the other galaxy, would seem to be going toward it. Each galaxy would be totally invisible to the other. Moreover, the memories of observers in the two galaxies would be operating in opposite directions. If you somehow succeeded in communicating something to someone in a time-reversed world, he would promptly forget it because the event would instantly become part of his future rather than of his past. "It's a poor sort of memory that only works backward," said Lewis Carroll's White Queen in one looking-glass, time-reversed (*PT*-reversed!) scene. Unfortunately, outside of Carroll's dream world, memory works only one way. Norbert Wiener, speculating along such lines in his book *Cybernetics,* concluded that no communication would be possible between intelligent beings in regions with opposite time directions.

A British physicist, F. Russell Stannard, pursues similar lines of thought in an article on "Symmetry of the Time Axis" (*Nature,* August 13, 1966) and goes even further than Wiener. He concludes (and not all physicists agree with him) that no interactions of any kind would be possible between particles of matter in two worlds whose time axes pointed in opposite directions. If the universe maintains an overall symmetry with respect to time, matter of opposite time directions would "decouple" and the two worlds would become invisible to each other. The "other" world "would consist of galaxies absorbing their light rather than emitting it, living organisms growing younger, neutrons being created in triple collisions between protons, electrons and antineutrinos, and thereafter being absorbed in nuclei, etc. It would be a universe that was in a state of contraction, and its entropy would be decreasing, and yet the faustian observers ["faustian" is Stannard's term for the "other" region] would not be aware of anything strange in their environment. Being constructed of faustian matter, their subjective experience of time is reversed, so they would be equally convinced that it was they who grew older and their entropy that increased."

Instead of one universe with oscillating time directions, as in the vision of Plato's stranger, Stannard's vision bifurcates the cosmos into side-by-side regions, each unrolling its magic carpet of history simultaneously (whatever "simultaneously" can mean!) but in opposite directions. Of course, there is no reason why the cosmos has to be sym-

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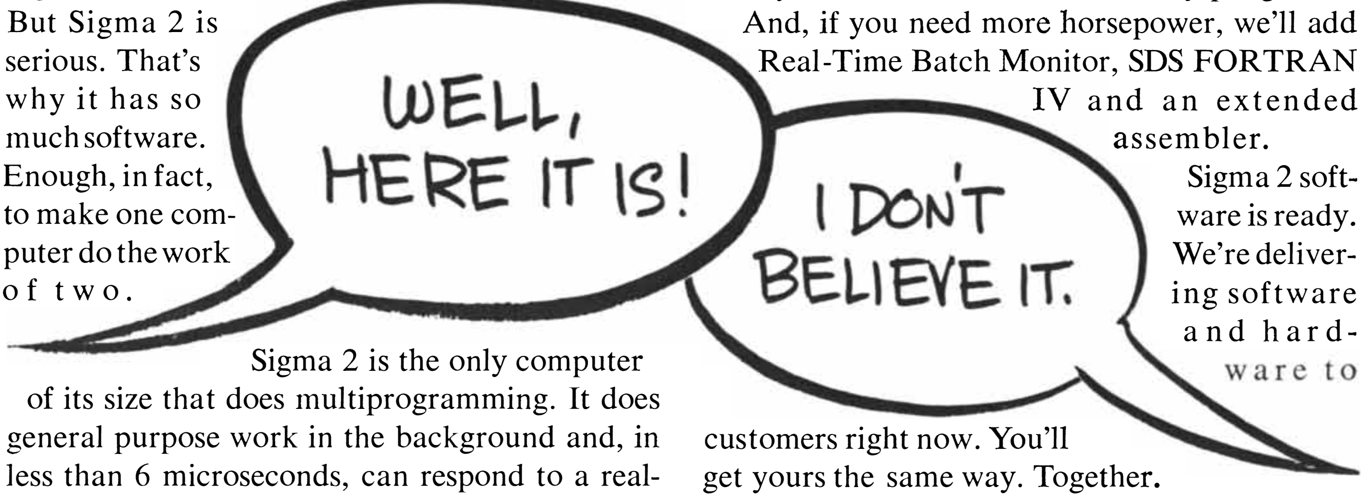

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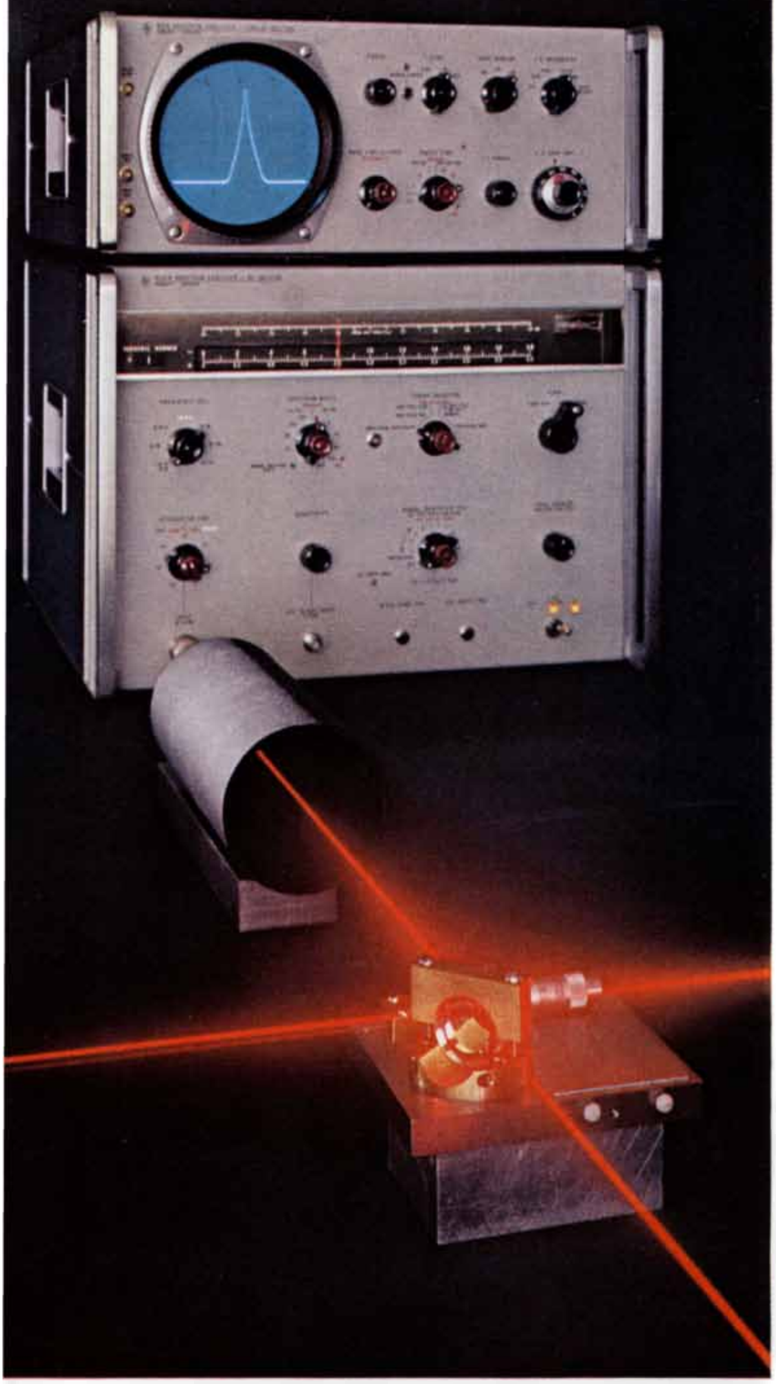

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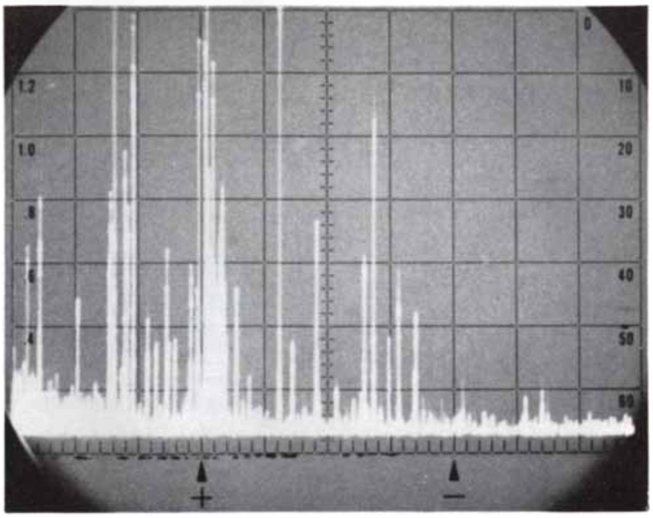


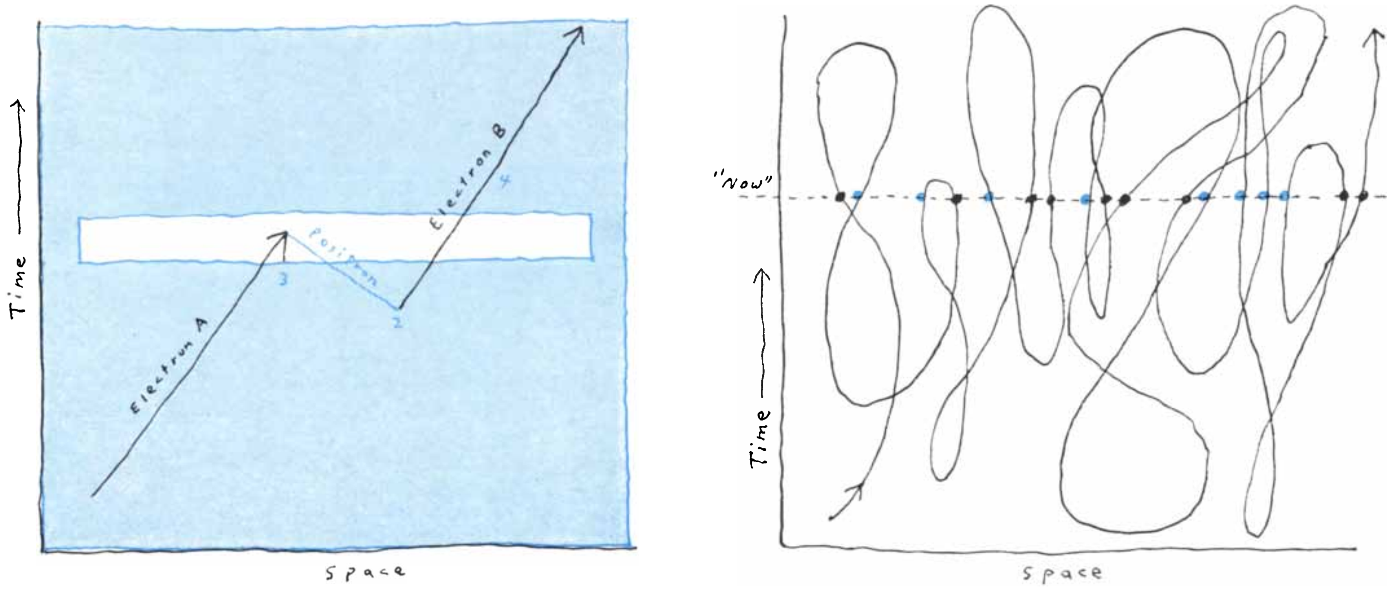
metrical in an overall way just to satisfy the physicist's aesthetic sense of balance. The universe may well be permanently lopsided in regard to all three aspects—charge, parity and time—even if there is no theoretical reason why all three could not go the other way. If a painting does not have to be symmetrical to be beautiful, why should the universe?

Is it possible to imagine a single individual living backward in a time-forward world? Plato's younger contemporary, the Greek historian Theopompus of Chios, wrote about a certain fruit that, when eaten, would start a person growing younger. This, of course, is not quite the same thing as a complete reversal of the person's time. There have been several science-fiction stories about individuals who grew backward in this way, including one amusing tale, "The Curious Case of Benjamin Button," by (of all people) F. Scott Fitzgerald. (It first appeared in *Colliers* in 1922 and is most accessible at the moment in *Pause to Wonder,* an anthology edited by Marjorie Fischer and Rolfe Humphries.) Benjamin is born in 1860, a 70-year-old man with white hair and a long beard. He grows backward at a normal rate, enters kindergarten at 65, goes through school and marries at 50. Thirty years later, at the age of 20, he decides to enter Harvard, and he is graduated in 1914 when he is 16. (I am giving his biological ages.) The Army promotes him to brigadier general because as a biologically older man he had been a lieutenant colonel during the Spanish-American War, but when he shows up at the Army base as a small boy he is packed off for home. He grows younger until he cannot walk or talk. "Then it was all dark," reads Fitzgerald's last sentence, "and his white crib and the dim faces that moved above him, and the warm sweet aroma of the milk, faded out altogether from his mind."

Aside from his backward growth, Mr. Button lives normally in forward-moving time. A better description of a situation in which the time arrows of a person and the world point in opposite directions is found in Carroll's novel *Sylvie and Bruno Concluded.* The German Professor hands the narrator an Outlandish Watch with a "reversal peg" that causes the outside world to run backward for four hours. There is an amusing description of a time-reversed dinner at which "an empty fork is raised to the lips: there it receives a neatly cut piece of mutton, and swiftly conveys it to the plate, where it instantly attaches itself to the mutton already there." The scene is not consistent, however. The order of the dinner-table remarks is backward, but the words occur in a forward time direction.

If we try to imagine an individual whose entire bodily and mental processes are reversed, we run into the worst kind of difficulties. For one thing, he could not pass through his previous life experiences backward, because those experiences are bound up with his external world, and since that world is still moving forward none of his past experiences can be duplicated. Would we see him go into a mad death dance, like an automaton whose motor had been reversed? Would he, from his point of view, find himself still thinking forward in a world that seemed to be going backward? If so, he would be unable to see or hear anything in that world, because all sound and light waves would be moving toward their points of origin.

We seem to encounter nothing but nonsense when we try to apply different time arrows to an individual and the world. Is it perhaps possible, on the microlevel of quantum theory, to speak sensibly about part of the universe moving the wrong way in time? It is. In 1948 Richard P. Feynman, who shared the 1965 Nobel prize in physics, developed a mathematical approach to quantum theory in which an antiparticle is regarded as a particle moving backward in time for a fraction of a microsecond. When there is pair-creation of an electron and its antiparticle the positron (a positively charged electron), the positron is extremely short-lived. It immediately collides with another electron,



FEYNMAN GRAPH, shown at the left in a simplified form devised by Banesh Hoffman of Queens College, shows how an antiparticle can be considered a particle moving backward in time. The graph is viewed through a horizontal slot in a sheet of cardboard (*color*) that is moved slowly up across the graph. Looking through the slot, one sees events as they appear in our forward-looking "now." Electron *A* moves to the right (*1*), an electron-positron pair is created (*2*), the positron and electron *A* are mutually annihilated (*3*) and electron *B* continues on to the right (*4*). From a timeless point of view (without the slotted cardboard), however, it can be seen that there is only one particle: an electron that goes forward in time, backward and then forward again. Richard P. Feynman's approach stemmed from a whimsical suggestion by John A. Wheeler of Princeton University: a single particle, tracing a "world line" through space and time (*right*), could create all the world's electrons (*black dots*) and positrons (*colored dots*).

***CP*-REVERSED GALAXY** (where charge is reversed and matter mirror-reflected) would be indistinguishable as such from the earth. But explorers from the earth would soon find out.

both are annihilated and off goes a gamma ray. Three separate particles—one positron and two electrons—seem to be involved. In Feynman's theory there is only *one* particle, the electron [*see illustration on opposite page*]. What we observe as a positron is simply the electron moving momentarily back in time. Because our time, in which we observe the event, runs uniformly forward, we see the time-reversed electron as a positron. We think the positron vanishes when it hits another electron, but this is just the original electron resuming its forward time direction. The electron executes a tiny zigzag dance in space-time, hopping into the past just long enough for us to see its path in a bubble chamber and interpret it as a path made by a positron moving forward in time.

Feynman got his basic idea when he was a graduate student at Princeton, from a telephone conversation with his physics professor John A. Wheeler. In his Nobel-prize acceptance speech Feynman told the story this way:

"Feynman," said Wheeler, "I know why all electrons have the same charge and the same mass."

"Why?" asked Feynman.

"Because," said Wheeler, "they are all the *same* electron!"

Wheeler went on to explain on the telephone the stupendous vision that had come to him. In relativity theory physicists use what are called Minkowski graphs for showing the movements of objects through space-time. The path of an object on such a graph is called its "world line." Wheeler imagined one electron, weaving back and forth in space-time, tracing out a single world line. The world line would form an incredible knot, like a monstrous ball of tangled twine with billions on billions of crossings, the "string" filling the entire cosmos in one blinding, timeless instant. If we take a cross section through cosmic space-time, cutting at right angles to the time axis, we get a picture of three-space at one instant of time. This three-dimensional cross section moves forward along the time axis, and it is on this moving section of "now" that the events of the world execute their dance. On this cross section the world line of the electron, the incredible knot, would be broken up into billions on billions of dancing points, each corresponding to a spot where the electron knot was cut. If the cross section cuts the world line at a spot where the particle is moving forward in time, the spot is an electron. If it cuts the world line at a spot where the particle is moving backward in time, the spot is a positron. All the electrons and positrons in the cosmos are, in Wheeler's fantastic vision, cross sections of the knotted path of this single particle. Since they are all sections of the same world line, naturally they will all have identical masses and strengths of charge. Their positive and negative charges are no more than indications of the time direction in which the particle at that instant was weaving its way through space-time.

There is an enormous catch to all of this. The number of electrons and positrons in the universe would have to be equal. You can see this by drawing on a sheet of paper a two-dimensional analogue of Wheeler's vision. Simply trace a single line over the page to make a tangled knot [*see illustration on opposite page*]. Draw a straight line through it. The straight line represents a one-dimensional cross section at one instant in time through a two-space world (one space axis and one time axis). At points where the knot crosses the straight line, moving up in the direction of time's arrow, it produces an electron. Where it crosses the line going the opposite way it produces a positron. It is easy to see that the number of electrons and positrons must be equal or have at most a difference of one. That is why, when Wheeler had described his vision, Feynman immediately said:

"But, Professor, there aren't as many positrons as electrons."

"Well," countered Wheeler, "maybe they are hidden in the protons or something."

Wheeler was not proposing a serious theory, but the suggestion that a positron could be interpreted as an electron moving temporarily backward in time caught Feynman's fancy, and he found that the interpretation could be handled mathematically in a way that was entirely consistent with logic and all the laws of quantum theory. It became a cornerstone in his famous "space-time view" of quantum mechanics, which he completed eight years later and for which he shared his Nobel prize. The theory is equivalent to traditional views, but the zigzag dance of Feynman's particles provided a new way of handling certain calculations and greatly simplifying them. Does this mean that the positron is "really" an electron moving backward in time? No, that is only one physical interpretation of the "Feynman graphs"; other interpretations, just as valid, do not speak of time reversals. With the new experiments suggesting a mysterious interlocking of charge, parity

TIME-REVERSED INHABITANTS of a time-reversed world are not aware of anything strange in the environment because their own subjective experience of time is reversed.

and time direction, however, the zigzag dance of Feynman's electron, as it traces its world line through space-time, no longer seems as bizarre a physical interpretation as it once did.

At the moment no one can predict what will finally come of the new evidence that a time arrow may be built into some of the most elementary particle interactions. Physicists are taking more interest than ever before in what philosophers have said about time, thinking harder than ever before about what it means to say time has a "direction" and what connection, if any, this all has with human consciousness and will. Is history like a vast "riverrun" that can be seen by God or the gods from source to mouth, or from an infinite past to an infinite future, in one timeless and eternal glance? Is freedom of will no more than an illusion as the current of existence propels us into a future that in some unknown sense already exists? To vary the metaphor, is history a prerecorded motion picture, projected on the four-dimensional screen of our space-time for the amusement or edification of some unimaginable Audience?

