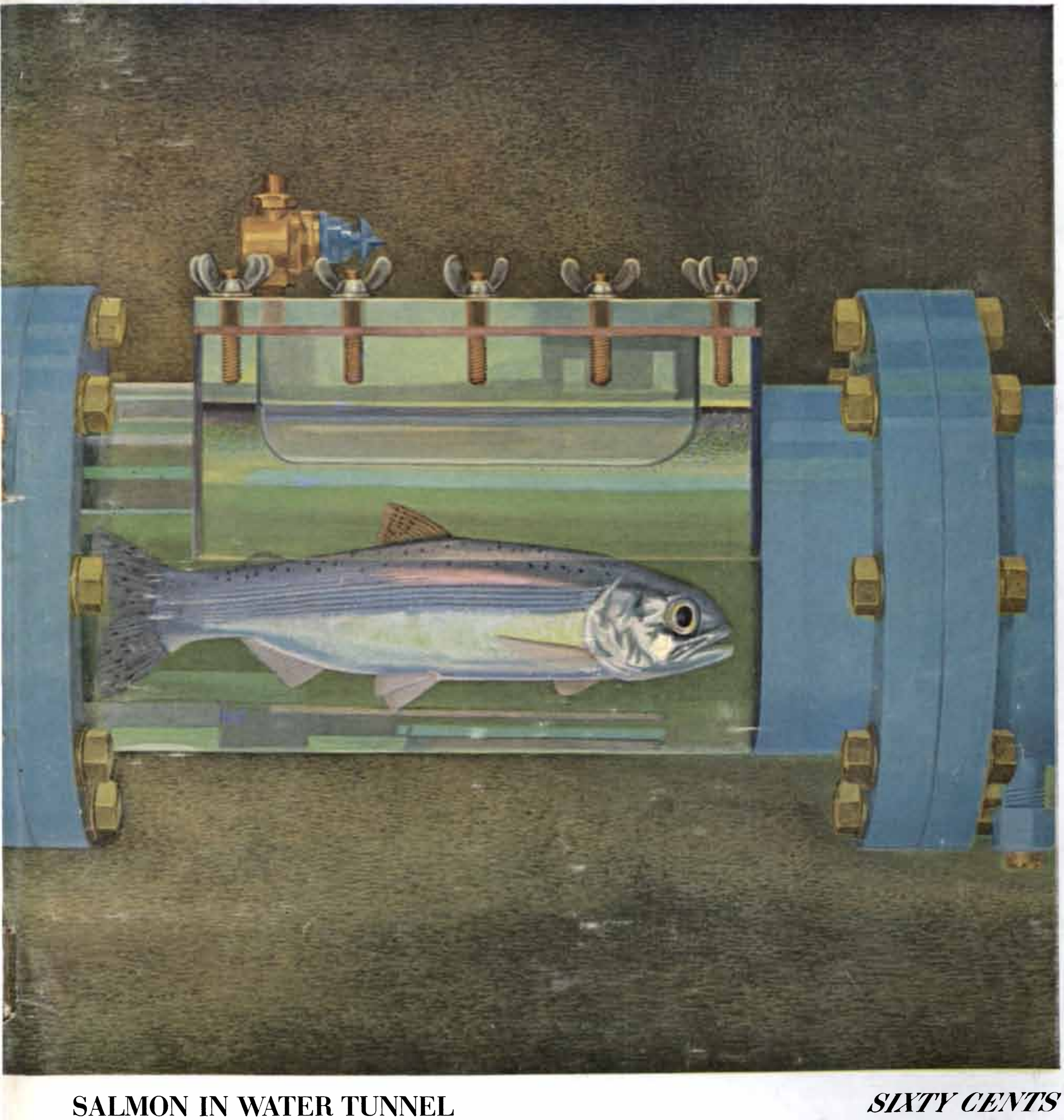
SCIENTIFIC AMERICAN

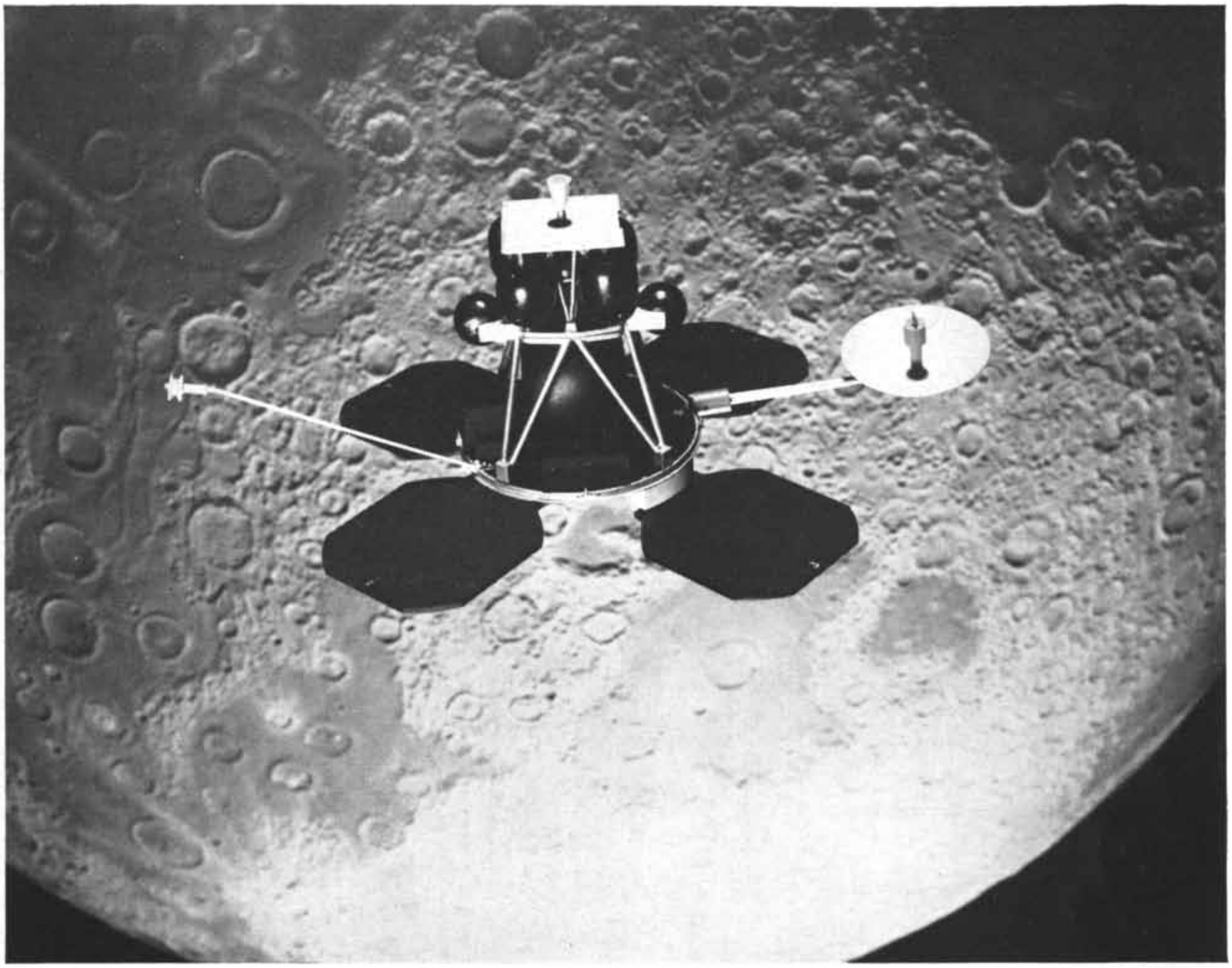


SALMON IN WATER TUNNEL

SIXTY CENTS

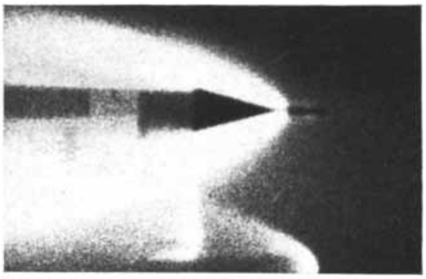
August 1965


500
60
80
400
100
300
200
150
M&T



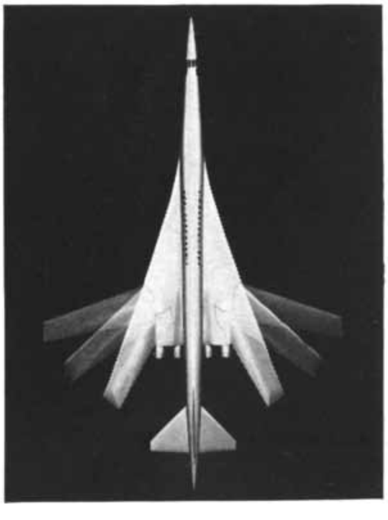
LUNAR ORBITER is camera-carrying spacecraft which will be launched into lunar orbit to photograph and transmit to earth pictures of large areas of moon's surface. Mission is to help locate best landing spot for astronauts, and to sense and report density of micrometeoroids and radiation near moon. Scientists will also track Orbiter to learn more about moon's gravity. Boeing is building 8 Orbiters for NASA, 3 for ground test, 5 for flight. First launch is scheduled next year at Cape Kennedy.

Capability has many faces at Boeing



BIG BLOW. Wind tunnel tests are used in air-to-ground missile studies. Boeing's vast missile, space booster and electronics experience in radar, guidance and penetration aids is helping to develop advanced attack missile system concept.

SUPERSONIC jetliner, under development by Boeing, could carry over 200 passengers across U.S. in two hours. Variable wing gives ideal sweep-back choices for supersonic and subsonic flight, plus straight wing for slow landings.



U.S. NAVY'S versatile new transport helicopter, UH-46A, built by Boeing's Vertol Division. UH-46A's replenish combat ships while underway (permitting maintenance of task force integrity), also perform search and rescue, personnel transfer, and other missions.

BOEING

Space Technology • Missiles • Military Aircraft Systems • 707, 720, 727, 737 Jetliners • Systems Management • Helicopters • Marine Vehicles • Gas Turbine Engines • Also, Boeing Scientific Research Laboratories

Established 1845 **SCIENTIFIC AMERICAN** August 1965 Volume 213 Number 2

ARTICLES

DEPARTMENTS

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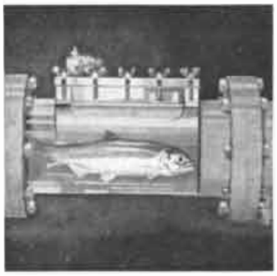

THE COVER

The painting on the cover shows a yearling Pacific salmon swimming in a laboratory tunnel that measures its uptake of oxygen and hence indicates its rate of metabolism (see "The Swimming Energetics of Salmon," page 80). The apparatus, which is called a respirometer, was devised by J. R. Brett and his colleagues at the biological station operated by the Fisheries Research Board of Canada at Nanaimo in British Columbia; their objective was an investigation of the remarkable metabolic performance achieved by migrating salmon. The salmon is in a chamber through which water is pumped at velocities that can be changed, thus varying the amount of energy required by the fish. Behind the fish, but not shown in the painting, is a screen that delivers a mild electric charge if the salmon touches it; the fish quickly learn to avoid the screen and so are induced to continue swimming. The fish depicted in the painting is a hatchery-reared member of the species known as the sockeye salmon (*Oncorhynchus nerka*); it is also frequently called the blueback or red salmon.

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Cover painting by Eric Mose

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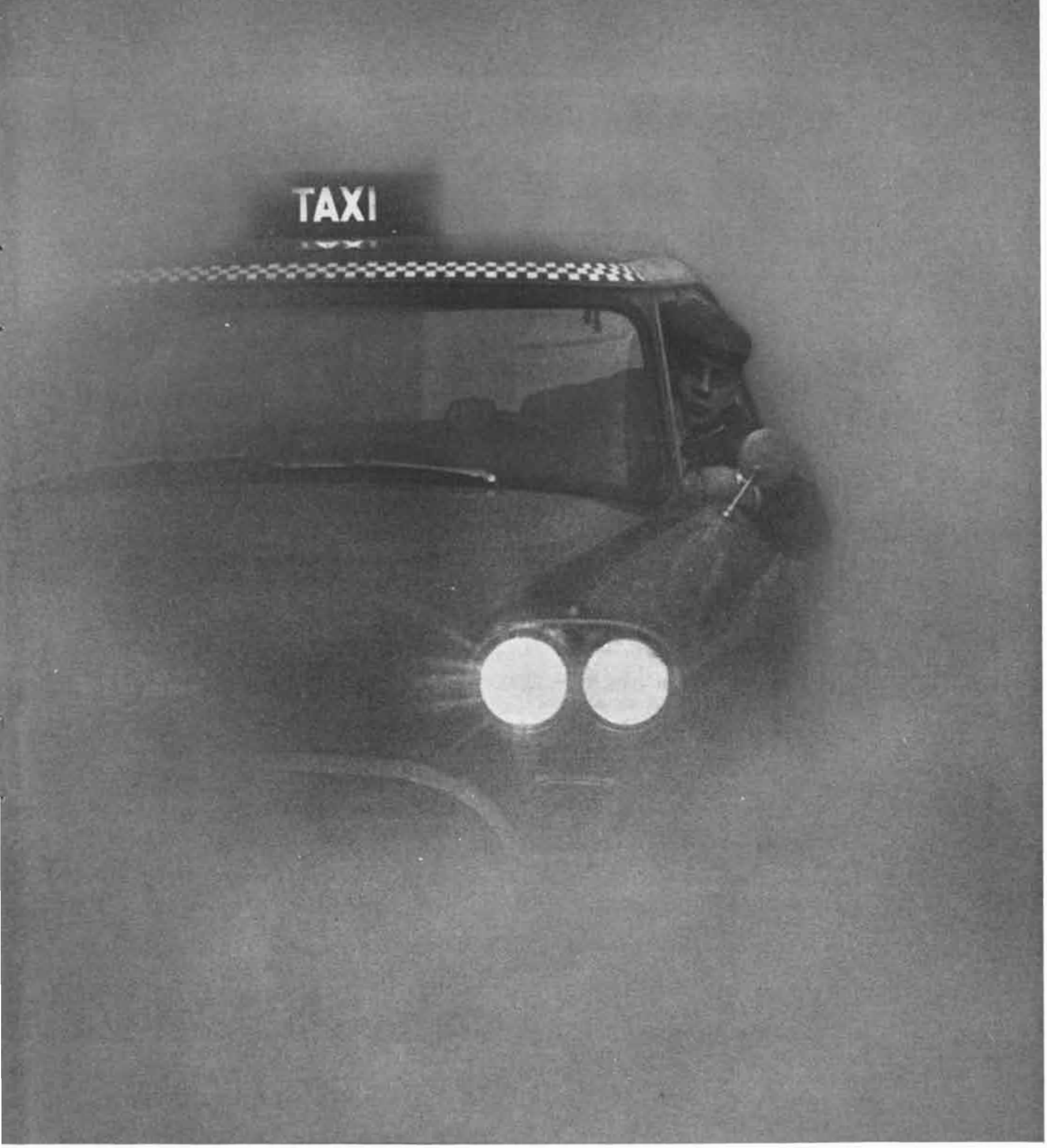

He'll soon have It Tougher than a Jet Pilot.

A cabbie driving from a fogbound airport into town has his hands full. And soon, more so than the pilot who brings in your jet.

Why?

Because completely automatic landings are not far off.

Flight delays and cancellations will then be only bad memories. (Last year, low ceilings cost airlines $70 million.)

A new ITT radio altimeter is a critical component of the BLEU Systems that has 15,000 test landings behind it.

This altimeter guides the aircraft via the autopilot during the final 60 feet of the approach and touchdown.

It's the latest refinement in instrument landing techniques. The ILS (Instrument Landing System) was developed by an ITT company. Every 30 seconds somewhere in the world an aircraft lands safely using an application of ILS.

Another significant ITT advance is DME (Distance Measuring Equipment) which continuously tells pilots their precise distance from the ground station within a radius of 300 miles.

International Telephone and Telegraph Corporation, New York, New York.

ITT

LETTERS

Sirs:

After reading the article by Professor Cyrus H. Gordon ["The Greeks and the Hebrews," SCIENTIFIC AMERICAN, February] I should like to enter a caveat on the subject of translations of the Phaistos disk (page 106).

In *The Times* for May 20 it is said: "The Professor is working on the assumption that...the disc...should be regarded as a ceremonial or decorative form of writing the language of Linear A script, i.e. North-West Semitic." It is clear from both this and your account that Professor Gordon reads the text from the center of the spiral outward. Gordon's statements are properly hedged with doubts.

Other recent authors, however, have stuck their necks out. Professor Benjamin Schwartz (*Journal of Near Eastern Studies,* Vol. 18, pages 105–112, 222–228; 1959) writes: "The language of the Phaistos Disc is Indo-European, probably the same as or similar to the Mycenaean Greek of the Linear B tablets.... The Phaistos Disc...now stands solved [by Schwartz], at least in its main features." Schwartz reads the inscription from the outside toward the center.

H. D. Ephron (*Harvard Studies in Classical Philology,* Vol. 66, pages 1–91; 1962) finds that the language of the inscription is a dialect of Mycenaean Greek. "We must conclude that the printing was done from the center outward, left to right." He has no doubts as to the correctness of his own solution and remarks of Schwartz's work: "Ignore any claims of solution for reasons discussed...."

Professor S. Davis writes (*The Phaistos Disk,* Witwatersrand University Press, and by implication in *Greece and Rome,* Vol. 11, No. 2, page 106; 1964): "The decipherment of the Phaistos Disk [by Davis] proves beyond the slightest doubt that the language of the inscription is Hittite." He reads the inscription from the edge of the disk toward the center.

Personally, as a result of physical experiments, which none of the authors quoted appears to have attempted, I must agree with John Chadwick. He writes (*The Decipherment of Linear B,* page 19): "The direction of the writing is from right to left" (meaning from the periphery inward). If this is so, then Gordon's partial translation falls.

Comparing the judgments of the four scholars quoted above (Gordon, Schwartz, Ephron and Davis), we must conclude: (1) that their results are absolutely incompatible with one another and (2) that at least three out of four—a majority—are certainly mistaken. Furthermore, since all four believe themselves to be correct, not only must a majority be mistaken in their techniques but also (3) the standards of self-criticism and of assessment of evidence of the majority (from which we must except Gordon, who qualifies his statements) must be illusory.

As a spectator of this parade of scholarship I am tempted to shout: "But the Emperor has no clothes on!"

ALAN MACKAY

Department of Crystallography
Birkbeck College
University of London
London

Sirs:

The crowding of signs on the Phaistos disk always takes place on the right-hand end of words; therefore the script must go from left to right, because crowding is never called for at the beginning but only at the end when space runs out. As a glance at the disk will show, this direction of the script means that the writing starts out at the center. Other Minoan texts found on Crete confirm the Cretan origin of the disk and show that it was not imported. Accordingly it is no surprise that the direction of the writing (from left to right) agrees with Linear A and B and that the signs in profile face right exactly as their equivalents in Linear A and B do.

The principle of acrophony is the new factor that marks an advance over earlier studies; it provides an additional and objective control over the phonetic values. It yields a number of consistent and interlocking readings including a whole formula attested in Ugaritic literature. In other words, the internal evidence now has external support.

CYRUS H. GORDON

Chairman
Department of Mediterranean Studies
Graduate School of Arts and Sciences
Brandeis University
Waltham, Mass.

Sirs:

On reading the article in the March issue of *Scientific American* on "Learning in the Octopus" I was inspired to write this poem.

The brain of an octopus
Surrounds its esophagus;
An outstanding feature
Of this tractable creature!
It shows no animosity
To our curiosity,
And feels little strain
When deprived of its brain.
(But it does show signs
of a memory wane.)

Upon seeing a crab
It may reach out and grab.
But a crab plus a square
Tells this creature, Beware,
You might get a shock
Or a powerful knock!
It's easy to train,
But it cannot retain.
(This marvelous octopus
minus a brain.)

ANN M. MAYER

Cambridge, Mass.

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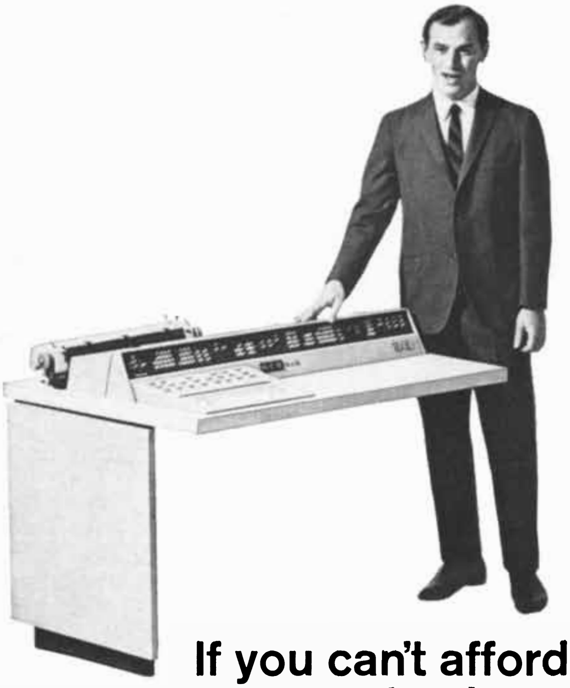
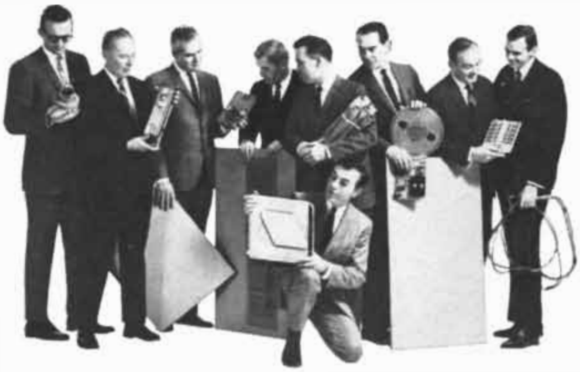




50 AND 100 YEARS AGO

AUGUST, 1915: "A year ago the assertion frequently was made that the Teutons would meet with their greatest success in the opening months of the war, and that the greater numbers and superior resources of the Allies would soon begin to tell. The truth has turned out to be just the reverse. The Teutons' star was never so dim as during the first few months of the war and never so bright as now at the end of the first year. Their resources in trained soldiers have been vast enough to enable them as the war progressed to overcome the disparity in numbers and match man for man on the battlefields, while in ammunition and other essential war materials their supplies have been greater than those of the Allies. With a condition of stalemate in France and the Dardanelles and with Italy checked on the Isonzo, while victory perches on the banners of the Teutons in Russia, the beginning of the second year of the great war promises to mark the beginning also of the first decisive stage of the conflict."

"Not long ago there appeared a notice in Swiss papers saying that England was building aeroplanes of immense size, able to carry 16 men. SCIENTIFIC AMERICAN is informed that Germany will soon begin the construction of similar aeroplanes (triplanes) of enormous dimensions. These machines are to be three times as big and strong as the ordinary flying machine. They are to carry as many as 20 men. This crew has to work four machine guns and one light field piece mounted in a special little armored turret. Eight Maybach motors, similar to those used by the Zeppelin airships, are to drive the apparatus through the air. The motors are coupled in pairs and drive four propellers. The propellers can be shifted in position so that they serve for steering in a horizontal plane. Manual steering is resorted to only for elevating or depressing the machine. All other movements are effected by the motors. The triplane will fly with two propellers only, if need be, and travels at high speed when four of the propellers are turning. The machine is armored."

"The number of naked-eye variable stars has recently been computed by Mr. Harlow Shapley and is much larger than was supposed a few years ago. According to Mr. Shapley's enumeration, there are five variables of the first magnitude or brighter, two between the first and second, eight between the second and third, 20 between the third and fourth, 22 between the fourth and fifth and 49 between the fifth and sixth, making a total of 106. This is about 3 per cent of the total number of stars (3,330) visible to the naked eye. Moreover, these figures do not include a number of bright stars which have recently been suspected of small variation by Lau and Guthnick, although, says Mr. Shapley, many of them will probably be admitted soon to the list of known variables. If these were included, the percentage of naked-eye variables would be increased from 3 to more than 5."

AUGUST, 1865: "A new railway, worked by stationary steam-engines, has of late been exhibited near Camberwell Gate in London. This railway is the invention of a Mr. Halliwell and is worked, somewhat like the old atmospheric line at Croydon, by forced or exhausted air in a tube, which is placed between the rails and runs along the whole length of the line, by which the use of the locomotive engine is superseded. The patentees, Messrs. Halliwell and Allison, claim for the invention that lighter rails and sleepers can be used, one-half of the coal saved and the tear and wear on the rails made not half so great. The tube, which is of cast iron, is 18 inches in diameter, more or less. On the tube is a sliding valve of iron, which is so tight, it is said, that it will stand as much pressure as any other part of the tube. A lifting valve of leather, which could not be made tight and was the main cause of its failure, was used by the old atmospheric railway. A stationary engine will be placed at intervals of five miles, more or less, with self-acting valves, so that through trains may be run any distance without stopping. With regard to the speed of the train, that, it appears, may be carried as high as 50 or even 100 miles an hour."

"Professor Wheatstone has constructed a very powerful thermo-electric battery on the principle of that exhibited by Mr. Ladd at the Royal Institution. The battery constructed by Professor Wheatstone consists of 60 pairs of small bars, and its electro-motive force is said to be equal to that of two of Daniell's cells. Not unnaturally, this thermo-electric battery is exciting the imaginations of men of science, causing them to call up wonderful visions of a future when much of the work of the world shall be done by *sunshine.* A contemporary suggests that, 'like windmills, thermo-electric batteries might be erected all over the country, finally converting into mechanical force, and thus into money, gleams of sunshine, which would be to them as wind to the sails of a mill. What stores of fabulous wealth are, as far as our earth is concerned, constantly wasted by the nonretention of the solar rays poured on the Desert of Sahara. Nature here refuses to use her wonderful radiation net, for we cannot cover the desert sands with trees, and man is left alone to try his skill in retaining solar energy. Hitherto helpless, we need not be so much longer, and the force of a Sahara sun may be carried through wires to Cairo and thence irrigate the desert, or possibly, if need be, it could pulsate under our streets and be made to burn in Greenland.' "

"By the time this notice reaches the public the *Great Eastern* will probably have begun her eventful voyage. All that the experience of previous attempts at laying the Atlantic cable could suggest, all that the most earnest and painstaking foresight could anticipate, has been done; everything now rests with the weather."

"On the 28th day of August, just 20 years ago, Rufus Porter issued to the public the first number of SCIENTIFIC AMERICAN in a brief address, wherein he announced to the sovereign people that he should advocate the pure Christian religion, without forming any particular sect, and should develop the beauties of nature, which consists in the laws of mechanics, chemistry and other branches of natural philosophy. The present editors and proprietors assumed the control of the paper on July 30, 1846."

Report from
BELL LABORATORIES

PULSE-CODE MODULATION— Experimental terminals operate at 220 megabits per second

Demonstration of the effect of Pulse-Code Modulation coding of television images transmitted over experimental 220-megabit system. With black and white images, each code corresponds to a shade of gray. In the extreme case where samples are coded to only one digit (left), two shades (dark and light or black and white) are possible—producing a high-contrast image. With 4-digit coding (center) up to 16 shades of gray are possible—producing an image with objectionable contouring. With 7-digit coding (right) there are sufficient levels to produce good television picture quality. Up to 9 digits per code may be required, however, when signals are transmitted over a number of Pulse-Code Modulation systems used in tandem.

Pulse-code modulation—one of the most interesting and promising techniques of communications technology—is simple in concept (see drawing). As with all new system concepts, however, PCM requires thorough research and skillful design to make it a practical reality.

A PCM system has been developed at Bell Telephone Laboratories and is now in widespread commercial service. This system, operating at 1.5 megabits per second, is proving useful in transmitting telephone voices and data over short distances, particularly in large cities, and other PCM transmission systems are being actively studied.

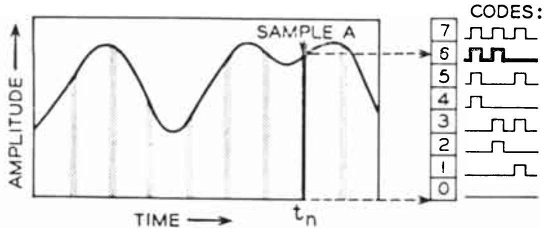
To realize more of PCM's potential, it is necessary to go to higher and higher rates of transmission. In doing this, ever more difficult problems are encountered—problems that lie on the frontiers of the technologies of devices, materials, circuits and systems design.

To demonstrate what can be done in this field and to gain valuable experience with PCM at high transmission rates, Bell Telephone Laboratories engineers have developed experimental PCM terminals that operate at 220 megabits per second.

At the transmitting terminal a color or black and white television signal and hundreds of telephone voice or other signals are sampled, coded and "mixed" (multiplexed) together. The receiving terminal demultiplexes or separates the various signals, decodes them, and restores them to their original form.

This experimental system has demonstrated that PCM systems with pulse rates up to 220 megabits per second are indeed feasible. High-speed electron-beam and solid-state encoders, a thin-film decoder, and other advanced components and techniques are utilized. These advanced techniques include arrangements for removing time "jitter" from the received pulse stream and provision for synchronizing terminals in a network of interconnected PCM systems.

Bell Telephone Laboratories
Research and Development Unit of the Bell System



Concept of PCM: Wavy line shows a time-varying current, which represents an analog communication signal such as human speech or a television picture. Electronic PCM circuits periodically "look" at or sample the signal, measure its amplitude, and convert each measurement into a digital code. For example, at time t_n the PCM circuits look at the signal at A. The height or level of sample A is then electronically compared with a built-in "scale." In this simplified illustration the level of the sample is 6, so 6 is encoded (in the binary number system, 6 would be 110, represented as shown by pulse, pulse, no-pulse). Codes from many signals may be interleaved in time, and a stream of electrical pulses representing all signals is sent over a transmission line. At the receiving terminal, other PCM circuits perform the inverse functions to restore the signals to their original analog forms. The experimental terminals operate with up to 512 codes per sample, and can code a sample into a 9-bit code in 80 nanoseconds.

INNOVATION!

"INSTANT INVENTORY" FOR RAILROAD CARS
(It's as fast as a flash camera!)

With a furious clatter a freight train barrels by at 60 mph. The car numbers? A blur. Impossible to read with the naked eye. But a fast "electronic reader" can do it. That's what the scientists of a GT&E subsidiary have developed.

Why this "instant inventory"? Because railroads rent each other's cars—and pay daily charges. Some roads could save $10,000 a day, by knowing the position of every car at all times. "Visiting" cars could be quickly returned.

That's why our scientists developed the KarTrak* automatic car identification system. A trackside optical scanner sweeps the passing train with a beam of light, cutting through fog, snow—even thick dirt. The light bounces back from stripes of SCOTCHLITE® Reflective Sheeting. Each stripe represents a number which the scanner reads, translates into digits, transmits instantly to headquarters.

At GT&E, research gets results—in communications, chemistry, electronics, lighting, metallurgy. Research, in a climate of innovation, is our solid base for future growth. General Telephone & Electronics Laboratories, Inc.

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THE AUTHORS

KARL E. TAEUBER ("Residential Segregation") is associate professor of sociology at the University of Wisconsin. He was graduated from Yale College in 1955 and received master's and doctor's degrees at Harvard University. For two years he worked at the National Cancer Institute on a study of smoking habits. From 1961 to 1964 he was a research associate at the Population Research and Training Center at the University of Chicago, going to the University of Wisconsin last September. Taeuber's wife is also a sociologist specializing in population studies; together they have written a book, *Negroes in Cities,* scheduled for publication this summer.

BRUCE C. MURRAY and JAMES A. WESTPHAL ("Infrared Astronomy") are respectively assistant professor of planetary science and senior research engineer at the California Institute of Technology. Murray received bachelor's, master's and doctor's degrees in geology from the Massachusetts Institute of Technology. He describes himself as "a geologist turned geophysicist turned planetary astronomer." His primary interest is "the use of ground-based telescopes to learn about the geology and geophysics—mostly the latter—of the moon, planets and larger satellites." His nonprofessional activities include lacrosse and local Democratic politics. Westphal is a graduate of the University of Tulsa. Before taking his present post in 1961 he did research for the Sinclair Oil Corporation.

L. K. EDWARDS ("High-Speed Tube Transportation") is president of Tube Transit, Inc., a position he occupies while on extended leave of absence from the Lockheed Missiles and Space Company, where he served from 1956 to this year, most recently as assistant chief engineer in the Space Systems Division. He is a graduate of Miami University in Ohio, where his major subject was geology. Subsequently he took courses in aerodynamics, aircraft performance and aircraft structures at Washington University, the University of Buffalo and Cornell University. From 1943 to 1956 he was an engineer with the McDonnell Aircraft Corporation.

R. B. LEACHMAN ("Nuclear Fission") is a group leader in the cyclotron operation of the Los Alamos Scientific Laboratory. He took an undergraduate degree in electrical engineering at the Case Institute of Technology in 1942 and a Ph.D. in physics at Iowa State University in 1950. It was at the latter institution that he became interested in nuclear fission, to which he was attracted by J. K. Knipp, one of the first theorists in the field. Leachman joined the Los Alamos laboratory in 1950; since then he has also spent a year at the Nobel Institute of Physics in Stockholm and a year at the Institute for Theoretical Physics—the Bohr institute—in Copenhagen. He writes that much of his current research is on "the nuclear reaction of carbon ions bombarding carbon."

MICHAEL J. R. DAWKINS and DAVID HULL ("The Production of Heat by Fat") began their collaboration at the Nuffield Institute for Medical Research at the University of Oxford. On June 27, shortly before their article went to press, Dawkins died after a brief illness. He was 34 years old. Hull writes: "Michael was an exceptional person with great ability. He was highly qualified as a physician and practiced as a pediatric pathologist. His original work on the biochemical and physiological changes occurring after birth had already gained him a considerable reputation both in Britain and abroad." Dawkins, who was graduated from the University of Cambridge, had received his medical training at University College Hospital in London. At the time of his death he was senior lecturer in pathology at the Institute of Child Health in London. Hull, who is lecturer in pediatrics at the medical school of the University of Oxford, received degrees in physiology and medicine at the University of Liverpool. He writes that he is "currently investigating the problem of resuscitation of the newborn human." He took his present post in 1963.

GERALD OSTER ("Density Gradients") is professor of polymer chemistry at the Polytechnic Institute of Brooklyn. His scientific interests include the structure of DNA; he writes that in 1951 "D. P. Riley and I proposed, on the basis of our X-ray studies, a helical model for DNA—a *single*-strand helix, unfortunately." Oster is also interested in the visual psychology of "optical art"; he was coauthor of the article "Moiré Patterns" in the May 1963 issue of SCIENTIFIC AMERICAN. A New York gallery recently held a one-man show of his moiré constructions, two of which were also exhibited in the Museum of Modern Art's "op art" show. Oster continues his work in art while conducting research in the photochemistry of chlorophyll and in stimulated emission from organic phosphors. His present work on moiré patterns is concentrated on their development as an analogue-computing technique.

J. R. BRETT ("The Swimming Energetics of Salmon") is an investigator with the Fisheries Research Board of Canada. In 1951 he established the laboratory for experimental biology at the board's biological station at Nanaimo in British Columbia, and until early in July of this year he served there in charge of the physiology section. He is now on a year's sabbatical leave at the University of Cambridge. Brett is a native of Toronto and obtained bachelor's, master's and doctor's degrees at the University of Toronto. From 1944 to 1948 he was a field biologist at the Nanaimo biological station, "investigating the life history of Pacific salmon." He then spent three years obtaining his doctorate at the University of Toronto before returning to Nanaimo. There he has conducted research with the broad objective of "conserving salmon from hydroelectric developments and pollution." In 1963 Brett was elected to the Royal Society of Canada.

VICTOR A. McKUSICK ("The Royal Hemophilia") is professor of medicine at the Johns Hopkins University School of Medicine and chief of the division of medical genetics there. He has been at the school, as a student and member of the faculty, since 1943, when he took his undergraduate degree at Tufts College. For several years McKusick pursued two main interests: the analysis of heart sounds and the study of medical genetics. In recent years he has concentrated on the latter field. It is from that work that his interest in hemophilia arises; he writes that he has also given special attention to "hereditary disorders of connective tissue, the human *X* chromosome and the population genetics of the Old Order Amish." McKusick is the author of five books—four on genetics and one on heart sounds.

MAX BLACK, who in this issue reviews *Beyond the Edge of Certainty: Essays in Contemporary Science and Philosophy,* edited by Robert G. Colodny, is Susan Linn Page Professor of Philosophy at Cornell University.

Established 1845 SCIENTIFIC AMERICAN August 1965 Volume 213 Number 2

Residential Segregation

An objective index shows that in every American city Negroes live separately from whites. Of the three principal causes—choice, poverty and discrimination—the third is by far the strongest

by Karl E. Taeuber

Some eight years ago this magazine carried a prediction that "the 'racial problem' of the U.S., still festering in the rural South, will become equally, perhaps most acutely, a problem of the urban North" [see "Metropolitan Segregation," by Morton Grodzins; SCIENTIFIC AMERICAN, October, 1957]. One need only recall the headlines of the past few years concerning racial strife in New York, Birmingham, Montgomery, Cleveland, San Francisco and many other cities to recognize that the "racial problem" has indeed moved into the urban North—and also into the urban South. A profound social change underlies these events; it is reflected in the figures of the 1960 census, which show that a higher percentage of Negroes than of whites live in cities. Ten large cities in the North and West contain the overwhelming majority of the Negroes in those regions, which in turn contain 40 percent of the nation's Negro population. In the South more than half of the Negroes are city dwellers.

Perhaps the most striking feature of the life of Negroes in cities is the segregation of their residences from the residences of whites. This ghetto situation is one of the most pronounced and most tenaciously maintained forms of segregation the Negro American faces. Residential segregation in turn underlies many other problems. From it arises *de facto* segregation in schools, hospitals, libraries, parks, stores and a variety of activities carried on within neighborhoods.

Residential segregation is particularly amenable to quantitative study because it is expressed in the physical location of white and Negro households. This situation is readily apparent in the illustration on page 14, which shows the distribution of the Negro population in Chicago. Even a cursory inspection shows that Negro residential areas are clearly distinct from white residential areas. A similar map of any other large city in the U.S. would also show a high degree of residential segregation.

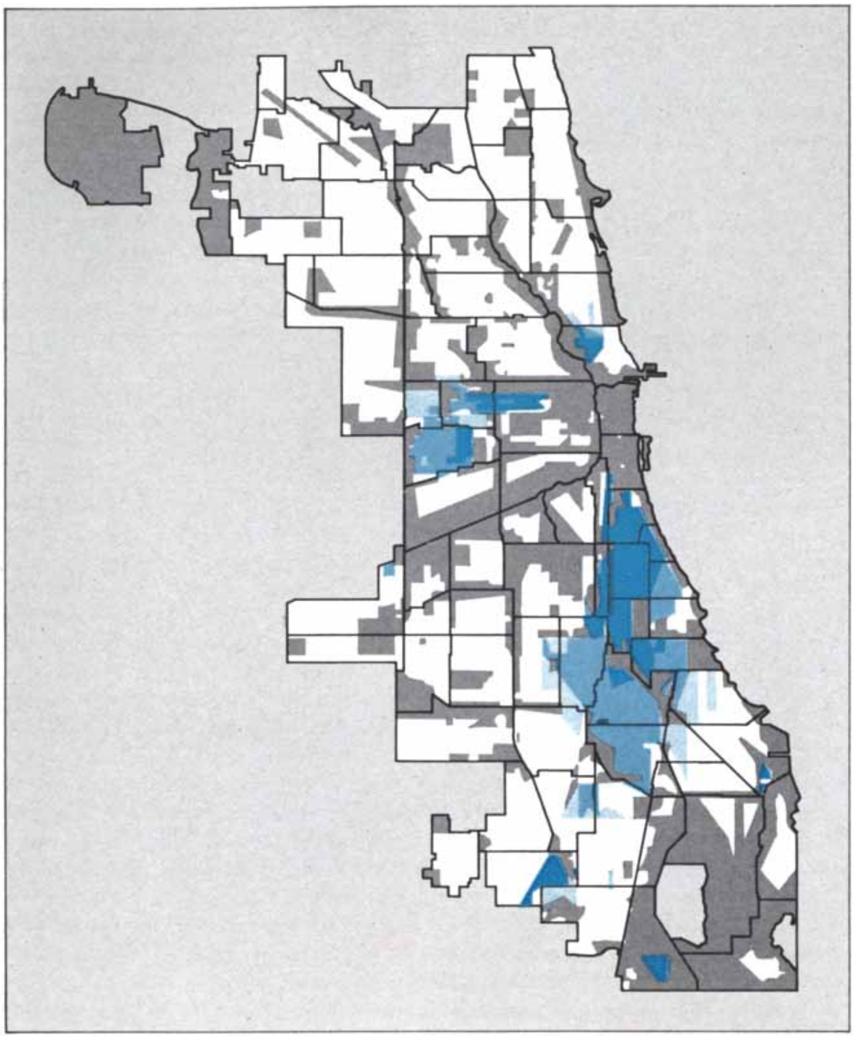
Work of this kind has a deficiency, however, in that it leaves open a question: Which of two or more cities being compared has the greater degree of segregation? The kind of ambiguity that can arise is indicated by two maps published by a newspaper in Chicago a few years ago showing the patterns of residential segregation in Chicago and Birmingham. The accompanying headline declared that Chicago was the more segregated because its all-white areas were more extensive than Birmingham's. The same maps could have been used to argue that Chicago was the less segregated because its all-Negro areas were less extensive than Birmingham's. Both statements are true, and both reflect the fact that Negroes constitute a much larger proportion of the population in Birmingham than in Chicago.

What is needed in the measurement of residential segregation is a technique that does not lend itself to ambiguous interpretation. Such a technique would summarize the degree of residential segregation in a city independently of the percentage of Negroes in the city and of any subjective judgments. A measure of this kind is the "index of dissimilarity," which is widely used in studies of population distribution. The index compares two percentage distributions. When it is adapted to the comparison of white and Negro residential distributions, it is commonly called a "segregation index."

The rationale of the segregation index is that if there were no forces working toward residential segregation in a city, any given neighborhood would show about the same proportion of whites, Negroes and other races as one would find in the city as a whole. In other words, if the population of a nonsegregated city were half Negro and half white, the residents of any city block would be equally divided between the two races. Such a situation would produce a reading on the segregation index of zero. A reading of 100 is obtained when there is complete residential segregation: there are no Negro residents in white neighborhoods and no white residents in Negro neighborhoods.

With the necessary data in hand anyone can calculate a segregation index for a city by the method I use. First identify each neighborhood in which the percentage of Negro house-

PATTERN OF SEGREGATION appears in these photographs of playgrounds in New York City. The photograph above shows a playground at a public school in Harlem, an overwhelmingly Negro section of the city. The photograph below shows a playground at a public school on East 81st Street in a predominantly white section. Similar segregation by race is evident in every major American city.



CHANGING CHARACTER of Chicago neighborhoods is reflected by the colors in this map. Dark color shows areas with more than 25 percent Negro population in 1950; medium color, the same information for 1960; light color, for 1964. White areas are all-white neighborhoods; gray shows nonresidential sections. Data are based on a map prepared by the Chicago Urban League. Boundaries define 76 "community areas" set up by researchers at University of Chicago for statistical purposes; light gray shows water or noncity areas.

holds is higher than the percentage in the city as a whole. Find the number of Negro households and of white households in these areas. Calculate the percentage of the city's Negro households contained by the areas (a figure that is often above 90 percent) and the percentage of the city's white households in the areas (typically about 10 percent). The difference between the two percentages is the city's reading on the segregation index. To put it another way, a reading of 80 on the segregation index would indicate that 80 percent of the Negroes would have to be redistributed to predominantly or exclusively white blocks if the city were to achieve an unsegregated pattern of residence.

Two particular advantages can be cited for this index in comparison with other techniques that have been proposed for the measurement of residential segregation. The index has no direct dependence on the percentage of Negroes in a city, and it is relatively easy to calculate. On the other hand, certain hazards should be noted. Like any single index used to represent a complex phenomenon, the segregation index is a summary device that does not reflect all the subtleties of the actual situation. It does not indicate the character of the residential segregation in a city—that is, the strength of white feelings about where Negroes should live or the strength of segregation's emotional impact on Negroes—nor does it reveal the precise spatial configuration of Negro residential areas. In short, the best way to summarize the index is to say that it is a strictly objective measure, based on census data, of the general unevenness in the distribution of white and Negro households among residential neighborhoods.

The segregation index can be calculated from data for any set of residential areas: wards, precincts, census tracts, blocks and even the usually vague concept of a neighborhood. In general, the smaller the areas used in the calculation, the higher the degree of segregation that will be found. I prefer to use data for individual city blocks, because a calculation made on this basis shows the "fine structure" of the segregation pattern.

I have calculated the segregation indexes for 207 American cities—all the cities for which block data are available and that had at least 1,000 nonwhite households in 1960. The readings for these cities range from 60.4 in San José, Calif., to 98.1 in Fort Lauderdale, Fla. Half of the cities have segregation indexes above 87.8, half below.

No elaborate analysis is necessary to conclude from these figures that a high degree of residential segregation based on race is a universal characteristic of American cities. This segregation is found in the cities of the North and West as well as of the South; in large cities as well as small; in nonindustrial cities as well as industrial; in cities with hundreds of thousands of Negro residents as well as those with only a few thousand, and in cities that are progressive in their employment practices and civil rights policies as well as those that are not.

Negroes are of course not the only minority group subjected to prejudice and discrimination. How does the residential segregation of Negroes compare with that of Puerto Ricans in New York City, of Mexican-Americans in Los Angeles, of Japanese and Chinese in San Francisco? The segregation index is adaptable to questions of this type. One change is necessary in the method of calculation: instead of using data from city blocks, one must switch to census-tract data, which provide a more detailed ethnic classification. (Census tracts are statistical areas established by the Bureau of the Census for the study of small sections within cities; the tracts average about 5,000 in population.)

On the basis of census-tract data for 1960 it is possible to consider three groups in New York City: Negroes, Puerto Ricans and "other whites." (This discussion will ignore the fact that a few Puerto Ricans are Negroes.) Indexes calculated for each group show that

Puerto Ricans and Negroes are both segregated from "other whites." The degree of Negro segregation, however, is much higher. In addition there is considerable residential segregation of Puerto Ricans from Negroes [*see bottom illustration on next page*].

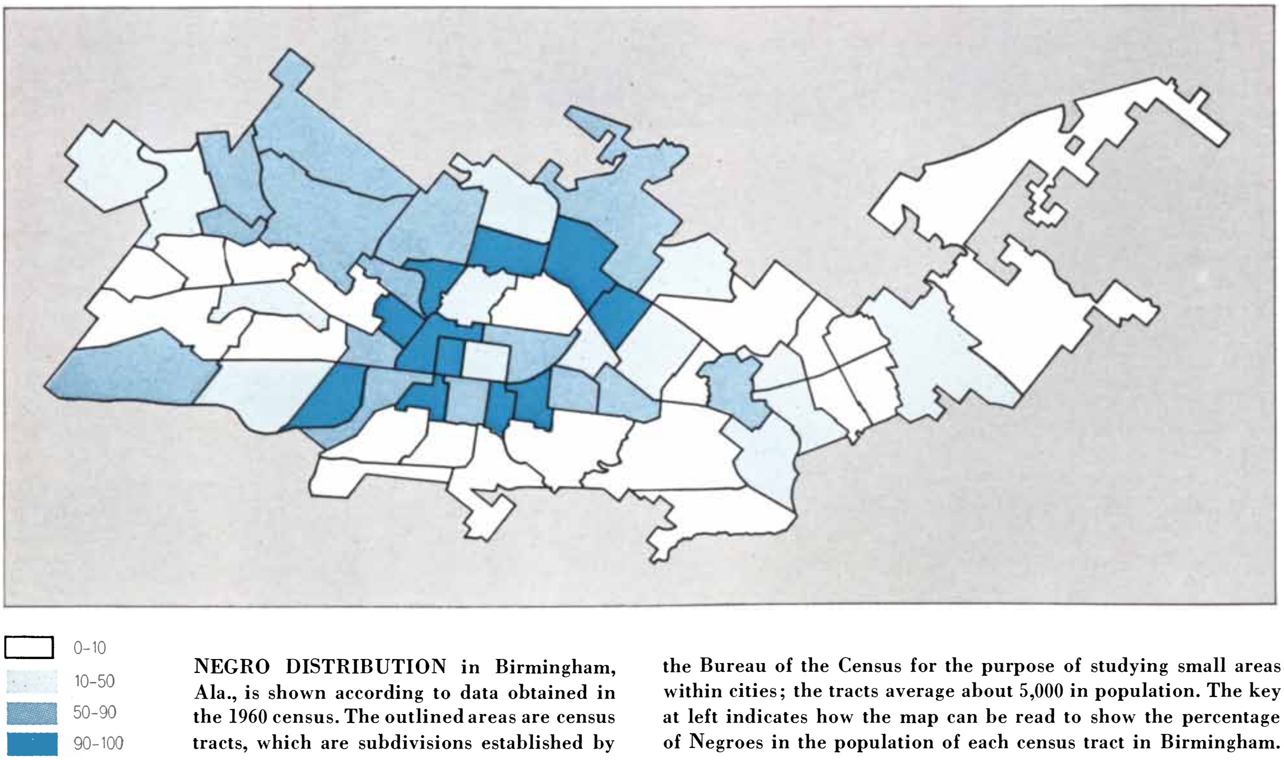
For Los Angeles in 1960 census-tract data permit identification of four groups: (1) Negroes; (2) other races, meaning nonwhites other than Negroes —mainly Japanese and Chinese; (3) whites of Spanish surname, a classification that provides a rough approximation of the Mexican-American population, and (4) "other whites." Segregation indexes making six comparisons among these groups are shown in the bottom illustration on the next page. The highest of the six indexes is the one comparing Negroes and "other whites." The second- and third-highest indexes are for the other comparisons involving Negroes. In other words, Negroes are markedly segregated from all other residents of the city. Lower index values appear in the comparisons of "other races," "whites of Spanish surname" and "other whites" with each other.

A different kind of analysis can be made for San Francisco. For that city data are available allowing assessment of the trends in segregation between 1940 and 1960 among whites, Negroes and other races. In 1940 San Francisco's Negro population was quite small, numbering only 5,000. During and after World War II it increased rapidly, reaching 74,000 by 1960. The population of other races also grew, from 27,000 to 62,000. (Chinese make up the largest portion of this group, although it also includes a sizable number of Japanese.) In the early 1940's the rapidly growing Negro population took over much of the housing vacated by the Japanese when they were moved to wartime relocation centers. The Japanese returning after the war developed new residential patterns. These trends are evident in the illustration at the left on page 17, which shows that the segregation of whites from other races has diminished sharply since 1940. As members of other races have dispersed from Chinatown and the Japanese colony they have adopted a residential pattern more like that of the city's whites. Concurrently their segregation from Negroes has increased. In contrast, residential segregation of Negroes from whites has remained at a high level throughout the two decades.

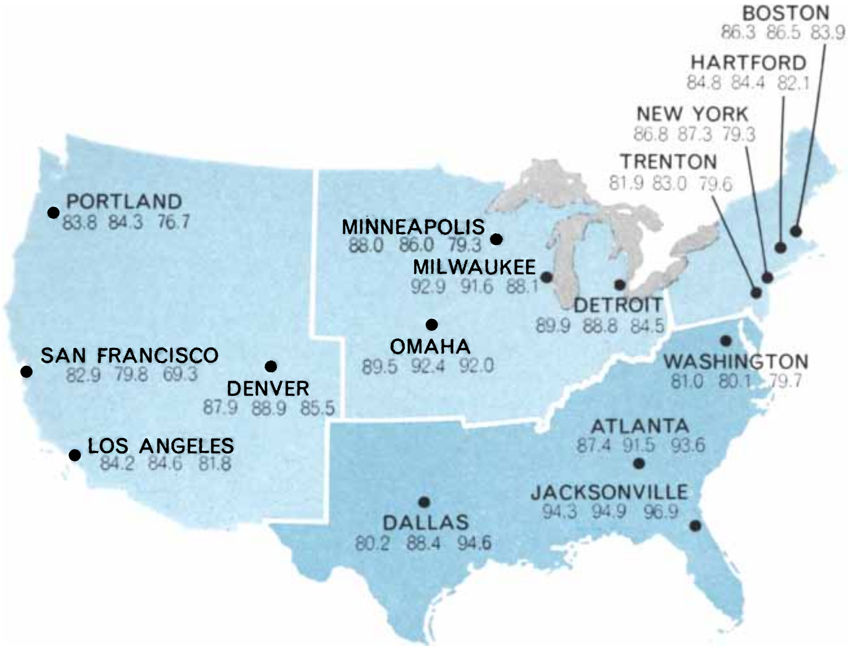
Similar trends can be found in many Northern cities, although the explanation is different. Half a century ago, when the immigration of Europeans was at its peak, Northern cities contained assorted ethnic colonies. At that time the Negro population in these cities was small. The vast migration of Negroes from the South to the North began during World War I, which marked the period when European immigration dropped sharply. Stanley Lieberson, one of my colleagues at the University of Wisconsin, has examined the changing patterns of residential segregation among the European immigrants and has found that in 1910 some ethnic groups were as segregated from native whites as Negroes were. Since 1910, however, the residential segregation of every group of European descent has been declining, whereas segregation of whites from Negroes has been increasing.

In the South historical data also show a long-term trend of increasing residential segregation of Negroes from whites. A special census of Charleston, S.C., in 1861 showed that whites and slaves were only slightly segregated from each other. In that era, of course, most urban slaves were housed in a walled-off portion of their owner's residence or in separate slave quarters on his property. By 1910 Negro-white segregation had risen appreciably in Charleston. Segregation indexes calculated for subsequent census years confirm a century-long increase.

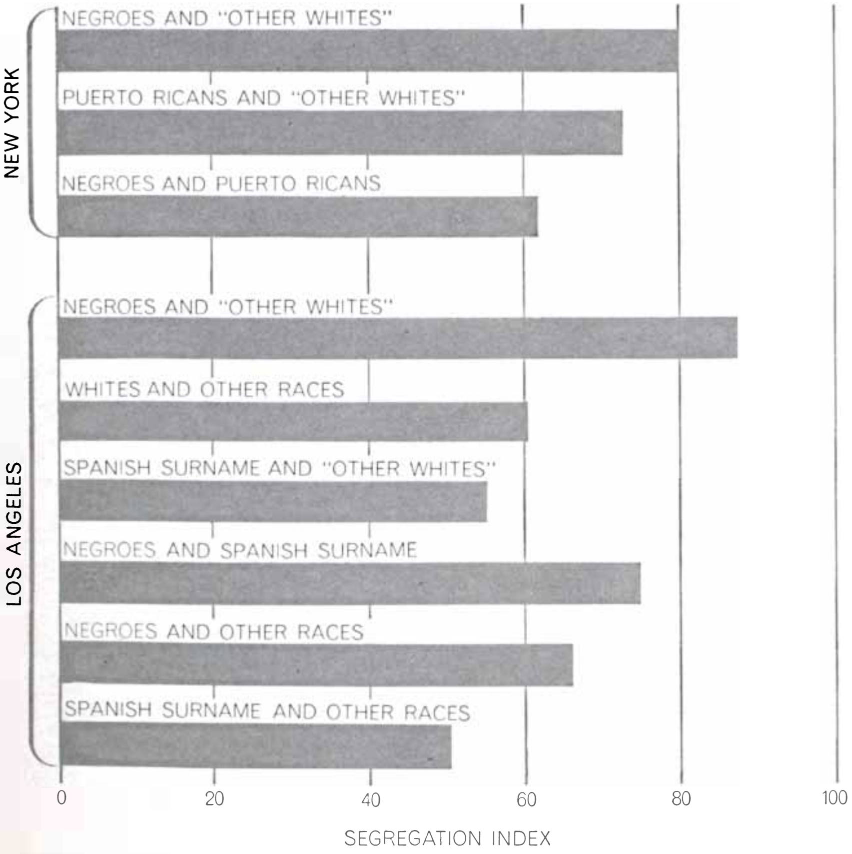
The best-documented pattern of steadily increasing residential segregation in Southern cities uses special compilations of data from city directories for Augusta, Ga., which distinguish between whites and Negroes [*see illustration at right on page 17*]. Similarly detailed information is not available for other cities. Many miscellaneous data,



NEGRO DISTRIBUTION in Birmingham, Ala., is shown according to data obtained in the 1960 census. The outlined areas are census tracts, which are subdivisions established by the Bureau of the Census for the purpose of studying small areas within cities; the tracts average about 5,000 in population. The key at left indicates how the map can be read to show the percentage of Negroes in the population of each census tract in Birmingham.



REGIONAL CHANGES in residential segregation between 1940 and 1960 are indicated for four regions: Northeast, North Central, West and South. The numerals give each city's "segregation index" for 1940, 1950 and 1960; a rising index indicates increasing residential segregation in the city. The trend of segregation in each region between 1950 and 1960 is indicated by the colors: light for a downward trend and dark for an upward trend.



COMPARATIVE SEGREGATION of Negroes and other racial or ethnic groups is shown for two cities. Readings are in terms of segregation indexes for 1960. For example, comparison of Negroes with "other whites" (meaning whites other than Puerto Ricans) in New York shows that 80 percent of Negroes would have to be redistributed to achieve desegregation.

however, support the supposition that residential segregation was at a minimum during slavery and that subsequent years have brought the gradual obliteration of older patterns in favor of more segregated ones.

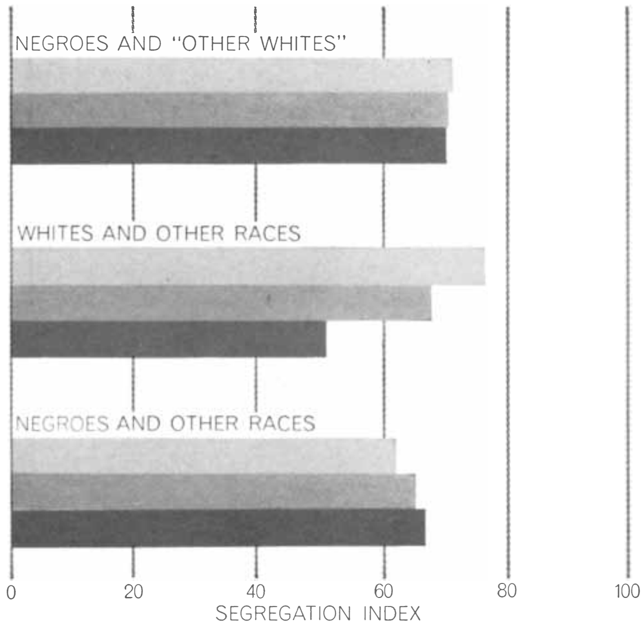
Systematic analysis of trends in residential segregation can begin with 1940, when the Bureau of the Census started publishing data for city blocks. On the basis of these data I have constructed a series of segregation indexes covering 1940, 1950 and 1960. The indexes show the trends in the 109 cities for which block data were published and that contained at least 1,000 nonwhite households in 1940. Residential segregation of whites from nonwhites was quite pronounced in all 109 cities by 1940. Even so, by 1950 the segregation scores for 83 of these cities had advanced to new peaks. The average among the 109 cities was an increase of 2.1 points, from 85.2 to 87.3.

A different story appears in the next decade. Between 1950 and 1960 only 45 cities registered increases; 64 showed decreases. The average for the 109 cities went down 1.2 points to 86.1 [*see top illustration at left*].

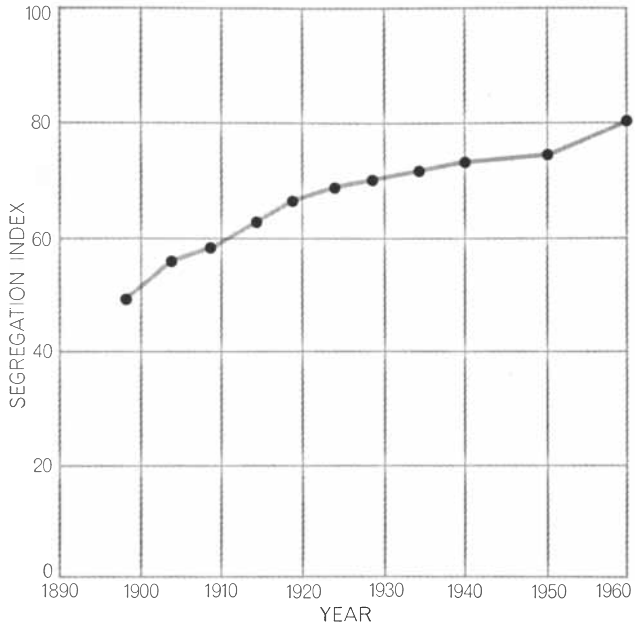
An average, of course, conceals individual performances. Examination of the changes in the two decades reveals some interesting variations between regions. From 1940 to 1950 the majority of cities in every region—Northeast, North Central, West and South—experienced increases in segregation, but the average increase was larger in the South (3.6 points) than in any other region. Cities in the North Central region showed an average increase of 1.5 points; the change among cities in the Northeast and the West was upward but negligible.

The contrast between Southern cities and those in other regions became more pronounced in the next decade. Among Southern cities the average of the segregation indexes rose 2.2 points between 1950 and 1960. In each of the other regions the average went down—rather sharply in the West (6.5 points) and the Northeast (4.7), less markedly in the North Central states (1.5).

Two generalizations can be made on the basis of these trends. The first is that many Southern cities are approaching the upper limit of complete segregation. Secondly, even if the 1970 census should show that the declines in the other regions continued during the present decade, it would still be many decades before residential segregation of



SEGREGATION TRENDS in San Francisco are shown in comparisons of whites, Negroes and other races from 1940 (*light bars*) to 1950 (*medium bars*) and 1960 (*dark bars*). The term "other races" refers mainly to the city's residents who are of Oriental origin.



RISING TREND of residential segregation in the South is indicated by the situation in Augusta, Ga. The data for the years before 1940 are based on city directories, which distinguished between white and Negro residents. Later data are from census reports.

whites from Negroes reached low levels in any part of the country. The modest declines during the 1950's in three regions do not conceal the fact that throughout the nation residential segregation continues to be a serious social problem.

Discussions of regional differences in segregation often bog down in unsubstantiated generalizations or outright polemic. Rather than attempt an intuitive interpretation of the changes in segregation, I undertook a more formal assessment. For each of 69 cities for which all the necessary data could be obtained I calculated five variables showing changes in the city's characteristics between 1940 and 1950 and between 1950 and 1960. The five variables were: rate of growth of the white population; rate of growth of the nonwhite population; rate of suburbanization; rate of new housing construction, and degree of improvement in the occupational level of nonwhite workers. With these figures in hand I assessed by statistical methods whether or not a city's change in segregation during a decade was related to changes in any of the five variables.

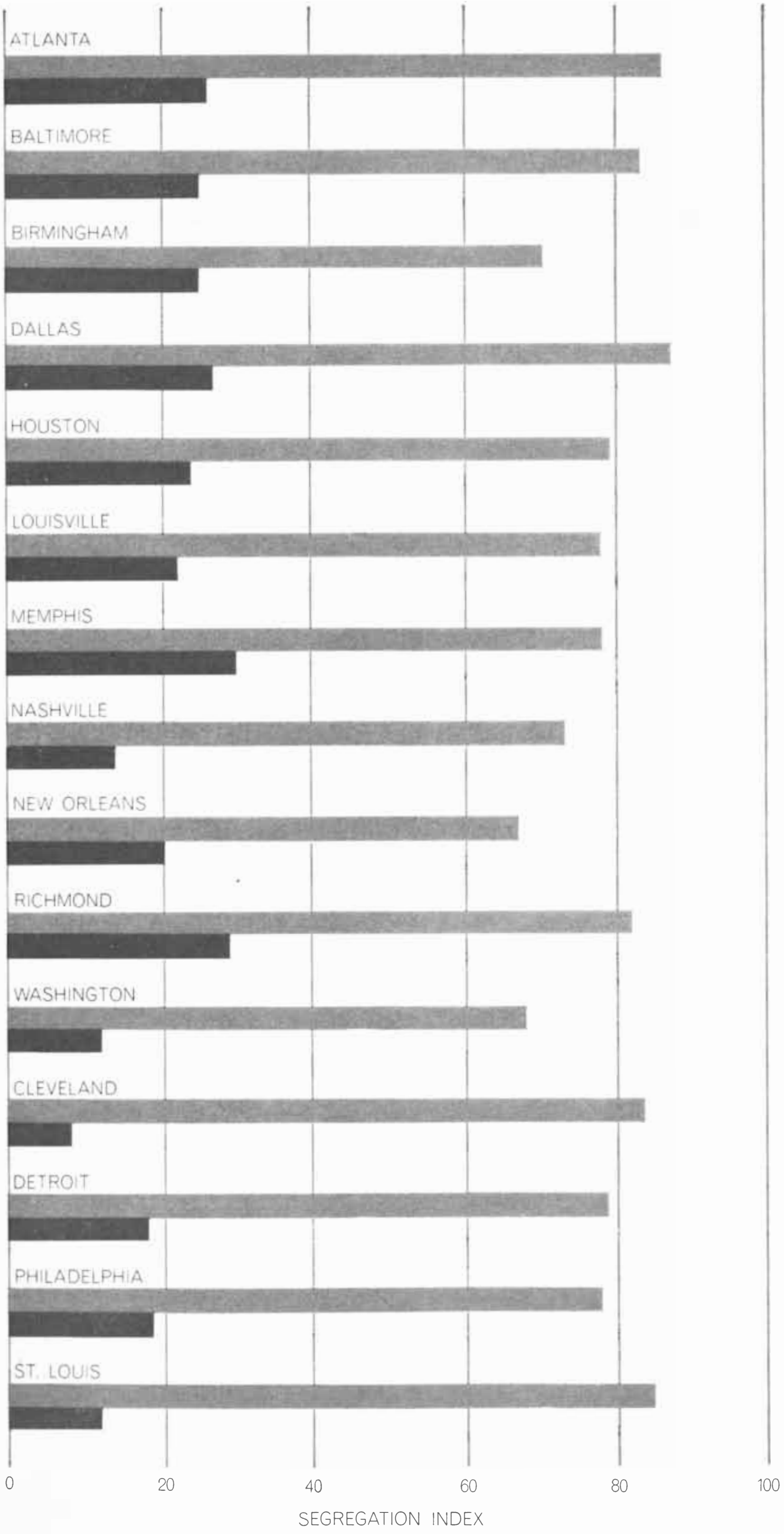
This is not the place to go more fully into the methodology of the study. Suffice it to say that the results of the analysis allow an interpretation that avoids the pitfalls of regional chauvinism. The analysis led to the following interpretation of the changing trends in residential segregation.