Or is the future, as William James and others have so passionately argued, open and undetermined, not existing in *any* sense until it actually happens? Does the future bring genuine novelty—surprises that even the gods are unable to anticipate? Such questions go far beyond the reach of physics and probe aspects of existence that we are as little capable of comprehending as the fish in the river Liffey are of comprehending the city of Dublin.

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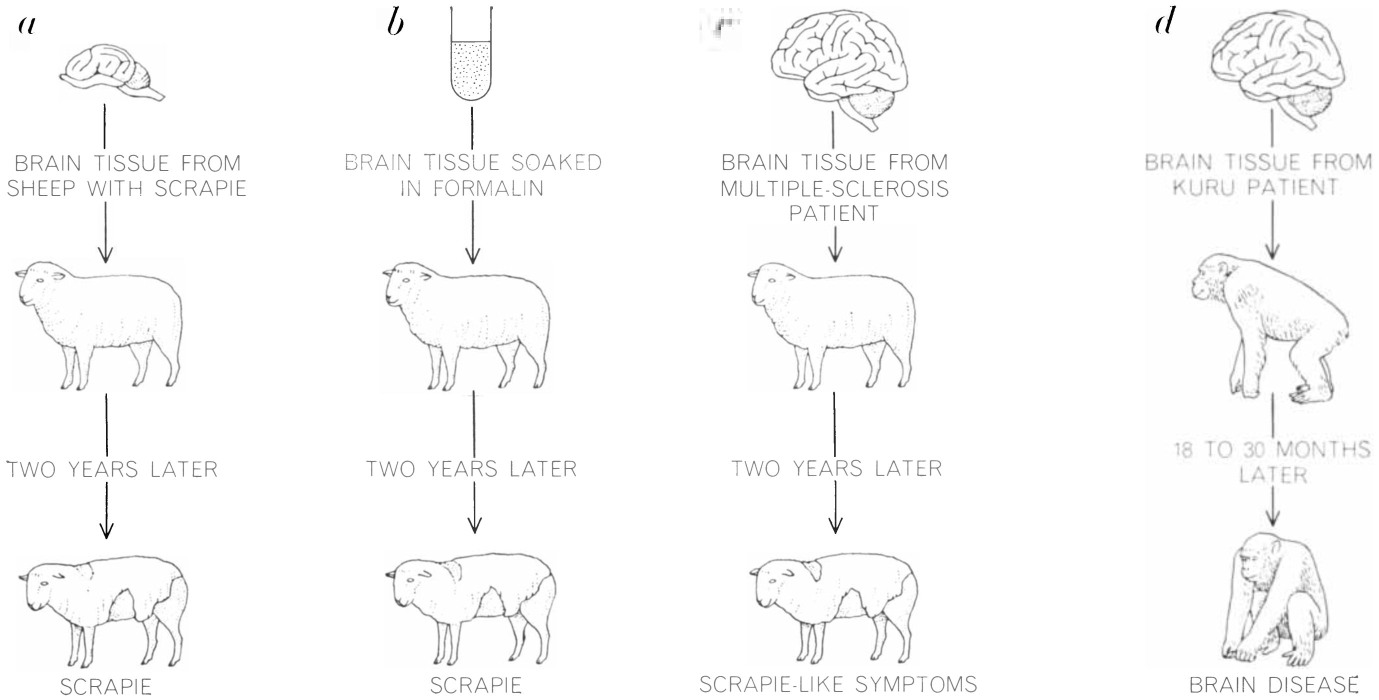
The Kinship of Animal and Human Diseases

Knowledge of human diseases has been greatly advanced by inducing similar diseases in experimental animals. It now appears that there is still much to be learned from animal diseases that occur naturally

by Robert W. Leader

The study of disease in animals has made a profound contribution to the understanding of disease in man. The large majority of such studies, however, have had a distinct limitation. The main tradition of experimental medicine has been to induce in an animal a disorder that resembles a disorder in man (often a disorder that does not occur naturally in the animal); the experimenter is then able to draw useful analogies between the animal disorder and the human one. Far less attention has been paid to animal diseases that occur naturally. A fairly widespread attitude was reflected by a physician to whom I once mentioned that workers in New Zealand had discovered a genetic disease in mice that was similar to lupus erythematosus in man. "The next time a mouse comes to my waiting room," he said, "I'll call on you."

Today it is becoming increasingly clear that there is much to be learned about certain human diseases from the spontaneous diseases of animals. The approach is often termed comparative pathology, and recently it has been stressed by the founding of new departments in many medical schools and medical research institutions. This is not to say that work on natural diseases in animals has not already made important



CERTAIN BRAIN DISEASES of animals and man show similarities, including a long incubation period. Scrapie, a natural disease of sheep, can be transmitted to normal sheep by injection (*a*). The incubation period is two years or more. The agent is remarkably hardy, producing scrapie even after diseased tissue has been soaked for long periods in Formalin, which inactivates most agents of disease (*b*). Sheep injected with tissue from the brain of a human being with multiple sclerosis develop scrapie-like symptoms (*c*). Kuru (*d*) is a brain disease occurring among certain tribesmen in New Guinea; injection of chimpanzees with tissue from the brains of kuru patients usually produces kuru-like symptoms in the chimpanzees after incubation periods ranging from 18 to 30 months.

contributions to our knowledge of diseases in general. An example is the study of the chicken sarcoma, for which Peyton Rous of Rockefeller University has just received a share in the Nobel prize for physiology and medicine.

In 1910 Rous was approached by an amateur chicken breeder who was concerned about a lump on the leg of one of his prized inbred chickens. At that time almost nothing was known about tumors of chickens. Rous became interested, and undertook to find out if the lump could be transmitted. He succeeded in transplanting the tissue to other chickens of the amateur's inbred stock, and identified it as the malignant tumor called a sarcoma.

Rous then wondered if a causative agent could be isolated from the tumor. He discovered not only that there was such an agent but also that it would pass through filters able to hold back the smallest bacteria. Further experiments proved the agent to be a virus. This was a startling discovery in a time when it was believed that cancers were growths that arose without causative factors. Indeed, for many years the Rous sarcoma was regarded as a biological oddity. Then several other virus-caused cancers were found in animals, and today there is active research on the possibility that viruses cause cancers in man. Moreover, Rous's original work generated a wave of activity from which ripples are still being felt in virology, genetics and immunology.

Many other significant results have flowed from the alert observation of animal diseases. The demonstration in 1893 by Theobald Smith and F. L. Kilborne of the U.S. Department of Agriculture that Texas cattle fever was spread by ticks led directly to Walter Reed's work on the transmission of yellow fever by mosquitoes. F. L. Schofield of the Ontario Veterinary College investigated the poisoning of cattle that had eaten spoiled sweet-clover hay; his work led to the isolation from the hay of dicoumarol, an important means of controlling blood clotting. The most familiar examples of all are Edward Jenner's observations on cowpox, which resulted in his vaccine against smallpox; Robert Koch's isolation of the anthrax bacillus from sheep and cattle and his demonstration that the same bacillus causes anthrax in man, and Louis Pasteur's studies of rabid animals, which led to the development of the rabies vaccine.

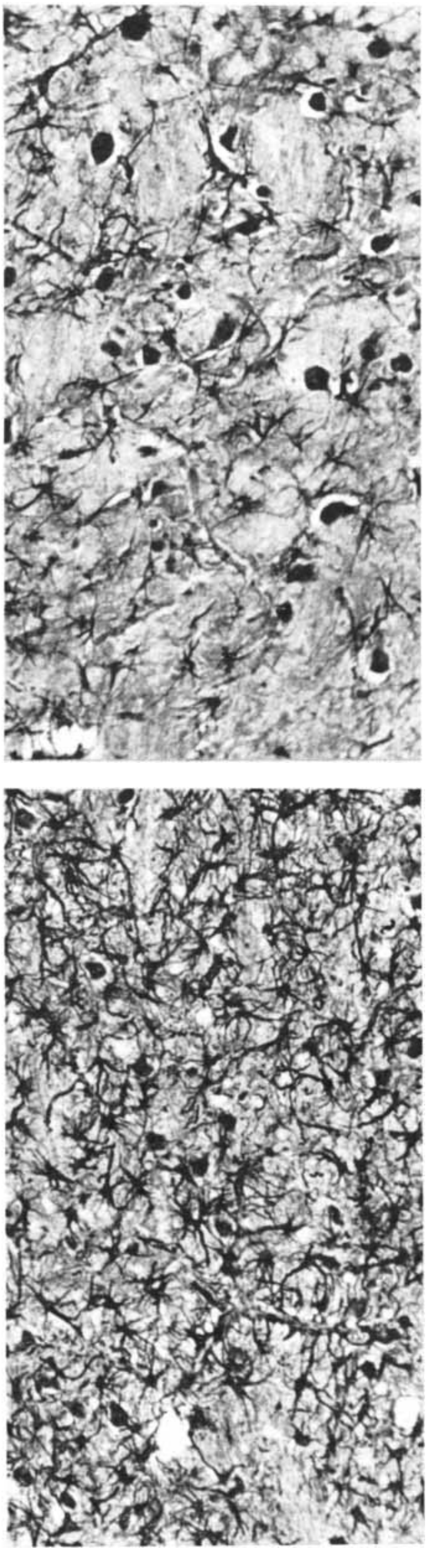
Modern research in comparative pathology involves animals as diverse as the mink and the horseshoe crab, the sheep and the hagfish, the pig and the axolotl (a large salamander). Here it would be best to concentrate on a few lines of investigation and follow them where they lead. As the reader will discover, they often lead quite unexpectedly from one species to another.

One of the most intriguing lines of investigation has to do with the brain. Perhaps the most tragic human brain disease, because of its slow but inexorable course, is multiple sclerosis. The cause of the disease and the nature of the mechanisms that perpetuate it are unknown. Allergies, viruses, bacteria and fungi have all been implicated and investigated without result, and the disease remains a worldwide problem.

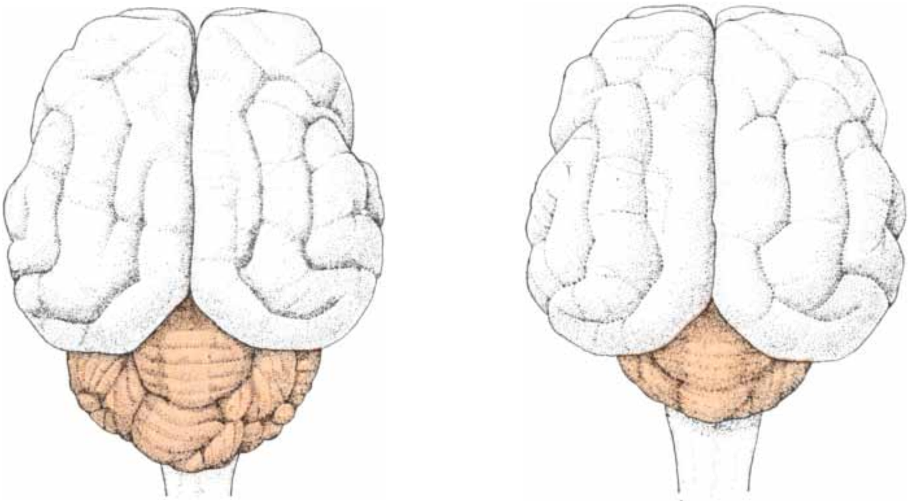
Even though no solution to the problem is imminent, some seemingly unrelated facts throw light on it. For many years veterinarians have known of a disease of sheep called scrapie, so named because intense itching of the skin causes the animals to scrape their wool off by rubbing against fences, gates or any other firm object they can find. The principal lesions of the disease, however, are in the brain, which slowly but relentlessly degenerates.

Groups of investigators in England, Scotland and the U.S. have been working on the disease. They have found that it can be reproduced by inoculating a healthy sheep with material from the brain of an infected sheep. They have also observed a strong hereditary tendency toward scrapie; the Cheviot and Suffolk breeds are extremely susceptible, whereas some other breeds are seldom affected. The genetic predisposition is so apparent that some workers still regard the disease as being purely genetic, although the fact that the agent has been adapted to and transmitted through mice and other laboratory animals would seem to refute that idea. It is also evident that the incubation period of scrapie in sheep can be more than two years. Hence even the keenest observer of sheep under field conditions would find it difficult to connect the disease with a causative factor.

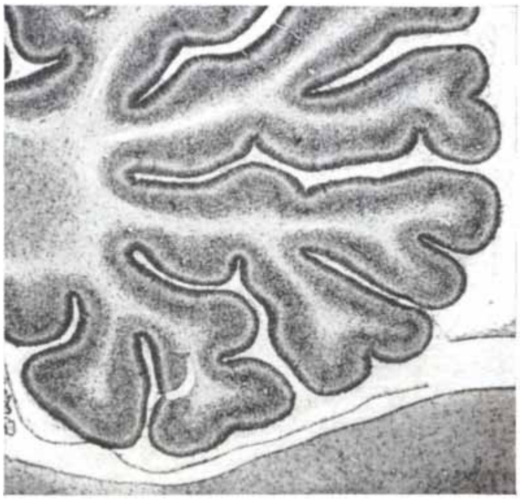
Opposed to the meager store of facts about scrapie are many puzzles, some of which present bewildering inconsistencies. One of the first workers to study the disease, W. S. Gordon of the Institute for Research on Animal Diseases in England, exposed one puzzle while he was engaged in a program to control another disease of sheep called louping ill (after the Scottish word "loup," or "leap," referring to muscular spasms in the animal). The program entailed the inocu-



EFFECT OF SCRAPIE on brain structure is evident in a comparison of these photomicrographs. The upper one shows tissue from the brain of a healthy goat; the lower, tissue from the brain of a goat in which scrapie had been induced experimentally. The diseased tissue shows an abnormal proliferation of glial cells (*black*). The photomicrographs, enlarged 130 diameters, were made by William J. Hadlow of the National Institute of Allergy and Infectious Diseases.



DAMAGED CEREBELLUM is a consequence of a viral disease (cerebellar hypoplasia) that afflicts newborn cats. At left is a normal cat brain; at right, the brain of a cat with the disease. In each case the cerebellum is shown in color. By the time the disease manifests itself in the form of ataxia, or faulty motor coordination, resulting from the damaged cerebellum the virus has disappeared. It is possible that other brain diseases have a similar origin.



FERRET BRAINS show differing results from two experiments. At left is the normal cerebellum of a ferret inoculated both with virus from a cat that had cerebellar hypoplasia and with serum from a cat that had

lation of a vaccine prepared from the brains of sheep afflicted with the disease. The brains had been soaked for several weeks in Formalin (a solution of formaldehyde) at a concentration that would kill most bacteria and many viruses. Three batches of the material were used as vaccines against the disease.

A year later ranchers began to complain that scrapie had appeared in their herds and that it had been caused by Gordon's vaccine. Gordon investigated and found that the scrapie had appeared only in sheep inoculated from one of the three batches of vaccine. That batch contained brain tissue from a herd with a history of scrapie.

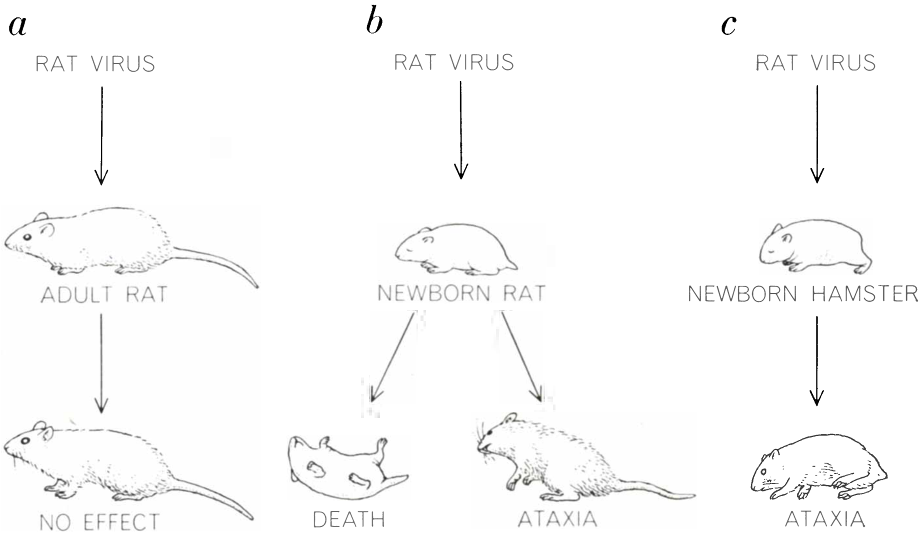
Thus the agent of scrapie was accidentally found to be highly resistant to inactivation by Formalin. Other workers have enlarged on this finding about the hardiness of the scrapie agent. Brains from sheep with the disease have remained infectious after being soaked in 10 percent Formalin for 28 months. Even tissue embedded in paraffin (to cut sections for microscopy) and then stored in the laboratory has yielded infectious material. Furthermore, the agent is extremely resistant to heat: it has survived boiling for as long as three hours.

Let us now turn our attention to the inhabitants of a small area of New Guinea called the Okapa region. For several years a group headed by D. Carleton Gajdusek of the National Institute of Neurological Diseases and Blindness has been studying a peculiar degeneration of the brain that afflicts the Fore tribe and several neighboring groups. The disease, which is invariably fatal, is known as kuru, a Fore word meaning trembling associated with fear or cold.

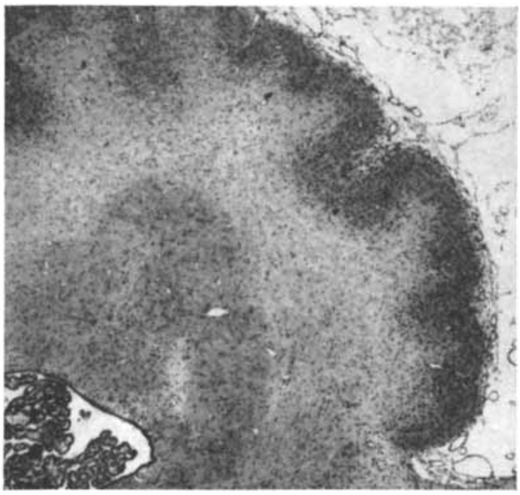
Kuru first appeared in two small villages about 45 years ago and spread slowly. The incidence is appallingly high in the affected population; in some tribes and families kuru is the main cause of death. Several aspects of the disease led Gajdusek and other workers to suspect that an infectious agent was implicated, but they were unable to prove it. For a time their efforts to understand the disease appeared to be blocked.

An unanticipated break came in 1959 from work by William J. Hadlow of the National Institute of Allergy and Infectious Diseases. Hadlow, who is a veterinarian, was in England studying scrapie in sheep. He made the observation that in tissues under the microscope there were many similarities between scrapie and kuru. Gajdusek, Clarence J. Gibbs, Jr., and their colleagues took up the lead. One of their main efforts was to see if a viral agent of kuru could be isolated.

Conventional methods for isolating a virus require the observation of inoculated animals for no more than a few weeks or months. Gajdusek's group, alerted by the knowledge that incubation periods in scrapie can be two years or more, decided to wait at least five years for the results of inoculating animals with material from the brains of New Guinea tribesmen who had died of kuru. For the program of inoculations the group used several species of small animals and some primate species. The



COMPARATIVE PATHOLOGY involving two viruses and several species of animal showed the strong tendency of the viruses to attack rapidly growing cells, such as those



survived the disease. At right is the cerebellum of a ferret inoculated only with virus. Tissues were supplied by Lawrence Kilham and George Margolis of Dartmouth Medical School; enlargement is 225 diameters.

chimpanzee, the primate most closely related to man, was included because of the strong genetic features exhibited by kuru. In Gajdusek's group the prevailing mood was pessimistic; there was little reason to expect anything but negative results.

Indeed, none of the small animals or lesser primates have developed any kuru-like abnormalities. The chimpanzees, however, present a different picture. The brains of eight chimpanzees were inoculated with .2 milliliter of brain tissue taken from seven patients who had died of kuru. In May, 1965, 18 months after the inoculations, one of the eight chimpanzees began to show neurological abnormalities. The trouble progressed steadily until the animal was unable to sit up without assistance.

During the next three months two more chimpanzees became ill. Since then all but one of the eight have developed similar symptoms. The longest incubation period was 30 months; the course of the illness was from five to nine months, ending in almost complete paralysis. Extensive neurological examinations have shown that the disease closely resembles human kuru.

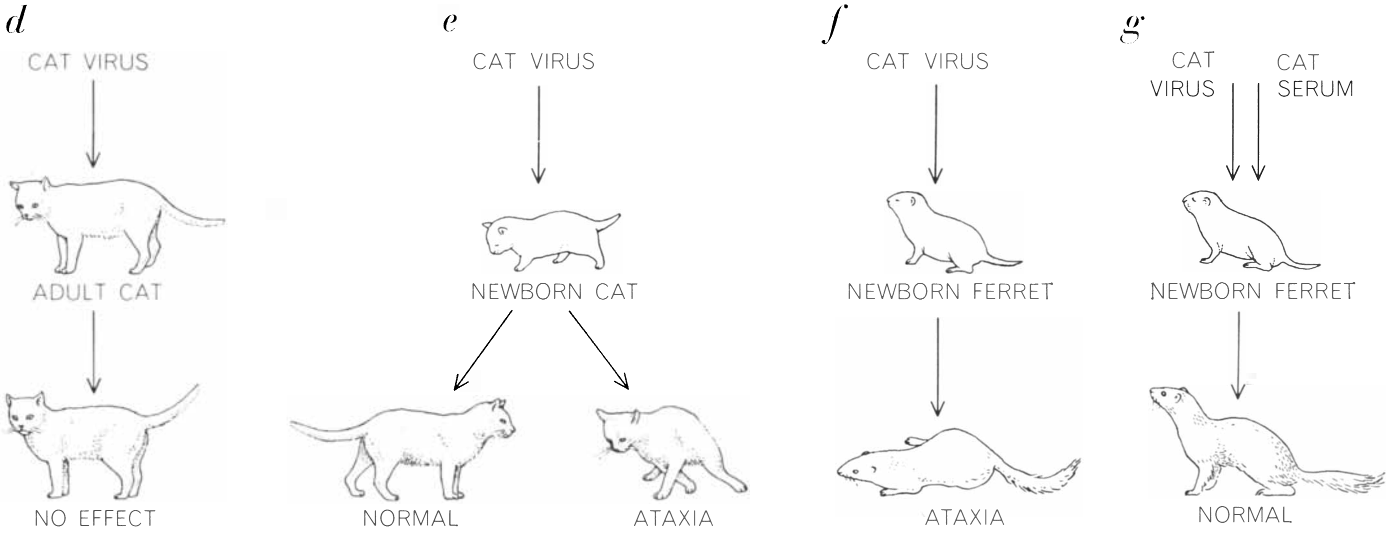
Another thread in the story leads back to multiple sclerosis. I. H. Pattison and E. J. Field of the Institute for Research on Animal Diseases in England and Pall A. Pálsson of the University of Iceland have injected sheep with material from the brains of human patients who had died of multiple sclerosis. Several of the sheep have developed a disease similar to scrapie.

The work that produced these results must be regarded as preliminary. One must not jump to the conclusion that multiple sclerosis is an infectious disease or that it is related to scrapie. Still, the possibilities are there. Indeed, David C. Poskanzer of the Harvard Medical School, citing extensive epidemiological evidence, has presented the hypothesis that multiple sclerosis may be an infectious disease with a long incubation period, perhaps 20 years or more.

A somewhat similar chain of circumstances begins with a brain disease of cats and may lead to an understanding of one or more human afflictions. The disease, hypoplasia (underdevelopment) of the cerebellum, causes kittens to lose their sense of balance and coordination because the Purkinje layer of nerve cells in the brain fails to develop properly. Veterinarians have recognized the disease for many years and have generally regarded it as hereditary because it tends to occur in families of cats. Since the disease was first described in 1888, however, there have been strong reservations about its genetic character, because often entire litters of kittens are affected. Such a pattern is inconsistent with that of most genetic diseases; they are usually transmitted by recessive genes, requiring that both parents be carriers of the unfavorable trait. The mathematical probabilities of genetics are that about one offspring in four of such a mating will exhibit the disease.

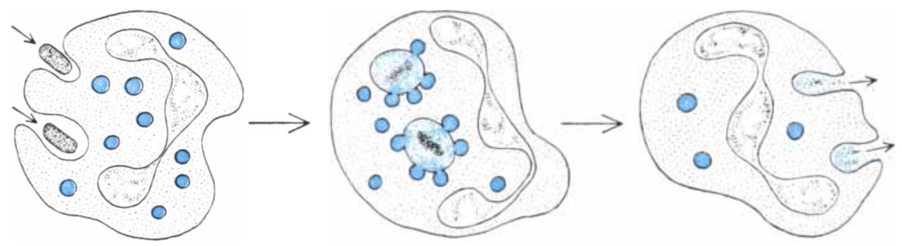
The story must shift to another species—the rat—and another disease—cancer—before the stage can be set to show how significant the feline disease may be. In 1958 Lawrence Kilham and his associates at the Dartmouth Medical School isolated an infectious agent from rat tumors. At first they thought it was a previously unrecognized virus with the ability to produce cancer. A long series of experiments showed that it was not a cancer-producing virus but that it had a particular ability to replicate in cells that were themselves rapidly dividing, as in cancer or in the growth of a young animal. It often caused a fatal disease when it was inoculated into very young animals but gave rise only to latent disease in adults.

At that stage in the investigation George Margolis, a neuropathologist, joined Kilham. They began experiments to determine the effect of injecting the rat virus into the brain of young hamsters. One result was that the virus produced severe ataxia, or loss of motor control, because it attacked the nerve cells

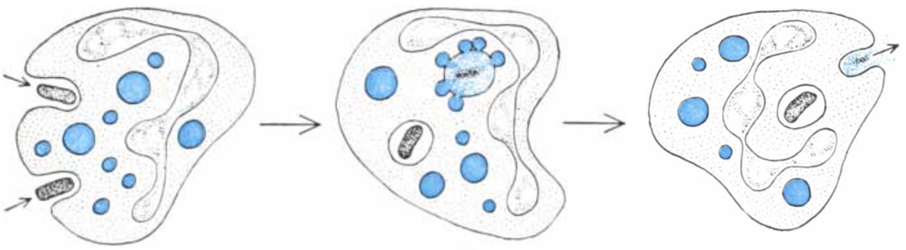


found in the young and in cancer patients. The first experiments (*a–c*) entailed the inoculation of a rat virus; in other experiments (*d–f*) animals were inoculated with cerebellar-hypoplasia virus from cats. Serum from cats that survived disease counteracted virus (*g*).

NORMAL



BLUE MINK



FAULTY GRANULES in cells appear in Chédiak-Higashi syndrome of animals and men. A typical granule is the lysosome (*color*), a membranous structure containing enzymes that digest viruses and bacteria invading a cell. The process of attack and digestion in a normal cell is shown at top. In the disease the granules are abnormally large and often fail to attack invaders (*bottom*). The abnormality is believed to be in the membrane of the granule.

of the cerebellum during the active stage of its formation just after birth.

The effect resembled the symptoms of cerebellar hypoplasia in kittens and so directed the thoughts of Kilham and Margolis to that disease. Eventually they were able to isolate from the brain of an affected cat a virus that would reproduce the cat disorder. It was difficult to evaluate the results of inoculating healthy cats with the agent, however, because many cats carry antibodies against the disease. Kilham and Margolis succeeded in adapting the disease to ferrets, which were uniformly susceptible. Furthermore, it was found that ferrets could be protected from the virus by neutralizing the infectious material with serum from cats that had survived the infection.

By pulling together the separate threads involving cats, rats and ferrets one can dispel some of the mystery surrounding feline cerebellar hypoplasia and see the possible significance of the disease for a number of human afflictions. The confusion surrounding feline cerebellar hypoplasia has persisted mainly because the virus selects actively multiplying cells for its attack. Therefore it does its damage to the brain at a very early age–probably within one or two days after birth. At that time of life it is impossible to detect abnormalities of equilibrium in kittens, but the damage to the brain has been done. Later, when the animals should be able to walk and play, the defect becomes obvious. Then an examination of the brain shows a markedly small cerebellum but no evidence of viral infection [*see illustration at top left on page 112*].

The work of Kilham and Margolis has shown that the small cerebellum is the result of a destructive process that has virtually stopped but has left a damaged brain. The cause of destruction was a viral infection that had occurred in infancy and left no trace other than the brain damage. The findings explain the persistence of an important misconception: that feline cerebellar hypoplasia is a genetic disease, when in fact it results from the lesions of an acute viral infection.

Again one should not jump to conclusions. The findings do not mean that every similar lesion found in the cerebellum is of viral origin, but they do raise several important questions. Is cerebellar hypoplasia in cattle, horses and human beings sometimes caused in the same way it is in kittens? Are there viruses that attack cells in other regions of the central nervous system, resulting in lesions that mislead us in a similar fashion? Could some cases of mental retardation in children be the result of structural damage caused by unsuspected viral infections?

Another group of human diseases that resist understanding are those affecting the mesenchyme: the supporting tissues of the body. They are known as the connective-tissue diseases and include rheumatoid arthritis, lupus erythematosus, diffuse scleroderma and polyarteritis. They are crippling and debilitating diseases affecting millions of people, and yet in spite of intensive research they continue to resist explanation.

One of the ways in which the diseases manifest themselves is an exaggerated but ineffective activity in the mechanism of immunity to infection. Such activity is reflected by high levels in the blood of gamma globulin, the protein fraction that includes antibodies against foreign substances (antigens). Another manifestation is the proliferation in the body of plasma cells, the cells that manufacture antibody proteins. Frequently there is also diffuse degeneration of the connective tissues and marked inflammation of the arteries.

An animal disease that has received considerable attention because of its similarity to the human connective-tissue diseases is the Aleutian disease of mink. The disease is not an exact counterpart of the human diseases, but it has characteristics that overlap with several of them. Aleutian disease, which affects the highly prized Aleutian (or blue) mink, was discovered some 20 years ago. At the time it was thought to be directly related to the genetic character of the Aleutian mink. We now know that it can occur in other mink, although it has a strong predilection for the Aleutian.

Aleutian disease is slowly progressive. It causes the fur of its victims to become valueless, and it culminates in death by damaging the kidneys, liver and blood vessels. Several investigators have shown that the blood of diseased mink yields infectious material that resembles a virus in many ways: it passes through fine filters and consists of particles (as is indicated by the fact that it forms a sediment when it is spun at high speed in a centrifuge). Still, no actual virus has been isolated.

The disease has other mysterious aspects, conspicuous among which is the behavior in it of gamma globulin. The substance is usually regarded as an antibody that is produced by the plasma cells in response to an infective agent and enables the host to resist the agent. Although the level of gamma globulin rises sharply in Aleutian disease, it is possible to isolate the infectious agent from the bloodstream at any time during the long course of the illness. In other words, the gamma globulin responds to the infectious agent but fails to act effectively against it.

In several of its aspects Aleutian disease resembles the human connective-tissue diseases. Aleutian disease is limited to the mink (and possibly the ferret). One can see that if there were a parallel in a human disease, it would be most difficult to demonstrate the presence of the agent. C. L. Christian of the Columbia University College of Physicians and Surgeons has put the situation in these words: "If a microbial agent responsible for human [connective-tissue] disease were as difficult to characterize as the agent involved in Aleutian disease of mink, present methods might not permit its detection."

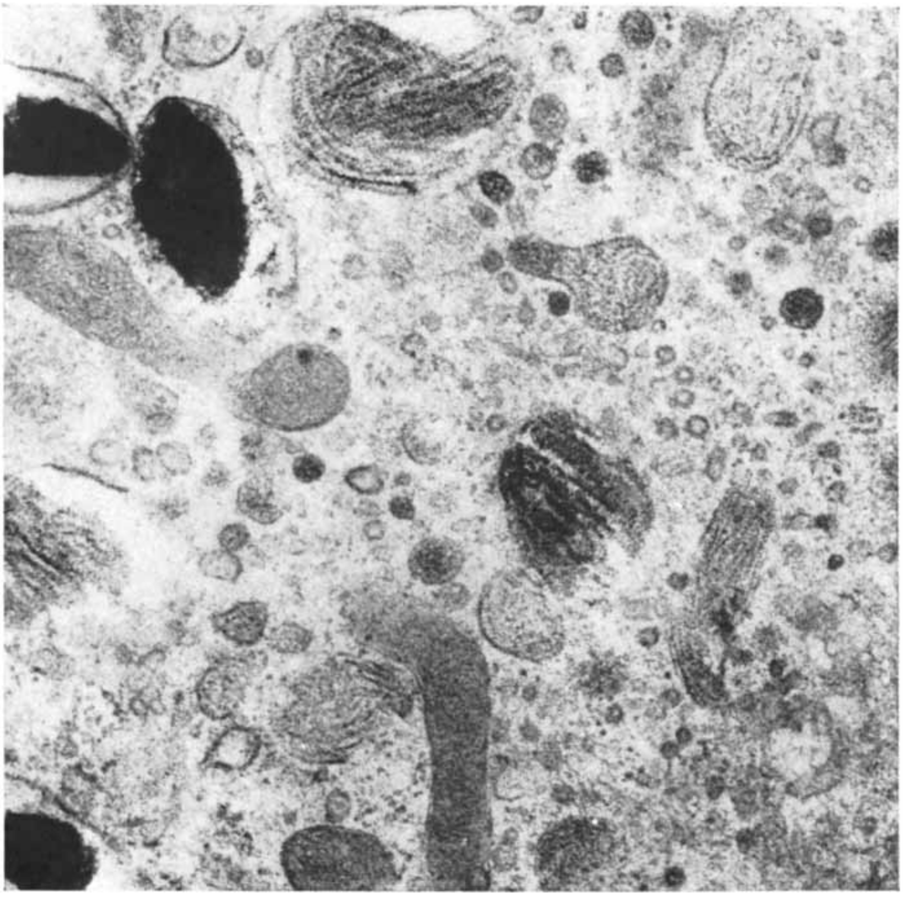
Several experimental approaches are being made to the question of how the agent of Aleutian disease stimulates the plasma cells of the mink to produce gamma globulin that apparently lacks the normal antibody activity. Cells from infected animals are being studied under both the light and the electron microscope in an effort to determine where the first attack occurs. Substances labeled with radioactive atoms will be used to ascertain which cells begin to multiply in response to the infectious agent. Still another approach involves exploration of the analogies between Aleutian disease and multiple myeloma, a malignant disease of the blood in which plasma cells grow wildly and produce abnormal kinds of gamma globulin. The work entails intensive studies of the chemical nature of the gamma globulin produced in Aleutian disease.

For my final chain of circumstances I shall take up the research on white blood cells that has arisen from the genetic differences in susceptibility to Aleutian mink disease. A genuine genetic disease that occurs in children is the Chédiak-Higashi syndrome. (The disease is named for the two physicians who discovered it independently some 15 years ago, Moisés-Chédiak of Cuba and Ototaka Higashi of Japan.) The disease is considerably more complex than it seemed at first, when it appeared to be distinguished mainly by enlargement of granules in the leukocytes, or white blood cells. Accompanying the abnormalities of the leukocytes were other characteristic patterns, including pale pigmentation of the hair and eyes, photophobia (unusual sensitivity of the eye to light) and extreme susceptibility to bacterial infections.

The vulnerability to bacterial infection indicates that the leukocytes are unable to fulfill their normal function of inactivating bacteria. Various workers have recently shown that the bacteria-inactivating property of leukocytes resides in the granules, which are in effect tiny bags filled with digestive enzymes. The granules have been given the name lysosomes, and it is now known that similar granules exist in the cells of many organs, including the liver, the kidney and the pancreas [see "The Lysosome," by Christian de Duve; SCIENTIFIC AMERICAN, May, 1963]. In the leukocytes, when foreign material enters the cell, the enzymes are discharged to digest the invader; at other times the powerful digestive substances are sequestered by the membrane of the lysosome.

In 1963 George A. Padgett of Washington State University, working in the laboratory where I was until recently, discovered that an animal counterpart of the Chédiak-Higashi syndrome had existed unnoticed for more than 20 years. It was found in the Aleutian mink. The blue mink is a genetic mutant bearing the *aa,* or Aleutian, gene. Padgett showed that all mink carrying the *aa* gene had the same abnormality of leukocyte granules as children with the Chédiak-Higashi syndrome. Moreover, the distinctive light color of the mink's coat was a manifestation of defective formation of pigment and so was akin to the paleness of hair and skin in children with the Chédiak-Higashi syndrome. The mink also lacked adequate pigmentation in the iris of the eye and so exhibited photophobia.

Further studies have shown that the membranes of the leukocyte granules are faulty, which may explain the ineffective performance of the leukocytes. The work has led to studies of granules and their membranes in other kinds of cell. Dorothy B. Windhorst of the University of Minnesota Medical School showed with the electron microscope that the reason for the paleness of pigmentation was that the granules of pigment were extremely enlarged, resulting in poor dispersion of the pigment [*see illustration below*]. Marvin A. Lutzner of the University of Washington School of Medicine and his co-workers used the



MELANIN GRANULES in a child with Chédiak-Higashi syndrome show defective pigmentation similar to that found in blue mink and albino cattle. The dark granules (*upper left*) have normal pigmentation; nearby are large, gray and streaky granules with defective pigmentation. The photomicrograph was made by Alvin S. Zelickson at the University of Minnesota for his colleague Dorothy B. Windhorst; enlargement is 46,300 diameters.