In cities throughout the country little new housing was built during the depression years of the 1930's and the war years of the 1940's. About the only exceptions were public housing and war-housing projects. These were almost invariably occupied on a segregated basis—either by public policy, the location of the site or informal controls. Rapid population growth stimulated by wartime industrialization gave rise to severe strains on the urban housing market. Extremely low vacancy rates were one index of the tight housing market that persisted throughout the 1940's. The situation was particularly serious for Negroes: Negro residential areas could not be expanded into surrounding white areas, but Negroes continued moving into the cities.

In these circumstances neither the pressures of rapidly growing Negro populations nor the improving economic status of Negroes could have much effect on patterns of residential segregation. With Negro residential areas becoming increasingly overcrowded, slight increases in the segregation index were common. In some cities, particularly smaller and more recently settled Southern cities that still had vacant land available for residential development, there was considerable new construction in the late 1940's. Virtually all of it was occupied on a segregated basis. These developments account for the large increases in the segregation indexes of the South.

The housing shortage eased tremendously during the 1950's. As millions of people—mainly white—flocked to new suburban housing, vacancy rates in cities climbed, levels of overcrowding among Negroes as well as whites were drastically reduced and Negro residential areas expanded. In Northern cities Negro populations continued to grow at a rapid rate. There was a large-scale turnover in the housing market as many higher-income whites obtained new housing, and lower-income whites and Negroes abandoned some of the worst of the old housing. Extensive highway construction, urban renewal and public housing projects contributed to residential change.

The statistical analysis shows that in this more permissive housing-market situation the pressures for housing for the growing Negro populations, together with the demand for improved housing created by the improving economic status of Negroes, were able to counteract and in many cases to overcome the historical trend toward increasing residential segregation. In Southern cities Negro population growth was slower and economic gains were less. The long-term trend toward



ACTUAL AND EXPECTED segregation indexes are shown for 15 cities on the basis of 1960 census-tract data. The comparison relates to the argument that the poverty of Negroes is the sole cause of residential segregation. The "expected" indexes (*dark bars*) show how much racial segregation there would be if the amount paid for housing were the only cause of segregation. Actual segregation indexes (*light bars*) are much higher, indicating that factors other than poverty are involved in the determination of Negro housing patterns.

increasing segregation slowed but was not reversed.

Improved economic circumstances among Negroes can, in a permissive housing market, be effective in reducing levels of residential segregation. This much is demonstrated by events of the decade from 1950 to 1960. The implications of this finding, however, should not be exaggerated. The relation shown by the statistical analysis also indicates that even if Negroes gained full economic equality at some time in the distant future, their residential segregation from whites would still be considerable.

Gunnar Myrdal suggested in *An American Dilemma,* his classic study of the race problem, three principal factors that could explain the prevalence of residential segregation. The first was choice: perhaps Negroes prefer to live in Negro neighborhoods. Myrdal granted that there was some truth in this notion, but he observed that the choice can hardly be considered a free one because it is made in a society in which discrimination and prejudice are widespread—often to the point where many Negroes who move into white neighborhoods are threatened with physical violence as well as social ostracism.

The second factor is discrimination. Sometimes this may be outright, as it still is in the housing markets of most cities, both North and South. Sometimes it may be more subtle, as tends to be the practice in cities with "fair housing" legislation, where Negroes who seek housing in white areas are often put off by various stratagems and evasions.

The third factor noted by Myrdal was poverty. To the extent that Negroes are unable to afford living in many areas of a city, segregation can result from economic factors rather than from discrimination in housing. Opponents of fair-housing legislation are often among those who are most vociferous in support of this point of view, arguing that efforts to combat residential segregation should be directed primarily toward improving the Negro's economic ability to compete in the housing market. Because this argument has such a plausible ring it is instructive to examine its empirical underpinnings.

Empirical data usually turn out to be more complex than any simple hypothesis would suggest, and this is certainly the case with data on race, income and residential segregation. In Chicago, for example, nonwhite families in 1960 constituted 20 percent of all families but only 8 percent of those families with incomes of $10,000 and over. Clearly the city's nonwhites are on the average poorer than the whites and hence are less able to pay high housing costs. Yet 1960 census data on rental housing show median rents for both white and nonwhite households to be $88 per month. If poverty were the only explanation for residential segregation, it would follow that rental housing should be comparatively unsegregated. In fact it is not. In the ownership market it is apparent that Negroes are at a competitive disadvantage and that relatively few families can afford the more expensive new housing in the city and the suburbs. Most owners, however (both Negro and white), live in moderately priced housing.

One might conclude at this point that the poverty explanation for the residential segregation of Negroes has some merit but is obviously not the full story. Before I leave the reader with that conclusion I should like to discuss the matter more fully. The poverty argument is seldom stated explicitly but seems to depend on four assumptions: (1) that families with different incomes live in different areas of the city; (2) that Negroes have lower incomes than whites; (3) that nonwhite families at any given income level are able to obtain the same housing as whites at that level, and (4) that the observed pattern of residential segregation by race results from the first three assumptions.

To test the poverty argument I shall accept the first three assumptions and subject the fourth to empirical examination. Researchers at the University of Chicago have divided the city of Chicago into 76 "community areas" for statistical purposes [*see illustration on page 14*]. The 1960 census provides data on the distribution of income among the families in each area. Since nonwhite families account for 8.3 percent of all families with incomes of $10,000 and over, assume that in each community area they do likewise. By making similar assumptions for each income bracket one can calculate the "expected" number of nonwhite families in each community area. This calculation gives the distribution of white and nonwhite families that could be expected if Negro poverty were the sole explanation for residential segregation.

It should follow, if the poverty explanation is valid, that the expected distribution of nonwhites is similar to the actual distribution. This, of course, is not the case. In contrast to the wide range in actual percentages of nonwhite residents, every expected figure is between 13 and 33 percent. The actual segregation index calculated from the data for community areas is 83; that calculated from the expected data is 10.

The conclusion is inescapable that the poverty explanation for residential segregation has little merit. This conclusion does not apply only to Chicago. Experiments with several similar techniques for 15 other cities revealed the same findings. In fact, the more refined the technique, the more unequivocal the finding, that is, the less the portion of residential segregation that could be attributed directly to economic factors.

This point is reflected in the illustration on the opposite page, which shows the actual and expected segregation indexes for the 15 cities on the basis of 1960 census-tract data. In making these calculations I did not use the income distribution of families; instead I used the distribution of households—by value for owner-occupied units and by rent for renter-occupied units. In contrast with income, which indicates potential ability to compete in the housing market, this technique uses data on what families actually pay for housing. On this basis too the results show that Negroes are excluded from many residential areas in which their economic status would allow them to live.

There is an even simpler demonstration of the inadequacy of the poverty explanation for residential segregation. The crucial assumption that white and Negro families at the same income level are not residentially segregated is patently false. In no city do high-income Negroes live randomly scattered in the same neighborhoods as high-income whites. In no city do low-income Negroes live in the same neighborhoods as the majority of low-income whites. Regardless of income, most Negroes live in Negro neighborhoods and most whites live in white neighborhoods.

A summary assessment can now be made of the three factors cited by Myrdal. Neither free choice nor poverty is a sufficient explanation for the universally high degree of segregation in American cities. Discrimination is the principal cause of Negro residential segregation, and there is no basis for anticipating major changes in the segregated character of American cities until patterns of housing discrimination can be altered.

IMPACT OF SEGREGATION on Negroes who might otherwise be expected to exercise a free choice in housing is indicated by this block in the Harlem section of New York. Houses were designed by the architect Stanford White when Harlem was a white section; after it became Negro the block acquired the name "Strivers' Row" because so many white-collar and professional Negroes—barred from other areas by segregation—aspired to live there.

INFRARED ASTRONOMY

The radiation in the spectral region between light and radio waves carries much information about celestial objects. New detectors are making this information increasingly available

by Bruce C. Murray and James A. Westphal

The basic task of the astronomer is to record samples of the radiation emitted and reflected by celestial objects. The obstacles to the fulfillment of this task are numerous. Historically they have included ignorance of the kind of radiation to look for, ignorance of the filtering action of the earth's atmosphere, and lack of instruments to detect radiation of certain wavelengths.

In this article we shall describe briefly how the obstacles have largely been surmounted in the infrared region of the spectrum. The radiation in this region, which lies between the visible spectrum and the microwave region of the radio spectrum, carries information needed to determine the surface temperature of the moon and some of the planets and the nature of planetary atmospheres; it also bears unique clues to the nature of luminous objects throughout the universe—from very cool stars to the extraordinarily brilliant quasi-stellar sources.

Until World War II advances in infrared astronomy were few and far between. Since then there has been rapid progress in infrared techniques and in the volume of new findings. Up to now the most important work has been done with earth-based instruments. The next stage, which is just beginning, is the use of balloons to carry instruments above most of the earth's atmosphere. Eventually, when satellite laboratories are large enough and reliable enough, they may make a valuable contribution. There is no danger, however, that ground-based observers will soon be unemployed: their infrared techniques are still being developed much faster, and yielding richer dividends, than those associated with balloons and space vehicles.

Infrared astronomy had its origin in observations made by Sir William Herschel in 1800, long before there were photographic plates or other means for recording radiation. Using his eye as a detector, he observed the sun through "differently coloured darkening glasses" (that is, filters). "What appeared remarkable," he wrote, "was that when I used some of them, I felt a sensation of heat, though I had but little light; while others gave me much light, with scarce any sensation of heat."

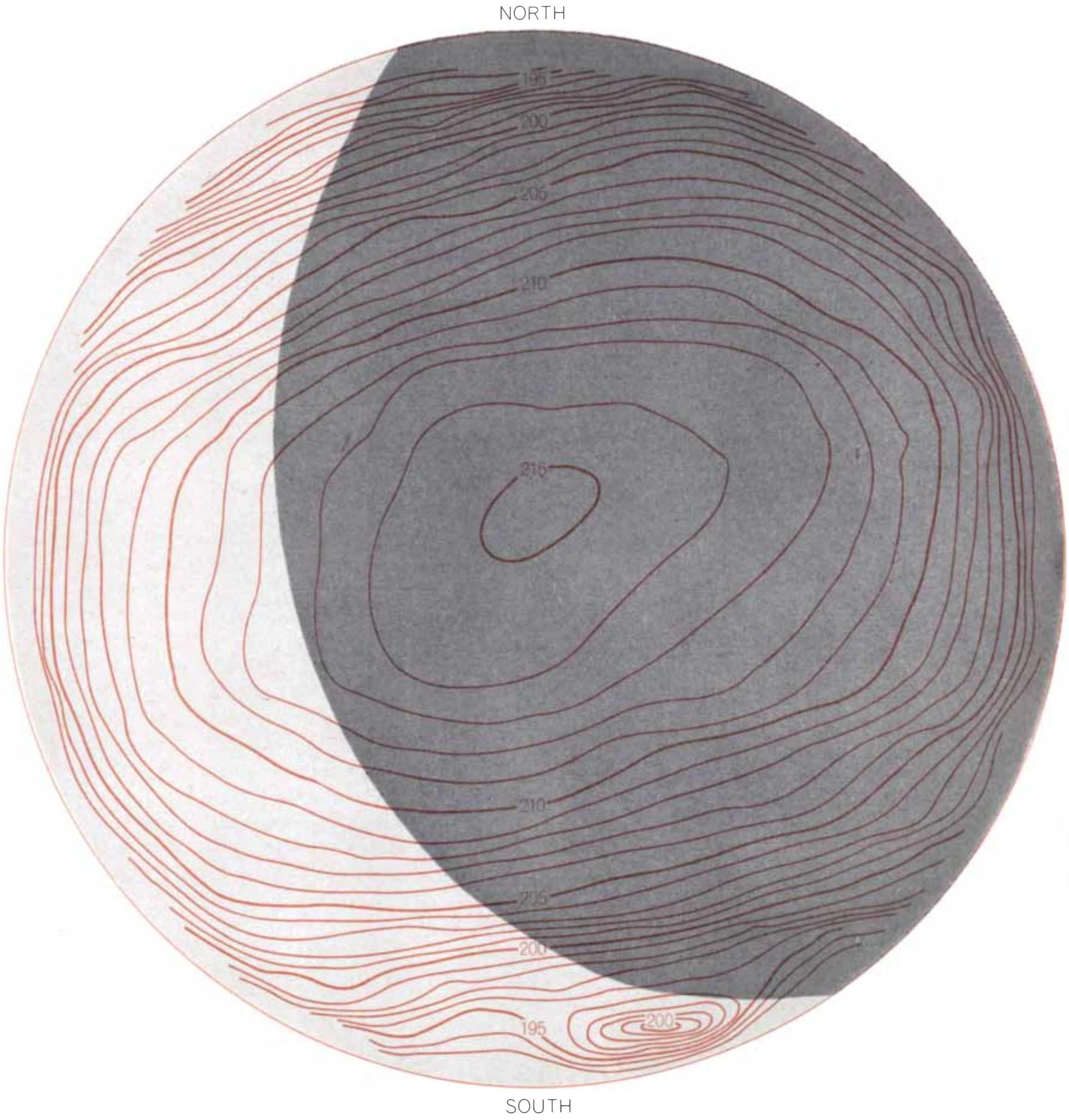
This prompted Herschel to conduct a famous experiment in which he used a prism to separate sunlight into its various colors and compared the temperature at different points in the spectrum by means of a glass thermometer whose mercury bulb had been blackened with ink. Two other thermometers located out of the path of the sun's rays served as controls. Herschel was surprised to find that the sunlit thermometer showed a steady increase in temperature as he moved it from the violet end of the spectrum to the red end—and that the temperature remained high for some distance beyond the visible red. Herschel subsequently demonstrated that this "infra-red" radiation was produced not only by the sun but also by other sources, and that it obeyed the same laws of reflection and refraction that apply to visible light.

Today the term "infrared radiation" is commonly used to describe electromagnetic radiation whose wavelength lies between .75 micron (750 millimicrons), which is just beyond the red end of the visible spectrum, and roughly 3,000 microns (three millimeters), the beginning of the region that can be detected by microwave radio techniques. The distinction between infrared astronomy and radio astronomy is therefore an arbitrary one, based entirely on differences in detection techniques. In radio astronomy celestial radiation that has been collected by an antenna system is fed into a device that operates as a wave detector. Although strenuous efforts have been made to reduce the wavelengths at which such detectors operate, progress has been slow. World War II radar technology pushed the detectable wavelength down to 1.2 centimeters, or 12 millimeters. After 20 years of effort the shortest operating wavelength for a wave detector has been lowered to about three millimeters. Between .75 micron and three millimeters the only practical detectors are those the infrared astronomer can use in conjunction with optical telescopes, so this piece of the electromagnetic spectrum remains his by right of occupancy. The region between 22 microns and 1,000 microns is still almost entirely unexplored, however, largely because little radiation in this region can penetrate the earth's atmosphere. The transparency of the earth's atmosphere to infrared radiation of various wavelengths is plotted at the top of the illustration on page 22.

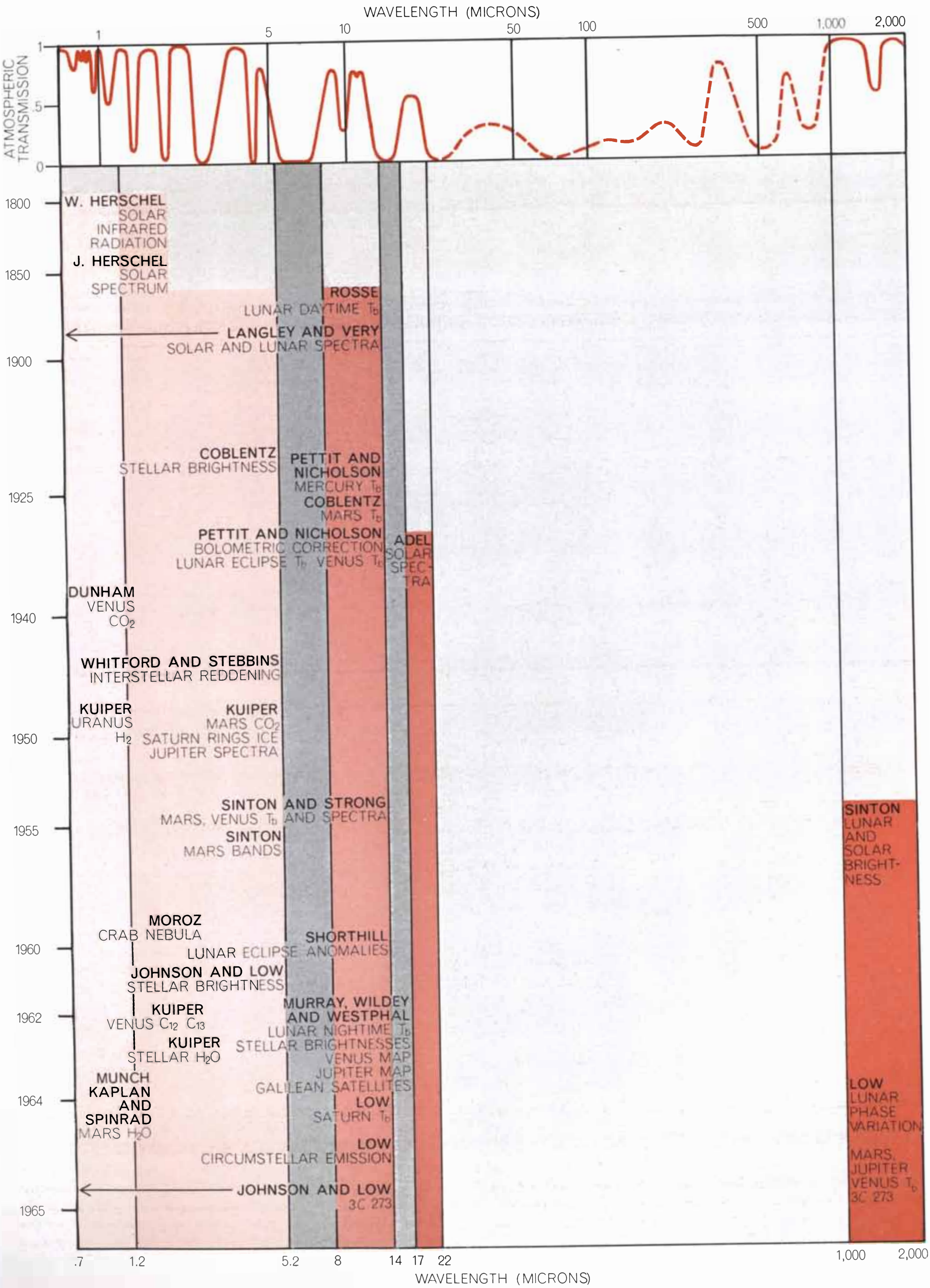
For convenience infrared astronomers have labeled portions of the infrared region according to the mode of detection or to the bandwidth of particular "windows" in the atmosphere. Thus the region from .75 micron to 1.2 microns is called the photographic infrared, because photographic emulsions still respond to radiation of such wavelengths. In fact, the first photograph in the infrared was made by Sir John Herschel (Sir William's son) in 1840, before suitable silver-salt emulsions were available. He recorded a portion of the infrared spectrum of the sun by exposing paper that had been soaked with alcohol containing particles of carbon black; the heat of the infrared radiation evaporated the alcohol in such a way as to leave a detectable image. Some 100 years later the photographic infrared provided the first evidence of carbon dioxide on Venus, water vapor and carbon dioxide on Mars and hydrogen on Jupiter. These and other landmarks in the history of infrared astronomy are listed in the illustration on the next page.

All astronomical observations beyond 1.2 microns are currently made with one-dimensional detectors, that is, detectors that respond only to the radiant energy collected at a single point in the image. The region from 1.2 to 5.2 microns is usually called the near infrared. In the region from 5.2 to 8 microns the earth's atmosphere is completely opaque. There is then a window between 8 and 14 microns, loosely described as the long-wavelength infrared; the term can be stretched to include radiation that enters through still another window from about 17 to 22 microns. No important astronomical measurements have yet been made in the region between 22 and 1,000 microns, but it is suspected that somewhere in this large expanse of the spectrum there are a few windows of potential significance for ground-based astronomy.

The first of the one-dimensional infrared detectors was the thermocouple, which consists of a junction of two dis-



INFRARED MAP OF VENUS was made by the authors and Robert L. Wildey of the California Institute of Technology, using an 8-to-14-micron infrared detector in conjunction with the 200-inch Hale telescope on Palomar Mountain. The infrared radiation that can be observed by scanning the disk of Venus at 8 to 14 microns is thermal radiation emitted by the sun-heated atmosphere. The figures in the diagram represent in degrees Kelvin (degrees centigrade above absolute zero) the "brightness temperature" of Venus. The brightness temperature is equivalent to the actual temperature if an object emits at all wavelengths as though it were a black body. On the Kelvin scale the range from 195 to 220 degrees represents a range from −78 to −53 degrees C. These are temperatures in the upper atmosphere of Venus; the surface temperature is believed to be above the boiling point of water. Note that the temperature across the disk does not change at the terminator: the dividing line between the sunlit hemisphere (*left*) and the dark hemisphere.



WAVELENGTH (MICRONS)
1
5
10
50
100
500
1,000
2,000
ATMOSPHERIC TRANSMISSION
1
.5
0
1800
1850
1900
1925
1940
1950
1955
1960
1962
1964
1965
W. HERSCHEL
SOLAR INFRARED RADIATION
J. HERSCHEL
SOLAR SPECTRUM
ROSSE
LUNAR DAYTIME T_b
LANGLEY AND VERY
SOLAR AND LUNAR SPECTRA
COBLENTZ
STELLAR BRIGHTNESS
PETTIT AND NICHOLSON
MERCURY T_b
COBLENTZ
MARS T_b
PETTIT AND NICHOLSON
BOLOMETRIC CORRECTION
LUNAR ECLIPSE T_b VENUS T_b
ADEL
SOLAR SPEC-TRA
DUNHAM
VENUS CO_2
WHITFORD AND STEBBINS
INTERSTELLAR REDDENING
KUIPER
URANUS H_2
KUIPER
MARS CO_2
SATURN RINGS ICE
JUPITER SPECTRA
SINTON AND STRONG
MARS, VENUS T_b AND SPECTRA
SINTON
MARS BANDS
SINTON
LUNAR AND SOLAR BRIGHT-NESS
MOROZ
CRAB NEBULA
SHORTHILL
LUNAR ECLIPSE ANOMALIES
JOHNSON AND LOW
STELLAR BRIGHTNESS
MURRAY, WILDEY AND WESTPHAL
LUNAR NIGHTIME T_b
STELLAR BRIGHTNESSES
VENUS MAP
JUPITER MAP
GALILEAN SATELLITES
KUIPER
VENUS C_{12} C_{13}
KUIPER
STELLAR H_2O
MUNCH KAPLAN AND SPINRAD
MARS H_2O
LOW
SATURN T_b
LOW
CIRCUMSTELLAR EMISSION
JOHNSON AND LOW
3C 273
LOW
LUNAR PHASE VARIATION
MARS, JUPITER VENUS T_b 3C 273
.7
1.2
5.2
8
14
17
22
1,000
2,000
WAVELENGTH (MICRONS)

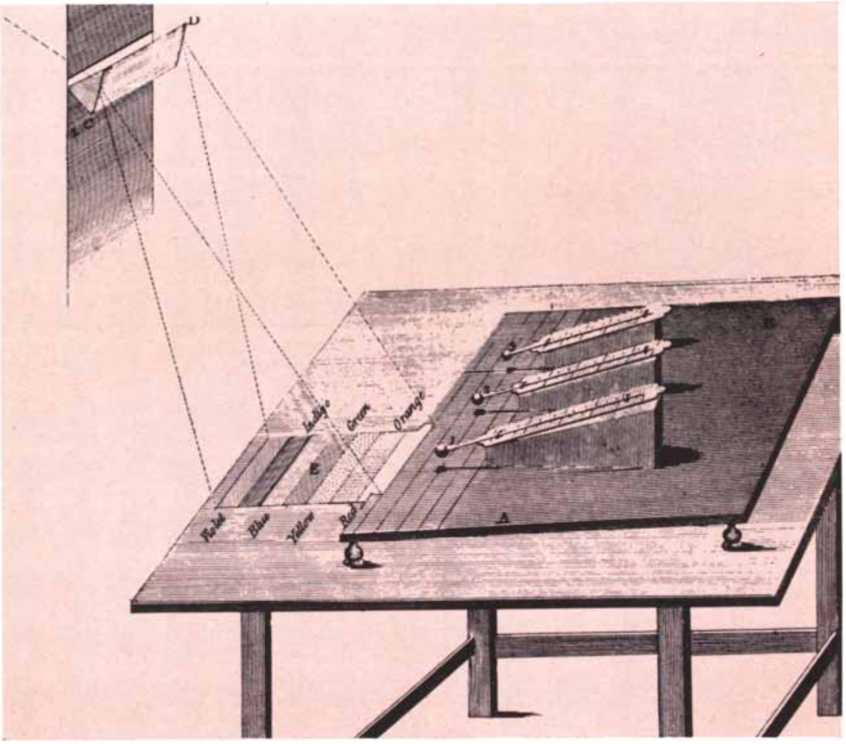
similar metals; heating of the junction generates a small flow of electric current. A parallel array of thermocouples is known as a thermopile; it was first used in astronomy almost 100 years ago by William Parsons (Lord Rosse) to measure the 8-to-14-micron radiation emitted by the full moon and collected by a reflecting telescope. (The glass lenses in a refracting telescope will not transmit radiation much beyond 1.5 microns.) In 1880 Samuel Pierpont Langley invented another one-dimensional detector: the bolometer, a device that measures the increase in electrical resistance that results when a blackened metal foil is heated by absorbing radiation. With the bolometer Langley and Frank Washington Very made crude measurements of the infrared spectra of the sun and moon out to about 14 microns.

Early in this century the sensitivity of the thermocouple was increased by placing it in a vacuum. This improvement enabled W. W. Coblentz to measure the near-infrared emission of stars for the first time. In the late 1920's Edison Pettit and Seth B. Nicholson introduced the concept of the stellar bolometric correction, a correction applied to estimates of the energy output of stars that is based on infrared measurements out to 14 microns. They also took the first infrared readings of the moon during an eclipse. Soon thereafter Arthur Adel pushed infrared measurements of the solar spectrum out to about 22 microns.

The next big advance in infrared detectors was the Golay cell, invented by Marcel J. E. Golay in 1942. In this device the heating of a confined gas creates a pressure that slightly distorts a mirror against which a beam of light is directed; thus any change in temperature within the cell results in a displacement of the beam of reflected light. With the Golay cell, shortly after World War II, William M. Sinton and John Strong made new measurements of the 8-to-14-micron radiation from Venus and Mars and brought up to date the values Coblentz had obtained some 30 years earlier for the "brightness temperature" of these planets. The brightness temperature of an object is equivalent to its kinetic (that is, actual) temperature only if the object emits at all wavelengths as if it were a black body. The emissivity of a planet is influenced, however, by such things as the roughness of its surface. If the planet has an atmosphere, the transparency and the temperature of the atmosphere also contribute to the planet's overall brightness temperature. For Venus, Sinton and Strong obtained a brightness temperature near the center of the planet's disk of 235 degrees Kelvin (38 degrees below zero centigrade, the freezing point of water). For Mars they confirmed Coblentz' estimate that the surface temperature is only a few degrees above the freezing point of water (273 degrees Kelvin).

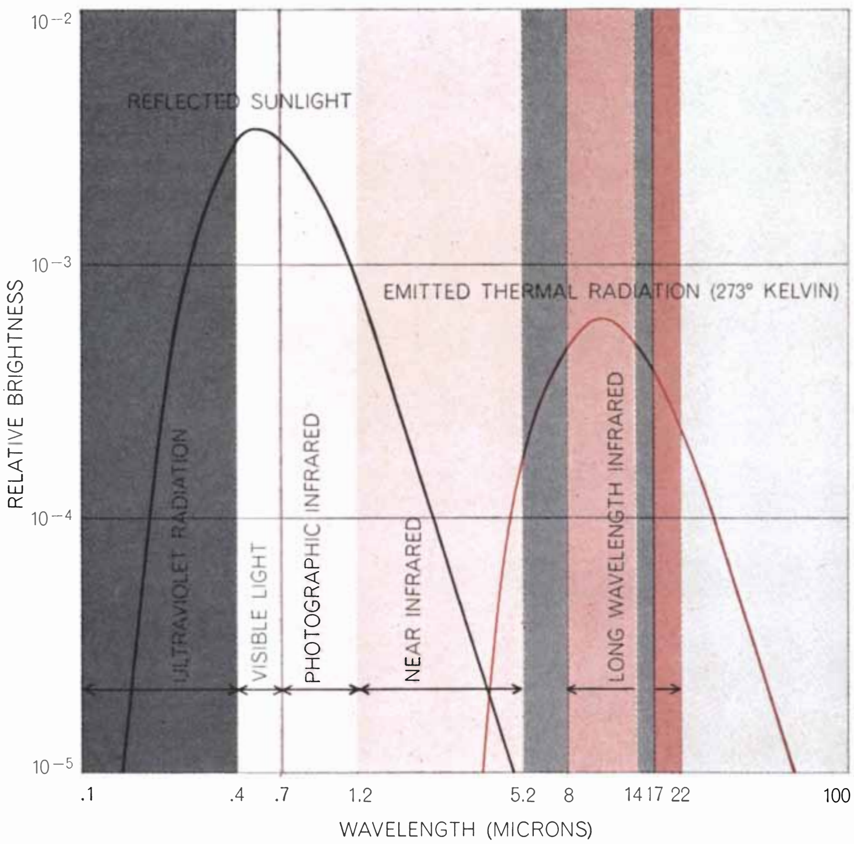
The Golay cell in its present form approaches the limit of sensitivity attainable by any detector operated in thermal equilibrium with a room-temperature environment. An uncooled and unshielded detector responds to all the infrared radiation that impinges on it. When the background brightness of the sky is also taken into account, the infrared astronomer's situation can be compared to the one in which a visible-light astronomer would find himself if he tried to observe the stars by day with a luminous telescope.