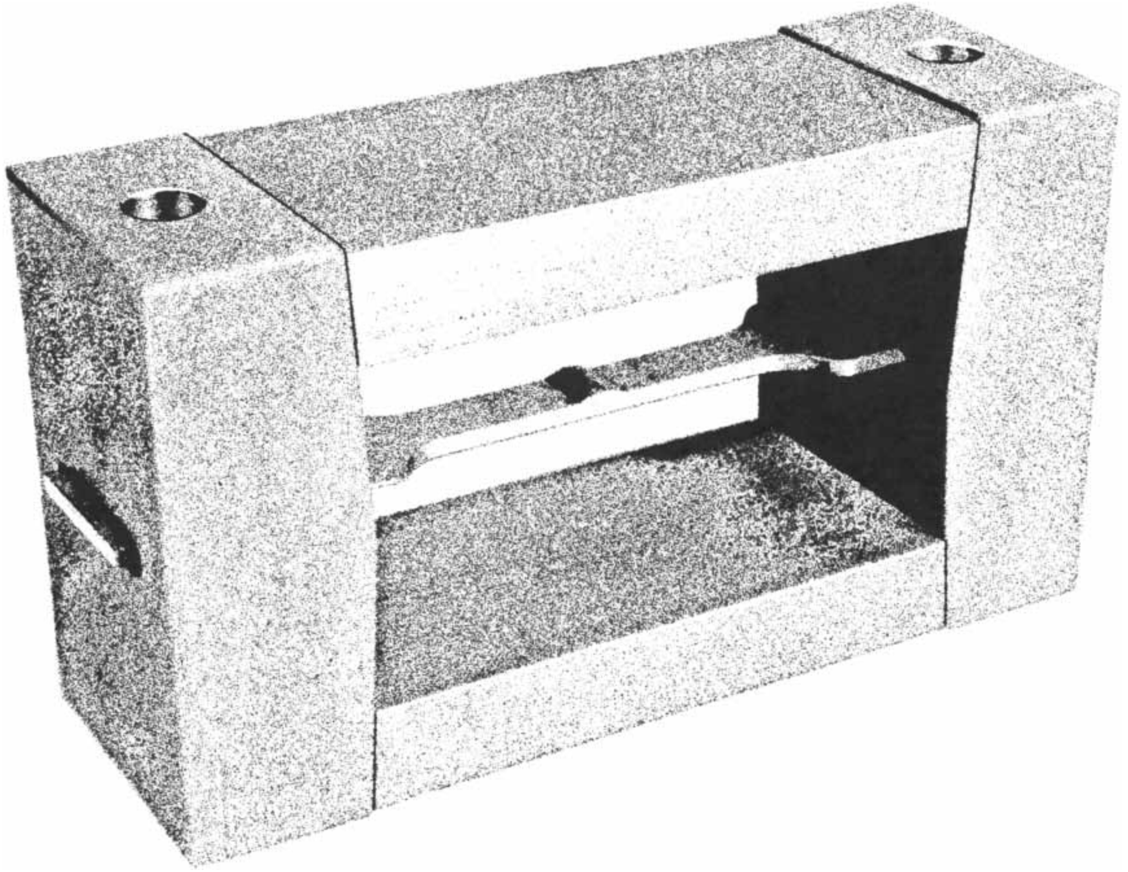
electron microscope to study granules in the cells of other organs of mink, including the liver, the pancreas and the salivary glands. They found similar abnormalities of the membranes in all the granules.

Thus what appeared at the beginning to be a defect limited to white blood cells has proved to be a generalized disease probably involving all organs whose cells contain granules covered by membranes. The disease appears to be related to one gene and possibly to one enzyme; hence studies of it offer a new avenue for exploring the genetic basis for the control of physiological function. A natural model of the disease had been available for more than 20 years in perhaps a million mink, but the presence of the model went unrecognized for lack of attention to comparative pathology.

In the work of our group at Washington State University a bit of unanticipated luck enhanced the opportunity to study the Chédiak-Higashi syndrome. A herd of partial albino cattle at the university (the only group of its kind in the world) had been under study for years as genetic oddities. When Padgett examined their blood, he discovered that they had the same genetic defect found in children with the Chédiak-Higashi syndrome and in blue mink. Hence two kinds of animal with different experimental advantages are available for further research. The mink can be kept in considerable numbers; the cattle can provide large quantities of leukocytes and other cells that will be helpful in biochemical studies.

Future work on the syndrome I have described in man, mink and cattle should elucidate the peculiarities of the disease. It should also provide valuable leads to understanding how the genes control the development of cells, how pigment is formed and how lysosomes carry out their normal functions.

It would be unfair to close without an apology to the investigators whose work has been omitted from this discussion. My approach has been to consider in some depth the interspecies relations of a few diseases. Much other work is in progress at the boundaries that have long restricted the development of medicine as a comparative discipline. Full appreciation of the biological unity of disease can be achieved only when the fences between species are removed and investigators cease to regard medicine as a compartmented structure. As Sir William Osler put it, there is only one medicine.



MATHEMATICAL GAMES

Dr. Matrix delivers a talk on acrostics

by Martin Gardner

For almost a year after Dr. Matrix and his daughter Iva had disappeared from Philadelphia with a $50,000 donation to Dr. Matrix' Psychonumeranalytical Institute (see this department for last January) neither I nor the police had been able to discover their whereabouts. Iva usually communicates with me in some cryptic way after a suitable lapse of time, however, and so I remained on the alert for a message. One day I received a printed announcement of 12 public lectures on "Combinatorial Aspects of English and American Literature," to be given every Friday evening in Shade Auditorium at Wordsmith College in New Wye, N.Y. Professor T. Ignatius Marx of the mathematics department was the speaker. The admission charge was $3 a lecture or $25 for the entire series. The weekly topics were listed as follows:

1. The Acrostic Poem.
2. The Palindromic Poem.
3. Concealed and Accidental Verse.
4. Macaronic and Patchwork Verse.
5. Nonsense Verse from *Jabberwocky* to Gertrude Stein.
6. Lipograms, Anagrams, Pangrams.
7. Misplaced Commas.
8. Keys to the Nomenclatures of *Gulliver's Travels,* the *Oz* Books and Other Descriptions of Imaginary Lands.
9. Lawrence Durrell and the 4.
10. Vladimir Nabokov and the "Stinky Pinky."
11. Deciphering the Ten Thunderclaps of *Finnegans Wake.*
12. Poetry Programming for Digital Computers.

Who, I wondered, was T. Ignatius Marx? Suddenly it came to me: "T. I. Marx" is an anagram of "Matrix." He had probably counterfeited credentials as a mathematician and the Wordsmith College administrators had failed to penetrate the disguise.

The announcement arrived by special delivery late Friday afternoon, the day of the first lecture. I dropped everything and drove north to New Wye, in the lower Catskills. It was a good thing I arrived early; the seats in Shade Auditorium were rapidly filling to capacity. Marx was Dr. Matrix all right, although when he first emerged from the wings I did not immediately recognize him. The reddish-brown goatee he had sported in Philadelphia was gone. His prominent nose now overhung a brown handlebar moustache. He was obviously wearing contact lenses, because his green eyes had been transformed to bright blue.

"In the beginning," he started, reading his lecture in a clipped British accent, "was the word. What is a word? It is a combination of sounds that advanced cultures symbolize by combinations of letters. What is a poem? It is a combination of words, chosen not only for their semantic referents but also for their melodic patterns. As Ramón Lull so clearly recognized in the 13th century, the poet, like the artist and the musician, is simply an expert in combinatorics. What is the rhyming dictionary if not a Lullian combinatorial device? With or without such mechanical aids, the poet must explore possible combinations of words until he finds a pattern that maximizes his aesthetic satisfactions. A good poem, like a magic square or a crossword puzzle, is an exercise in the great Lullian art of combinatorial thinking. A dictionary is like a box containing thousands of pieces of glass of different sizes, shapes and colors. As the American poet Jack Luzzato has written:

In orderly disorder they
Wait coldly columned, dead, prosaic—
Poet, breathe on them and pray
They burn with life in your mosaic."

In addition to maximizing aesthetic values, Dr. Matrix continued, the poet can fashion other remarkable kinds of combinatorial pattern. The acrostic, in which initial letters of lines are in a meaningful order, is perhaps the oldest form of what Dr. Matrix called "meta-aesthetical verse play." The earliest crude examples, he asserted, are found in the Old Testament, where nine Psalms are "abecedarian acrostics," the initial letters of each stanza consisting of the Hebrew letters in alphabetical order. The first four of the five poems that make up the Book of Lamentations, Dr. Matrix said, are also acrostics of this type, as well as the poem in Proverbs 31, verses 10 through 31, which lists the virtues of the good wife.

Dr. Matrix picked up a pointer that had been leaning against the lectern and tapped it on the floor. Before the lights dimmed I looked quickly behind me to see who was operating the projector that had been set up in the middle of the center aisle. Yes, it was Iva. Her striking Eurasian features were entirely without makeup. She was obviously masquerading as a student: her dark hair hung below her shoulders and she wore a gray sweater, red boots and a tweed miniskirt that revealed a splendid pair of knees. I learned later that she was enrolled for undergraduate courses in mathematics and music.

When the room was dark, a picture appeared on the screen of the first stanza of the famous 119th Psalm as it looks in the original Hebrew. Dr. Matrix called attention with the pointer to the fact that each of the stanza's eight verses begins with the letter aleph. The second stanza of the Psalm was then flashed on the screen to show that each of its eight verses begins with beth. The eight verses of the third stanza each start with gimel, and so on through the 22 letters of the old Hebrew alphabet to tau, the last letter.

The lights went on. It was the Greeks and the Romans, Dr. Matrix declared, who introduced the word and sentence acrostic. He cited numerous instances and showed a slide of each. The prophetic verses of the Greek Sibyls—old ladies who spouted hexameters while in a state of pretended religious frenzy—were often acrostics. Cicero, in his book *On Divination,* argued that those acrostic features proved that the Sibylline verses were not uttered spontaneously but were carefully composed in advance. The most famous of such acrostics, Dr. Matrix said, was attributed to the Erythraean Sibyl, believed by many scholars to be the same Sibyl who, in Book 6 of *The Aeneid,* leads Aeneas into the underworld. The Greek lines were shown on the screen alongside a Latin translation provided by St. Augustine in Book 18 of *The City of God.* With the pointer Dr. Matrix showed how the initial letters of the Greek lines formed the five words

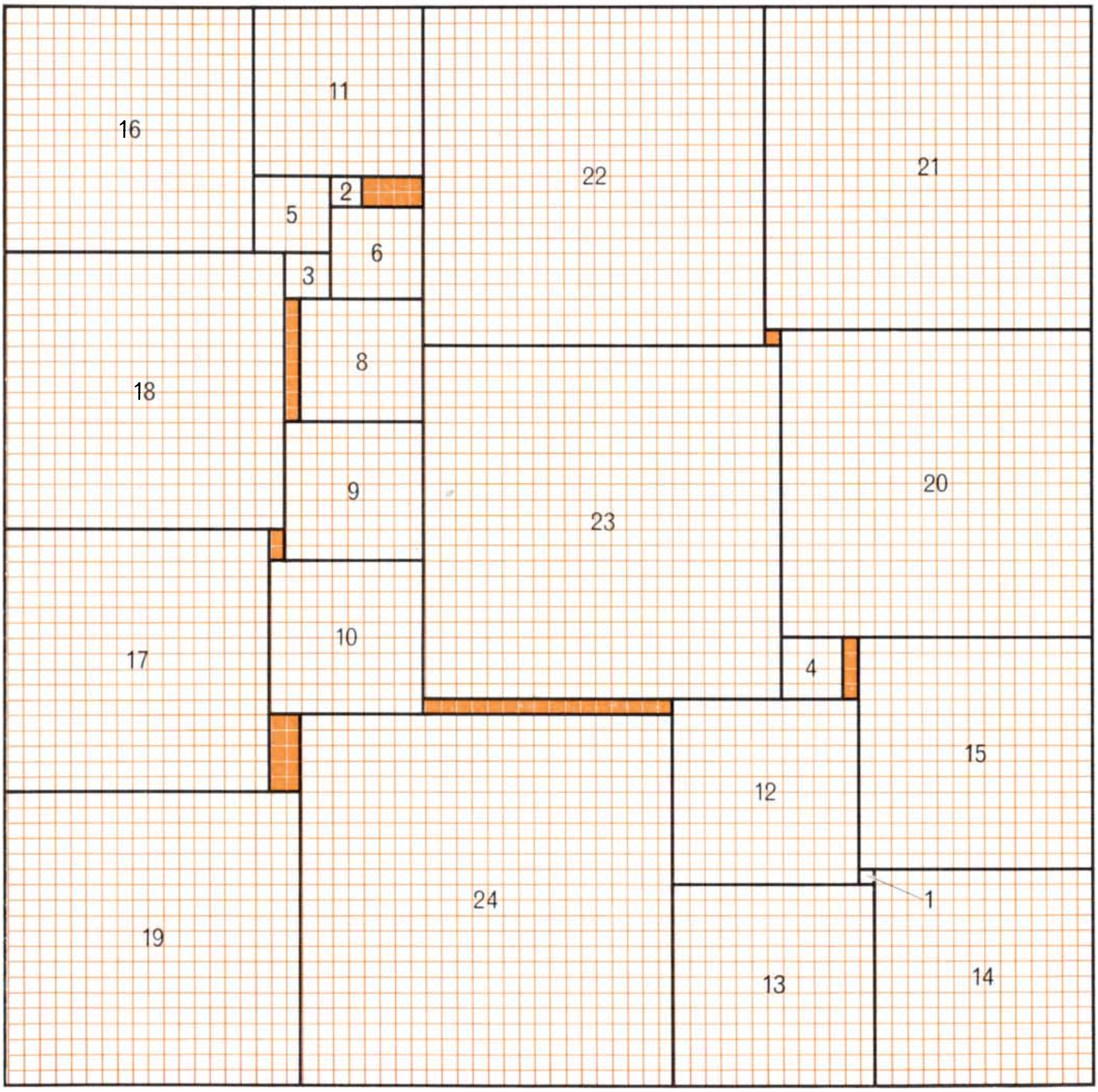
Ἰησους Χριστος Θεου Υἱος Σωτηρ,

which translate as "Jesus Christ, the Son of God, the Savior."

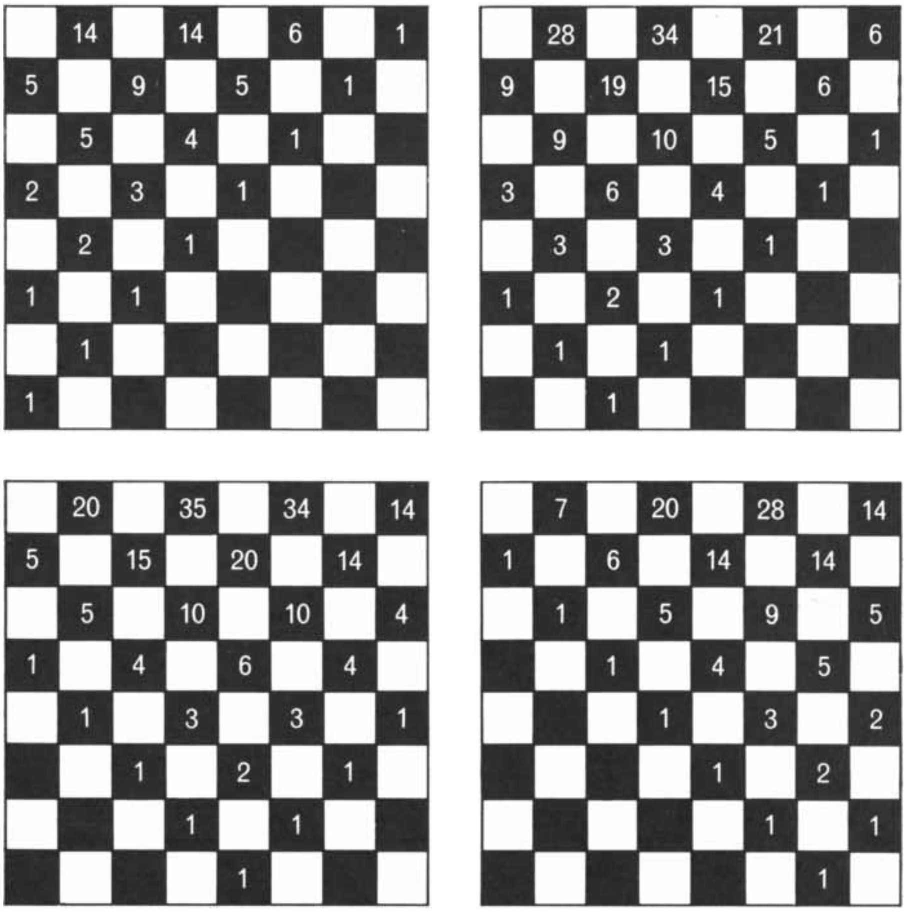
But there is more. The five initials of the five Greek words form a second acrostic, ιχθυς, the Greek word *ichthus*, "fish." This explains, said Dr. Matrix, why the fish became such a popular early symbol of Christ. It was often carved on monuments in the Roman catacombs and was widely used as a religious symbol in medieval paintings.

In a rapid series of slides Dr. Matrix showed many examples of acrostics from the medieval and Renaissance periods, including selections from the 50 acrostic cantos written by Giovanni Boccaccio. He also showed some of the 26 graceful acrostics (each on the words "Elizabeth Regina") in *Hymns to Astraea*, a 1599 book by the English philosophical poet Sir John Davies, and some of the 420 acrostics on names of famous people in Mary Frege's 1637 work *Fame's Roule*. There were a number of baroque specimens by minor Elizabethan poets, some with the acrostic letters in reverse order and some with a name running down the middle of the poem as well as down both sides.

After the Elizabethan period, Dr. Matrix continued, the English acrostic fell into disrepute. Joseph Addison, writing in Volume 60 of *The Spectator*, was unable to decide who was the greater blockhead, the inventor of the acrostic or the inventor of the anagram. Samuel Butler, in his "Character of a Small Poet," described the acrostic writer as one who would "lay the outside of his verses even, like a bricklayer, by a line of rhyme and acrostic, and fill the middle with rubbish." Among the many acrostics by the romantic



A solution to September's square-packing problem



Solution to last month's checker problem

poets, Dr. Matrix thought the best was John Keats's lyric on the name of his sister Georgiana Augusta Keats. It begins:

Give me your patience, sister,
while I frame
Exact in capitals your golden name.

Lewis Carroll was fond of writing acrostics on the names of his young friends. Dr. Matrix displayed several specimens of Carrollian dedicatory verse in which the second letter of each line, instead of the first, spelled the little girl's name. Among American writers he singled out James Branch Cabell as a skillful writer of acrostics, citing the dedicatory poem *Jurgen* (an acrostic on the name of the critic Burton Rascoe) as a typical Cabellian specimen. As instances of the off-color acrostic (I shall not repeat them here) Dr. Matrix exhibited an amusing acrostic attack on Nicholas Murray Butler by the poet Rolfe Humphries (unwittingly printed in *Poetry* magazine under the title "Draft Ode for a Phi Beta Kappa Occasion"), and "A Recollection," from page 71 of *The Collected Poems of John Peale Bishop.*

The finest acrostic by an American poet, Dr. Matrix insisted, is the following sonnet:

"Seldom we find," says Solomon Don Dunce
"Half an idea in the profoundest sonnet.
Through all the flimsy things we see at once
As easily as through a Naples bonnet—
Trash of all trash!—how can a lady don it?
Yet heavier far than your Petrarchan stuff—
Owl-downy nonsense that the faintest puff
Twirls into trunk-paper the while you con it."
And, veritably, Sol is right enough.
The general tuckermanities are arrant
Bubbles—ephemeral and so transparent—
But this is, now—you may depend upon it—
Stable, opaque, immortal—all by dint
Of the dear names that lie concealed within't.

The lady's full name is hidden in an unorthodox way. Can the reader discover it and also identify the poet before the information is revealed in this department next month?

J. A. Lindon of Addlestone in England was singled out by Dr. Matrix as the most expert, among living writers of light verse, in the weaving of meta-aesthetic patterns. Lindon's poem "To Those Overseas" was projected on the screen:

A merry Christmas and a happy new year!
Merry, merry carols you'll have sung us;
Christmas remains Christmas even when you are not here,
And though afar and lonely, you're among us.
A bond is there, a bond at times near broken.
Happy be Christmas then, when happy, clear,
New heart-warm links are forged, new ties betoken
Year ripe with loving giving birth to year.

It was easy to see that the first line was repeated acrostically by the first words of each capitalized line. Dr. Matrix went on, however, to show that Lindon had ingeniously worked into his poem a second pattern that is much more unusual. This pattern too will be explained next month.

"For the combinatorial critic," Dr. Matrix continued, "the unintentional acrostic is even more interesting than the intentional one. The field is virtually unexplored. What is the longest word to appear acrostically in Milton's *Paradise Lost?* In Pope's *Essay on Man?* In the works of Yeats, Eliot, Pound, Auden? In the King James Bible?"