The infrared emission of the earth's atmosphere is particularly strong in the 8-to-14-micron region of the spectrum [*see bottom illustration on next page*]. In a typical case photons of these wavelengths will strike an uncooled detector at a rate of 10^{15} per second. The statistical fluctuation under such circumstances will be about 3×10^7 photons per second; therefore any signal of this strength or less cannot be distinguished from "noise" in one second of observing time. By lengthening the observing time and integrating the detector output the effect of noise can be reduced, but to obtain an improvement

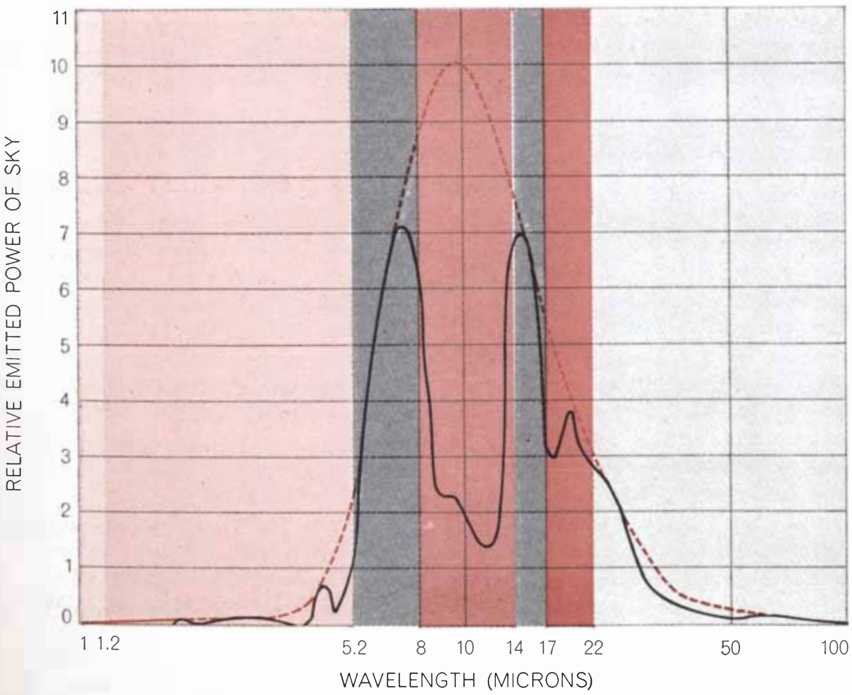


INFRARED RADIATION WAS DISCOVERED by Sir William Herschel in 1800 with the experimental apparatus depicted in this contemporary engraving. Herschel used a prism (*D*) to separate sunlight into its various wavelengths and compared the temperature at different points in the spectrum by means of a glass thermometer whose mercury bulb had been blackened with ink (*1*). Two other thermometers (*2 and 3*) located out of the path of the sun's rays served as controls. He was surprised to find that the sunlit thermometer showed a steady increase in temperature as he moved it from the violet end of the spectrum to the red end and, moreover, that the temperature remained high beyond the visible red.

LANDMARKS in the history of infrared astronomy are listed in this chart, which is vertically logarithmic in time backward from the present. The surnames of the major investigators are given, together with short identifications of their achievements. The transparency of the earth's atmosphere to infrared radiation of various wavelengths is plotted at top. The symbol "T_b" signifies brightness temperature. The label "3*C* 273" (*bottom*) denotes a quasi-stellar radio source, or quasar. Light gray region is unexplored; very little radiation in this region can penetrate the earth's atmosphere.



RADIATION FROM MARS falls into two main categories, reflected solar radiation *(left)* and emitted thermal radiation *(right)*, which overlap in the near-infrared region of the spectrum. "Windows" in the earth's atmosphere that admit infrared radiation are in color. The peak of the emitted radiation happens to be centered in the 8-to-14-micron window.



RADIATION EMITTED BY EARTH'S ATMOSPHERE *(black curve)* is substantial at 8 to 14 microns. If, however, the atmosphere emitted as much radiation as a black body does at 300 degrees K. *(colored curve)*, the 8-to-14-micron window would be all but useless.

by a factor of 10 the observing time must be increased by a factor of 100.

The long-sought goal of producing a cooled and shielded thermal detector was attained in 1960 by Frank J. Low at the firm of Texas Instruments, Incorporated. Low, who is now associated with the National Radio Astronomy Observatory in Greenbank, W.Va., developed a bolometer that operates at a few degrees K., the temperature at which liquid helium evaporates. The bolometer is at the bottom of a cylindrical metal shield that is refrigerated by liquid nitrogen. Thus few infrared photons can reach the detector except those defined by the cylinder's field of view. (An arrangement similar to the one used by Low is illustrated at the bottom of the opposite page.) With his cooled detector Low was successful in observing the 8-to-14-micron radiation from Saturn for the first time; he has also measured the one-millimeter emission from Jupiter and other objects.

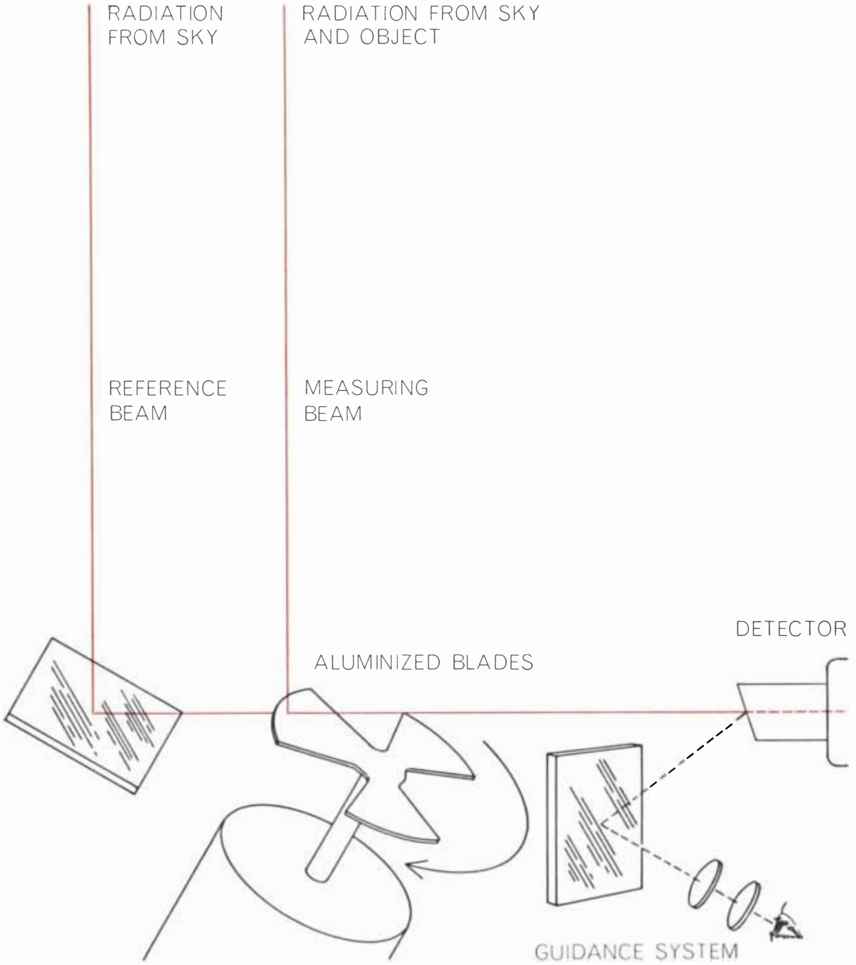
Efforts since World War II to exploit the infrared region of the spectrum for military purposes have led to the development of an entirely new class of detector that uses semiconducting crystals. These devices, known as quantum infrared detectors or photoconductive detectors, have the ability to absorb individual infrared photons and to release a unit of electric charge for each photon absorbed. The conductivity of the crystal depends on the number of charge carriers released; thus conductivity can be used as a measure of infrared flux. Although the new detectors are noisier than Low's bolometer, they have been steadily improved, are easy to obtain and have given a great impetus to infrared astronomy. For the first time detector sensitivity is no longer the most serious limitation in carrying out infrared observations with earth-based telescopes.

A standard arrangement for using sensitive detectors in infrared astronomy is illustrated at the top of the opposite page. The detector is exposed alternately to two beams; one beam consists of radiation from the celestial object and the surrounding sky, the other of radiation from the sky alone. A rotating chopper blade determines which beam reaches the detector. If the infrared flux of the two beams is different, the detector will produce a fluctuating signal proportional to differences in radiation energy in the two beams; in this way a steady sky background is eliminated. The signal is rectified to yield a direct-current voltage, which is then recorded. Finally, after suitable calibration of the instrument, the observed voltage is used to compute the infrared flux intercepted by the aperture of the telescope. The major remaining source of error in such measurements is a persistent uncertainty involving the irregular transparency of the atmosphere to radiation of various wavelengths. To reduce this uncertainty to a negligible level will require an intensive study of the absorption and emission properties of the atmosphere at various times of the day and in various seasons.

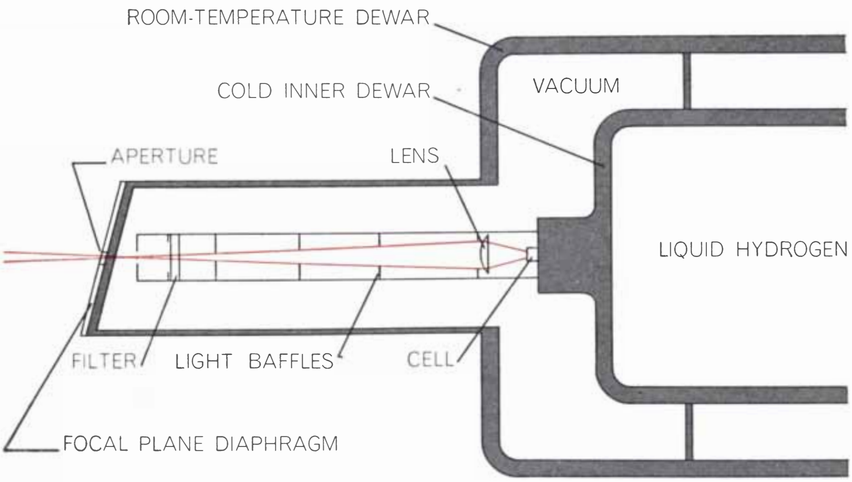
Let us now turn to some of the things that have been accomplished in infrared astronomy with the new detectors. Among the topics that have received much attention is the composition of the atmospheres of the nearby planets. Because Mars has long seemed to be the planet most hospitable to life it has been intensively studied. One discovery, which caused a considerable stir at the time of its announcement in 1956, has since been shown to have an explanation other than the one first proposed, but it provides a good example of the pitfalls that abound in this new and difficult field.

In 1956 Sinton, then at the Smithsonian Astrophysical Observatory, conceived of a way to test the hypothesis that the dark regions of Mars, which change in appearance with the Martian seasons, may consist of vegetation. If the vegetation contains complex compounds of carbon and hydrogen, they should absorb infrared radiation at characteristic wavelengths. Such absorption is a general property of organic compounds, whether they are produced by living organisms or not.

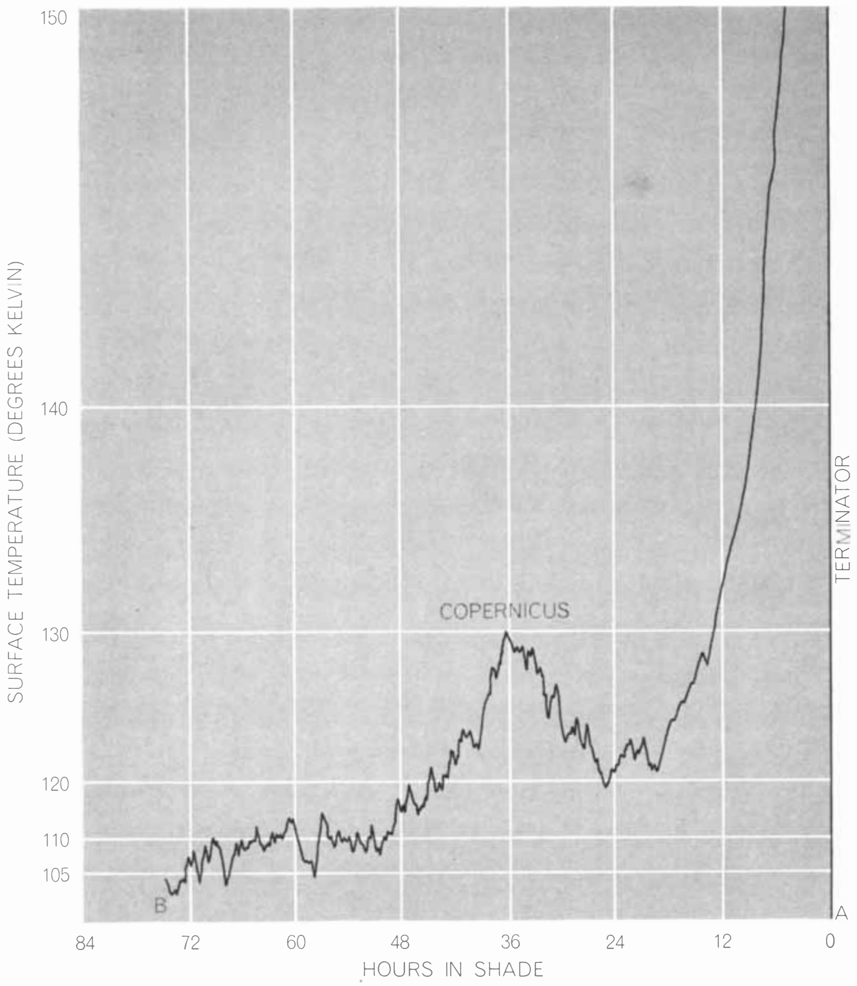
Sinton therefore examined the sunlight reflected from Mars to see if any of the incident radiation in the region between 3 and 4 microns might be missing. If it were, one could assume that it had been absorbed by vegetation, particularly if the absorption changed with the seasons. When Sinton compared the sunlight reflected from a typical bright region on Mars with that from a dark region, he found that the latter had seemingly absorbed a small amount of infrared radiation at 3.43, 3.56 and 3.67 microns, which suggested the presence of complex organic compounds [*see top illustration on page* 27]. Sinton repeated his observations again in 1958 with more sensitive equipment and found he had to make a slight upward revision of .02 micron in

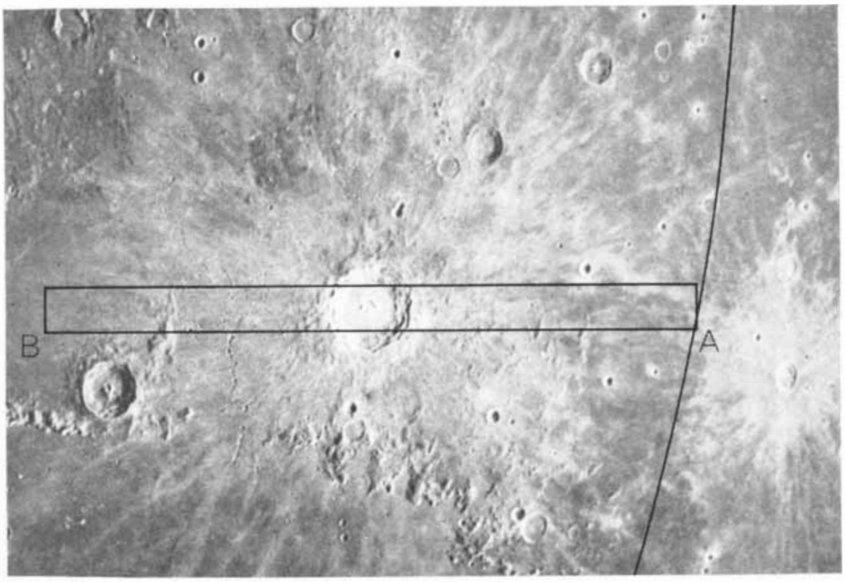


OPTICAL SYSTEM used in infrared astronomy exposes a sensitive detector (*right*) alternately to two beams; one beam consists of radiation from the celestial object and the surrounding sky, the other of radiation from the sky alone. A chopper blade determines which beam reaches the detector. If the infrared flux of the two beams is different, the detector yields a fluctuating signal, which is then rectified to produce a direct-current reading.



COOLED AND SHIELDED DETECTOR provides a very sensitive means for measuring infrared radiation. The diagram at the top of the page shows how the whole device is located in an optical system. The detector is placed at the bottom of a cylindrical metal shield that is refrigerated by liquid hydrogen, which boils at about 20 degrees K. So shielded, few infrared photons can reach the detector except those defined by the cylinder's field of view.





LUNAR NIGHTTIME COOLING CURVE (*top*) shows that the surface of the moon normally cools rapidly after the sun has gone down. This smooth decline is interrupted in this case by an anomaly in the region of the crater Copernicus (*see photograph at bottom*), which cools more slowly. Presumably such regions consist of bare rock, or of rock that is at most only thinly covered by the otherwise ubiquitous lunar dust. When this observation was made, nighttime was to the left, daytime to the right of the terminator line, which was itself moving to the right. Infrared radiation in the 8-to-14-micron range was recorded.

the wavelength of each of the three absorption bands. For several years these "Sinton bands" lent considerable support to the hypothesis that there was vegetation on Mars.

Early this year James S. Shirk, William A. Haseltine and George C. Pimentel of the University of California at Berkeley pointed out that deuterium oxide (heavy water) could account for the two most prominent bands (at 3.58 and 3.69 microns) if it were present in large amounts in the Martian atmosphere. This explanation, however, seemed unsatisfactory. Finally, in March, D. G. Rea and B. T. O'Leary of the University of California at Berkeley, together with Sinton himself, reported their conclusion that deuterium oxide present in the earth's own atmosphere had not been adequately taken into account in the Mars observations. The presence of the third band at 3.45 microns remains to be explained.

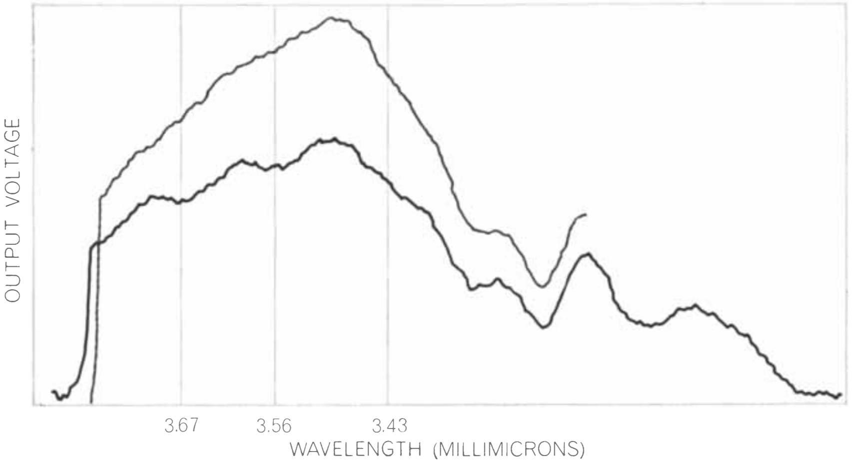
Another kind of investigation of Martian atmospheric absorption bands seems well substantiated and has led to a sharp revision in estimates of the density of the Martian atmosphere. In 1963 Lewis D. Kaplan, Guido Münch and Hyron Spinrad of the California Institute of Technology used the 100-inch reflecting telescope on Mount Wilson to make new measurements of the carbon dioxide absorption bands in the photographic infrared radiation reflected from Mars; they concluded that carbon dioxide is less plentiful than had been indicated by earlier and less accurate measurements. This implied that the pressure of the atmosphere at the surface of Mars is only about .37 pound per square inch, or 2.5 percent of the earth's atmospheric pressure of 14.7 pounds per square inch at sea level. The Martian atmosphere therefore may be too rarefied to support either a winged vehicle or a parachute, both of which had been considered for landing instrument capsules from spacecraft. Now it appears that a large fraction of the payload available for landing a first probe on Mars may have to be taken up by a structure for absorbing impact or by braking rockets. Thus the whole approach to the problem of exploring the Martian surface in the near future has been influenced by the results of ground-based infrared astronomy.

Perhaps the most fascinating—and certainly the most perplexing—results in infrared astronomy have to do with the surface temperatures of the moon and planets as indicated by their infrared thermal emission. As long ago as 1926 Pettit and Nicholson had shown that the moon cools with unexpected rapidity during a lunar eclipse. The surface temperature falls from about 390 degrees K. (117 degrees C.) to about 150 degrees K. in a few hours. Evidently the heat stored immediately below the surface is prevented from moving upward to replace the heat radiated into space. It appears, therefore, that the moon is covered by a millimeter or so of material 100 times more insulating than any substance that occurs naturally on earth. This observation provided the original basis for the belief that there is at least a thin layer of dust on the moon.

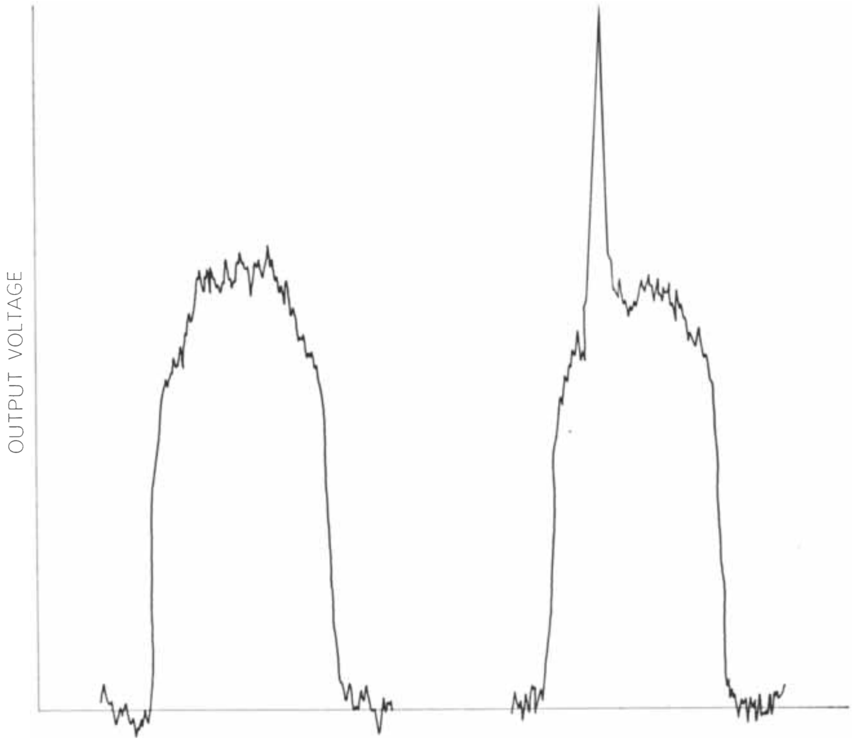
In 1960 Richard W. Shorthill, Howard C. Borough and Joseph M. Conley of the Boeing Aircraft Company made the additional discovery, with the aid of the 60-inch reflecting telescope on Mount Wilson, that the lunar crater Tycho cools more slowly than the surrounding areas during a lunar eclipse. This was the first detection of a geographical variation in the thermal properties of the lunar surface.

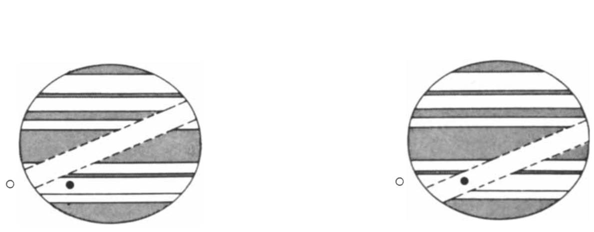
In the summer of 1962 we and Robert L. Wildey, one of our colleagues at the California Institute of Technology, extended the search for such thermal variations to the cooling that occurs during the normal lunar night. Ours was the first study of the moon to be made with a quantum infrared detector in the 8-to-14-micron region. Using the detector in conjunction with a special 20-inch telescope, we found that the kind of anomalous cooling discovered by Shorthill and his associates persisted more than 60 hours after the sun had set on an anomalous area [*see illustration on opposite page*].

Our observations strongly suggest that the slow-cooling areas, in particular the large rayed craters, consist partly of bare rock, or of rock that is at most only thinly covered; this would allow heat from below to reach the surface readily. Moreover, our nighttime cooling curves supply clues to the nature of the lunar surface at a depth measured in centimeters rather than in millimeters—the depth to which cooling is limited during the brief period of a lunar eclipse. We and others have been surprised to find that the physical model that best satisfies the eclipse observations does not fit the nighttime cooling observations. In fact, it does not appear that any simple homogeneous model for the lunar sur-

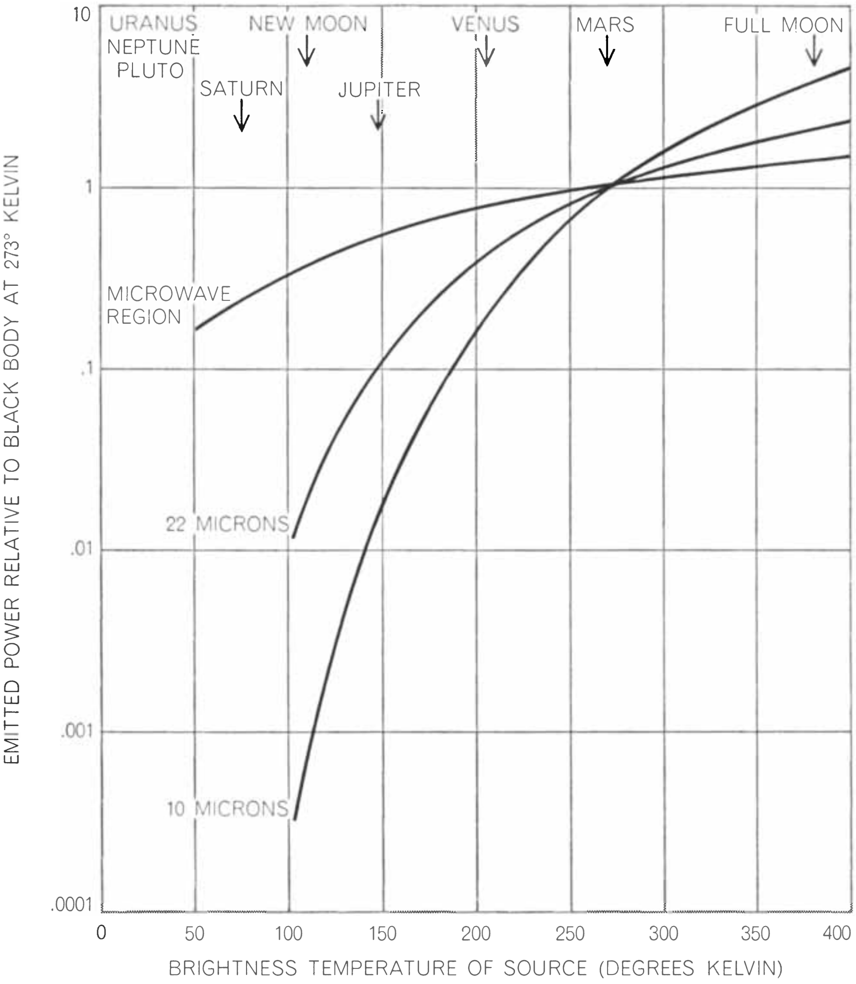


ERRONEOUS EVIDENCE for the presence of vegetation on Mars was obtained by William A. Sinton in 1956. When he compared the sunlight reflected from a typical bright region on Mars (*curve at top*) with that from a typical dark region (*curve at bottom*), he found that the latter had seemingly absorbed a slight amount of infrared radiation at 3.43, 3.56 and 3.67 microns, suggesting the presence of complex organic compounds. It now seems that the last two bands represent deuterium oxide (heavy water) in the earth's atmosphere.





BAFFLING PHENOMENON was first observed by Wildey in 1962 while he was mapping the 8-to-14-micron radiation from Jupiter with the 200-inch telescope. When the scanning field included the shadow of one of the four largest moons of Jupiter (*right*), the infrared flux was enhanced by as much as thirtyfold directly under the moon's shadow. A normal scan is at left. The strange phenomenon was observed twice and has not been seen since.



RELATIVE POWER EMITTED at three wavelengths is plotted against the brightness temperature of the source. The response at each wavelength is taken to be unity when the recording system is aimed at a black body of large angular size whose temperature is 273 degrees K. The brightness temperatures of the moon and planets are indicated at top. The graph shows that longer wavelengths are desirable for observing the colder planets.

face will be able to explain our observations. Evidently the lunar surface is more heterogeneous under its thin veneer of dust than anyone had thought. This is one of several instances in which the observations of infrared astronomers have outrun the ability of theorists to provide explanations.

Later in 1962 we trained our 8-to-14-micron detector on the surface of Venus, this time using radiation collected by the 200-inch reflector on Palomar Mountain. The surface of Venus, of course, is obscured by a dense atmosphere that reflects and absorbs most of the sun's incident radiation. The infrared radiation that can be detected by scanning the disk of Venus at 8 to 14 microns is thermal radiation emitted by the sun-heated atmosphere. It had been discovered as early as 1927 by Coblentz that the infrared brightness temperature across the disk does not change at the terminator: the dividing line between the sunlit and the dark hemisphere. This was confirmed in our more detailed survey [*see illustration on page 21*].

Our 1962 observations also showed clearly that the temperature is highest at the equator of Venus and falls considerably (about 20 degrees C.) toward the poles. The temperature also decreases generally toward the edge of the disk. Known as limb-darkening, this phenomenon is characteristic of emission from planetary atmospheres. (The atmosphereless moon, for example, does not show limb-darkening.)

It was originally surprising to discover that the distribution of heat within the atmosphere of Venus—and possibly at the surface of the planet—is practically independent of the location of the sun. It was even more surprising to discover last year, in our most recent series of observations, that *more* 8-to-14-micron radiation is emitted from the totally dark side of Venus than from the sunlit side. Once again observations have outstripped theory.

An interesting feature of the 8-to-14-micron map of Venus shown on page 21 is the small hot spot near the south pole. This was one of several that came and went within a period of about 24 hours. It seems reasonable to describe them as storms in the upper reaches of Venus' atmosphere.

We have also carried out infrared surveys of Jupiter with the 200-inch telescope. Photographs of Jupiter made with visible light show that the atmosphere of the giant planet is divided into a number of distinct horizontal bands, the pattern of which shifts with the passage of time. One might therefore expect to find some evidence of these bands in infrared maps of the planet. Instead maps of Jupiter's emission at 8 to 14 microns contain few distinctive features of any kind.

In our 1962 observations of Jupiter we twice detected phenomena that were completely baffling and that to our further surprise have not recurred since. As we were scanning the image of the planet to map its 8-to-14-micron emission, our detector happened to pass across a region darkened by the shadow of one of Jupiter's four largest moons. We were astonished to find that the infrared flux was enhanced by as much as thirtyfold at a point directly *under* the moon's shadow [*see bottom illustration on preceding page*]. Since the last observation of this curious phenomenon was made in 1962, it has not been detected again.

In the compass of this article we have had to make a somewhat arbitrary selection of the work that has been done at infrared wavelengths. For example, we have barely mentioned infrared studies of stars and other objects beyond the solar system. This omission can perhaps be justified on the basis that some of the most interesting work is so recent that it is only now reaching the technical journals. Infrared observations of stars and of objects that are of interest to radio astronomers—such as radio galaxies and the remnants of supernovae—are of considerable importance for the development of astrophysical theory.

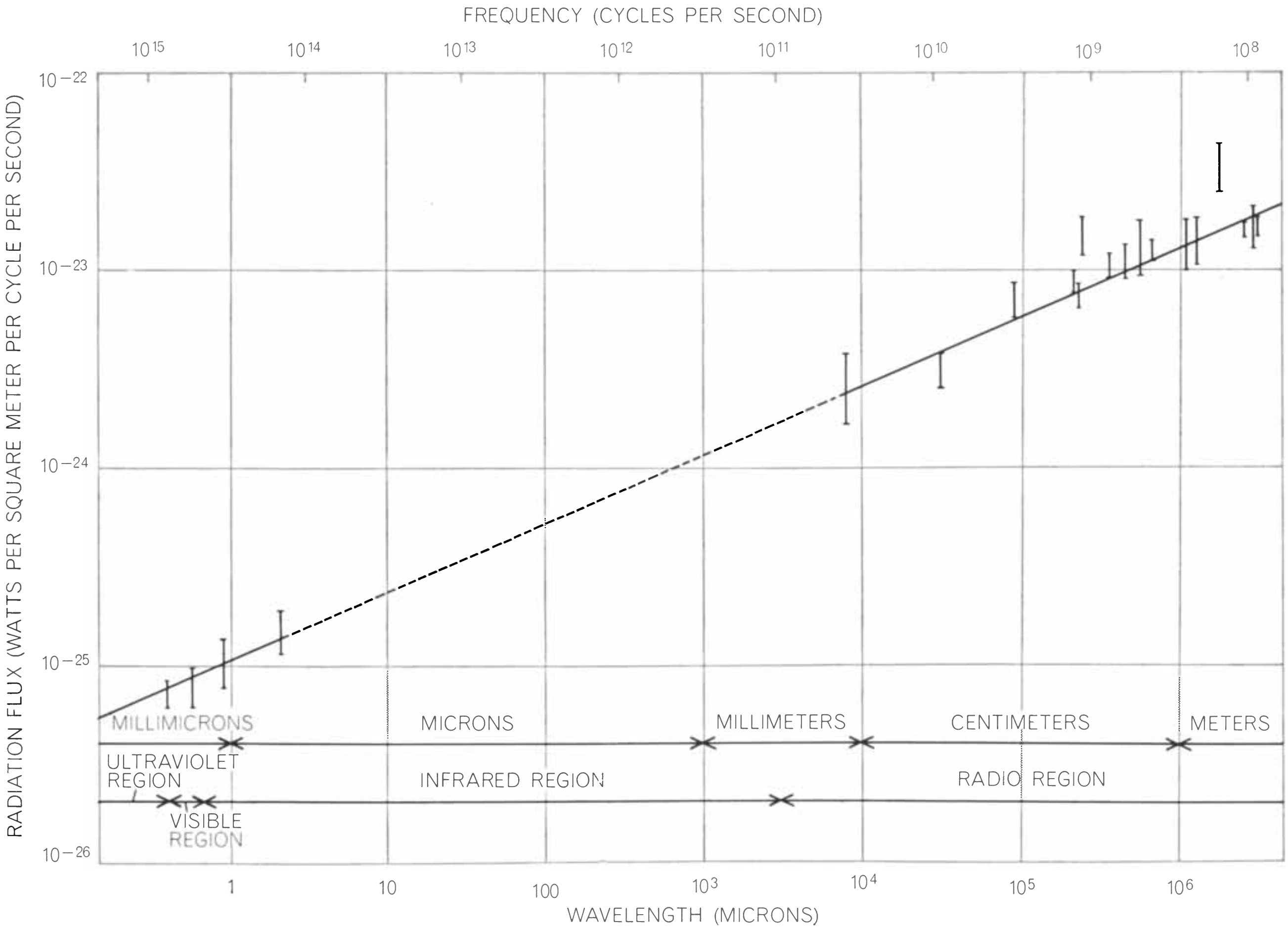
One supernova remnant, the Crab nebula, has already been extensively studied in the infrared region by the Soviet astronomer V. I. Moroz [*see illus-*

tration below]. At the University of Arizona, Harold Johnson and Low have made the first recording of the infrared emission of the brightest quasi-stellar radio source—3C 273. Low has also recorded the source's emission at one millimeter. These objects, now commonly called quasars, are among the brightest and most distant objects in the universe. The incentive to study their infrared emission is great, and they will doubtless receive increasing attention in the years ahead.

The future should also see major efforts to explore the infrared region between 22 and 1,000 microns, in which no important astronomical observations have yet been made. In this region the only major source of opacity in the earth's atmosphere arises from water vapor, the absorption bands of which are broadened by atmospheric pressure. The magnitude of this pressure-broadening at very high, dry sites has still not been investigated with care. It may well be that there are adequate windows at various places in the long-wavelength infrared region all the way to the radio-astronomy portion of the millimeter region. If such windows can be found, it should be possible for ground-based instruments to close the present gap between the domains of infrared astronomy and short-wavelength radio astronomy.

Perhaps the principal problem that each infrared astronomer must solve for himself is where to place his detectors in order to get the greatest return on his investment of time and energy. Should he operate with ground-based telescopes or should he send his instruments aloft in balloons and perhaps into space with rockets? Each platform has its advantages and disadvantages. Our own feeling is that balloons have many advantages over space vehicles for making a spectral reconnaissance of the infrared regions that cannot be explored from the ground. At an altitude of from 80,000 to 100,000 feet a balloon is above virtually all the components of the atmosphere that absorb infrared radiation. The fact remains that if a detailed inspection of a planet's thermal emission is desired, there is no substitute for a suitably instrumented space vehicle, preferably one placed in orbit around that planet.

The advantages offered by ground-based telescopes, however, are hard to duplicate on small, remote moving platforms. These advantages include the ability to make long exposures and the ability to use complicated instrument systems, such as those that must be cooled by liquid nitrogen and liquid helium. The greatest advantage of all is the ability to repeat one's observations and to pursue a program until a satisfactory level of reproducibility has been obtained. Thus we feel reasonably sure that ground-based instruments will provide the major volume of infrared observations, and perhaps the observations of greatest significance, for decades to come.



SYNCHROTRON EMISSION SPECTRUM of the Crab nebula includes the observed intensities (*solid black line*) and the interpolated intensities (*broken black line*) for the entire range of the electromagnetic spectrum from the visible to the radio wavelengths. The longest wavelength infrared observation, at 2.2 microns, was made by the Soviet astronomer V. I. Moroz, from whose paper this illustration has been adapted. Synchrotron radiation is caused by the rapid gyration of charged particles in a strong magnetic field.

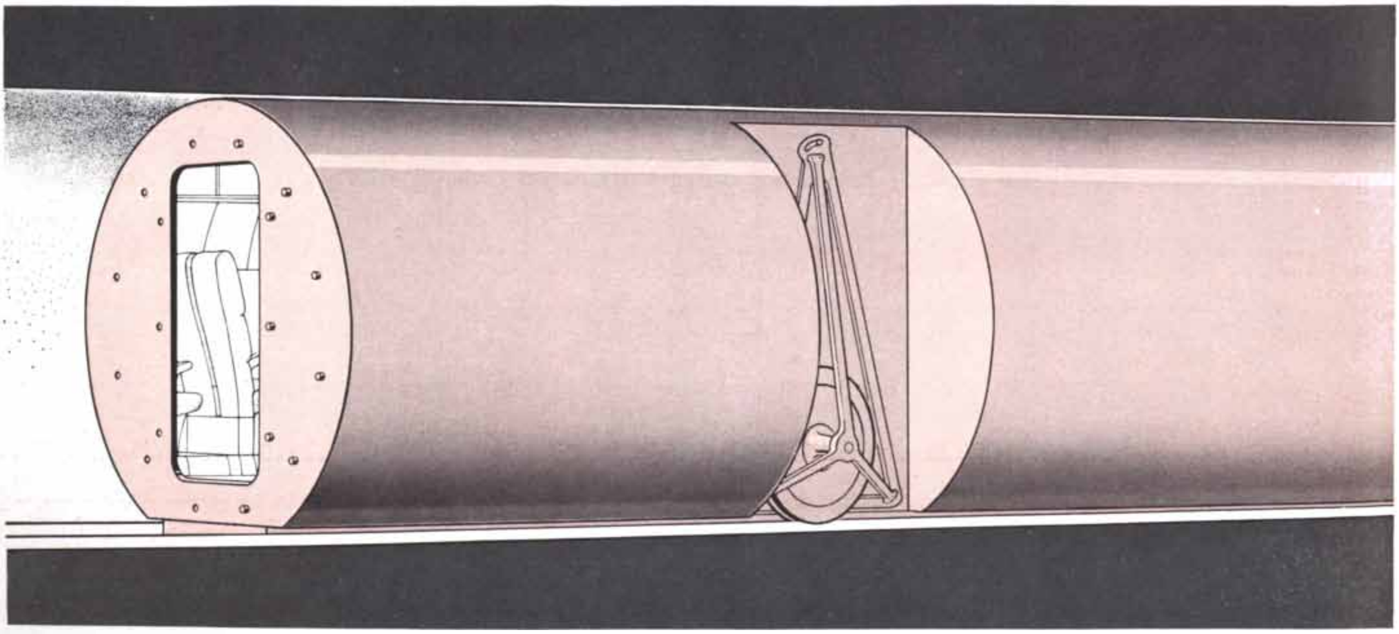
High-Speed Tube Transportation

In which a system is proposed that would carry passengers from Boston to Washington in 90 minutes. Its vehicles would travel at speeds up to 500 miles an hour through dual evacuated tubes

by L. K. Edwards

Contemporary technology can orbit an astronaut and send photographs back from Mars, but so far it has not been able to cope with the mundane problem of mass transportation. Proliferating superhighways are clogged as soon as they are built. Air travel is inefficient for short trips, and some air lanes are crowded to the danger point. Railroads move passengers no faster than they did 50 years ago, and they lose money in the process. Is it possible that the techniques and methods of the aerospace industry, and in particular the special approach known as "systems engineering," could be brought to bear on the vexing tasks of moving passengers between the country's closely spaced metropolitan centers and getting commuters to work? This article will describe the evolution, findings and potentialities of one effort to accomplish that end.

The effort began nearly two years ago when, as an engineer in the Space Systems Division of the Lockheed Missiles and Space Company at Sunnyvale, Calif., the writer suggested: Why not develop airplane-speed surface transportation? Lockheed authorized a small group of us to consider the proposition. Our investigation was brought to a focus last fall by the Federal Government's desire to attack the problem of rail transportation in the "Northeast Corridor," the densely urbanized strip along the East Coast from Boston through New York to Washington. After conversations with people in the Northeast Corridor Transportation Project of the Department of Commerce and in the School of Engineering at the Massachusetts Institute of Technology, which is making technical studies for the project, we have evolved two specific proposals. One is a "Corridor" system to provide intercity passenger service, downtown-to-downtown, for several thousand passengers an hour. The other, an "Urban" system, is a commuter network. (Early this year Lockheed decided to concentrate on projects more closely related to its traditional activities; I obtained an option to acquire the company's interest in the transportation project and have since been proceeding on my own responsibility, although with



"CORRIDOR" TUBE TRAIN is made up of cylindrical cars 65 feet long running on steel tracks welded to the floor of an underground tube. Each car has four steel wheels fitted with roller bearings. Entrance and exit doors, on opposite sides of the cars, are pres-

some valuable technical support from Lockheed personnel.)

The general elements of the Corridor design emerged rather quickly from a logical sequence based on common sense and a few simple calculations. In retrospect, at least, the logic seems inexorable:

1. To compete with foreseeable improvements in air travel and its associated surface connections, the average speed along the Corridor must be at least 200 miles an hour. Time must be allowed for intermediate stops in addition to those in Boston, New York and Washington, so the cruising speed must be increased accordingly—to something over 400 miles an hour.

2. Such high speeds are unthinkable unless one protects the train from ice and from objects falling or thrown into its path. The vehicle should therefore travel through a continuous enclosure—a tube.

3. Drag forces due to air resistance are substantial at present-day railroad speeds; they increase with the square of the velocity, and they would be prohibitive in the case of aircraft speeds in air at sea-level density. Therefore most of the air should be pumped out of the tube.

4. Given external power plants to exhaust the tube, why not make these the sole source of propulsive power for the train? It is only necessary to admit air at atmospheric pressure behind the train to accelerate it through the evacuated tube; similar pneumatic effects can decelerate the train to a stop.

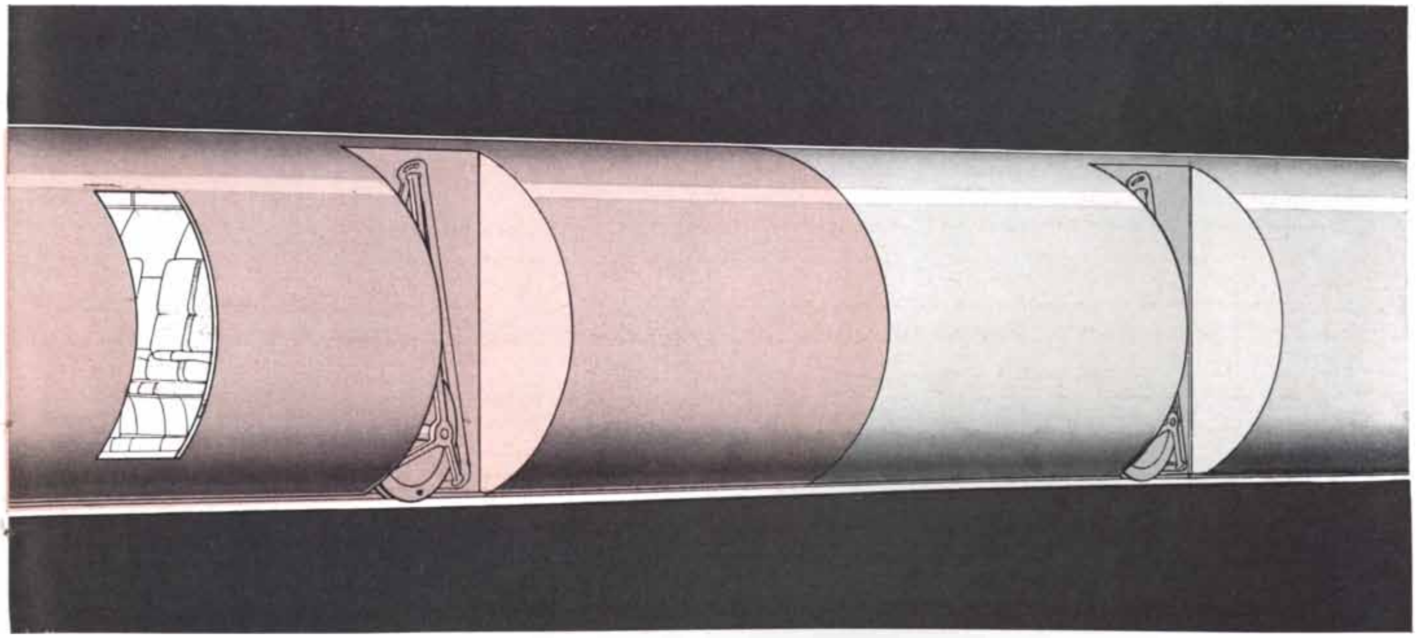
5. For heavy, continuous traffic a pair of tubes is needed. Convenience of installation and maintenance suggest that they should be installed side by side. They can then be interconnected with controllable valves to improve the efficiency of airflow.

6. At ground level or elevated above it the tubes would be an unsightly nuisance. Moreover, a reasonable degree of straightness would call for large numbers of bridges or tunnels. (The high-speed Tokaido railroad between Tokyo and Osaka in Japan, with a design speed of 150 miles per hour, includes some 40 miles of tunnels—an eighth of its total length.) In the central districts of major cities there is no alternative to tunneling. One should therefore consider putting the tubes in a tunnel all the way from Boston to Washington—a little more than 400 miles.

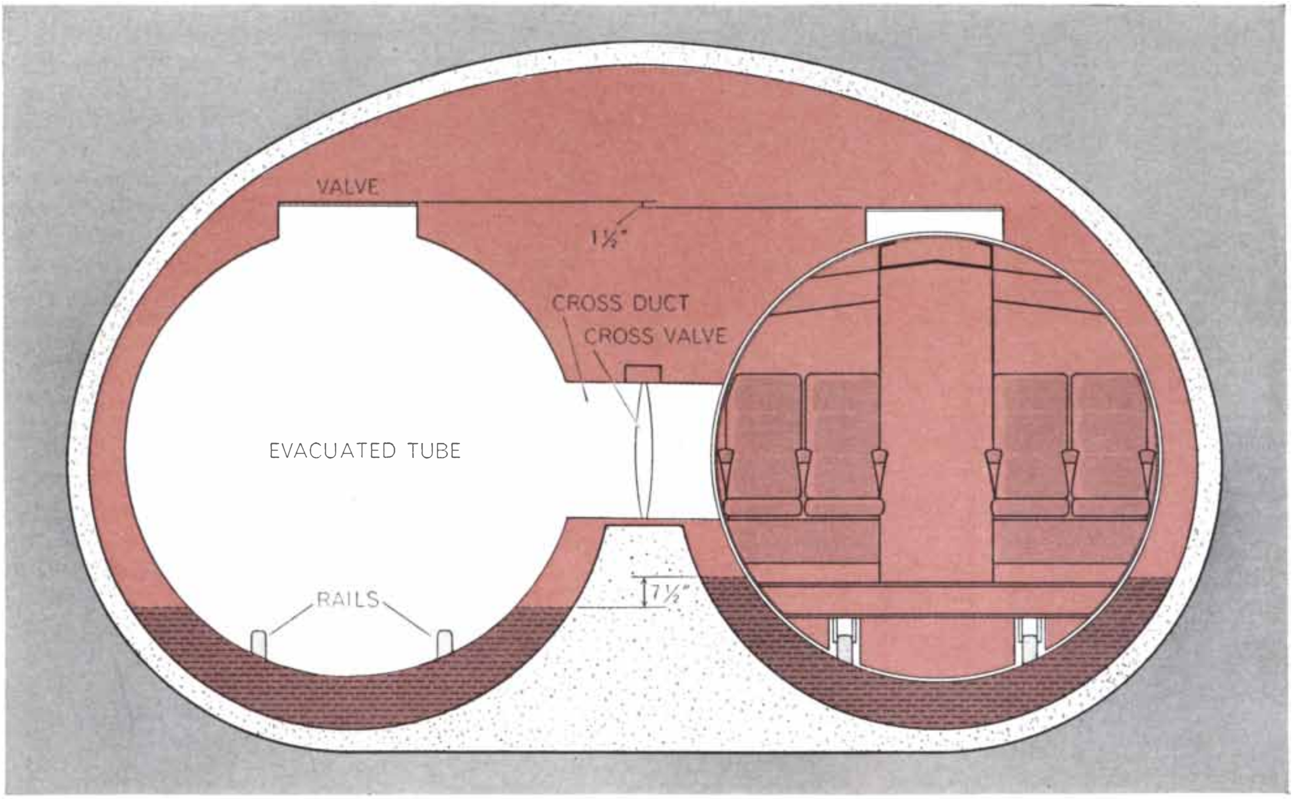
At this point a practical person might well call a halt, pointing out that anyone with any sense knows that 400 miles of tunnel would be prohibitively expensive. The systems engineer is trained to ask, "Would it?" and to study the pros and cons before either discarding or accepting the idea. On investigation we found that the tunnel, at $4 to $5 million per mile including the dual tubes and valves, may well be less expensive than any other high-speed solution to the Corridor problem. (According to an authoritative estimate it would cost some $6 million per mile to duplicate even the largely conventional Tokaido line in the Northeast Corridor.)

Several factors make the tunnel seem particularly attractive. Because pneumatic propulsion permits tubes of small diameter, the tunnel's cross-section area need be only about 270 square feet, smaller than some of the water tunnels supplying New York, only two-thirds as large as a two-track subway tunnel and only a third as large as a standard railway tunnel. Impressive new machinery has been developed for automatic tunneling through hard rock, and a Corridor tunnel can be dug in bedrock most of the way. In the case of a tunnel, moreover, heavy right-of-way costs and real estate taxes would presumably be replaced by nominal payments for easements. Finally, at depths below 50 feet the temperature does not fall below the freezing point of water; it remains constant all year; there is no weathering. Transportation tunnels typically remain in use for at least a century, whereas most surface-transportation facilities survive only a few decades without substantial renovation.

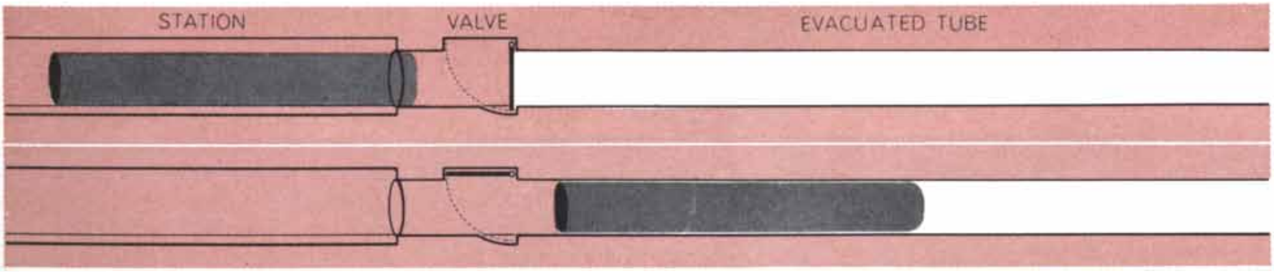
We therefore decided in favor of the tunnel concept. Mounting the tubes in the tunnel calls for one of the few real innovations we considered necessary for a genuinely high-speed system. The maximum speed attainable in surface transportation is heavily influenced by the smoothness of the surface traversed,



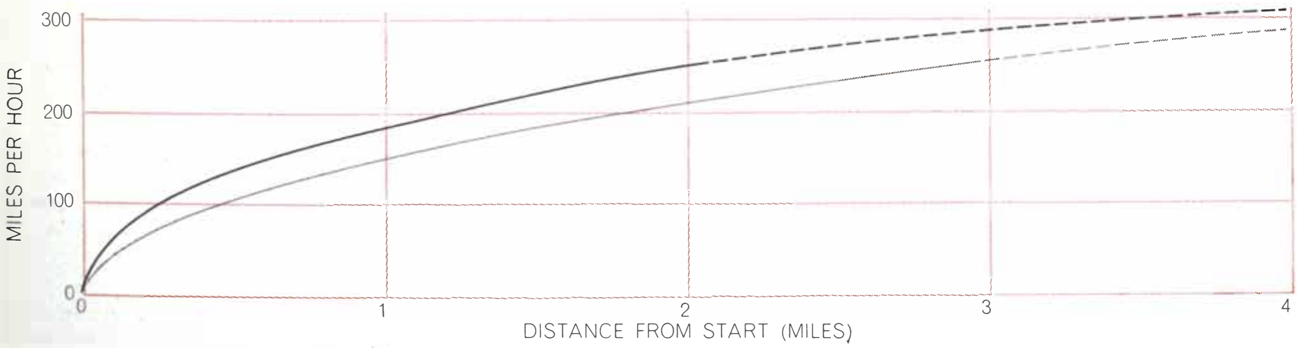
sure-tight sliding panels that retract into the ceiling. The end of an ordinary car rather than of an actual lead car is exposed at the left in order to show the flat faceplate by which the cars are coupled rigidly. Each car will have room for 64 seated passengers.



DUAL TUBES are floated in water to ensure a smooth ride. The empty tube will be submerged in the water as shown at left; when a train passes, the tube must displace more water but will only be depressed $1\frac{1}{2}$ inches out of line because the water, being confined in a narrow channel, will itself rise $7\frac{1}{2}$ inches (*right*). The tubes are evacuated by external compressors; the tunnel air is at normal pressure (*color*). Cross valves interconnect the tubes, and other valves, in the top of the tube, open to admit outside air for acceleration.



"DYNAMIC AIR LOCK" accomplishes the transition from a standing start to high-speed motion in the evacuated tube. As it waits in the station the train has its nose at the end of the tube, the evacuated portion of which is sealed off by the "start" valve (*top*). The valve swings open (*bottom*) and the train, with a near vacuum in front of it and full pressure behind, is pushed into the tube.



ACCELERATION AND SPEED depend on the train's weight and how much full-pressure air is admitted to the tube. The curves show the acceleration in the first four miles for trains weighing 700,000 pounds (*black*) and a million pounds (*gray*). The unbroken portions of the curves show how many "miles of air" are used for acceleration, or how far the train is when the start valve is closed.

and the smoothness requirement becomes more stringent as speeds increase. The Tokaido railroad's operating speed has been significantly limited, for example, by uneven settling of the roadbed, although it was specially designed. "Smoothness" has two aspects: the initial, or no-load, condition and uniform "compliance," or flexing, under load. The Stephensons learned about this when they first built railroads across England in the 1840's. In spite of expensive and time-consuming efforts to provide a level, solid support under every yard of rail, they found the smoothest ride of all was achieved where the tracks were virtually floated across a bog so soft that a man could hardly stand on it!

In the tube-transportation system we therefore propose to float the tubes in water throughout the level portions of the path. In the no-load condition the tube will be submerged in the water to a depth of about 20 inches [*at left in top illustration on opposite page*]. Regardless of small shifts in the supporting earth, the rigidity of the tube and the self-leveling of the water will keep the alignment of the tube itself undisturbed. When a train comes along, of course, the tube will become heavier and must sink deeper into the water—nine inches deeper in the case of a typical train. The tube will not be seriously deformed by this further immersion, however. Since the water supporting each tube will be constrained in a trough, it will not be able to "seek its own level" under the speeding train; instead the water level will rise 7½ inches and the tube will actually settle only 1½ inches [*at right in top illustration on opposite page*].

This "dynamic flotation" in water can provide the ultimate in uniform compliance under load. It should also have advantages in shock absorption and sound deadening. It does raise a number of questions about the longitudinal water movements and stresses induced in the tube when the train passes and about corrosion, but these problems seem either to be inconsequential or to have ready solutions.

What should the train run on? For half a century patents have been granted on various ways of supporting a vehicle without wheels, and most "advanced" land-transportation concepts incorporate one or another of these schemes. Our investigation confirmed what railway engineers have known all along: with roller bearings a steel-rimmed wheel running on a steel rail is amazingly efficient. It takes only about two pounds of tractive force per ton of railroad train weight to overcome rolling friction—almost regardless of speed. Few airplanes can cruise with less than 130 pounds of thrust per ton of the plane's weight, of which half is chargeable to producing lift. In other words, the wheel-on-rail is more than 30 times more efficient than the airplane in this lift-to-drag relation; helicopters and "ground effect," or hovering, machines tend to be less efficient than airplanes.

There are other advantages to wheels. They avoid the need for an air blower or other active lifting device aboard the vehicle. They position the vehicle in the tube more precisely than other systems can. And it is easy to gear shafts to the wheel axles as a source of auxiliary power for air conditioning and other requirements.

Can wheels run safely at very high speeds? The answer is yes. Specially built "automobiles" have exceeded 500 miles an hour in record runs on wheels with standard roller bearings; the bearings showed no signs of heating or incipient breakdown. An individual bearing on the tube train might suddenly "freeze," but installing the bearings in pairs would allow for that eventuality; moreover, any wheel experiencing such a partial failure could be immediately and automatically lifted off the track for the remainder of the trip. Will the wheel rim fly apart? No, the circumferential stresses are less than those attained in the compressors of some turbojet engines. The wheels can be tested from time to time by "overspeeding" in a test pit, but in general trouble is unlikely—particularly if the wheels are not abused by having to transmit heavy propulsive and braking forces.

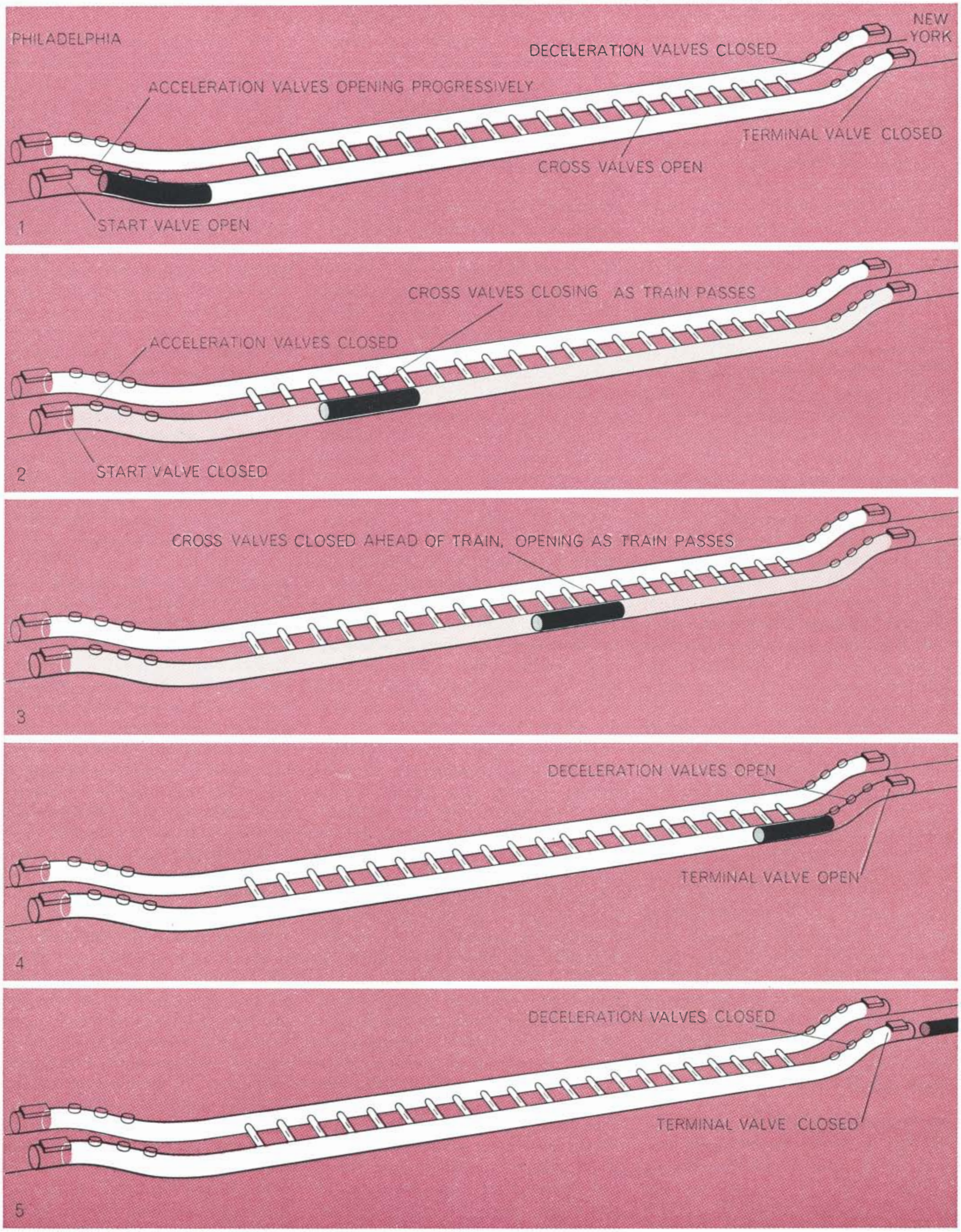
Do wheels not require springs? Hardly any, if the roadbed is really smooth. "Consider the billiard ball," an M.I.T. professor once told his class. "It is a hard object rolling on a hard surface. But it does not need springs because the surface is smooth." Aerospace engineers have learned, moreover, that springs and shock absorbers often create more dynamic problems than they solve. (The tube train would, however, have rubber bushings at several points in the wheel mounts to absorb slight shocks and deaden noise.) The lubricants required for wheels will of course have to function in a low-pressure environment, but space technology has solutions available for any problems that arise. The final decision was to use wheels, old-fashioned though they may seem—double-flanged wheels running on continuous steel rails welded to the floor of the tubes.

The passenger car itself is remarkably simple: a 65-foot-long thin-walled cylinder with wells for four wheels [*see illustration on pages 30 and 31*]. The loading on each wheel is well within present railroad practice. The coupling between cars is no more than a strong, flat faceplate with a number of push-button-operated bolts and with no provision at all for flexing. The rigid connection between cars assures pressure integrity throughout the train and keeps objects from falling to the track; it will also avoid the familiar car-to-car swaying motions, which get much worse as the speed increases. Rigid coupling is possible because the track is so straight: the sharpest curve through which the train must turn will have about a five-mile radius, and even this will only be at reduced speeds. With nominal loads at the wheel flanges, the entire train will flex to conform to such gentle curves with much less induced stress than is applied to an airplane wing.

Construction of the cars will be considerably simplified by the nature of the stresses that will be encountered. The greatest loads will result from the maintenance of sea-level pressure inside the car as it moves through a low-pressure environment. These loads produce "hoop tension" in the circular wall, which is ideal. Even the longitudinal stresses turn out to be primarily tension rather than compression, since the train will be accelerated by low pressure in front of it and decelerated by low pressure behind it. The shell can therefore be sheet metal of moderate gauge, with little bracing except at the doors and wheel wells.

At each end of the train we propose to place a special "lead car." This car will have at its forward (or rear) end a pressure enclosure with an emergency exit through it and will include a compartment for the "safety attendant," who replaces the conventional engineer or motorman, a battery-powered low-speed motor for emergency and in-station propulsion, batteries and generators, public telephone booths and perhaps lounge space and dressing rooms.

Entering a clean and quiet station that looks something like the lobby of a large office building, travelers will board the train through gates much like the outer doors of a modern elevator, behind which the openings in the train will be positioned. (Passengers will not see the exterior of the train



PNEUMATIC PROPULSION would function as shown here on the 85-mile leg from Philadelphia to New York. The train is forced into the tube as shown in the middle illustration on page 32 and is accelerated at maximum rate by the full-pressure air admitted behind it (*1*). After two to three miles the start valve and accelerator valves are closed (*2*); the train continues to accelerate, but at a diminishing rate. The cross ducts close as the train passes in order to contain the air behind it. After a while the train begins to compress the residual air in the tube ahead of it and is decelerated gradually (*3*). When the air ahead of the train reaches atmospheric pressure, the deceleration and terminal valves are opened (*4*). Each of them closes again as the train passes (*5*).

any more than a passenger sees the exterior of an elevator.) The openings in the train will be pressure-tight curved segments that retract into the top of the car, like the doors on some present-day airplanes. The entrance and exit will be on opposite sides.

The car's nine-foot-six-inch inside diameter will allow two-plus-two seating for 64 passengers with spacing comparable to that on luxury airliners. We have tentatively provided luggage space both above and below the seats in the belief that most passengers prefer to keep their luggage with them. There will, of course, be no windows. (There is growing evidence, incidentally, that looking out of windows while traveling on the surface at high speeds would make passengers dizzy, if not actually sick.)