Dr. Matrix displayed several accidental acrostics from the New Testament. I particularly liked one in which the three statements of Matthew 7:7 (Dr. Matrix called attention to the triple repetition of seven—twice as a numeral, plus the seven letters of "Matthew") are arranged like this:

Ask, and it shall be given you;
Seek, and ye shall find;
Knock, and it shall be opened unto you.

More remarkable, however, is the following accidental acrostic Dr. Matrix said he had first learned about when he checked galleys for a forthcoming book on Scribner's spring list: *Beyond Language,* by his old friend Dmitri Borgmann, the wordplay expert of Oak Park, Ill. In Act 3, Scene I of *A Midsummer Night's Dream* the fairy queen Titania speaks the following lines to Bottom the Weaver:

Out of this wood do not desire to go:
Thou shalt remain here, whether thou
wilt or no.
I am a spirit of no common rate;
The summer still doth tend upon my
state;
ANd I do love thee; therefore, go with
me.
I'll give thee fairies to attend on thee,
And they shall fetch thee jewels from
the deep.

The capital letters on the left spell "O Titania." "Surely," Dr. Matrix said, "that is the most remarkable unintended acrostic in all English literature. Or was it unintended?"

The lecture was over. The lights came on, people clapped, and I lost no time in disclosing my presence to Iva. I helped her to carry the projector and box of slides to her car, then she drove us to her father's rented house on the outskirts of New Wye. She had assumed the Chinese name Iris Ho Toy, an anagram of her Japanese surname, Toshiyori, and was living in her own apartment near the college. No one suspected, she told me, that Professor Marx was her father.

Dr. Matrix' career at Wordsmith ended abruptly a few weeks after his final lecture. He had announced in that lecture that he had programmed the mathematics department's computer to write modern poetry. All the words in the new *Random House Dictionary of the English Language* had been stored in the computer's memory along with rules for combining them in ways derived from an intensive study of the work of 10 contemporary poets. The computer had typed out exactly 100 copies of a long poem, which, suitably bound in imitation leather, could be obtained from Professor Marx for $50 a copy. It was a most impressive poem, albeit dull in spots (for example, "I've measured it from side to side;/'Tis three feet long, and two feet wide").

Three weeks later a young instructor in Wordsmith's English department discovered that the poem the computer had typed out was word for word the first version of William Wordsworth's narrative poem "The Thorn." By the time the fraud was discovered, however, Marx and Miss Toy were gone.

Last month's questions about Pascal's triangle are answered as follows:

1. The sum of all numbers above row n is $2^n - 1$.

2. All numbers in row 256 are odd.

(This is true of every *n*th row when *n* is a power of 2.)

3. All numbers in row 67, except the two 1's at the ends, are evenly divisible by 67. (This is true of every *n*th row when *n* is a prime. A proof will be found in Stanley Ogilvy's *Through the Mathescope*, page 137.)

4. The checker problem is quickly solved by numbering the squares as shown in the illustration on page 120. For each starting position the numbers form inverted Pascal triangles modified by the restricting sides of the board. Each number indicates the number of different ways a checker can reach that cell from the starting position. The maximum number of possible paths is to the square marked 35 when the checker starts from the third black square on the bottom row.

5. The value of the apex card in Harry Lorayne's trick is determined as follows. Let *n* be the number of cards in the initial row. The row of Pascal's triangle that contains *n* numbers provides the formula for calculating the apex. This can be explained by an example.

Assume that there are six cards in the bottom row with the values 8, 2, 9, 4, 6, 7. The corresponding row of Pascal's triangle is 1, 5, 10, 10, 5, 1. Reduce the 10's to their digital root (by adding their digits), making the row 1, 5, 1, 1, 5, 1. These numbers are taken as being multiples of the six cards. The cards that are second from each end are multiplied by 5, summed, then added to the values of the four remaining cards. The final sum, reduced to its digital root, is the apex. This is easily done in the head because you can reduce to digital roots as you go along. When the second-from-end cards are multiplied by 5 to obtain the numbers 10 and 30, those numbers are immediately reduced to their digital roots 1 and 3, which have a sum of 4. To 4 you now add the values of the remaining four cards, reducing each sum to its digital root as you proceed. The final result, 5, is the apex number.

Finding the apex is even faster for a row of 10 numbers. In this case the corresponding row of Pascal's triangle, reduced to digital roots, is 1, 9, 9, 3, 9, 9, 3, 9, 9, 1. The number 9 is the same as 0 (modulo 9), so that we can write the formula: 1, 0, 0, 3, 0, 0, 3, 0, 0, 1. To obtain the apex, therefore, we have only to multiply the fourth numbers from each end by 3, add the two end cards and reduce to the digital root. The other six numbers can be ignored completely! A good presentation (suggested by L. Vosburgh Lyons of New York) is to let the spectator himself predict the apex number by naming any digit he pleases. He then writes a row of nine random digits, allowing you to add a 10th digit at whichever end of the row he designates. Add the three key numbers of the formula in the usual manner, then supply whatever fourth number is needed to make the apex correspond with his prediction.

The trick need not be limited to "casting out nines" addition. Any integer may be cast out. Pascal's triangle, with its numbers reduced by the same kind of casting out, gives the required formulas. For example, suppose the trick starts with eight digits and the pyramid is formed by casting out sevens. The eight-number row of Pascal's triangle, reduced by casting out sevens, is 1, 0, 0, 0, 0, 0, 0, 1. To determine the apex merely add the end numbers and, if necessary, reduce to a digit by casting out seven. I leave it to the reader to determine why the triangle produces the desired formulas in all such cases.

So far 239 readers have sent solutions to the September problem of covering as much as possible of a side-70 square with nonoverlapping squares of sides 1, 2, 3 . . . 24. Almost all the solutions reduce the exposed area to fewer than 100 square units. Twenty-four minimal solutions were received, each reducing the exposed area to 49 square units, or exactly 1 percent of the total area. All the patterns are identical (aside from rotations and reflections) in their placing of squares 11 through 24 (except for an interchange in some of them of squares 17 and 18), and in their omission of only the 7-square. The first such solution received was from William Cutler of Bethlehem, Pa. The others came from Richard Babcock, Robert L. Becker, Alan F. Berndt, O. Chateaubriand, C. A. Cross, K. N. Duncan, A. M. Freer, Raymond Gouge, Constantine Gumacos, R. W. Hahn, Luther S. Harris, Robert H. Matthew, William C. May (and two friends whom he called Hartman and Hartman), James N. Parnell, Robert L. Patton (whose solution is shown in the illustration on page 119), Robert L. Patton, Jr., Pierre M. Renders, James S. Robertson, Philippe Rosselet, Allan L. Sluizer, Burris Smith, Richard C. Windecker and James R. Wyman. The packing has not yet been proved minimal.

In September I reported that Leo Moser and J. W. Moon had proved that any set of squares with a combined area of 1 could be packed into a square of side 2. This should have read "a square of *area* 2."

THE AMATEUR SCIENTIST

The study of electrostatic effects and convection currents in liquids

Conducted by C. L. Stong

This is the season when you are most likely to get a shock of static electricity by touching a doorknob, when woolen garments crackle as they are removed and when your hair tends to stand on end after a few strokes with a comb. The electrical energy responsible for these effects is always generated when two substances rub together, but during humid weather it leaks away through the air and across moist surfaces before a substantial charge can accumulate. When the air is dry, as it is during the crisp days of winter, a person can become charged to a potential of as much as 50,000 volts simply by walking across a thick carpet. Well-insulated objects can store charges for days on end. For this reason winter is the best time to do experiments in electrostatics.

Roger Hayward, the illustrator of this department, recently performed a series of experiments that involve the response of dielectric liquids to electric fields of high potential and the reaction to the fields of both conducting and nonconducting particles suspended in the liquids. Hayward writes: "Most of the classic electrostatic experiments that usually are performed in air can be done to advantage in a dielectric liquid such as carbon tetrachloride or kerosene. The relatively high viscosity of the liquid causes the effects to proceed in slow motion, so that you can observe what is going on.

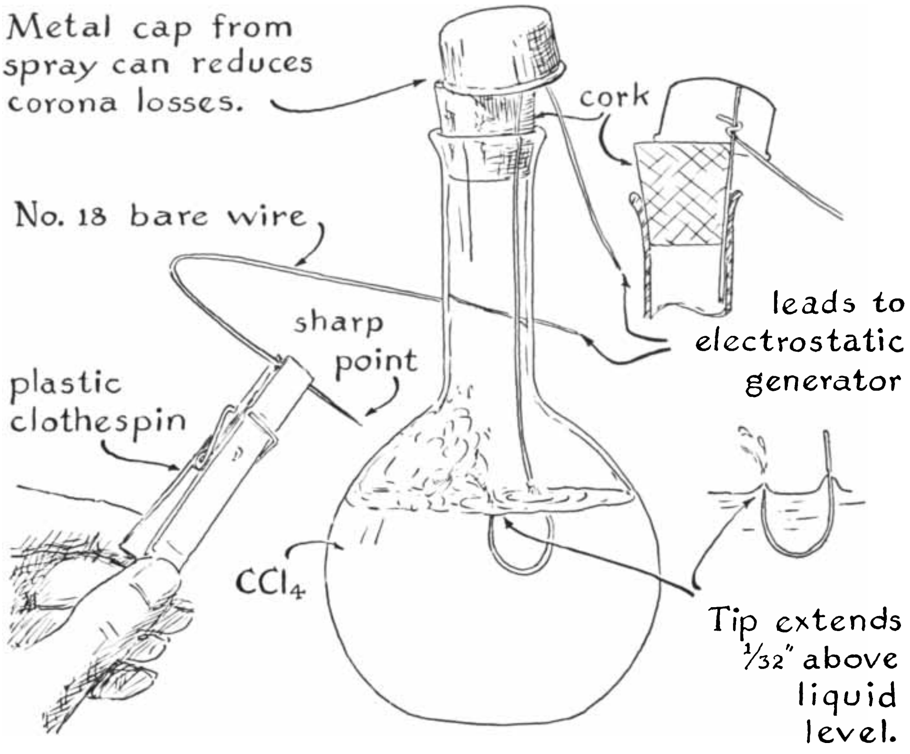
"In addition, a number of effects that appear in liquids cannot be observed in air. For example, elongated dielectric particles suspended in kerosene align themselves in the direction of the electric force and thereby trace the pattern of the potential field just as iron filings disclose the shape of a magnetic field when they are scattered on a sheet of paper held over the magnet. This was the first experiment I tried, because I wanted to see just where the electric force was most intense before attempting to observe its influence on transparent liquids.

"To set up the experiment I poured about a pint of kerosene into a Pyrex pie plate eight inches in diameter. With a pair of scissors I cut the hairs of a camel's-hair brush into pieces about a sixteenth of an inch long. The short hairs were stirred into the kerosene. The dish was placed on a slab of Styrofoam about an inch thick.

"The pattern of a potential field is determined in part by the shape of the electrodes. My first pair of electrodes consisted of (1) a thin wire immersed vertically in the liquid at the center of the dish and (2) a wire circle that ran around the inner edge of the dish. The electrodes were connected to the terminals of an inexpensive electrostatic generator of the Wimshurst type that I bought from the Edmund Scientific Co.

"When the machine was cranked, the hairs turned in the direction of the electric force to form a symmetrical pattern of radial lines that joined the center to the circumference. In a potential field of this kind the strength of the electric force varies with the density of the lines. In the case of the radial field the line density and the force are greatest at the center. Indeed, when I started the generator the force at the center was so large that the liquid climbed up the wire more than a quarter of an inch, and the violent streaming destroyed the pattern in that region. I restored the pattern by cranking with less vigor, thus reducing the applied voltage. Reversing the polarity made no change in the shape of the field.

"Next I removed the ring and inserted in the field a pair of vertical wires spaced several inches apart. They were connected to one terminal of the Wimshurst



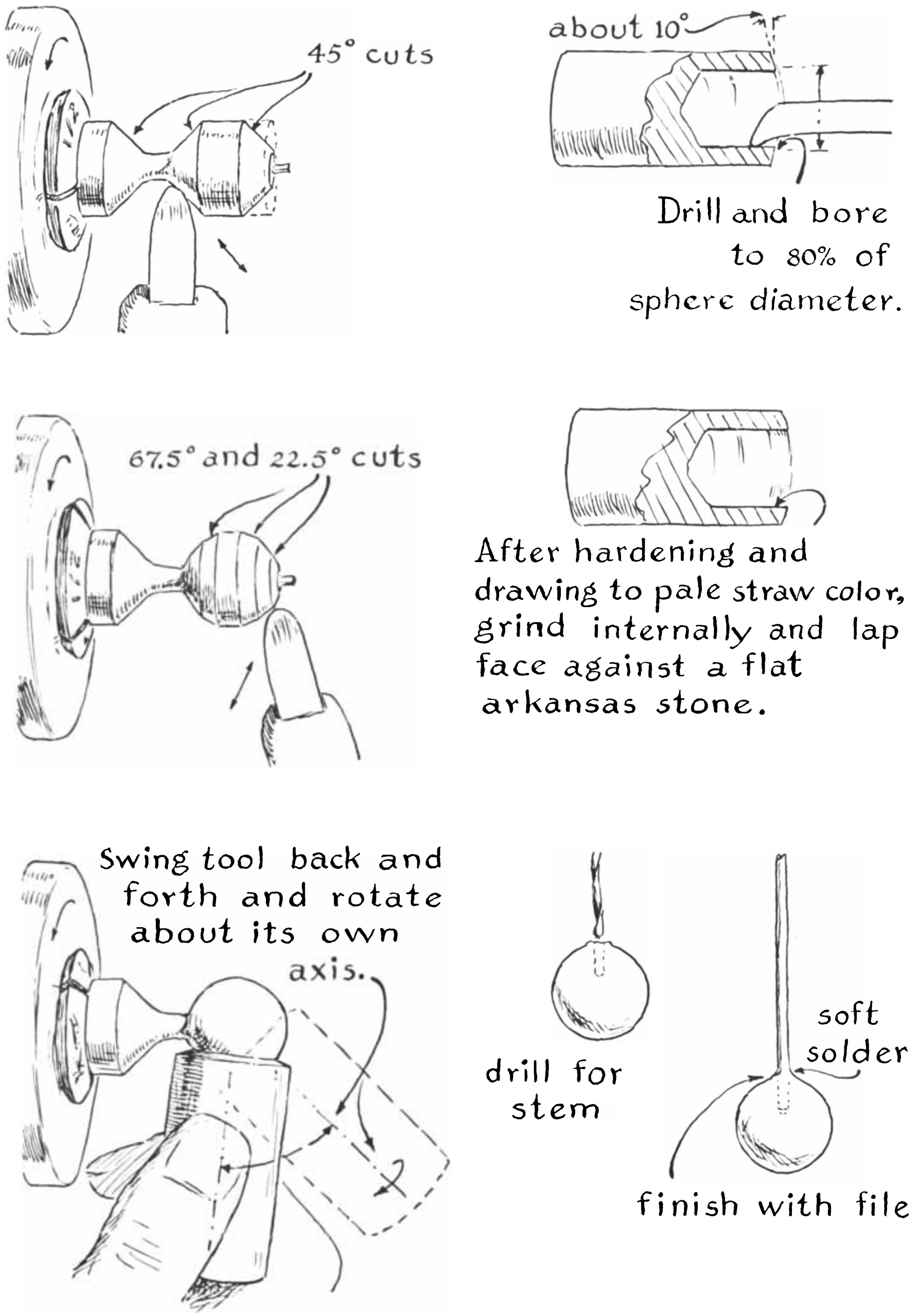
Arrangements for using an electrostatic field to create a jet of liquid machine. The other terminal of the machine was grounded. Radial patterns now extended outward from each electrode, the lines curving sharply away from each other along the narrow middle zone. Connecting the wires to opposite terminals of the machine produced a pattern of arching curves that looked just like the pattern produced by dusting iron filings on a sheet of paper above the poles of a horseshoe magnet. The lines were densest between the wire electrodes.

"A pair of straight electrodes was made by cutting two flat strips of metal about five inches long and half an inch wide from an aluminum pie plate. A short length of 18-gauge copper wire was crimped over the center of each strip to serve both as a connection and as a brace to support the strips on edge in the liquid. The strips were placed parallel to each other and about two inches apart. The resulting field turned out to be uniform, as one would expect. The lines were perfectly parallel except at the ends of the plates, where they arched outward. With only a single strip in the liquid and the second terminal of the generator grounded, a uniform field extended symmetrically from both sides of the electrode.

"Single electrodes of various shapes—circular, elliptical, egg-shaped and so on—were then cut from aluminum foil and placed flat in the middle of the dish. These were connected to one terminal of the generator by placing a wire vertically against the center of the electrode. The wire made the necessary connection and also held the aluminum foil in place.

"The second electrode again consisted of a circle of wire that ran around the edge of the dish. In every case the field lines made right angles with the edge of the electrodes, just as the textbooks predict. In the case of an egg-shaped electrode the lines bunch together at the small end of the egg, thus demonstrating that the strength of the field varies inversely with the radius of the electrode.

"That the field strength does in fact reach the maximum in the vicinity of a sharply pointed electrode was demonstrated by another experiment. A pound of carbon tetrachloride was placed in a 500-milliliter Florence flask along with a pointed U-shaped wire positioned so that the point protruded about 1/32 inch above the surface of the liquid. The wire was held in place by a groove cut in the side of a cork that closed the flask. (The stopper should be of cork rather than rubber because carbon tetrachloride attacks rubber. The bottle must be closed because the fumes of carbon tetrachloride are toxic. The chemical should be handled only in a well-ventilated room.)

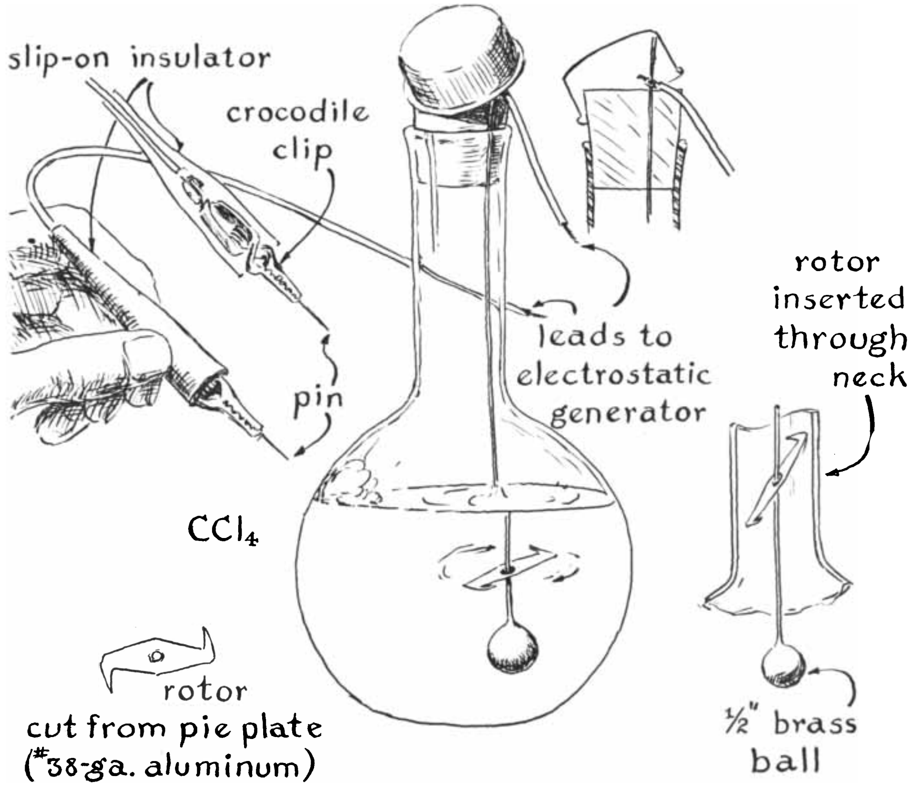


Steps in machining the brass ball

"Current leaks from the upper end of the wire in the form of a corona discharge. This loss can be reduced by covering the cork with a rounded metal shield such as the cap from a spray can. The other electrode is also a pointed wire that can be manipulated with a handle such as a clothespin, which should be of plastic because of the high voltage involved [*see illustration on opposite page*].