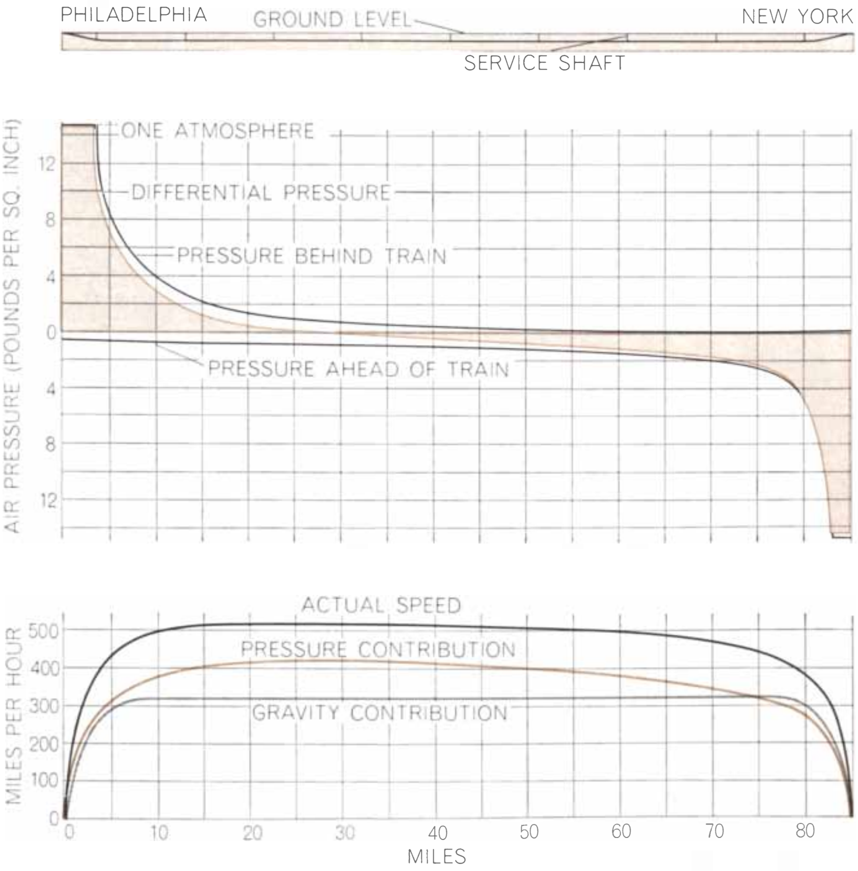
The principle of pneumatic propulsion is obviously not new. Pneumatic delivery tubes were once common in department stores and are still in use in libraries and other institutions. Even pneumatic passenger transportation has a history. One of the oldest such systems on record was built in Ireland during the 1840's. The train was propelled by a piston that extended from the bottom of a car into an externally pumped tube, 15 inches in diameter, laid between the tracks. The train displayed speed, power, efficiency, smoothness, cleanliness and silence far superior to the best steam railroads of the day, and similar installations were soon built in England. All were abandoned within a few years, however, because of one tremendous trifle: a leather flap, which ran the full length of the tube to seal the slot through which the train was connected to the piston, could not withstand the onslaught of the elements and of rats!

New York City's first subway was a pneumatic one, built in 1870 by a proprietor and editor of *Scientific American,* Alfred Ely Beach. In an effort to get a franchise for a subway running the length of Manhattan, he had a one-block tunnel dug under Broadway from Warren Street to Murray Street, using a cylindrical tunneling shield of his own design. A blower propelled the 18-passenger car through the tunnel in one direction and then reversed to "suck" it back. The subway ride was a popular attraction for a year, but Beach never got his franchise; the elevated railroads went up instead.

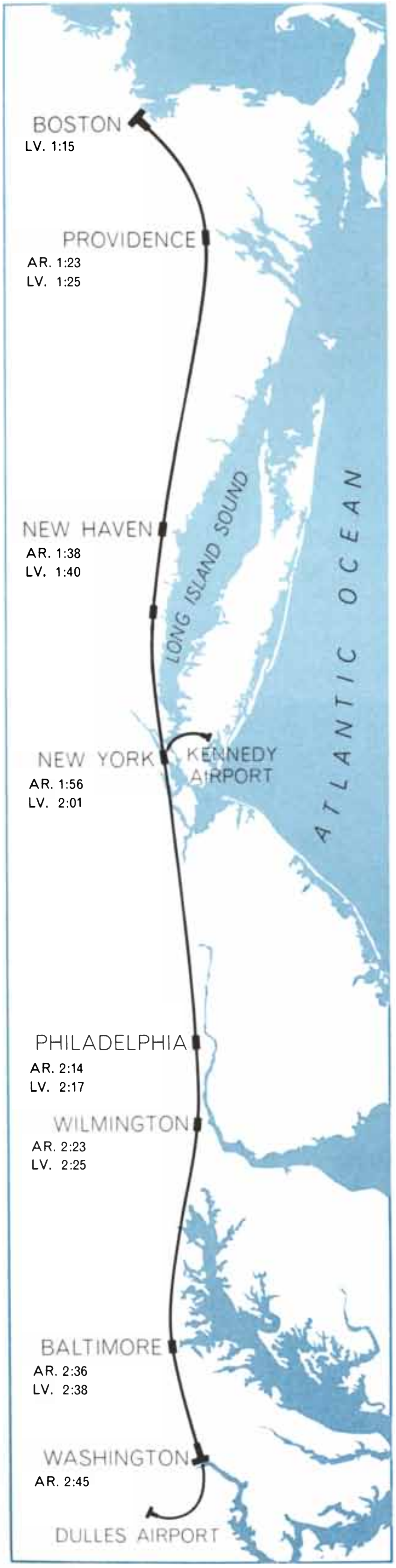
There is certainly no more attractive way to propel a heavy train at high speed than with the most available medium of all: free air. Sea-level atmospheric pressure applied to the 10,000-square-inch cross section of the train yields a propulsive force of 140,000 pounds, or 70 tons. At only 50 miles an hour this matches the pulling power of five large steam locomotives. Better yet, air can continue to push with this force at speeds as high as 200 miles an hour—at which point the effective power level is 70,000 horsepower. Yet the only power plant is a bank of perhaps four 2,500-horsepower electric motors driving air compressors at one or two points outside the tube. The explanation of this apparent inconsistency is that each train is accelerated for only about two minutes—whereas the external power plants work more or less continuously, storing the energy in the evacuated tube to be drawn on when needed. This is the principle of the pneumatic catapults that launch missiles and torpedoes; a catapult's low-horsepower, long-duty-cycle engine and compressor store a great amount of energy for release in seconds.

In a sense, then, the tube train will be the world's largest catapult, but with a big difference: instead of being almost instantaneous, the acceleration will be gradual. In fact, the rate of both starting and stopping accelerations can be kept below those of jet aircraft and even below those of a compact car. No seat belts will be needed; even standees will not experience accelerations appreciably higher than in present rapid-transit systems. It is the rate of change in acceleration, something called "jerk," that is most critical to comfort, and "jerk" is low in the tube train because the acceleration continues for a comparatively long time.

We already have some experimental data on how a cylindrical object behaves when it is accelerated to high speed in an evacuated tube. For the past five years the Army Research Office in Durham, N.C., in conjunction with Duke University, has been working on a "vac-



GRAVITY AND VACUUM combine to propel a million-pound train from Philadelphia to New York in 13 minutes. The tube profile has a maximum slope of 15 percent at the ends (*top*). The middle diagram shows how the pressures behind and ahead of the train vary along the route; the difference between the fore and aft pressures accelerates and then decelerates the train. The bottom diagram shows the speed contributions of vacuum and gravity, which add (on an energy basis) to produce a peak speed of about 500 miles an hour.



"NORTHEAST CORRIDOR" route, with spurs to airports at New York and Washington, is shown, along with the schedule for the 1:15 out of Boston. Site of one stop in Connecticut remains to be decided.

uum-air missile boost system" designed to get missiles or satellite-launching vehicles moving fast before the first-stage rockets are fired. Tests have been conducted with metal cylinders in tubes ranging from 1¼ inches to six inches in diameter; a six-inch, half-pound hollow projectile, for example, is accelerated to more than 750 miles an hour within the length of a 100-foot tube. The tests have shown that the compressibility of air, which degrades aircraft performance at high speed, actually assists in the operation of such a tube catapult. Another encouraging finding is that there appears to be an inherent centering effect that tends to maintain the projectile's stability and keep it away from the walls of the tube.

Although our tube train is driven by air pressure, no complicated air-lock arrangement is necessary for station stops. While the train is in a station, with its nose at the end of the tube, a large valve closes off the evacuated portion of the tube [*see middle illustration on page* 33]. Passengers leave and enter freely and then the car doors are closed pressure-tight. Now the valve close to the end of the tube is opened; atmospheric air forces the train into the near vacuum in the tube. (The radial clearance between the cars and the tube is to be about an inch; our studies indicate that the power loss through this space should be insignificant, but if experience proves otherwise a brushlike seal could be added at each end of the train.) As the train moves down the tube the valve is kept open for a time to allow continued acceleration at maximum rate. When the proper amount of air has been admitted, depending on the weight of the train, the valve is closed. This traps a slug of air in the tube behind the train; it expands, and in doing so it applies further, although decreasing, force to accelerate the train still more. Within the first four miles the train will have reached a speed of about 300 miles an hour.

The air behind the train becomes increasingly attenuated; the very-low-pressure air in the long tube in front of it is steadily compressed. After a while the pressures are balanced fore and aft; then the decreasing pressure behind the train begins to decelerate it. When the air ahead reaches atmospheric pressure, the valves at the destination end are opened; the train is brought to a stop—and the tube behind it has largely been restored to low pressure [*see illustration on page* 34]. If one ignores the losses due to the circulation of air through the tube and to the trifling amount of rolling friction, the train has had a free trip! In general, the magnitude of the compressor's task—which is to restore the initial near vacuum within the tube—is equal to the amount of these two losses. A normal surface vehicle, on the other hand, consumes energy in proportion to its weight in getting up to speed and then wastes that energy in the form of air turbulence and heat at the brakes before coming to a stop. Aircraft are inherently even more wasteful: a jet airliner consumes billions of foot-pounds of energy in climbing to cruising altitude, all of which is wasted by the descent at the end of the trip.

Pneumatic propulsion, then, is an effective and comparatively efficient means of transportation. When we came to deal with the longer and heavier trains required in the Urban system, however, we found that satisfactory acceleration could not be achieved with atmospheric pressure alone. Fortunately another source of propulsive power is readily at hand—and as "free" as air. It is gravity. We decided to take advantage of the principle of the pendulum. As first-year physics students learn, a pendulum, in the course of a single swing, converts potential energy (the energy stored in the suspended mass of the pendulum) into kinetic energy (the energy of the pendulum's motion) and back again into potential energy. This double conversion is accomplished with a lovely 100 percent efficiency except for the tiny losses resulting from air drag and friction in the suspension. That is why a spring weighing two ounces can swing a four-ounce clock-pendulum weight back and forth for eight days; it would take a 300-pound spring to do the same job if the back-and-forth motion were entirely horizontal and wasted all its energy at the end of each stroke.

It was a simple matter to design a pendulum into our tube-train system. With the decision already made to put the tubes in a tunnel, it would add very little to the cost of the tunnel to slope it downward on both sides of each station. Leaving a station, the train is accelerated by the downgrade, and as it approaches the next station it is decelerated by the upgrade—interchanging potential and kinetic energy with the same high efficiency as a clock pendulum. In the case of the Urban system the pendulum effect can contribute more than half of the total energy required by the tube train. The technique affords other important benefits:

1. It brings most of the tunnel down into deep bedrock, where the cost of tunneling—by blasting or by boring—is reduced and incidental earth shifts are minimized; the rock is more homogeneous in consistency and there is less likelihood of water inflow.

2. The nuisance to property owners decreases with depth, so the cost of easements should be lower.

3. A deep tunnel does not interfere with subways, building foundations, utilities or water wells. The only really deep works of man in the Corridor area, as far as we can determine, are two New York City water conduits. (They were dug as deep as 1,100 feet, incidentally, precisely to save money and ensure long life.)

4. The pendulum ride is uniquely comfortable for the passenger. When a vehicle gains speed by coasting freely down a moderate slope, the passenger feels absolutely no sensation of fore-and-aft acceleration; he can stand up, write and pour water without difficulty. The same thing is true as the vehicle loses speed by coasting uphill at the end of the trip. Tube-train riders will feel some vertical acceleration during brief periods when the path changes slope, but at rates well below the criteria for passenger elevators.

The amount of "free speed" available from the pendulum technique varies with the square root of the depth. At 1,000 feet it would be some 175 miles an hour; at 4,000 feet, nearly 350 miles an hour. We propose to have the Corridor trains cruise at 3,500 feet, deriving 325 miles per hour of speed from gravity.

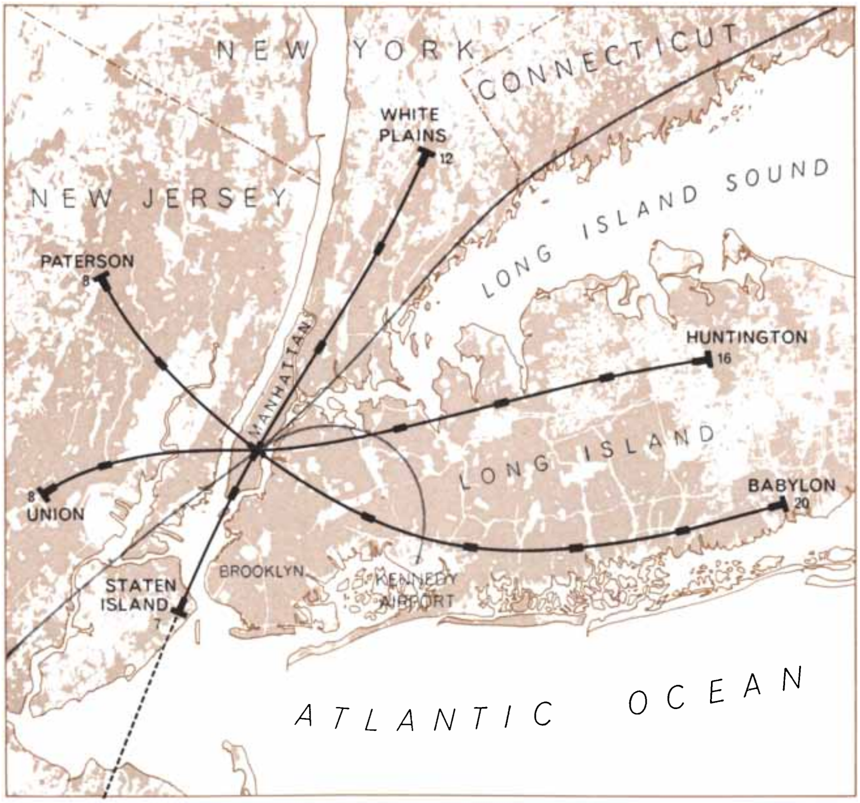
Is that too deep to go? We do not think so. The 12-mile-long Simplon Tunnel bores 7,000 feet below the surface of the Alps. (It has been giving good service for 60 years, incidentally.) Copper mines go down 5,000 feet and diamond mines 10,000 feet. The earth temperature at 3,500 feet in the Northeast Corridor area is unlikely to exceed 100 degrees Fahrenheit; air conditioning, which would have to be installed in any case, will keep the passengers comfortable. In order to construct the tunnel, vertical shafts 15 feet in diameter would be sunk every 10 miles along the route and fitted with high-speed elevators; these could be left in place to serve as emergency escapes in the unlikely event of a train breakdown within a tube. In the event of an emergency, air would be admitted to the tube from the tunnel, which will be at atmospheric pressure, simply by opening valves along the top of the tube.

In the case of the trip from Philadelphia to New York, the two elementary sources of power, gravity and vacuum, would combine to propel the train 85 miles in 13 minutes, or at an average speed of 390 miles per hour, with a peak speed slightly above 500 miles an hour [*see illustration on page* 35]. A single train will make the run from one end of the Corridor to the other in an hour and a half with seven intermediate stops en route, with New York just 45 minutes from either end. Spurs to Dulles Airport outside Washington and Kennedy International Airport outside New York may be desirable.

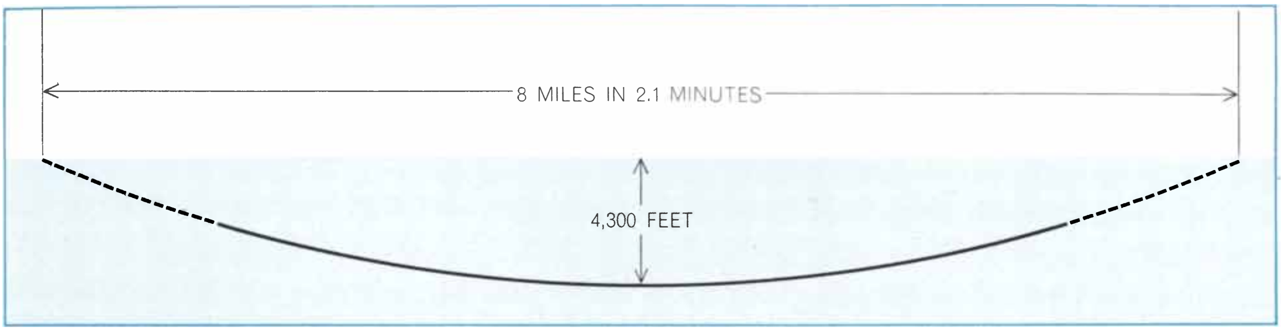
In our calculations we have provided for a peak capacity of 9,000 passengers an hour. This would be accomplished by running three trains per hour, each with seats for 1,500 people and liberal rush-hour standing room for another 1,500 who would presumably be willing to stand during such short segments as the Philadelphia–New York run. The capacity of the system could be doubled by running six trains per hour. (The Regional Plan Association has predicted that the rush-hour demand for this system would reach 7,000 passengers per hour in the near future and that the system should be able in time to handle 15,000 per hour.)

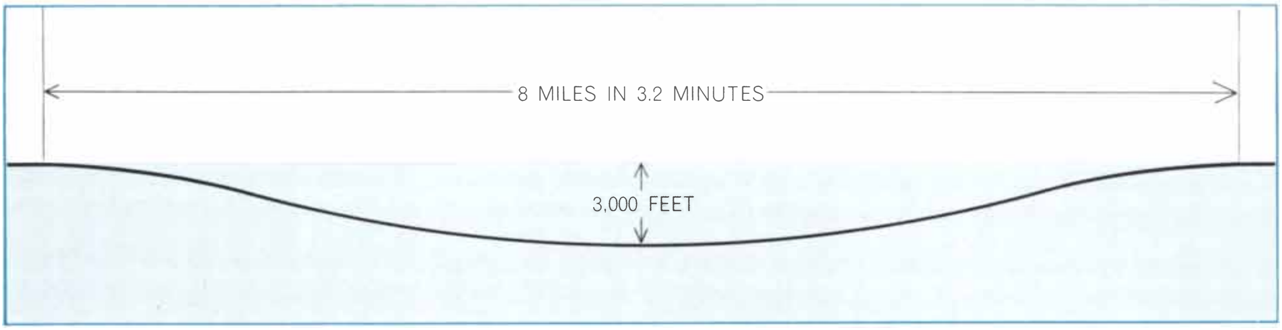
A single train will be able to make a round trip in about four hours, thanks to the high speed and the fast "turnaround" (which will not involve turning but merely shunting from one track to another and reversing). The three-trains-per-hour service could therefore be maintained with only 12 trains, plus some spare cars. This would mean a very low aggregate cost for rolling stock, crews and maintenance personnel, although individual employees would be highly trained and could be well paid.

In addition to carrying passengers the tube trains are designed to handle express cargo. This will be done during off-hours, providing ballast for trains that would otherwise accelerate too fast when the passenger load is light. Express cars will have the same length and coupling faceplates as passenger cars but will be open, like hopper cars, to receive standardized, pressure-tight modules preloaded with mail, newspapers and other high-grade cargo; the



"URBAN" SYSTEM for New York City has six lines radiating from midtown Manhattan. Tentative terminals for the lines and the elapsed time to each from Manhattan allowing for stops en route as indicated, are shown on the map, along with built-up areas (*color*) served by the system. The main line and spur of the Corridor system are shown in gray.



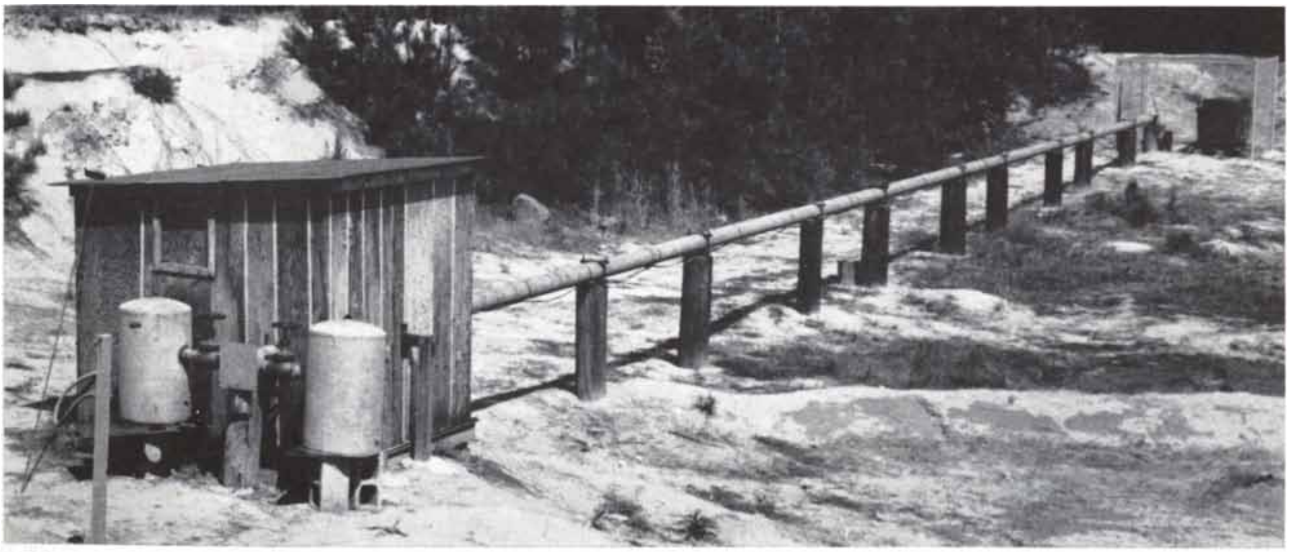


EIGHT-MILE TRIP could be accomplished by a pure passenger pendulum in only 2.1 minutes (*top*). The route, comparable to the arc traced by the end of a 10-mile-long pendulum, would descend 4,300 feet below ground level. The terminal segments of the pendulum route (*broken lines*) would be too steep for a practical system, however. In the proposed Urban system the pendulum path is flattened at each end (*bottom*). The depth of the tunnel becomes 3,000 feet. With pneumatic propulsion, the elapsed time is 3.2 minutes.

modules will be readily transferable to trucks. Any number of these express cars can be added to trains as the passenger load fluctuates.

As we were refining the Corridor system we were urged by several concerned individuals and agencies to see what might be done with a similar approach to help solve the commuter problem, particularly in metropolitan New York. The resulting Urban network is based on the same techniques as the Corridor system. Each Urban train would carry 2,600 passengers seated and 3,400 standing; the size of the seats, the space allowance for standees and the proportion of seats to standees would all be superior to present-day rapid-transit systems. If the train stops about once every eight miles, it can average two miles a minute—including the time spent in stations.

Urban-system lines might radiate in six directions from midtown New York [*see illustration on preceding page*]. Each line would have two tubes, but



TUBE CATAPULT has been tested by the Army Research Office at Durham, N.C., and Duke University. The 100-foot-long tube is evacuated by a compressor. Cylindrical metal projectiles, released at the far end, are forced down the tube by atmospheric pressure, reaching speeds as high as 750 miles an hour. Tests have shown that there is a tendency for the projectiles to remain centered in the tube.

there would be no need for cross-valving. Since the Urban tunnels would slope down and then up again, with no level run as in the Corridor tunnel, floating the tubes in water would not work; instead they can be suspended on springs. With a train every 10 minutes, the capacity of a single tube would be 36,000 passengers per hour; the frequency could be doubled to handle 72,000 per hour.

Each train would be half a mile long. This unusual length has some interesting advantages. At each suburban station there would be a long, narrow parking lot directly above the train, with numerous access roads passing through it. This would decrease local congestion and allow each passenger to park or alight from his bus near the section of the train that would put him closest to his midtown or downtown destination. In the city, passengers would be released into a larger area than that of a conventional station, again relieving congestion.

Most commuters drive or take a bus to their suburban stations. The Urban system would require that they drive a few miles farther. In return, however, they would find good parking, reliable round-the-clock service and a speed that would more than make up for the longer ride to the station and that would be far superior to expressway speed even under the best driving conditions. The system would also lend itself particularly well to feeder-bus service.

As now conceived, the New York Urban commutation system would consist of 140 miles of dual tubes and 19 stations and would require 18 trains. The original cost would be about $1.25 billion. This is about 25 percent more than the amount that, according to one estimate, would be required for thorough modernization of the area's commuter railroads, which are under continual criticism for providing poor service, are losing money on passengers and are trying to get out of the passenger business. The Urban system might well supplant these railroads; it would complement, rather than supplant, the existing subways. A similar Urban system, scaled down somewhat, might make sense for Boston (Route 128 to downtown in five minutes), San Francisco (San José to downtown, with stops about every eight miles, in 22 minutes) and other cities.

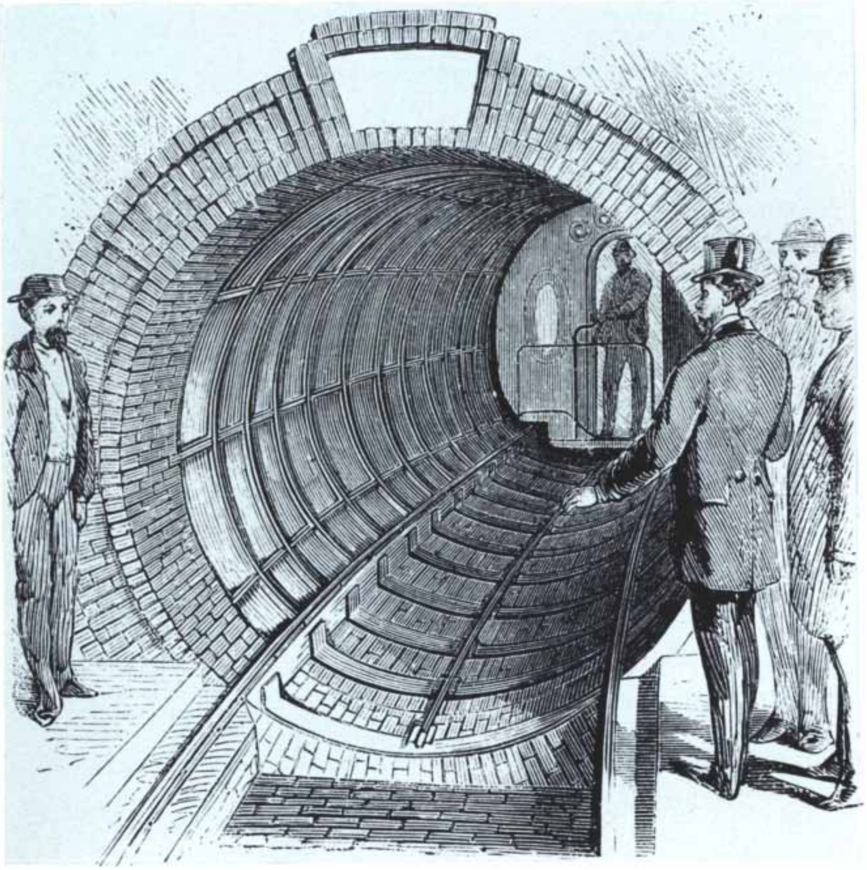
"CORRIDOR" TUNNEL might be bored through deep bedrock by hydraulic tunneling machines. This machine-drilled segment of a New York water conduit is 12 feet in diameter.

How close does the speed of the gravity-vacuum system come to the limits of what is practical in surface transportation of passengers? Consider a typical eight-mile Urban segment. Imagine, first of all, a hypothetical vehicle built to travel horizontally with unlimited power. It would accelerate until it would have to decelerate again, accelerating and decelerating at three miles per hour per second, the top rate to which passengers are subjected in present rapid-transit practice. (Actually no existing system has the power to maintain such acceleration beyond 30 to 40 miles an hour.) The speed at midpoint would reach 295 miles an hour and the accelerations would be high and continuous. The elapsed time for the eight miles would be 3.2 minutes, which must be about the theoretical limit for horizontal travel unless everyone is strapped into his seat. The power requirements would be prohibitively high.

Now imagine a "passenger pendulum," a gravity train swooping through a 4,300-foot-deep tunnel with no air resistance [*see top illustration on opposite page*]. It would make the swing in only 2.1 minutes without consuming any power at all, and there would be no sensation of horizontal acceleration. The speed at midpoint would be 360 miles per hour. The steep slopes at each end of the trip are not suitable for mass transportation, however.

Finally, consider the proposed gravity-vacuum system with a fully loaded Urban train (6,000 passengers and a gross weight for the train of 1.6 million pounds). Its path will partially parallel the pendulum's but will level off as it enters the stations, so the maximum depth of the tunnel will be only about 3,000 feet [*see top illustration on opposite page*].

Pneumatic acceleration and deceleration will be added, with one mile of full-pressure air applied at each end. The gravity-vacuum combination will impart an "equivalent horsepower" of 275,000 during acceleration, but the actual horsepower requirement will be no more than 7,700. The acceleration during the first and last miles will be two miles per hour per second, two-thirds as high as the continuous acceleration in the hypothetical horizontal vehicle; during the remainder of the trip the acceleration will be negligible. The elapsed time of 3.2 minutes will nevertheless match that of the horizontal trip, with a speed at midpoint of 335 miles an hour.



PNEUMATIC TRAIN was constructed under Broadway in New York City in 1870 by Alfred Ely Beach, editor of SCIENTIFIC AMERICAN. These engravings, which illustrated an account in the magazine, show the eight-foot tunnel (*top*) and the "richly upholstered" car (*bottom*).

It seems reasonable to expect, then, that the proposed tube train will cover a moderate distance in an elapsed time that cannot be matched by any other vehicle traveling horizontally and accommodating standing passengers. No advances in propulsion or braking technology can avoid this conclusion, since human comfort is the critical factor.

The system I have proposed seems to offer a number of broad social and economic benefits in addition to convenience for travelers. Its construction would, of course, employ a large number of workers. It would cut down automobile traffic in the heart of a metropolis, thereby reducing air pollution and the intrusion of expressways and garages. (Each tube, with its capacity of 36,000 passengers per hour, would be equivalent to 14 jammed lanes of expressway.) The casualties from grade-crossing, highway and airplane accidents would be reduced. Subsidies to passenger-carrying railroads might be obviated and railroads, free to concentrate on freight, might compete more effectively with trucks. Finally, putting much of the surface transportation underground would beautify the countryside and make it possible to redeem blighted areas of many cities and smaller communities.

How soon could the Corridor or the Urban system be completed? The pace of the project would probably be set not by technological development but by the speed of tunneling; it would normally take perhaps three years from ground-breaking to operational use. With strong leadership, the raising of capital and the necessary legislative processes might take as short a time as one year. If the best "concurrency" techniques of the weapons-system industries were brought to bear, then portions of either system could surely be opened for business on the 100th anniversary of the completion of the first transcontinental railroad. The Golden Spike was driven on May 10, 1869, ushering in a major era of growth in the U.S.

Our forefathers built a great railroad system that is still suitable today for heavy freight, but not for passengers. Will we merely patch up the passenger system and hand it on to our children along with its marginal service, saturated capacity and insatiable appetite for subsidy? Or will we select a new system with a new order of convenience, sound economics and capacity for growth—and do it now, so that we can enjoy it too?

Kodak reports on:

a strong desire to contribute to electron micrography . . . constructively vigorous molecules . . . an intermediate policy in lasers

Competence in customers

Delbert E. Philpott took this beautiful electron micrograph on a KODAK Projector Slide Plate, Contrast. It shows the ultimate source of the sticky secretion on the tube feet of starfish that gives them a grip powerful enough to open oysters. The sieve-like object is a cross-section of one of the secretory packets that Dr. Philpott discovered. Two more secretory packets are seen in longitudinal section above it. The large object beneath the packets is the cell nucleus.

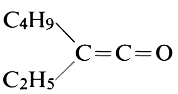
How much easier life would be for biology students without the long tale spilled out on KODAK Projector Slide Plates by electron microscopes over the past quarter century! Used to be KODAK Lantern Slide Plates. No difference. (Only the name was updated. The old name was redolent of coal oil.) In addition to "Contrast," they also come as "Medium." Very little difference in electron-exposure behavior. ("Not so," argue some customers. We don't argue back. The customer is always right.)