"When the two electrodes are connected to the terminals of the generator and the movable electrode is brought close to the side of the flask, the liquid surrounding the partly submerged electrode will become charged with the same polarity as the wire. The force of mutual repulsion is large enough to shoot a stream of liquid into the air perhaps an inch or so above the surface, depending on the voltage applied and the position of the outer electrode. The meniscus that surrounds the wire at the point where it enters the liquid will rise a quarter of an inch.

"Next I substituted for the U-shaped electrode a straight wire that terminated in a small metal sphere. Brass balls are simple to make if you have access to a



Submerged whirligig set in motion electrostatically

lathe. Place a brass rod of the desired size in the lathe chuck and make two opposing cuts at 45 degrees [*see illustration on preceding page*]. Trim the corners of the angled cuts at 67.5 and 22.5 degrees. The resulting shape is roughly spherical. It is reduced to a true sphere by means of a special tool in the form of a heavy-walled tube of steel, one end of which is sharpened to serve as a cutting edge. The finished diameter of the bore of the tool should be about 80 percent of the intended diameter of the sphere. With the lathe turning at its maximum speed, place the tool in light contact with the sphere and swing it back and forth over the brass while simultaneously rotating it on its own axis. With a little experience the truing operation can be completed in seconds and the finished piece will emerge with a bright, if not polished, surface. The sphere can then be drilled for soldering to a copper wire.

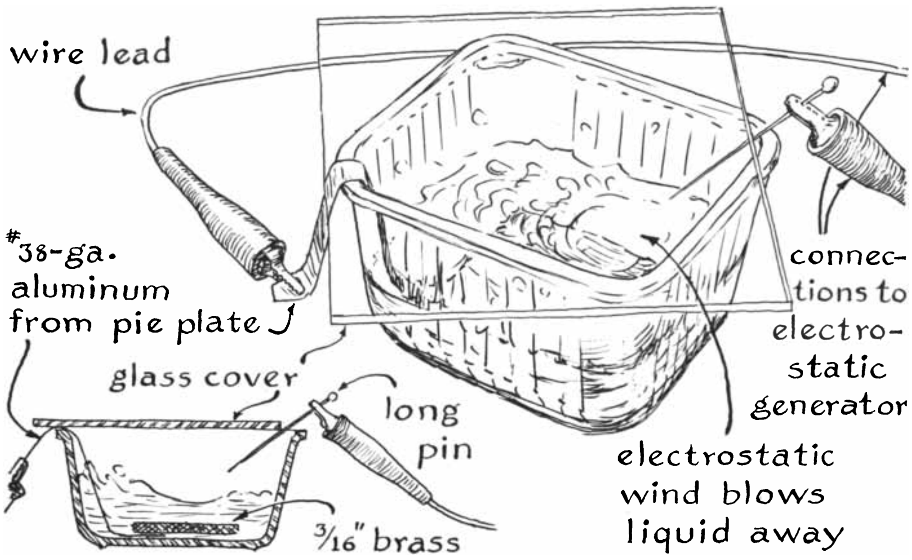
"I also made a little whirligig with pointed ends of sheet aluminum and poked a hole through its middle with an awl. The finished piece was threaded on the wire that terminated in the brass sphere and was installed in the flask [*see top illustration on this page*]. The second terminal of the generator was connected to a movable point close to the outer surface of the flask. When power was applied, the whirligig spun with much vigor and rose to the surface of the liquid. I turned the tips of the points upward in the hope that the downward thrust of the blades would keep the thing submerged, but it continued rising to the surface (where it made a great sloshing). The position of the external electrode made little difference in the behavior of the whirligig except when it was placed near the surface of the liquid. The rate of spin then increased.

"Thereafter I investigated the effect of a pointed electrode that was supported in air close to the surface of the liquid. Pointed electrodes in air create an 'electric wind.' I wanted to check the effect of the wind on the oppositely charged surface of the liquid. A rectangular brass electrode of opposite polarity was placed at the bottom of a refrigerator dish, which was covered by a sheet of glass to prevent the escape of toxic fumes [*see bottom illustration on this page*].

"When a sharp needle was held as shown, the liquid was blown off the brass electrode with a big whoosh. A Van de Graaff generator capable of developing 220,000 volts was then substituted for the Wimshurst machine. (The generator also came from the Edmund Scientific Co.) When the generator was turned on, most of the liquid was promptly blown out of the dish!

"After airing the room, I resumed experimenting with the Florence flask. This time I seeded the liquid with a small pinch of aluminum powder of the kind used as a pigment in aluminum paint. My purpose was to observe the interaction of many charged but individually insulated particles. Only a little powder is needed—about the amount that could be piled on the flat end of an unsharpened lead pencil. Most of the powder sank to the bottom of the flask, but many particles remained in suspension for more than 24 hours.

"The flask was fitted with a pair ot metallic electrodes; one was a thick, rounded disk and the other was a half-inch sphere spaced about an inch away from the center of the disk [*see top illustration on opposite page*]. The flask was lighted on one side by a shielded lamp so that the particles could be observed easily. When the field was applied, some

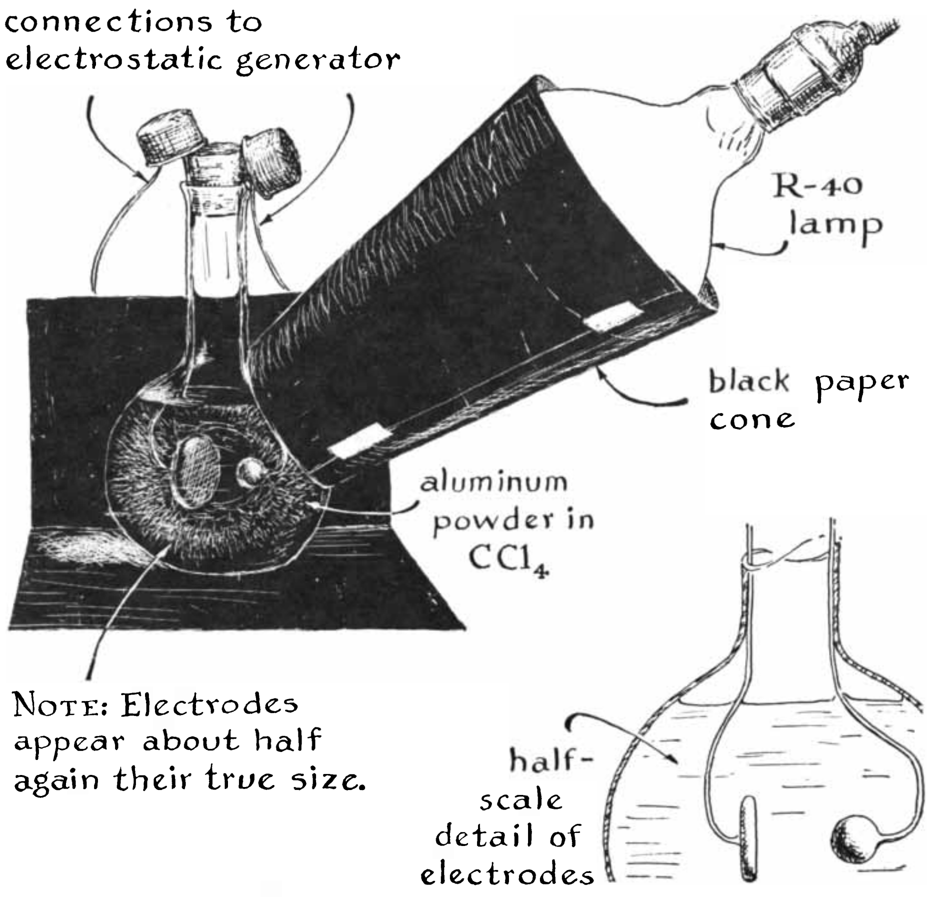


Equipment for inducing waves in a liquid electrostatically large areas of particles flashed brightly with reflected light and other areas became darker. Evidently the particles aligned themselves with their long dimensions in the direction of the field, some groups reflecting more light in the direction of the eye and others less light. Particles suspended between the electrodes darted continuously back and forth from the disk and the sphere, simulating the movement of electrons and ions in a gas-discharge tube. When one terminal of the machine is attached to the electrodes and the other to a sheet of aluminum foil placed under the flask, all the liquid becomes charged and most of the powder that has settled to the bottom boils up into suspension.

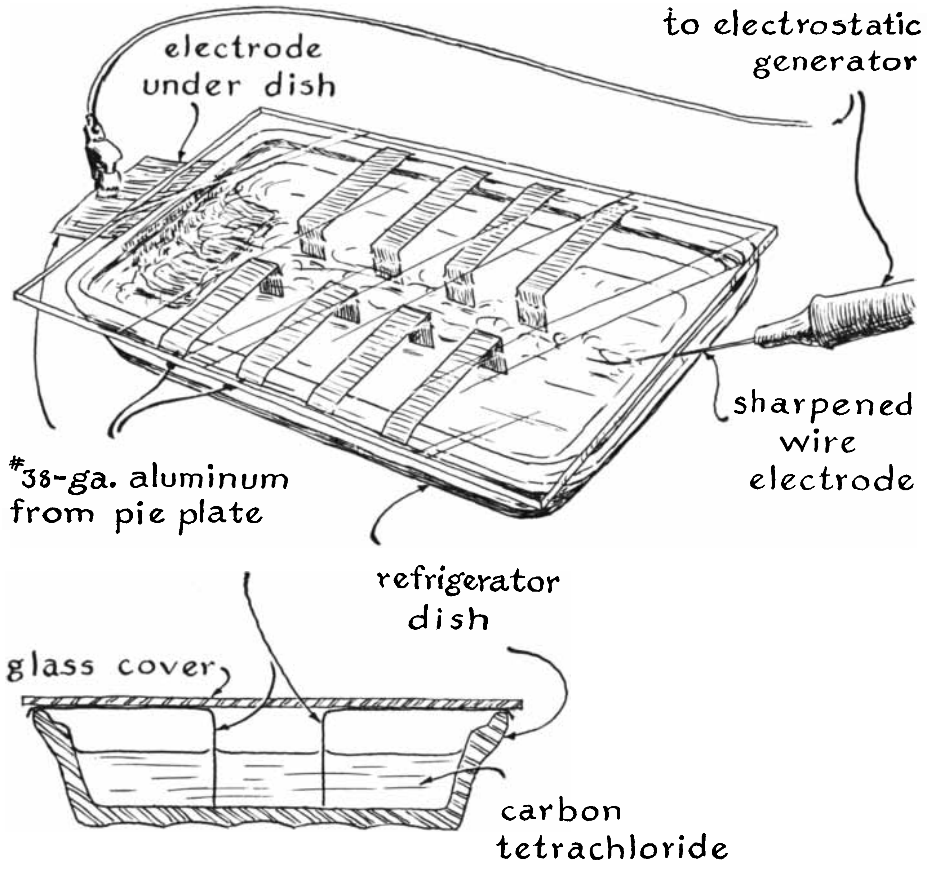
"A sewing needle was now attached to a flexible lead and fitted with an insulating handle so that it could be manipulated. The needle was substituted as an electrode for the aluminum foil under the glass. When the point was brought near the outer surface of the flask, the effect suggested that an electronic wind was blowing through the glass. The particles rushed away from the point in the form of a jet.

"This effect gave me the idea of simulating an atom smasher such as the electrostatic accelerator with which the British physicists J. D. Cockcroft and E. T. S. Walton transmuted lithium into unstable beryllium. The first model consisted of a rectangular refrigerator dish about eight inches long and an inch deep, fitted at one end with a sheet of aluminum that served as an electrode [*see bottom illustration at right*]. A needle point at the other end simulated the source of particles to be accelerated. The aluminum represented the target. Four electrodes were placed along each side of the dish to simulate the equipotential rings that distribute the electric field uniformly along the Cockcroft-Walton accelerator. When power is applied, aluminum particles stream to the target in a beamlike array. For best results the refrigerator dish must rest on a block of Styrofoam to prevent charge from leaking away. If the liquid is carbon tetrachloride, a sheet of glass should be placed between the dish and the plastic to protect the Styrofoam from the solvent. The dish must also be covered with a glass sheet to prevent the escape of the toxic fumes.

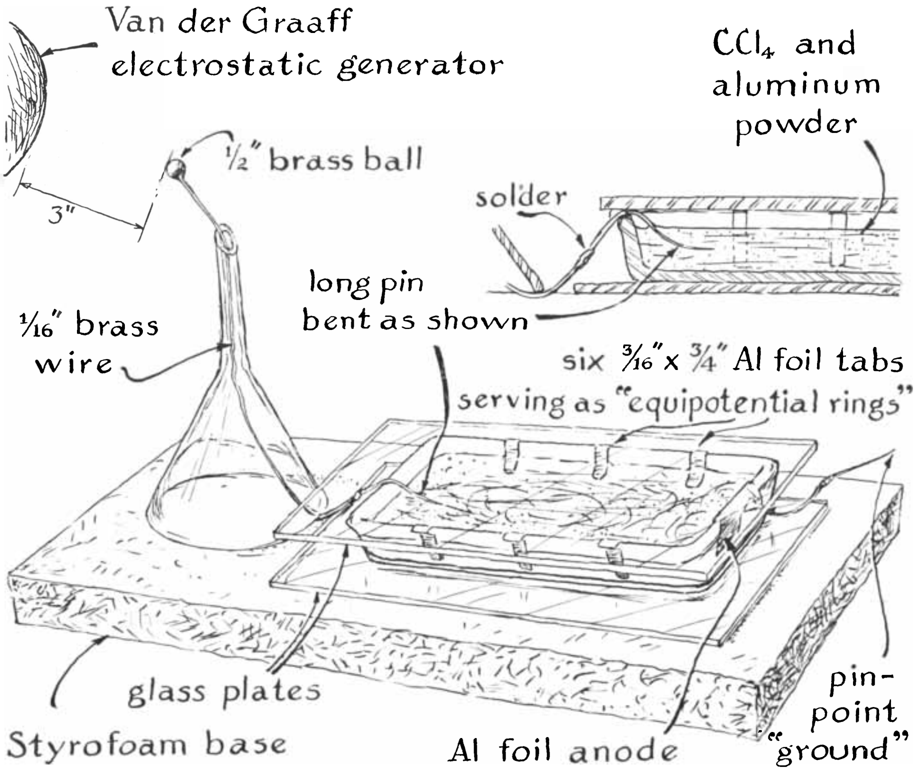
"I made a second version of the accelerator for use with the Van de Graaff generator. Because of the higher power the number of equipotential 'rings' was reduced to three on each side, and they were placed flat against the sides of the



Setup for observing electrified particles in a liquid



Apparatus for simulating an electrostatic accelerator at low power



Simulating an electrostatic accelerator at high power

dish [*see illustration above*]. These electrodes require no wiring. They become charged through the air. The target electrode was grounded, in effect, by a lead that terminated in a needle point facing away from the generator. The accelerating electrode was connected to a lead that terminated in a brass sphere.

"Corona discharge between the sphere and the high-voltage terminal of the Van de Graaff machine energizes the apparatus. Once I accidentally grounded the target and moved the generator within about an inch of the small sphere. When I applied power, the intense field blew most of the liquid out of the dish!"

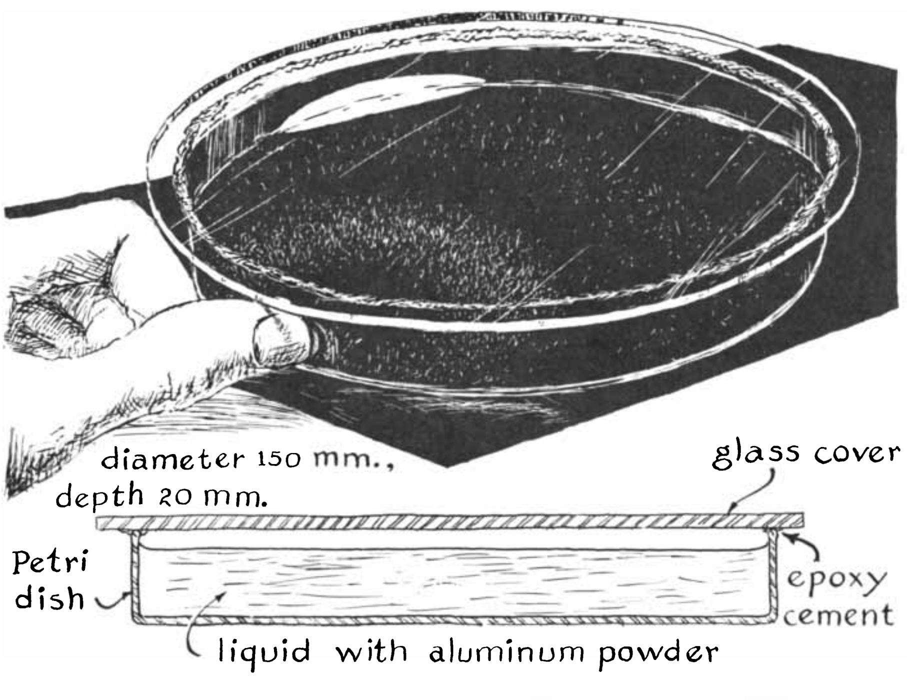
James R. Bailey, a high school student in Milwaukee, submits an interesting apparatus that also uses aluminum powder in suspension. It is for displaying convection currents: the streaming induced by gravity in gases and liquids when they are heated or cooled nonuniformly. Bailey writes:

"The simple apparatus consists of a shallow glass jar that contains aluminum powder suspended in a volatile solvent such as trichloroethylene, Freon T. F. or wood alcohol. The jar is covered by a glass disk, such as the crystal of an alarm clock, that is sealed in place with epoxy cement. A squat peanut butter jar can be used or, better, a large Petri dish. The aluminum powder can be obtained from dealers in art or sign supplies. Use a very small pinch of the powder, just enough to make fairly dense swirls when it is stirred into the liquid. Particles that persist in floating on the surface after the stirring can be skimmed off and discarded.

"Place the sealed jar in the refrigerator for a few minutes. When it has cooled, remove it and touch the side at any point with the tip of your finger. Almost instantly vivid silvery waves will rush away from the warmed point toward the center of the jar. The action will persist for several seconds until the glass cools. The reason for the effect is that heat lowers the density of a relatively thick zone of solution at the edge of the dish. Gravity then causes neighboring liquid of higher density to displace this zone, which spreads over the surface as a thin, high-velocity layer that sinks after cooling.

"Many other wave patterns can be generated by heating the jar in different ways. For example, support the jar on a pair of books or small boxes spaced about two inches apart and heat the center of the bottom of the jar with your finger. The resulting waves resemble the action of a boiling spring. Another interesting variation can be observed by letting the jar come to room temperature and then cooling a spot with an ice cube. By this means one reverses the action.

"Avoid exposing the device to excessive temperature. The resulting high pressure could break the seal. The solvents used are all toxic to some extent and most are flammable. The aluminum powder is not dangerous but makes a terrible mess if it is spilled. It can be dissolved with a strong solution of potassium hydroxide, sodium hydroxide or common lye. The finished apparatus is sturdy and inexpensive, and it never wears out. Like a kaleidoscope or an open fire, it generates abstract patterns of endless variety."



James R. Bailey's apparatus for demonstrating convection currents

ANNOUNCING
THE PUBLICATION OF

PSYCHOBIOLOGY
The Biological Bases of Behavior

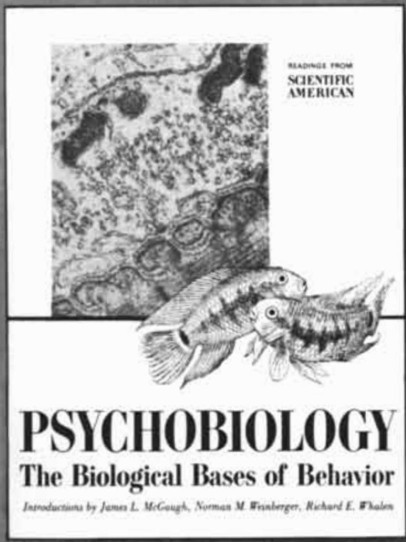
READINGS FROM SCIENTIFIC AMERICAN

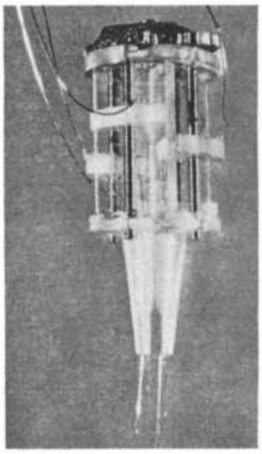
With Introductions by JAMES L. McGAUGH, NORMAN M. WEINBERGER, and RICHARD E. WHALEN, Department of Psychobiology, University of California, Irvine

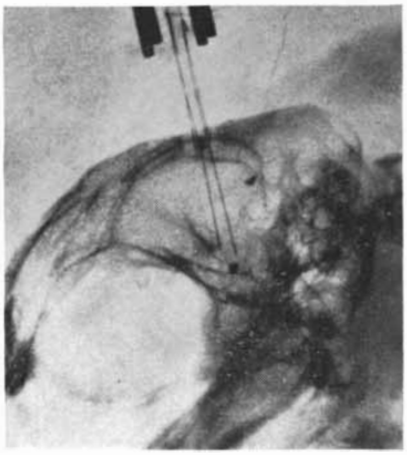
In the endeavor to understand, explain, and predict behavior, one of the most fruitful approaches has proved to be that of "psychobiology," an area of psychology that centers on the biological mechanisms underlying behavior. A large number of articles that have appeared in SCIENTIFIC AMERICAN have dealt with exciting recent findings of psychobiological research.

The present collection is of some 45 of the best articles, reproduced with full text, full illustration, and full color. They have been selected and organized so as to provide the reader with a representative view of some of the major areas of psychobiological investigation. Each group of articles has an introduction in which the editors put the readings into perspective and define the focus of each.

1966, 380 pages, illustrated, clothbound $10.00, paperbound $5.45







PSYCHOBIOLOGY, Readings from SCIENTIFIC AMERICAN

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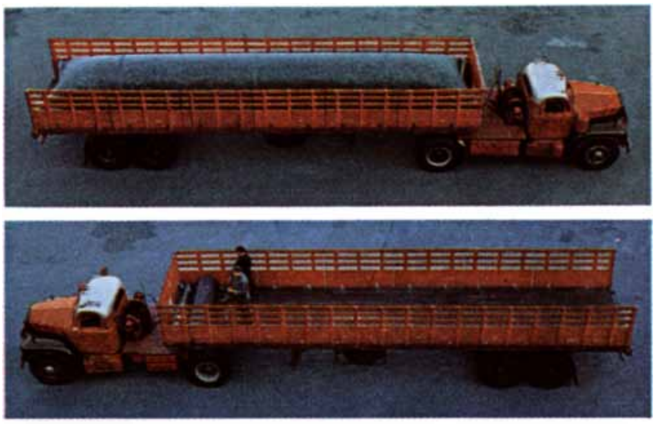
Collapsible containers: uses are expanding.

A,B,C,D,E: 50, 70, 300, 50, 66 cu ft Sealdbins. F,G,H,I,J: 375, 250, 500, 500, 55 gal. Sealdrums. K: 3,500 gal. Sealdtank.

Uniroyal collapsible containers are changing accepted ways of shipping, handling and storing a wide array of materials. Reason: substantial savings.



(Top.) Sealdtank and flatbed trailer can save some $10,000 compared with tank trailer of the same capacity. Empty, it frees 95 percent of cargo space for return shipment.

(Left.) Collapsible container is inflated to keep cargo from moving during shipment. (Right.) After run it can be deflated quickly to allow for unloading.

No non-rigid container can possibly be strong and totally protective. Ask any traditionalist.

Yet today, in application after application, this old assumption is being successfully challenged by Uniroyal (you might know us as United States Rubber Company).

Almost any material that is inherently fluid or flowable can be stored or transported in Uniroyal collapsible rubber containers.

Liquid cargoes, for example, include water, milk, petroleum products, vegetable oils, liquid sugars, alcohols, liquid fertilizers.

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Rubber containers save on handling and storage costs. They serve as a portable warehouse that can be left outside until the user needs the contents.

These Uniroyal multi-ply containers are tough as truck tires but far more flexible. When emptied they collapse to free as much as 95 percent of cargo space for the return trip.

The outside ply is an oil-resistant rubber which resists deterioration from heat, cold, sunlight and ozone.

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Uniroyal collapsible containers are effective in a wide temperature range from minus 30 to 135 degrees F. They are designed to operate at 5 psi.

Uniroyal makes three basic types of collapsible containers. The registered tradenames are: Sealdrum, Sealdbin and Sealdtank.

Sealdrums are extremely portable liquid-carrying containers. Even when fully loaded they can be lifted, rolled or safely dropped from trucks.

Sealdbins are used for handling exotic materials like corrosive chemicals and fine powders. The food industry employs them with nitrogen under pressure for protective storage of dehydrated foods.

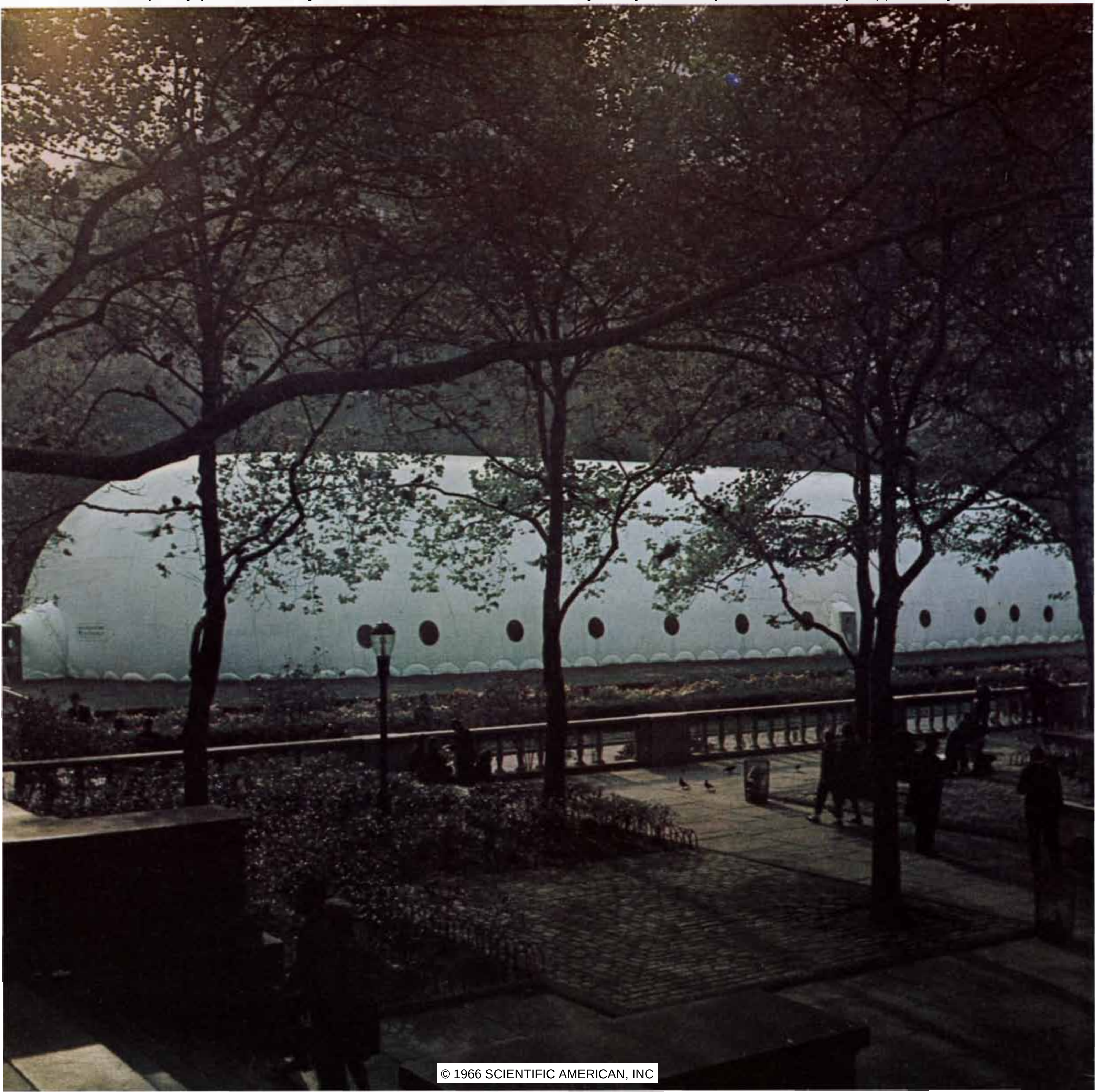
Sealdtanks with disposable polyethylene liners can handle liquid food and non-food products of all kinds. They eliminate the need for large investments in permanent tanks.

Another use for collapsible containers is cargo dunnage. Sold by Uniroyal under the Shor-Kwik tradename, they take the place of bracing, strapping, bolting.

Continued...

Collapsible container concept is practical for other applications.

Temporary pavilion built by Air-Tech Industries is made of Uniroyal vinyl-coated nylon and is entirely supported by air.



BOOKS

An examination of the quantum jumps in the growth of quantum mechanics

by Rudolf E. Peierls

The Conceptual Development of Quantum Mechanics, by Max Jammer. McGraw-Hill Book Company ($10.50).

The history of science is an interesting subject, and the growth of the quantum theory is one of its most fascinating topics. It is therefore good to have a thorough and readable account of it. To a physicist of the older generation, who saw the final formulation of quantum mechanics take shape before his eyes, the later chapters of such books bring the strange sensation that always comes with the realization that one has lived through a passage of history. By the same token one has an opportunity to verify that the author has done his job well and has faithfully reconstructed the spirit and the events of that time. In this Jammer has certainly succeeded, as only a writer trained in historical research and familiar with the content of quantum mechanics could succeed. Moreover, he presents many details I had either missed at the time or did not remember.

To the younger physicist, who found nonrelativistic quantum mechanics a completed discipline when he learned the subject, it is all ancient history. For him (as for us with the beginnings of quantum mechanics, in particular the work of Max Planck) the conceptual difficulties in getting used to the ideas make it seem a complete mystery how people could ever have arrived at them in the first place. It is to satisfy this kind of curiosity that we need books on the history of science.

Jammer's book is limited to nonrelativistic quantum mechanics and omits later developments such as field theories and the study of elementary particles (on which another book is promised). This is a good division; these later developments are still in progress, and a historical account of them would be of an entirely different nature. It is also logically consistent for Jammer to exclude the relativistic wave equation of P. A. M. Dirac. Although this equation was originally formulated as a one-particle wave equation, it can be given a satisfactory interpretation only if the description includes the creation and annihilation of particle-antiparticle pairs, and accordingly it is indivisible from field theory. As a price for this consistency Jammer has to forgo the opportunity of bringing in the Dirac theory in places (for example the discussion of particle spin) where it could have helped to complete and deepen the understanding of physical phenomena and of the structure of the strictly nonrelativistic theory.

The term "conceptual" in the title means, I take it, that the book is concerned only with the principles of the theory. Mathematical techniques are omitted unless they were essential for the development of the theory. Applications are likewise left out unless they were crucial for establishing the theory's validity.

Jammer's preface refers to the need for a "scholarly" study of quantum mechanics, and in implying that this is what he has provided he is not being immodest. He has taken material from original papers and from correspondence; he has used the "Archive for the History of Quantum Physics" and he has personally interviewed many of the surviving workers of the period. The result is certainly a scholarly piece of work, but it is by no means dry or pedantic. The presentation is lively and does not let detail obscure the main thread of the story. Each chapter centers on one main step in the development of quantum mechanics. The history of the subject is such that in most cases one name, or a small group of names, would have served equally well as chapter headings: "Planck," "Bohr," "Bohr-Sommerfeld-Pauli" and so on.

Perhaps the most interesting episode in the story is the introduction of the quantum itself by Planck. To the reader of a physics textbook it seems incomprehensible how anyone could have arrived at this postulate. Jammer's first chapter describes fully and well Planck's struggle to account for what he saw clearly as an important and general property of radiation, how he first regarded his attempts to construct a formula to fit the known distribution of black-body radiation as derivations within the framework of classical physics, and how he came to realize the revolutionary nature of his postulate (to which he never seems to have reconciled himself completely).

Jammer raises the interesting speculation of whether the development would have been simpler if instead of the black-body radiation, with its involved thermodynamic and statistical elements, some other fact, such as the specific heat of solids or the stability of atoms, had served as a starting point for modifying classical physics. It seems to me that the actual development was the natural one. The values of specific heat were a difficulty for classical kinetic theory, but this negative fact could only have served to show that the classical theory did not work. Specific heat did not present a quantitative and universal law calling for an explanation in the way black-body radiation did. The stability of atoms did not even point with certainty to a breakdown of classical physics until Rutherford's model of the atom was clearly established. In this connection I find it surprising that throughout the development of the theory of the atom it never seems to have been seriously suggested that forces other than electromagnetic ones were at work. In the face of many apparent contradictions it was always firmly taken for granted—rightly, as it turned out—that the familiar inverse-square law must be capable of explaining the structure of the atom.

In spite of its success Planck's hypothesis raised great conceptual difficulties. The greatest was the contradiction between the corpuscular nature of light, which was not a necessary implication in Planck's reasoning at first but was firmly brought out by Einstein, and the well-established wave nature of radiation. Jammer re-creates the state of bewilderment in which physicists found themselves over this paradox, and later found themselves over the similar duality of electrons with particle and wave properties. This bewilderment continues through the entire development until the final resolution of the paradox by the interpretation of waves as relating to probabilities, and by the uncertainty principle.

The second stage, Niels Bohr's theory of the hydrogen atom, was far more complex in origin than the simple argument by which one would sum up this step today in a presentation to students. The chapter follows Bohr's reasoning in fair detail, and describes it in its setting of other conceptual developments at the time. This chapter contains the one substantial lapse I was able to discover in the book. Jammer says of J. J. Thomson's model of the atom that it failed to account for the experiments on the scattering of alpha particles "which were carried out a few years later by Thomson's students, Geiger and Marsden." I have not checked whether Geiger and Marsden were at any time Thomson's students, but the phrase certainly would not lead one to think that these experiments were done in Rutherford's laboratory at Manchester at Rutherford's suggestion and under his guidance. The point is unimportant to the theme of the book, but the slip is surprising in a book written with so much care.

With the third chapter we enter the period in which quantum theory becomes a practical tool of the atomic physicist. It was a period of rapid progress, in which theory and experiment stimulated each other mutually. The theory was extended and deepened by Arnold Sommerfeld's generalization of Bohr's quantization rules, by Paul Ehrenfest's application of the adiabatic principle, and later by Wolfgang Pauli's exclusion principle and the idea of electron spin. New mathematical tools were developed for handling more complicated dynamical problems, the greatest tour de force probably being Pauli's theory of the hydrogen-molecule ion. These ideas led to a detailed understanding of atomic structure and of many features of atomic spectra.

Yet quantum theory was still incomplete. One had to use electron orbits taken from classical mechanics together with "quantum jumps" quite foreign to the classical picture. For some problems the quantum conditions could not be applied at all; for others they could be applied in different ways, which led to different statements about the orbits. In this context Jammer overrates the part played by the development of more powerful analytic techniques by P. S. Epstein, K. Schwarzschild and others. He refers to the ambiguity of the orbits in a "degenerate" system, in which there is more than one way to use the quantum conditions, and implies that the more sophisticated techniques could remove this ambiguity. This was not the case; the work described was related to the Stark effect, in which the external electric field removes the degeneracy.

For predicting the intensities or the polarization of the spectral lines one had to use Bohr's correspondence principle. The book does not give an explanation of the actual content of the correspondence principle; this is not surprising, because it is remarkably difficult to give a clear and brief summary of its substance. There was no general prescription for applying it, and in a sense it was a way of thinking rather than a theoretical rule. Yet it was an essential and deep part of the theory and yielded many predictions that were found to agree with experiment.

The next two chapters describe the completion of a coherent system of quantum mechanics, with its two independent and apparently unrelated beginnings: the matrix mechanics of Heisenberg and Max Born, starting from the idea of embodying the correspondence principle in a consistent mathematical scheme, and the wave mechanics of Schrödinger, starting from Louis de Broglie's idea of matter waves. The equivalence of these two formulations was demonstrated almost immediately by Schrödinger's recognition of the relation between wave functions and matrix elements, and was further clarified by Dirac's use of a general operator formalism.

The impressive thing about this development was not, as in the case of Planck's postulate, its unexpectedness but rather the speed with which, once the first step had been taken, all the consequences were thought out and appropriate mathematical techniques developed and applied, so that in an incredibly short time the tentative new ideas had become a complete theoretical system. For a while the old difficulty about the wave-particle duality remained, and there were other difficulties about relating the formal quantities appearing in the theory—the wave functions and matrices—to actual physical phenomena. The answer was provided by Born's interpretation of wave functions in terms of probabilities (which, as Jammer shows, had its forerunners in remarks made from time to time in the earlier discussions of the dilemma) and its generalization to any kind of measurement by the transformation theory of Pascual Jordan and Dirac. The consistency of this view, and the limitations on the use of classical concepts it implied, were brought out by the uncertainty principle of Heisenberg, and more generally and fundamentally by Bohr's formulation and elaboration of the concept of complementarity. To my taste Jammer puts rather too much emphasis on the work of John von Neumann and David Hilbert on these fundamental problems. This work undoubtedly added a welcome mathematical rigor to the foundations, but it did not have as large an impact on the physical interpretation and insight as one would gather from the weight given it in the book.

Chapter 7, which deals with the uncertainty principle and complementarity, is headed "The Copenhagen Interpretation." This term is used by very few physicists and seems to belong mainly to the vocabulary of the philosopher of science. Not that any physicist would fail to acknowledge the importance of the work of Bohr and others working with him in Copenhagen to a proper understanding of quantum mechanics. But the phrase suggests that this is only one of several conceivable interpretations of the same theory, whereas most physicists are today convinced that the uncertainty relations and the ideas of complementarity are essential parts of the structure of quantum mechanics, without which the theory would be like *Hamlet* without the Prince. Jammer does not maintain it to be otherwise but appears to leave the question open. A sentence in his preface says: "Though not necessarily the only logically possible interpretation of quantum phenomena, it is *de facto* the only existing fully articulated consistent scheme of conceptions that brings order into an otherwise chaotic cluster of facts and makes it comprehensible." A discussion of alternative interpretative attempts is promised for a later volume.