What, then, has happened to the spirit of progress in materials for electron micrography? This is a very difficult question on which we have been working for a long time. About all we have to show for this work is an article entitled "Some Things Every Electron Microscopist Ought to Know." It's free from Publications Service, Eastman Kodak Company, Rochester, N. Y. 14650. It chats a little theory (very, very lightly) about electron image structure. Dr. Philpott had never read it before making the electron micrograph that revealed the starfish's secretory secret. Neither did any of the people who uncovered all the other organelles for the biology students.

Wanted: more ketene millionaires

Ketene ($CH_2=C=O$) can be turned into money if you don't let it sit around for more than an hour or two, as we demonstrate in Kingsport, Tenn., by the millions of pounds per annum. Ketene is one of the most reactive organic molecules that a chemical engineer ever gets to tame. Lots of molecules are noted for coming apart with a loud bang. That's not what we mean. In ketene the cumulative double bond acts like a powerful spring, all set to grab something. When nothing else is available, a molecule of ketene will grab another molecule of ketene, forming diketene. This dimerization by no means uses up all the constructive vigor, and we have some very nice business in diketene to prove it. Who buys our diketene we have no intention of telling you, and just what they do with it we don't know ourselves. Obviously they are competent people, frightfully so.

In the industrial-chemical big league, where everybody is everybody else's competitor, supplier, and customer, one of the most thrilling parts of the game comes in deciding what not to tell. A few small points about handling ketene that we think we understand better than the other teams make ketene chemistry a profitable interest for us to encourage in others.



Currently we would like to see some company make a killing of their own through butylethyl ketene they'd buy from us. We doubt butylethyl ketene has been offered commercially heretofore. At $5 per pound of 20% n-hexane solution, some might hesitate to call BEK commercial even yet, but such a silly price would hardly prevail when a bit of volume develops and we start shipping straight BEK in bulk under refrigeration, the way we do diketene. The tricks we learned about trafficking in the latter will help with BEK, which is about as reactive undiluted but will keep quite a while in 20% hexane solution.

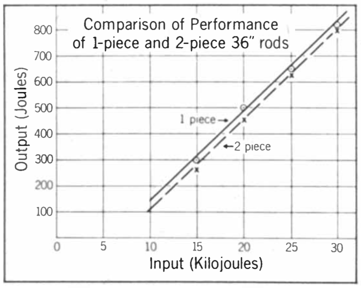
Eastman Chemical Products, Inc., Kingsport, Tenn. 37662, can supply a technical data pamphlet on BEK which labors under the impression that BEK will become the basis of a new cyclobutane industrial chemistry. What a pleasant surprise if we turned out to be right about that!

Long, long rods for the profession

All too easy it is to believe we know all the folks out there in laserland and their gals all know our phone number. That backward-looking viewpoint neglects the still unknown heroes who will save the skins of the generous makers of laser-development budgets.

These heroes are probably no amateurs. They have probably been devoting full time to keeping abreast. Now that they are ready to grab the lead instead of just staying abreast, they need rods from a supplier in an intermediate position. That's just what we are here—a supplier. We follow an intermediate policy between working directly in established projects only and offering raw glass only. We have a highly respectable background in high-precision optics. We make our own glass by our own methods. We welcome inquiries for neodymium-doped silicate glass rods around two inches thick and a yard or more long, with Brewster-angle or other kinds of ends. We welcome challenges to hold the loss coefficient under 0.1% per cm and to raise the damage threshold to 600 joules/cm^2 of cross-section.

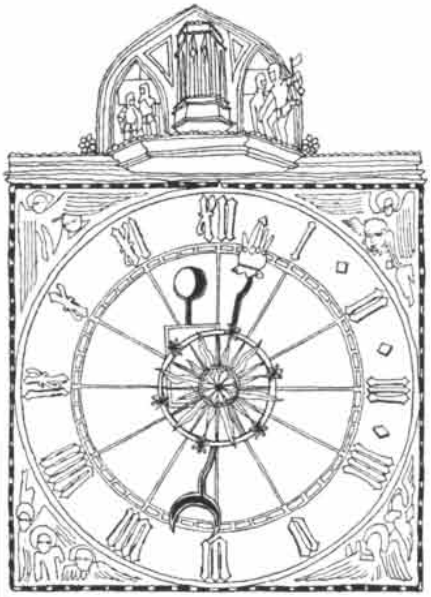
If there is anybody in the audience who has been wondering how much is lost by hitching two rods together with Brewster faces overlapped, as compared with an uninterrupted rod of equal length, let him note some input-output studies on one of our 36-inchers before (*solid*) and after (*dashed*) we busted it unintentionally and unhappily.



That phone number is (716) - 325 - 2000, Ext. 5166. It connects to Special Products Sales, Eastman Kodak Company, Rochester, N. Y. 14650. Mail to this address from residential return addresses is handled gingerly. At a recent science fair where a young blade kept firing, learnedly, a pocket-size laser rod that some kind-hearted physicist had bestowed on him for the advancement of his education, we walked over and told him to stop right then and there. We advised his proud mama and papa to get him to an ophthalmologist. What an ophthalmologist can do for damaged retinas we don't know.

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

SCIENCE AND



Giant Step

Almost 20 years to the day after human ingenuity contrived the world's first nuclear explosion, a more benign demonstration of that ingenuity produced the first close-up pictures of another planet. On July 14 the spacecraft *Mariner IV* came to within 6,118 miles of Mars after journeying 325 million miles through space in 228 days. The five million "bits" of information that *Mariner IV* collected in 25 historic minutes of picture-taking will absorb the attention of astronomers, geophysicists and other specialists for months to come.

The five million bits, relayed back to earth at the leisurely rate of 8.3 bits per second, represent a sequence of some 20 pictures. (This issue will be in circulation before the exact number is known.) The pictures were made alternately through red and green filters to provide information about the planet's surface coloration. Each picture, made up of an array of 40,000 (200 by 200) picture elements, shows an area approximately 130 miles on a side. (The oblique views show a somewhat larger area.) Each picture element, in turn, contains six bits of information, enough to identify 64 levels of brightness from pure white to black. This fine gradation of tone was selected to maximize the amount of detail visible in surface areas that were expected to have inherently low contrast.

The first few pictures to be received have the quality that was anticipated, but since the sun was almost overhead when the initial exposures were made, there are no strong shadows to bring out surface features. Workers at the Jet Propulsion Laboratory of the California Institute of Technology, which carried out the brilliant experiment, are optimistic that a great deal will be revealed about the Martian surface when pictures with longer shadows have been received and when the whole set has been carefully examined.

Apart from the photographs, a number of separate experiments conducted by *Mariner IV* during its flyby have apparently settled some important questions about Mars. First, the planet has virtually no magnetic field. This implies that the planet lacks a liquid metallic core, which is believed to account for the earth's magnetism. It remains to be seen from the photographs whether or not Mars has experienced tectonic processes of the kind that have shaped the surface of the earth by throwing up continents and mountain ranges. Second, Mars shows no evidence of a radiation belt, which is to be expected if the planet lacks a magnetic field to trap charged particles. As a result energetic particles directly bombard the Martian surface with an intensity many times greater than that at the surface of the earth. If there is life on Mars, it must be adapted to survive this considerable flux of radiation.

A third immediate finding is that the Martian atmosphere is almost certainly too thin to provide appreciable support for vehicles with conventional parachutes or wings, which might otherwise have been employed to achieve a soft landing on Mars in future expeditions. The density of the atmosphere was determined by its effect on radio signals when *Mariner IV* disappeared behind the planet and reemerged on the other side. The results confirm density measurements made earlier by infrared astronomers [see "Infrared Astronomy," page 20].

The triumph of *Mariner IV* demonstrates the vigor of the technology that has been developed in the U.S. space program in the half-dozen years since the launching of *Explorer I* on January 31, 1958. It also bears out a prediction made in *Introduction to Outer Space,* a report prepared by the President's

Science Advisory Committee and issued by President Eisenhower in March of that year. "Much that scientists wish to learn from satellites and space voyages into the solar system," said the report, "can be gathered by instruments and transmitted back to earth. This transmission . . . is relatively easy with today's rugged and tiny electronic equipment. . . . The cost of transporting men and material through space will be extremely high, but the cost and difficulty of sending *information* through space will be comparatively low." The Mars-Mariner program has cost about $120 million. The cost of landing a man on the moon by 1970 will be $20 billion.

Genetic Punctuation

Two groups of workers have recently found evidence supporting the hypothesis that the genetic messages used by the living cell to specify the construction of protein molecules may include some form of punctuation—a "period"—to signal the protein-synthesizing mechanism that a given message is ended and that a protein chain is to be terminated. The message itself is embodied in a genetic code whose "words" are various combinations of the four different bases in deoxyribonucleic acid taken three at a time. Each of the 20 different amino acids used in the synthesis of proteins is represented by one or more three-letter words, or codons. There are 64 possible kinds of triplet codon; more than 40 have now been shown to code for specific amino acids.

It has been difficult to demonstrate, however, that a given codon does *not* code for any amino acid, even though it was suspected that such codons—called nonsense codons—may exist. Evidence for such nonsense codons has now been presented in two papers published simultaneously in *Nature*. The feature of the nonsense words identified is that they signal the cell to break off the protein chain it is synthesizing; therefore they play the role of a period in the genetic message. One paper is by Sydney Brenner, A. O. W. Stretton and S. Kaplan of the University of Cambridge; the other is by Alan Garen and

Martin G. Weigert of Yale University.

The methods used by the two groups of workers both involved the search for codons that have mutated in certain bacterial strains. When a codon has mutated to a nonsense codon and has lost the ability to code for any amino acid, a protein that was formerly produced appears in a stunted form and ceases to perform its function as an enzyme; the effect can be observed in the organism. Primarily by studying the action of the chemical mutagens that induced the formation of nonsense codons the Cambridge group was able to identify in two such codons the sequence of bases: uracil, adenine and guanine in that order (UAG), and uracil, adenine and adenine (UAA). Brenner, Stretton and Kaplan discussed corollary evidence indicating that the UAG codon is probably an abnormal interruption of protein synthesis rather than the normal signal for chain termination. No such evidence exists, however, to rule out the role of the UAA codon; Brenner and his colleagues imply that it in fact plays the role of a normal period in the bacterial strains used in their experiments.

The UAG codon was also identified by Garen and Weigert. They studied a codon (for the amino acid tryptophan) that mutates, losing its ability to code for any amino acid in some strains of the bacterium *Escherichia coli.* They found that the mutant codon could mutate again to form a new codon and could thus regain the ability to code for an amino acid. By analyzing the new amino acid incorporated into the protein alkaline phosphatase as a result of such secondary mutation, Garen and Weigert were able to identify the base sequence of the nonsense codon.

Better Automobiles by Fiat?

The automobile industry got a strong nudge in the direction of safety engineering and the control of air pollution last month when the General Services Administration, the Federal Government's purchasing agency, listed 17 features to be required in all new cars and over-the-road trucks bought by the Government beginning with the 1967 models, or after September 28, 1966. The General Services Administration buys some 38,000 such vehicles a year; the Department of Defense buys at least another 15,000. These numbers are not large compared with total automobile purchases in the U.S., but because the Federal Government is the largest single buyer of automobiles, and because its move will probably stimulate corresponding legislation in several states, the new standards will have a heavy impact on the design of U.S. automobiles.

The major requirement is the installation of afterburners or other devices to reduce the amount of unburned hydrocarbons, which contribute to air pollution, in exhaust fumes. California law already requires the installation of such devices in cars bought in the state beginning with the 1966 models this fall; New York has been considering similar legislation. The General Services Administration move will tend to make exhaust controllers standard equipment on all cars by 1967.

The new Government standards also seek to control the lethal rearward displacement of the steering wheel in accidents by specifying that the assembly be so constructed that it cannot be driven backward more than five inches by a head-on collision at 20 miles per hour. Some of the other Federal requirements are stronger seat-belt anchors, recessed dashboard controls, a dual foot-brake system for the front and the rear wheels, standard bumper heights, backup lights and safety door locks and hinges. Some of these features are now standard on expensive cars and optional extras on lower-priced cars. General Motors announced that it would make a number of the features standard in all its 1966 models. If all the features become standard, according to automobile industry sources, they may add $100 to $150 to retail prices.

Animal Protein from Plants

A group of investigators at Purdue University has discovered a mutant strain of corn that may help to solve one of the world's most pressing nutritional problems: how to provide the protein needed for human growth in areas that have a chronic shortage of animal protein. Even when plant protein is abundant in such areas, it does not supply all the amino acids required to build animal protein; one result is the severe nutritional disorder called kwashiorkor. The new strain of corn—named opaque-2—contains protein that is exceptionally rich in lysine, the amino acid in which cereal plants are particularly deficient.

In recent months Edwin T. Mertz, a biochemist, Oliver E. Nelson, a plant geneticist, and their co-workers Olivia A. Veron and Lynn S. Bates have harvested enough opaque-2 to test its nutritional value. They report in *Science* that rats raised on opaque-2 gain weight three times faster than rats raised on ordinary corn. The investigators conclude that their experiments provide "a basis for assuming that opaque-2 proteins would also be superior to ordinary maize proteins in the diet of man and domestic animals." This assumption will be tested later this year by Ricardo Bressani, a biochemist at the Institute of Nutrition of Central America and Panama in Guatemala City. Bressani plans to introduce opaque-2 (in the form of tortillas, a flat corn bread) into the diet of a group of Guatemalan children. The children will then be tested to assess the extent to which the lysine-rich protein is retained by their bodies, and to what effect. If the results of this program are favorable, a seed bank operated in Mexico City by the Rockefeller Foundation plans to sponsor the widespread planting of opaque-2 in Central America, where kwashiorkor is common.

Because the gene responsible for the opaque-2 mutant is recessive, the corn must be grown so that exposure to stray pollen is minimized. The Purdue group is currently growing a crop expected to yield several thousand pounds of shelled corn; some will be given to Bressani and the rest to nutritionists at Purdue, who will feed it this fall to pigs, chickens and graduate students. Mertz and Nelson believe that analogous lysine-rich proteins may exist in mutant varieties of other cereals; they have undertaken to find a general method for detecting such strains.

Proteins by Machine

A recurrent dream of the hardworking chemist's is that someone will develop an apparatus that would automatically perform the dozens—sometimes hundreds—of steps in the synthesis of a complex compound. Such a machine has now been developed by two chemists at the Rockefeller Institute for the purpose of linking amino acids into the peptide chains that comprise proteins. Their achievement has special significance because, as chemists work out the sequence of amino acid units in proteins of special biological importance, they will undoubtedly undertake to synthesize them. Already several groups of workers have achieved the total synthesis—by laborious manual methods—of insulin, a protein that consists of 51 amino acid units arranged in two cross-linked peptide chains.

This is the movable contact assembly—the only moving part in all ratings of the Series K design. This particular starter is a Bulletin 709 Size 2, rated 15 hp, 240 v; 25 hp, 480-600 v.

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Special cushioning eliminates destructive pounding of the magnet—a built-in permanent air gap makes magnetic sticking impossible throughout the operating life of the contactor. The cadmium oxide silver contacts need never be serviced—they close "square" and thus, by eliminating the sideward motion, the corresponding contact wear is likewise eliminated, and contact life is substantially increased. And the overload relays—two are standard but three can be furnished just as readily—are truly trip free and tamperproof. They will provide dependable protection throughout the life of the control.

Don't make the mistake of trading the Allen-Bradley Series K quality features for a competitor's cut price—such exchange is not a bargain. Let your local Allen-Bradley appointed distributor prove to you that when you're up against a really tough control job, the Allen-Bradley Series K line is the only answer. It's trouble free! By the way, have you Publication 6110 in your engineering files? If not, please write Allen-Bradley Co., 1204 S. Third St., Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Ltd., Galt, Ont. Export Office: 630 Third Ave., New York, New York, U.S.A. 10017.

BULLETIN 709 Series K motor control in NEMA Type 1 enclosure. There is a modern, "family-like" appearance to all Series K general and special purpose enclosures, and—no starters take so little time to install. The white interior is a great help.

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QUALITY MOTOR CONTROL

The apparatus for synthesizing peptides was developed by R. B. Merrifield and John M. Stewart. They have demonstrated its capability by synthesizing bradykinin, a hormone with a peptide chain of nine amino acid units. Merrifield had only recently succeeded in synthesizing bradykinin manually by the method known as solid-phase peptide synthesis. The bradykinin made by machine is equal in yield, purity and biological activity to the substance synthesized manually. It should be feasible to synthesize larger peptides by machine, according to Merrifield, as soon as certain details of the solid-phase technique are worked out.

The first step of solid-phase peptide synthesis is to anchor the amino acid intended to form one end of the chain to a solid, insoluble particle. The product is then placed in a reaction vessel, and a soluble reagent is added to effect the bonding of the next amino acid. To achieve each bond may require as many as 80 operations such as pumping, shaking and filtering. After each amino acid is added the reagent is washed away; the procedure is repeated for each amino acid in the chain. Finally the peptide is removed from its anchor by a chemical cleavage.

The large number of operations involved in solid-phase synthesis is no drawback, since each step entails only the transfer of solution to or from a single vessel and can be performed readily by machine. A programmer such as the one designed by Merrifield and Stewart can be instructed to repeat any sequence involving only the addition and removal of reagents.

Soft and Hard Acids and Bases

A recent symposium indicates that the principle of "soft and hard acids and bases" can be widely applied to explaining and predicting the likelihood and speed of chemical reactions and the stability of the resulting compounds. The concept of soft and hard acids and bases—"SHAB," as it has come to be called—was put forward in 1963 by Ralph G. Pearson of Northwestern University, who sought to identify the factors that make some chemical reactions occur at faster rates than others and that determine the stability of compounds.

From the theoretical chemist's point of view an acid is a substance that accepts electrons in a reaction and a base is one that donates electrons. Stable compounds can be considered as having two parts, one an acid and the other a base. Even single atoms can be regarded as acids or bases in this sense. Examining data from a large number of his own experiments and those of other workers, Pearson concluded that reactions between acids and bases could be explained in terms of the deformability of electron "clouds," the smeared orbits of electrons surrounding the nuclei of the atoms involved.

The clouds tend to be spherical. Some atoms are easily "polarized," however, which is to say that their electron clouds can be readily distorted; these atoms Pearson calls "soft." In other atoms, less easily polarized, the cloud resists distortion; these atoms Pearson calls "hard." Soft atoms tend to donate or accept electrons easily and to form covalent bonds; hard atoms tend to share electrons less readily and to form ionic bonds. The heavier an atom is, the softer it is. Metals are soft. Atoms that are highly ionized, or have lost a number of electrons, tend to be hard.

Pearson found that hard acids prefer to combine with hard bases and soft acids to combine with soft bases. It follows, for example, that soft acids and bases react more readily on a metal catalyst than hard ones do; hard solvents are best for dissolving hard substances, and so on. The status of the SHAB principle was recently discussed at a symposium in Geneva sponsored by the American Cyanamid Company's European Research Institute and reported in *Chemical & Engineering News;* the participants generally agreed that it explains many phenomena, and can help workers to bring about many desired reactions, in inorganic and organic chemistry and in biochemistry.

Calendar-calculating Twins

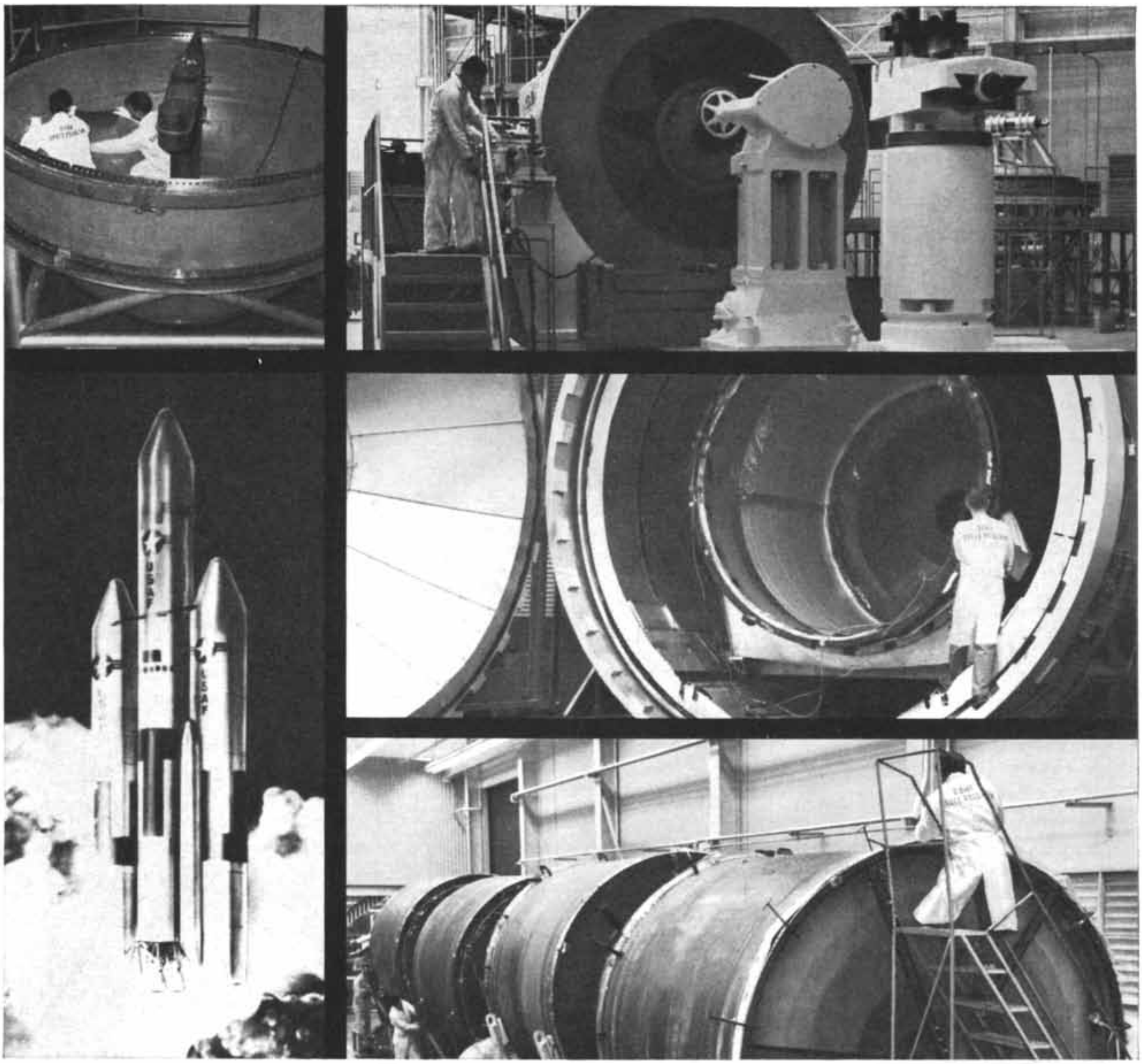
Psychologists have long been familiar with the phenomenon of the "idiot savant"; the term has traditionally been used to describe a person with subnormal intelligence—frequently in the imbecile range—who has a special, highly developed intellectual skill incongruous with the rest of his mental activity. Now a unique case has been reported of a pair of identical twins both of whom appear to fit into the traditional category of idiot savants.

The twins are 24-year-old men named Charles and George, who have spent 13 of the past 15 years at Letchworth Village, a state mental institution in Thiells, N.Y. Two years ago they were transferred to the New York State Psychiatric Institute in New York City, where they came under the observation of William A. Horwitz, Clarice Kestenbaum, Ethel Person and Lissy Jarvik, who report their findings in a recent article in the *American Journal of Psychiatry*.

The special skill of the idiot savant generally involves some kind of calculating; in this case both Charles and George are unusually adept at computing calendar dates and at very little else. Like many other calendar calculators, the twins have IQ's in the 60-to-80 range and cannot add, subtract, multiply or divide simple single-digit numbers. Their self-taught calendar calculations, however, go far beyond the range of any hitherto reported. Although Charles is completely accurate only for this century, George can project his calendar calculations over a range of at least 6,000 years. For example, he can instantaneously identify February 15, 2002, as a Friday or August 28, 1591, as a Wednesday. When asked in what years April 21 falls on a Sunday, both Charles and George will correctly answer 1968, 1957, 1953, 1946 and so on; when encouraged, George can go back as far as 1700. When asked in what month of the year 2002 will the first of the month fall on a Friday, George gave February, March and November—all correct answers. The twins can also specify that the fourth Monday in February, 1993, will be the 22nd and that the third Monday in May, 1936, was the 18th.

The development of George's special talent was observed earlier than that of his brother. At age six he would spend hours poring over an almanac that contained a perpetual calendar. From the beginning he made no errors. Charles became interested in telling dates only after the twins were institutionalized at age nine, and he was observed to go through a period in which he made many mistakes. Although both twins are severely myopic, there is no evidence that their common skills are genetically linked.

The fact that both twins operate in a range of calendar calculation far beyond that of the usual 200- to 400-year perpetual calendar makes it doubtful that their feats involve only memory. Moreover, they operate so rapidly that they probably use no formula, even if they were capable of learning one. The investigators write that they have no better explanation for the observed phenomenon than the one that is offered by the twins themselves, who answer the question of how they perform by saying, "I know" or "It's in my head."



NUCLEAR FISSION

Twenty years after the detonation of the first nuclear explosion the study of the splitting of the atomic nucleus in two is still the best source of information about highly deformed heavy nuclei

by R. B. Leachman

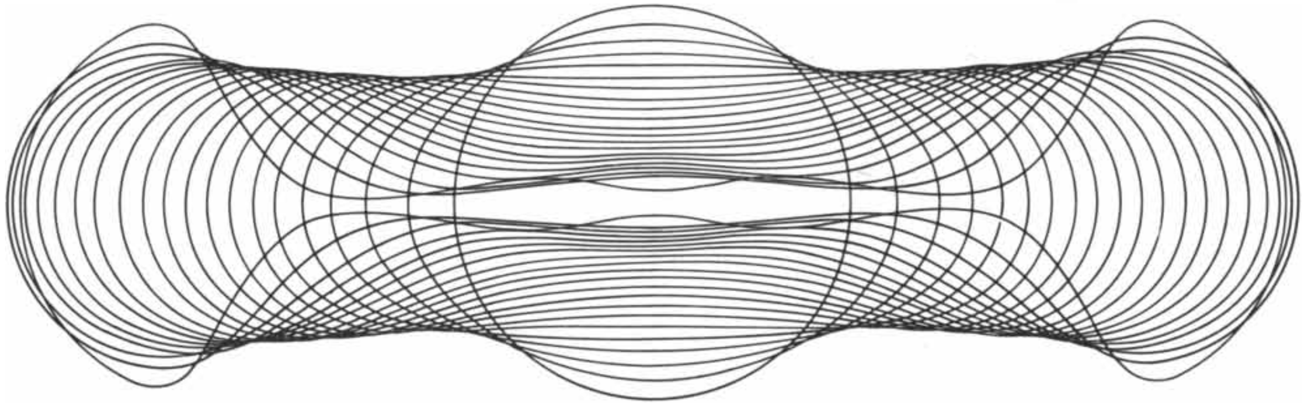
The interest of physicists in the process of nuclear fission did not subside after the achievement of a self-sustaining chain reaction and the detonation of the first nuclear explosive 20 years ago. Apart from the epoch-making technology to which it gave birth, the discovery of fission raised interesting new questions in basic physics. How could such a small input of energy—the mere absorption of a single neutron—so easily split the nucleus of an atom in two? Why did the cleaved uranium nucleus break into two pieces of unequal mass instead of splitting in half? These and other questions, offering a unique opportunity to study the inner workings of highly deformed atomic nuclei, have continued to absorb the attention of a number of investigators over the years, and they have led to considerable enlightenment about the internal structure and energy configurations of deformed heavy nuclei.

It is not easy to recall now with what surprise and incredulity physicists greeted the announcement of the fission of the atomic nucleus in 1939. Experimental workers had been attacking nuclei with particles from accelerating machines and had found that it took millions of electron volts of energy to chip one or two nucleons (protons or neutrons) out of the nucleus. It seemed that to cause a heavy nucleus to fission would require hundreds of millions of electron volts, an amount of energy that was not then available. Now it turned out that only six million electron volts, easily obtained by the insertion of an additional neutron in the uranium nucleus, was sufficient to tear the nucleus apart, with a consequent release of 200 million electron volts of energy. It was as if a hard rock had been split in half by tapping it with a pencil.

Niels Bohr of Denmark, who had hastened to the U.S. with the news, puzzled over this phenomenon with John A. Wheeler at Princeton University, and within the short span of a few months they had published a detailed model that explained the initial observations satisfactorily. Their proposal was the now famous liquid-drop analogy. They likened the fission of the uranium nucleus to the splitting of a drop of liquid by deformation.

The Liquid-Drop Model

In its lowest energy shape—the shape that requires the least amount of energy to maintain its form—a drop of water is spherical. By the application of energy from outside it can be pulled into an elongated shape [*see illustrations on next two pages*]. Up to a certain point the force of surface tension will hold the drop together. After it has been pulled out to a "threshold" elongation, however, the drop will find it energetically advantageous to break in two at its narrow waist. The two resulting drops are tear-shaped at first, but they quickly round into the minimum-energy spherical shape, converting the energy of their former deformation into heat. In short, the input of a certain threshold quantity of energy deforms the original drop to a shape in which it fissions, and each

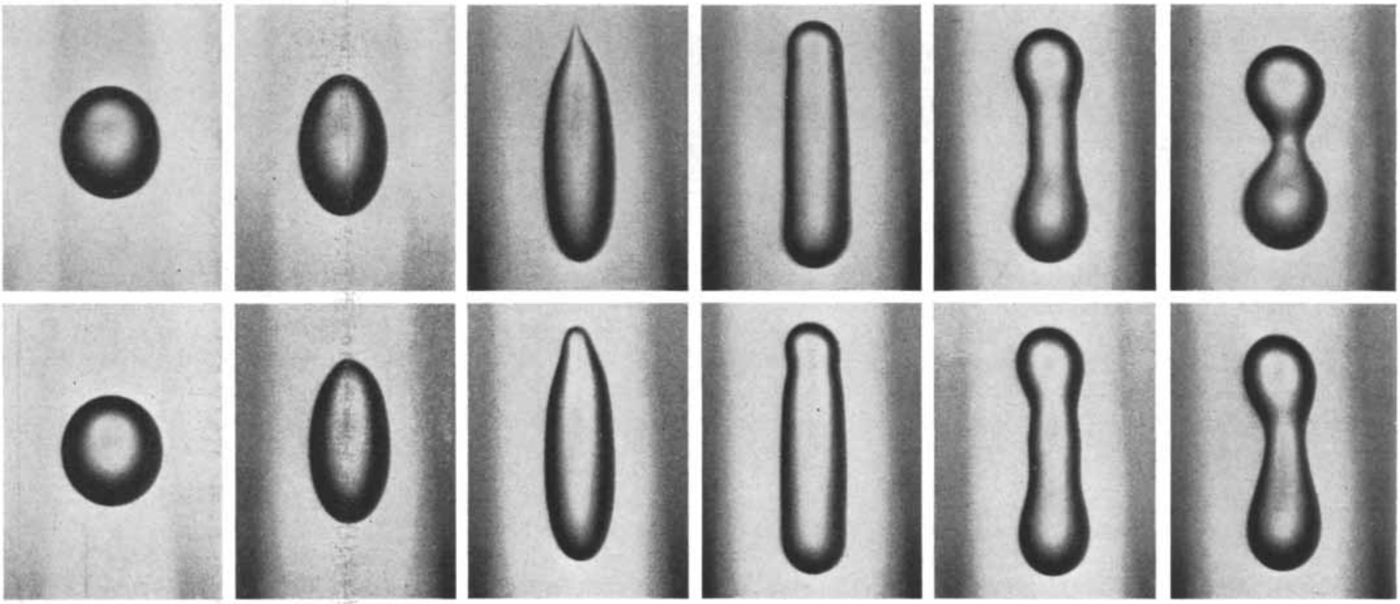


COMPUTER PATTERN shows the successive deformations undergone by an electrically charged drop of liquid prior to breaking into two pieces. These calculated shapes are useful in analyzing the actual deformations undergone by an atomic nucleus during fission (*see illustrations on next two pages*). The shapes were obtained by David L. Hill at the Los Alamos Scientific Laboratory.