We shall await this new book with interest, but meanwhile it may be a legitimate comment that even the cautious word "attempts" may be too positive a description for what are only programs to construct some new ways of interpretation that are not yet clear even in outline. Most of us would feel convinced that it will not prove possible to graft on to quantum mechanics some new kind of interpretation without changing the results, that is, the observable predictions of the theory. In particular it seems certain (as far as such a negative can ever be certain) that one cannot make such an alternative interpretation a causal one in the deterministic sense.

This is not to say that quantum mechanics is the last word. It may well have to be refined further to cope with the as yet unsolved problems of elementary particle physics, and together with changes in the basic laws new ways of thinking may well be required. This would be in the same sense in which quantum mechanics is a refinement of Newtonian mechanics. It would not be a new interpretation any more than quantum mechanics is a new interpretation of classical physics.

In a concluding chapter Jammer raises the question of "whether the resulting conceptual scheme... falls in line with the historical development of physics through the ages." Judging by its place at the end of the book this must be an important question, but its precise significance eludes me. I can think of ways of interpreting the question that would require a positive answer, and others that call for a negative one. The arguments used to find the answer do not really clarify the question for me, but I feel comforted by the final conclusion: "From this point of view quantum mechanics may rightfully be regarded as falling in line with the general development of theoretical physics."

I should like to comment on two asides in the book. One is the discussion of the influence of philosophy on the development of physics. Part of this discussion consists of evidence that in his thoughts about the basis of the quantum theory Bohr was strongly influenced by the philosopher Harald Höffding and indirectly by Kierkegaard. For this a good case is made out. The rest, however, is concerned with rather tenuous connections. It contains quotations to show that several writers, including Henri Poincaré and the Viennese physicist Franz Exner, had introduced concepts of probability in advance of their use in interpreting quantum mechanics, and that these differed "fundamentally from the traditional notions of probability as used, for example, in classical statistical mechanics." The quotations, however, might well have been taken from a textbook of statistical mechanics; they are consistent with precisely that kind of probability. Jammer does stress the incomplete and conjectural nature of this section.

The other aside is the question, raised in the preface, of the value to the physicist of a knowledge of the origins and the development of his subject. I would agree emphatically with Jammer's statement that "some knowledge of the dramatic struggle of ideas that preceded the formation of quantum conceptions ... is indispensable for a profound comprehension of its physical significance." I would even go somewhat further than he does. He seems to accept the practice of teaching quantum mechanics to the student in a deductive and axiomatic manner so as to save him trouble, but he would like some of the historical approach added. I find that most students develop a real understanding of the subject more quickly and more effectively if the principles are not just presented as axioms but their motivation is developed from the kind of reasoning from which they in fact originated historically. There are, of course, excellent texts using the deductive method, such as Dirac's, and there are always some students who find it easier to become acquainted with the subject that way, and to postpone an appreciation of its motivation and its significance until a later stage. But for the majority the other approach is better. In this respect quantum mechanics differs from subjects such as classical mechanics, which are normally taught by starting from Newton's laws, with perhaps a perfunctory introduction concerning their motivation. The difference is that, although the concepts of Newtonian physics are also by no means self-evident, and have to be abstracted from experience, they are so familiar from our everyday experience and our early education that we are ready to accept them without question. It requires an intellectual effort to appreciate that there are questions to ask. With quantum theory, whose concepts are so far removed from any direct experience, the situation is different.

For the first introduction to the subject, the arguments, and the account of the development, must of course be simplified; it is not necessary to raise every question that proved a difficulty in the past, nor is it important to distinguish the contributions to the subject of individual workers. A thorough historical study, such as Jammer's, is best appreciated by a reader already familiar with the substance of the subject.

Short Reviews

ANCIENT GREEK GADGETS AND MACHINES, by Robert S. Brumbaugh. Thomas Y. Crowell Company ($4.95). How delightful to meet Professor Brumbaugh! Learned professor, author of works on Plato and on Greek philosophy, he is a confessed and proved gadgeteer of talent. In this brief, informal and well-illustrated book he discusses the minor technology of Greek culture, from the days of Knossos up to Heron of Alexandria. His interest is caught not so much by great ships or smithies as by the odd gadgets he has found in abundance: coin-operated machines for dispensing holy water, lottery machines for fairly selecting jurors by strict chance, pull toys, commodes and ceramic sausage grills. One main source is the books of Heron of Alexandria, which are a mine of information about the application of siphons, jets and vacuum to the working of small machinery and of mechanical designs, aimed particularly at the effects of the theater. Heron's great lightning effect is here restored to sense after the errors of the copyists, and his spherical toy in which a ball is suspended in still air alone is shown to work, and doubtless to represent a cosmological proposition.

Two themes recur: Greek gadgetry was not laborsaving in general, because slaves did the work. It found its justification in the domain of amusement and surprise. The use of coin-operated vending machines for dispensing ablution water saved the attentions of a particular citizen, the priest, for whom no slave could easily substitute. The second point is the dependence of the cosmological ideas of the philosophers on similar gadgets. Brumbaugh makes a good case for the direct outgrowth of Plato's illusion of the cave from a form of automatic theater actually in use. The design of self-moving simulacra of life seemed to hold a special interest in Greek thought, as it does in our own day. The spheres of Aristotle, and certain devices of Heron, are viewed as genuine physical models of cosmological schools of thought. The crystalline spheres of Greek cosmology are almost hardware; indeed, the author has worked out a conceptual design for actually building Aristotle's cosmic model, using independent electric-motor drives. The present book is a mere sketch, in a light vein, of all these ideas; it is good reading, and one expects someday that scholarship will go deep in exactly these directions. It seems probable that the modern split of the philological sciences from the physical ones has vitiated a good deal of our view of Greek thought. The famous cogwheel planetary computer of Antikythera stands as witness to that, along with the mysteries of the Athenian Tower of the Winds. All these matters are broached here, but not finally winkled out. One large point is proved: If we learn all we know of a culture from its books, we are apt to see it in too bookish a light.

ZERO DEFECTS, by James F. Halpin. McGraw-Hill Book Company ($10.50). During the prewar Five-Year Plan, one Stakhanov became a byword in the U.S.S.R. He produced over and above all quotas. Paeans, widespread emulation, hero medals, editorials, posters, prizes—a flood of public exhortation sought to make all Russian workers Stakhanovites. Here is the up-to-date American counterpart of Stakhanov. America does not always need quantity of production, as perhaps your parking lot will demonstrate, but quality is quite another story. Halpin is the inventor (in 1962) of a management plan for seeking a new approach to the manufacture of goods of quality. He works for Martin Marietta, which builds missiles in Florida, and in this book he details the whole scheme, down to forms to be used in the various facets of the program. Just as around Stakhanovism hung the scent of the speedup, so in *Zero Defects* there is a note of wooden paternalism. But one cannot fail to admire the intentions of the program, striking as they do at some of the roots of the social ills of modern industry. The program speaks to craftsmanship and to human dignity; it tells the worker that whatever he does, it is important to himself, to the company, to the country. It is a positive program; no worker is ever blamed for defects, although he is praised for perfection. It includes the entire firm: management, unions, suppliers, workers' families, the community. The finished product is brought right into the first-assembly shops so that the workers can see what their many steps actually do for the user. Quality awareness, with measurements, charts, records and so on, comes next. Finally there arrives a phase of error-cause removal, with an organized effort to improve tools, procedures and working conditions. The company spends money on all of this, real money, but when it works, management receives a rich reward, ten- or twentyfold, for the bread cast on the waters.

And the program does work. A solderer makes half a million joints without error; a finance clerk makes hundreds of thousands of payroll computations without error. Hundreds of such records are set in a large plant. Everyone is concerned, from the research scientist ("the most difficult sin-

gle person... to measure") to the sweeper. Whatever one may think of the hortatory talk, of the sentimentality, the danger of hypocrisy, there is a deep human note under the gloss. Japanese export goods were once the hallmark of shoddiness; today Nikon and Sony are proud marks of quality. In Japan craftsmanship has long been supreme, although it was never exported from the lofts of Osaka. Now that the world knows the true Japanese worker, are not all men a little enriched?

The Department of Defense buys tested performance, not brand names. If American consumer-goods producers are not misled by the quest for immediate profits and by the charm of their copywriters, *Zero Defects* might spread. It is interesting that, among some 60 industries with two million workers listed as adherents to its message, trucks, buses and airplanes appear but not automobiles. Detroit papers please copy.

THE GRAPHIC TIMETABLE OF THE HEAVENS. Maryland Academy of Sciences (35 cents). INFORMATION PLEASE ALMANAC. Dan Golenpaul Associates ($1.60). THE WORLD ALMANAC, edited by Luman H. Long. Newspaper Enterprise Association ($1.65). CELESTIAL CALENDAR AND HANDBOOK, by Charles F. Johnson, Jr., Watertown, Conn. ($1). THE OBSERVER'S HANDBOOK, edited by Ruth Northcott. Royal Astronomical Society of Canada ($1). THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC, 1967. U.S. Government Printing Office ($3.75). Probably the first of natural orders to be perceived, the configurations of the heavens are still a yearlong display of beauty and wonder free to all who will watch with understanding. Here is a sequence of aids transmitting that knowledge won by science since long before the dawn of writing. *The Graphic Timetable* is a single sheet on which is plotted for each day of the year the time of rising, setting and meridian passage of sun, moon, planets and a number of other objects. Other configurations too are noted in due order. The sinuous curve of the way of the planets and the smooth progress of the stars are strikingly presented by this compact and rich best buy among almanacs. The two larger books of data contain the heavens as mere splashes from a spate of facts. There it is in words and tables, the entire sky for the year to come. *Information Please* is the simpler, written in better prose, a little more readable; *World* is terser, more nearly complete. One wry circumstance: these celestial tables are found in so popular a publication less for the astronomical value than for the astrological value they give; *World Almanac* admits that. The *Celestial Calendar* presents the visual sky in monthly-calendar style, but it adds much for the amateur with a telescope, for instance the satellites of Jupiter and Saturn. The Canadian booklet is a more finished and thorough version still, for watchers with unaided eye or telescope. The final work, internationally produced, born of computers, is a massive volume of tables, the fountainhead of all the others, and an indispensable guide for the profession.

In 1967 not much will occur to spice the wonder of the rounds. Jupiter and Venus will be a fine double evening star in early June, and all Americans who will rise in the small hours can watch a lunar eclipse on October 18. Californians have another such early-morning event on April 24. A modest partial solar eclipse can be seen by scientific Americans (except in Florida) on the morning of May 9. The nearly full moon will occult bright Saturn on the evening of October 16. Sun-grazing comets and supernovas may be displayed without notice, at the discretion of the Management.

SECRETS OF ELECTRONIC ESPIONAGE, by John M. Carroll. E. P. Dutton & Co., Inc. ($3.95). Generals, the adage tells us, always fight the previous war. Expert and candid interpretations, such as this book, are always forced to work on yesterday's headlines. About today's we must still guess.

This small, detailed but nontechnical narrative discusses the wars of the electromagnetic spectrum from their beginning in a British intercept truck in France during that August of 1914. The first tricks were as simple as recording on wax records Morse messages sent too fast to be directly transcribed! Now the radar-jammers cover wider and wider frequency bands. The ingenious receivers that record the opposition signals are magnetically tuned and fitted with extremely broad-band amplifiers, visually recording the signals picked up channel by channel, with intensity shown by brightness.

The "ferret" story of the Cold War years from 1949 to the U-2 and after is neatly told. More than 100 U.S. airmen were killed or imprisoned by the Eastern bloc while on these missions of intrusion between 1950 and 1964. We brought down no Russians, mainly because the Russians did not intrude often. They listened in from beyond the 12-mile limit. It seems that our gung-ho Air Force radio and radar practice is to stay on the air always, whereas the Russians prudently kill their signals once a ferret is near the borders, unless it actually intrudes. ("Once the Russians turned on their radar, they started shooting.") Current overflights into China are made by the Lockheed A-11, the 2,000-mile-per-hour and 100,000-foot-ceiling successor to the U-2. Some RB-57's are used and a few unmanned jet drones.

All of this is obsolescent. *Samos* satellites orbit each month or so, ejecting high-quality films and magnetic tapes over the sea as they pass near Hawaii, to be caught in the air by pairs of Flying Boxcars, maneuvering after the parachuting film with great nets. The spy in the sky picks up microwave and radio signals as well as photographs of remarkable detail—when the weather permits.

In Washington the red phones on the desks of the mighty form a wiretap-free system: they have cleared military operators, constant instrumental monitoring for unexpected new electrical loads added by would-be tappers, gas-filled cable shields with the pressure always measured, tricoaxial lines with a shielding conductor, which is also fed with strong noise signals to defeat inductive tappers. The sophisticated forms of "bugging," which surpass even the martini-olive transmitter, are also here. Modern debugging teams favor patrolling a room with a sensitive swept-frequency receiver whose output is a musical tone on a loudspeaker. Once the bug picks up its own signal it echoes it again, amplified. So the entire system emits the feedback squeal, dear to a generation that could put the telephone receiver up to the mouthpiece.

Spies are the commonplaces of the literature of adventure today. As John LeCarré explained, their lives are less careers of daring than they are pawns of cynicism. Electronic spying as well is by no means all ingenuity and courage; behind it lie the manipulation of news, the contagious cynicism of officials and the awful temptation to preventive attack. It is useful to have as antidote this rather gossipy and little-documented work, collecting what almost everyone knows but hardly anyone is willing to recount.

JANE'S WORLD RAILWAYS, edited by Henry Sampson. McGraw-Hill Book Company ($45). Since the turn of the century this London organization has published the world's standard naval

reference book. Growing with the navies and with time, *Jane's Fighting Ships* lists, depicts and details all naval ships, often even quite secret ones, with godlike omniscience and marvelous concreteness. For 50 years aircraft too have been recorded. Something about the knowing, factual, thorough treatment—the very idea of seeing the torpedo boats of, say, Uruguay, with their names and gunnery—has made the volume not only indispensable to the professionals but also enchanting to the mere browser.

With this book, published in earlier editions without Jane's august name but now acknowledged by the true parents, Jane's enters the lists of peaceful pursuits. Peace too has her victories. It is every bit as satisfying to read about diesels and maximum gradients and to see route maps as it is to pore over pages of gunboats, and it is far more constructive.

Where else could one hope to find the subway maps of Boston, Kiev, Osaka and Melbourne? Nearly everyone has seen photos of the superexpress trains of the Tokaido line, developing nine megawatts and having a top speed of 155 miles per hour. Here we also learn that they run at 60 cycles and 25 kilovolts, and are made by two firms, Hitachi and Kisha Seizo Kaisha. But who has seen photos of the charming small tank car, made in Spain for the transport of—what else?—olive oil? Or of the rakish four-car diesel-hydraulic train set made by VEB Waggonbau Görlitz in East Germany? These are in *Jane's* as a matter of course. It is understandable that the Chinese railways are very sketchily treated but less clear why Nigeria is so laconic. Finally, it is revealing to cite here the comment made about the 240-mile system of the Chemins de Fer Royaux du Cambodge (Cambodia): "Competition from road transport is increasing rapidly, and the Railway Administration are taking steps to combat it: 1. By demanding Government intervention for sensible coordination of all means of transport. 2. By improving the quality of service.... 3. By ...publicity. 4. By a reappraisal of freight tariffs." *Et tu,* Cambodge?

WILD FLOWERS OF THE UNITED STATES, VOLUME I, IN TWO PARTS: THE NORTHEASTERN STATES, by Harold William Rickett. McGraw-Hill Book Company ($39.50). By the pound this is not an expensive book. It is the first of five volumes (observe that it is one "volume" physically bound into two thick books) that will in the end cover the wild flowers of the entire U.S. It appears with the blessings of the New York Botanical Garden and with the support of many benefactors. The book has a costly glory: there are no fewer than 1,200 photographs of different flowers in stunningly beautiful and true color. All, or let us say nearly all, species of wild flowers belonging to the area are included in the text, some 1,700 species. For completeness and for visual clarity and beauty the book is unmatched. The textual apparatus is adequate, with some signs of editorial indecision. The index is excellent and includes both botanical and many common names.

THE PICTORIAL ENCYCLOPEDIA OF PLANTS AND FLOWERS, by F. A. Novak. Edited by J. G. Barton. Crown Publishers, Inc. ($10). This bargain volume, handsomely produced in Czechoslovakia, stands in contrast to the *Wild Flowers* reviewed above. It is no guide to the real fields and woods of any locality but a panoramic view of all that grows. Good rotogravure photographs of 1,000 growing things, 50 in color, fill these pages. You see bacteria and the great man-carrying lily pads of the Amazon, kelp, peyote, banana, pineapple and great cocoanut palm, orchids in color and even more beautiful in X ray, each with a compact botanical caption. It is a guidebook to an imaginary botanical garden, as rich as the 300,000 species of the plant kingdom. For browsing, reference, teaching and dreaming of travel.

THE THEORY OF THE MICROSCOPE, by L. C. Martin. American Elsevier Publishing Company, Inc. ($19.50). Physical optics has experienced a quantum change in the past decade, beginning with a rebirth of deep interest in the phase content of the optical signal and rushing on today with laser light so neatly coherent that linear amplifiers and superheterodynes for the optical wave band seem around the corner. Here is a superior text, stopping deliberately short of the great topic of reconstructed wave fronts, as in the holograph. Up to that point—in the study of the action of instruments with all degrees of coherence, of phase contrast, of interference microscopy and of all kinds of aberrations—the account is complete, up to date and helpfully illustrated. Professor Martin aims at a still higher goal: he sets all this out "for users of the instrument... who have no advanced knowledge of mathematics or physics." It is clear that a good deal of training is required—algebra, geometry, trigonometry and a smattering of calculus. Beyond that, the mathematics is developed here, up to the Fourier integral theorem, a tool of the greatest usefulness. This is a book of theoretical physics written for readers who are not theorists but who have patience, intelligence and a deep experience with the microscope, an experience that is bound to have enriched them with intuitions of wave phenomena better than those the physicist gains from his calculations. Recommended for serious microscopists of all trades.

AMPLIFIER HANDBOOK, Richard F. Shea, editor-in-chief. McGraw-Hill Book Company ($37.50). A brand-new definitive member of the class of engineering handbooks, this volume covers amplifiers of almost every kind: vacuum-tube, solid-state, magnetic, ionic (but not fluid amplifiers). There are 31 detailed chapters, divided into fundamental network analysis, with feedback and noise; devices, in catholic variety, and circuits, from direct-current to injection-laser. Graphs, circuit diagrams, component drawings and tables abound throughout.

THE OXFORD DICTIONARY OF ENGLISH ETYMOLOGY, edited by C. T. Onions, with the assistance of G. W. S. Friedrichsen and R. W. Burchfield. Oxford University Press ($16.50). This modest volume of 1,000 pages is a memorial to its chief editor, the last surviving editor of the Oxford English Dictionary. Compact and up to date, it is more than an accessible substitute for those 13 volumes. It dispels many myths in its clarity: *almanac* is not from the Arabic; *entropy* is based on a misunderstanding by Rudolf Clausius (called, alas, Clusius); *robot* reflects a real Czech meaning. Good reading, particularly where the tempo is less than staccato, and an invaluable reference.

THE RISE AND FALL OF MAYAN CIVILIZATION, by J. Eric S. Thompson. University of Oklahoma Press ($5.95). Grown 10 percent thicker in a decade, mainly with accounts of the great new digs at Palenque and Tikal of the Mayan Classic period, this authoritative and yet wonderfully clear and personal treatise appears anew in a second edition. Carbon-14 dates have supported Professor Thompson's correlations; Mayan Classic cities flourished in the time of Charlemagne. He is pretty hard on the claims of Russian computer experts of having "deciphered" the still illegible Mayan glyphs.

INDEX OF ADVERTISERS

JANUARY 1967

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