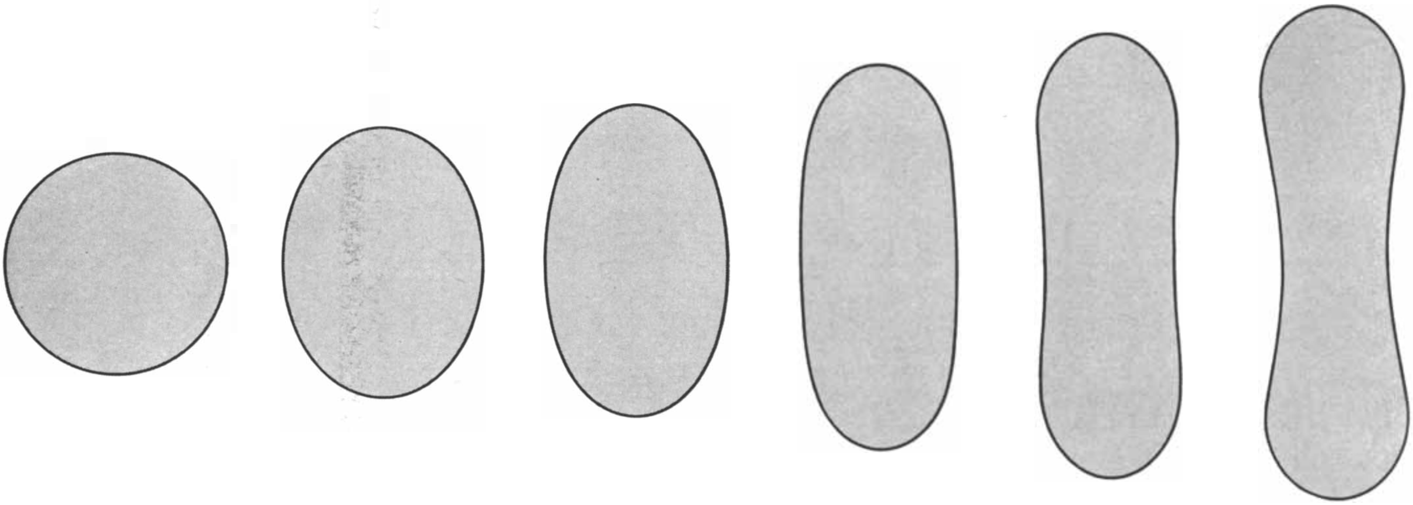
of the parts into which it breaks then assumes the stable spherical shape with the release of surplus energy.

In a general way the same principles apply to the fission of an atomic nucleus. On the basis of their liquid-drop analogy Bohr and Wheeler calculated that the energy required to cause the uranium nucleus to fission by a succession of deformations (as opposed to a conceptual nucleon-by-nucleon separation) should be just about six million electron volts. Such a deformation—a readjustment of the nucleonic configuration and therefore of the nuclear forces—would be produced by introducing a neutron into the nucleus of uranium 235 (converting it into uranium 236).

The forces at work in the atomic nucleus differ, of course, from those in a drop of water. The liquid-drop analogy



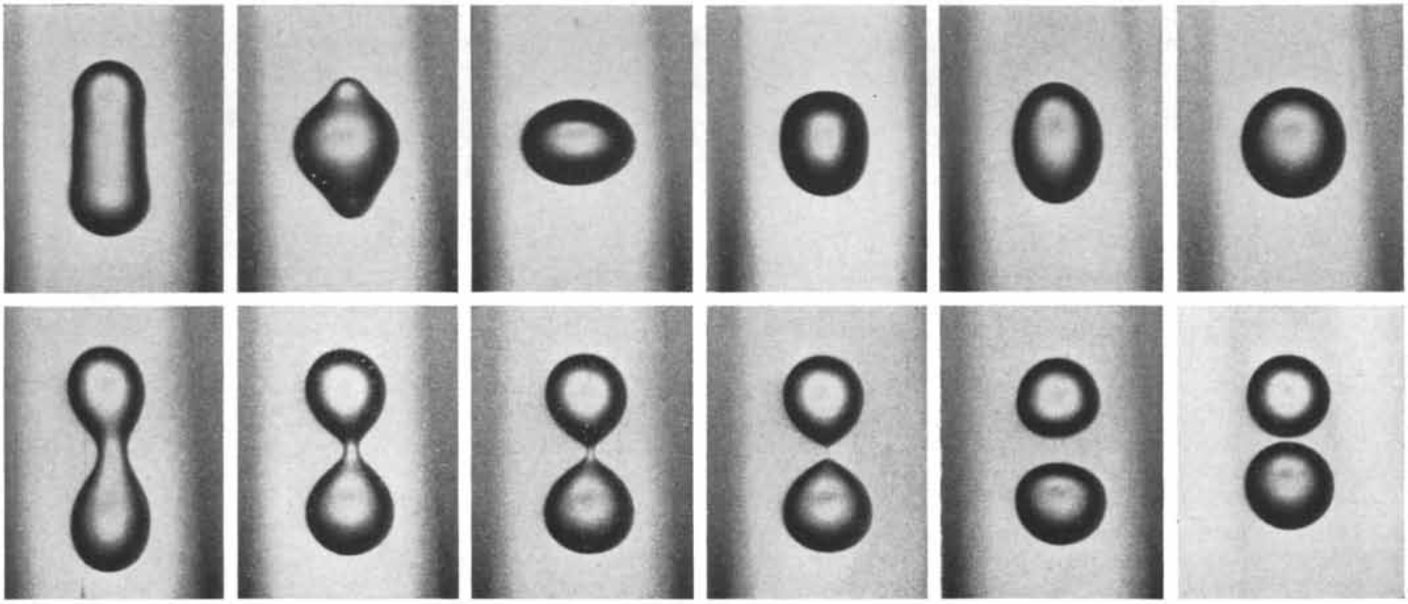
LIQUID-DROP ANALOGY of the phenomenon of nuclear fission is illustrated by these two sequences of photographs selected from a motion-picture film made by S. G. Thompson and his colleagues at the Lawrence Radiation Laboratory of the University of California. The photographs show an ordinary drop of water suspended in oil; the initial deformation of the drop was produced by applying a voltage across the oil. In the sequence at top the initial deformation was inadequate to cause fission and the drop has returned



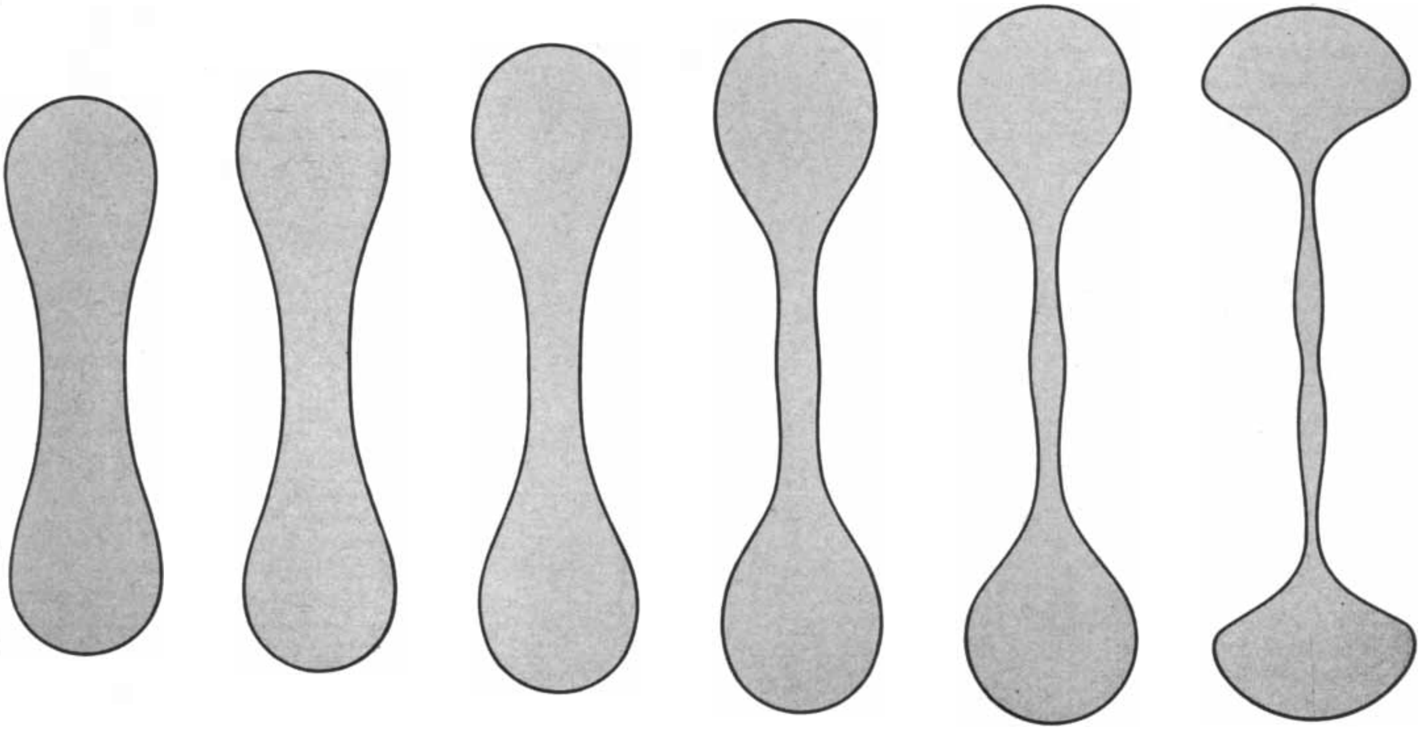
CALCULATED LIQUID-DROP SHAPES were derived from the pattern of nested computer shapes on the preceding page. In the computer program it was assumed that each successive shape would be the one requiring the minimal amount of energy. Just before this theoretical drop broke in two (*extreme right*) it had an extremely long neck that was thinner than the diameter of a nucleon.

pictures the nucleus as a sphere with electric charges distributed uniformly throughout its volume, the charges in the case of the uranium nucleus being the positive charges of its 92 protons. The protons and the 143 neutrons making up the U-235 nucleus are packed in a space only about 10^{-12} centimeter in diameter. Against the very strong force of electrostatic repulsion between the closely packed protons, which would tear the nucleus apart, there is a stronger nuclear force (corresponding to the surface tension of a spherical drop of water) that holds the nuclear particles together.

When the U-235 nucleus absorbs an extra neutron, however, the energy provided can agitate the nucleons within a nearly spherical nucleus or deform a nucleus of essentially unagitated nu-



to its original, minimum-energy spherical shape. In the sequence at bottom the initial deformation has pulled the drop out to its "threshold" elongation, following which the drop breaks in two at its narrow waist. The two resulting drops quickly round out to the minimum-energy spherical shape, converting the energy of their former deformation into heat. The analogy between the fission of the uranium nucleus and the splitting of a drop of liquid by deformation was developed by Niels Bohr and John A. Wheeler in 1939.



Its length was twice that of a real nucleus at the moment of fission. (The length of the latter had been calculated from the kinetic energy of the fission fragments flying apart, which indicates the distance between the centers of charge of the ends just before they separate.) This long stretching would not result if the actual neck-tearing mechanism were known and included in the calculation.

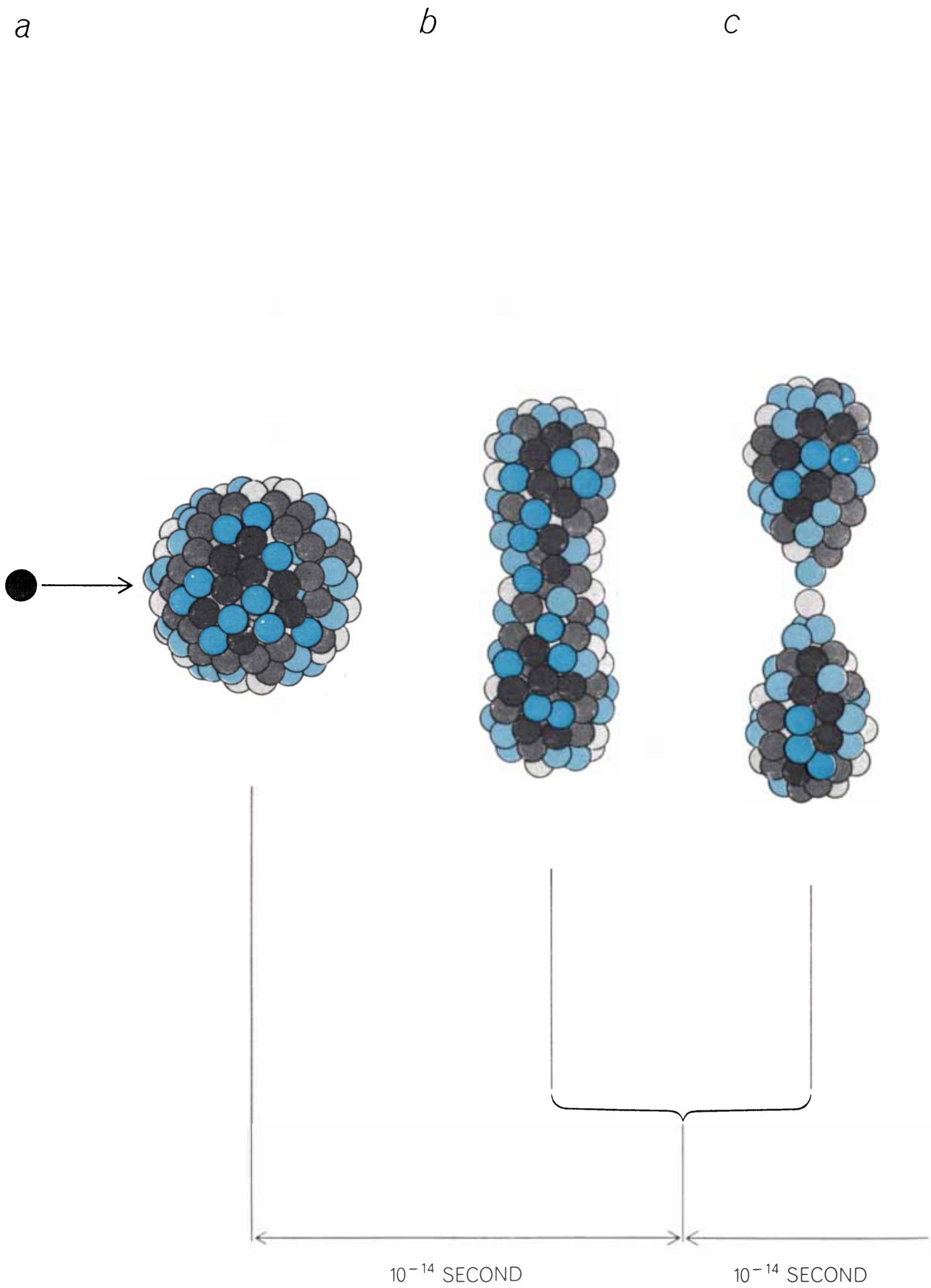
cleons into an elongated nucleus. The result is an elongation of the nucleus to the threshold point where the force of repulsion between the charges in the ends of the drawn-out nucleus becomes stronger than the even more reduced cohesive nuclear force for the elongated nucleus. After further elongation the nucleus splits into two fragments, and the electrostatic repulsion between them drives them apart at a thirtieth of the velocity of light, amounting to a large liberation of energy in the form of kinetic energy. Thereafter there are further liberations of much smaller amounts of energy as the two fragments, which are deformed at the moment of fission, revert to a shape of minimum energy; in this process they release energy in the form of emitted neutrons and gamma rays. Alternatively, the liberation of energy can be considered on the basis of Einstein's principle of the equivalence of mass and energy. The masses of the two new nuclei that finally result do not quite add up to the mass of the parent U-236 nucleus: the difference has been liberated as kinetic and radiant energy.

The liquid-drop analogy explains why heavy nuclei can be fissioned more easily than lighter ones. The more protons there are in a nucleus, the greater the repulsion is between the ends as the nucleus begins to elongate; therefore less energy is required to get the process under way. Bismuth can be fissioned by injecting an alpha particle (a helium nucleus) into its nucleus, increasing its 83 protons to 85. Although that nucleus is only a little lighter than the nucleus of uranium, having seven fewer protons, the fission of bismuth requires 15 million electron volts—two and a half times more energy than uranium fission requires. As one goes down the periodic table to the lighter elements, the energy requirement for fission increases rapidly. On the other hand, the man-made elements heavier than uranium can be split with ease. This factor sets one limit on the possible weight of an element: one can imagine a heavy, proton-loaded nucleus in which the deformation needed for the repulsive forces of the charges to exceed the cohesive nuclear forces is so slight that the nucleus will split of its own accord without any particle or energy being injected.

The Deformation of the Nucleus

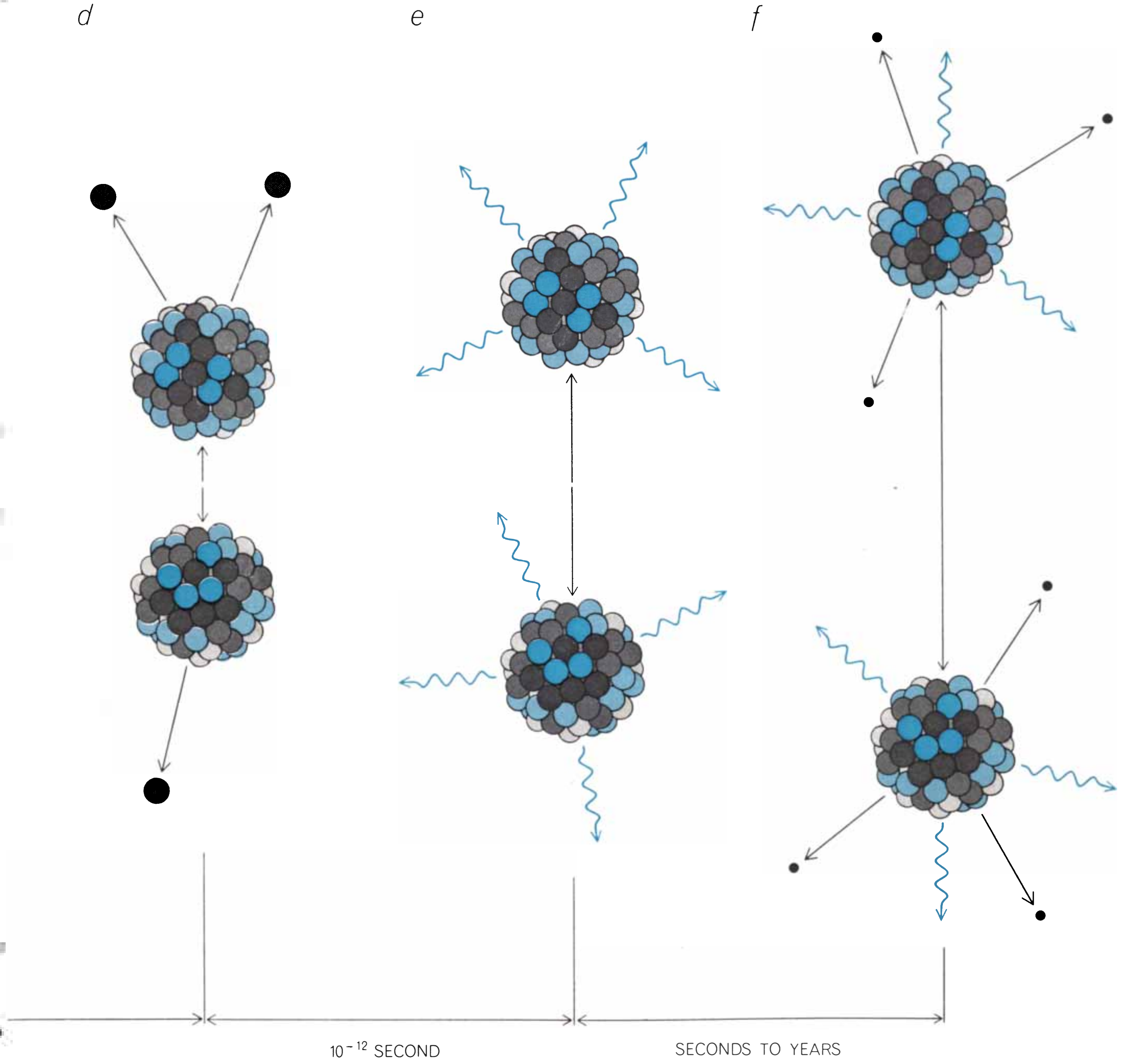
To describe what will happen as an atomic nucleus is deformed, two items of information are needed: how (1) the repulsive energy and (2) the nuclear cohesive energy change as the shape of the nucleus changes. The calculation of the dependence of electrostatic repulsion on the shape of the nucleus is a straightforward, although often complicated, matter. For the calculation of the dependence of cohesion on shape, the lore of nuclear studies shows that the surface tension of a liquid drop provides a satisfactory model; the same mathematical formulas can be used. With the aid of electronic computers it has become possible to calculate what energies are required to deform nuclei to various shapes and how much energy is needed to cause a given nucleus to fission.

These theoretical calculations show that a nucleus is fissioned most easily—that is, with the smallest input of energy—when it is deformed roughly

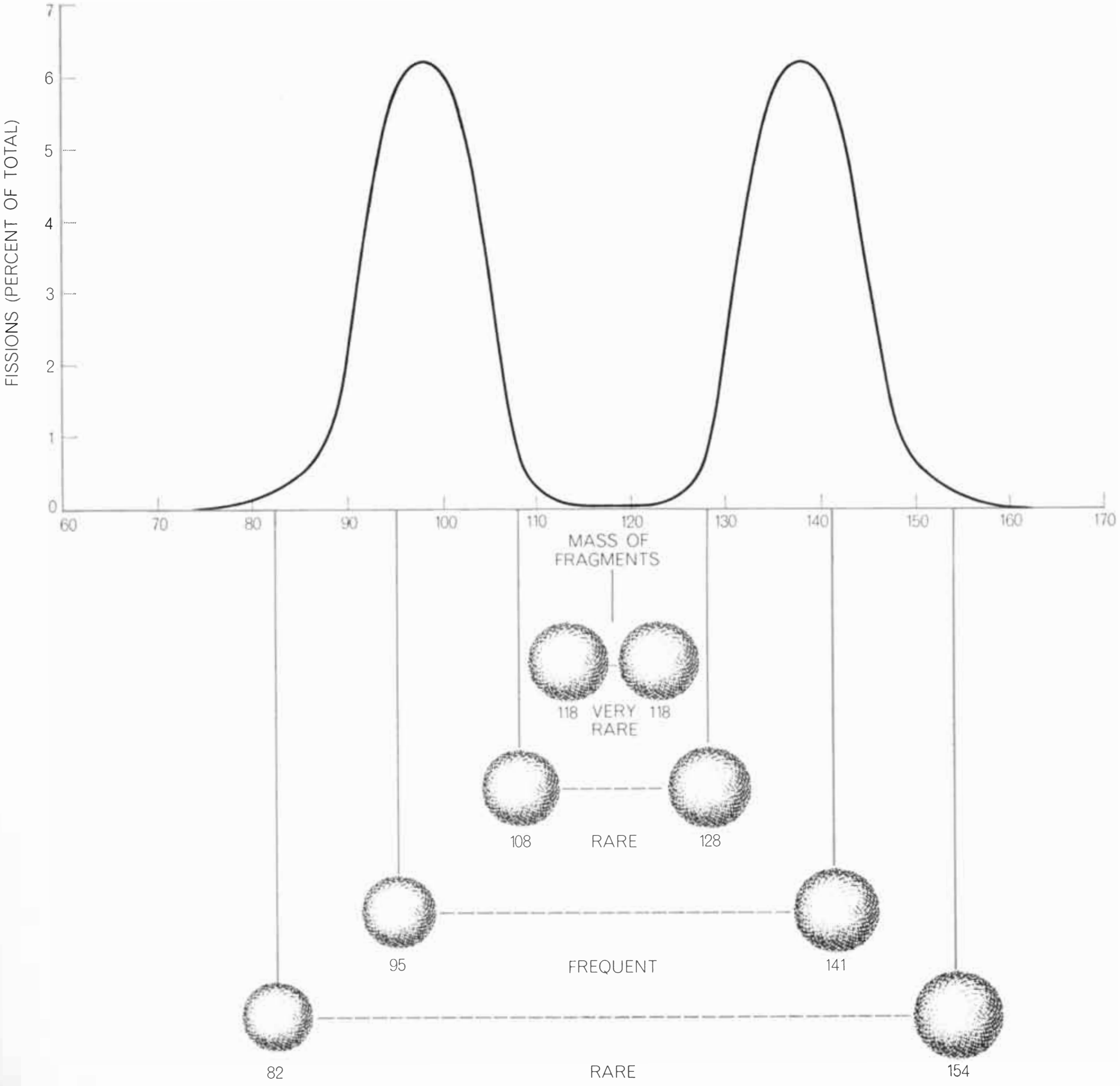


SEQUENCE OF EVENTS involved in the fission of a nucleus of uranium is depicted here. The U-235 nucleus consists of a closely packed collection of 92 protons (*colored balls*) and 143 neutrons (*gray balls*). The sequence begins when a neutron enters the U-235 nucleus (*a*), converting it into U-236 and producing deformations that eventually lead to fission. About a hundredth of a trillionth of a second later one of the deformations reaches a threshinto the shape of a peanut. The production of this shape, however, is not a simple or straightforward happening, like the elongation of the water drops in the photographs at the top of pages 50 and 51. An incoming neutron may impart or distribute energy within the nucleus in almost an infinity of ways, and usually the energy is likely to "play about" in a million different steps, so to speak, before it stretches the nucleus into the peanut shape. All of this takes place within about 10^{-14} second after the nucleus has absorbed a neutron.

David L. Hill, using a large electronic computer at the Los Alamos Scientific Laboratory, has calculated a sequence of deformations through which the charged liquid drop would successfully progress toward a final fission of the drop. In this program it was assumed that each successive change of shape would be the one requiring the minimal amount of energy. Unencumbered by many of the effects that would allow the drop to tear in two, this calculation permitted unreasonably long stretchings of the nucleus; in fact, in the last stages of the calculation Hill's theoretical drop had an almost incredibly long neck that was thinner than the diameter of a nucleon! We know, however, that its length was twice that of a



old shape (*b*) and the nucleus splits into two fragments (*c*). As the two fragments fly apart, they release a large amount of energy in the form of kinetic energy and, after another hundredth of a trillionth of a second (*d*), a smaller amount in the form of two or three emitted neutrons. About a trillionth of a second after this stage the fragments come to rest (*e*) and emit about eight gamma rays. During the last stage of the fission process (*f*), which may last anywhere from a few seconds to years, more gamma rays and about half a dozen beta particles, or electrons (*black balls*), are emitted. Separation of fragments after fission is much greater than shown here.



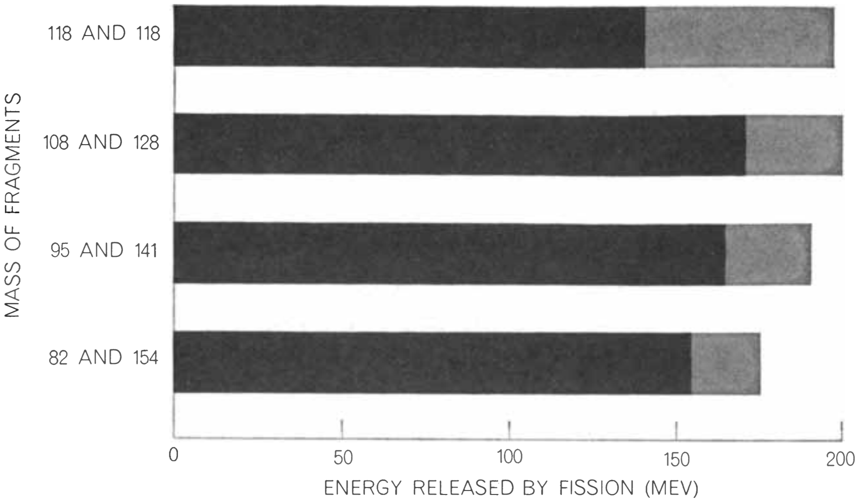
TWO UNEQUAL FRAGMENTS usually result from the fission of a uranium nucleus. The most frequent split is into fragments containing 141 nucleons (neutrons and protons) and 95 nucleons respectively. Although in this case one fragment has about half again as much mass as the other, they differ very little in diameter. Fissions into two equal fragments containing 118 nucleons each are very rare, accounting for only about .01 percent of the total number of fissions. Two other splits, classified as rare, are indicated.

real nucleus at the moment of fission. (The length of the latter has been estimated from the kinetic energy of the fission fragments flying apart, which indicates the distance between the centers of charge of the ends just before they separate.) This uninvestigated detail of neck-breaking is overshadowed by the successes of the liquid-drop model: the model has qualitatively illustrated the nuclear shapes leading to fission and has explained the small energy required for fission.

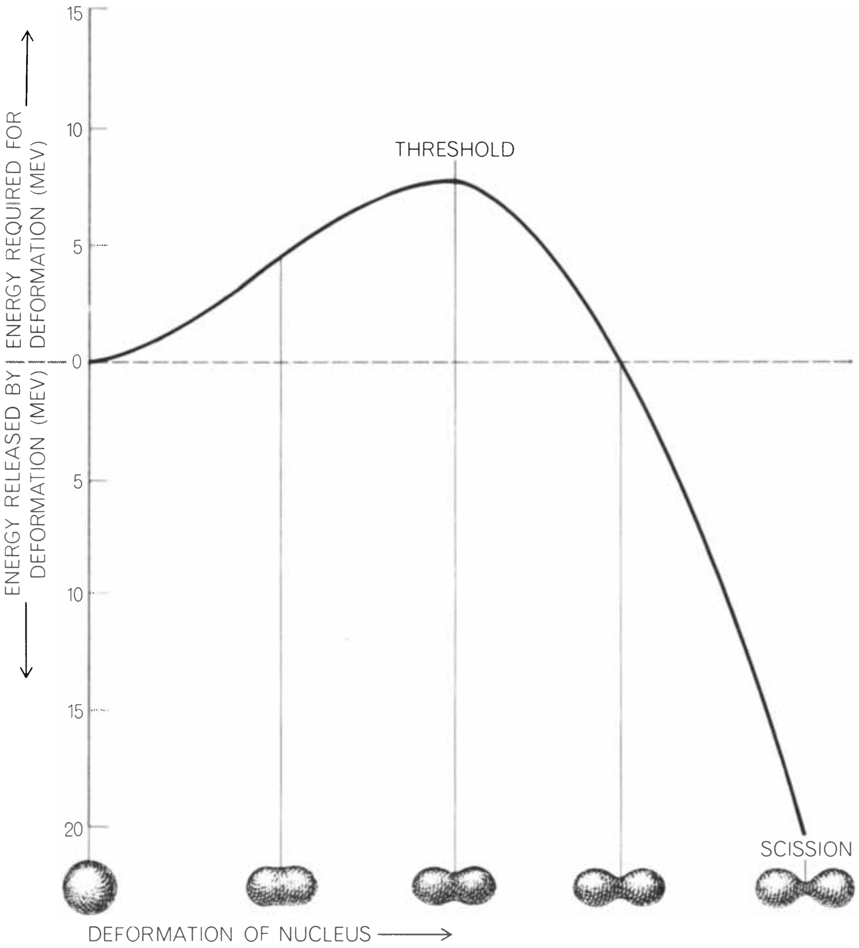
This brings us to a persistent question about nuclear fission that the liquid-drop model has not been particularly helpful in solving. According to the calculations based on that model, the two ends of the elongated nucleus should be equal in size and therefore the two fragments into which it splits should be of equal mass. The fission of uranium does not, however, obey this expectation of symmetry. Usually its two products are unequal: one has about half again as much mass as the other. Hence fragments are found in two equally populated groupings, one of smaller mass and the other of larger [*see illustration above*]. This behavior is surprising on more than one count. Fission into two unequal fragments releases less energy than a split into equal fragments, and so the uranium case departs from the usual rule that physical and chemical reactions tend to go in the direction that will release the maximum energy.

The puzzle is compounded by the

finding that lighter elements such as bismuth, in contrast to uranium, most often do break into exactly equal halves when they fission. Although the fission of bismuth seems well behaved in conforming to the liquid-drop model, unfortunately for the experimentalist the bismuth nucleus fissions only rarely. Many experiments on the fission of bismuth have nonetheless been performed in recent years. In most of these experiments the bismuth nucleus is bombarded with alpha particles at high energy (about 65 million electron volts) to increase the chance that it will be distorted to the threshold for fission instead of to some other unstable shape in which the nucleus discharges the absorbed energy merely by emitting neutrons. The experiments have shown that bismuth generally fissions into two equal fragments, just as the liquid-drop model predicts. In a certain proportion of the cases, to be sure, the fragments are not precisely equal, but J. R. Nix of the Lawrence Radiation Laboratory of the University of California has calculated that these small variations can be attributed to writhings of the nucleus, producing slightly different shapes, during the course of deformations leading to fission. This work is part of a large-scale program of liquid-drop-model studies led by Wladyslaw J. Swiatecki.



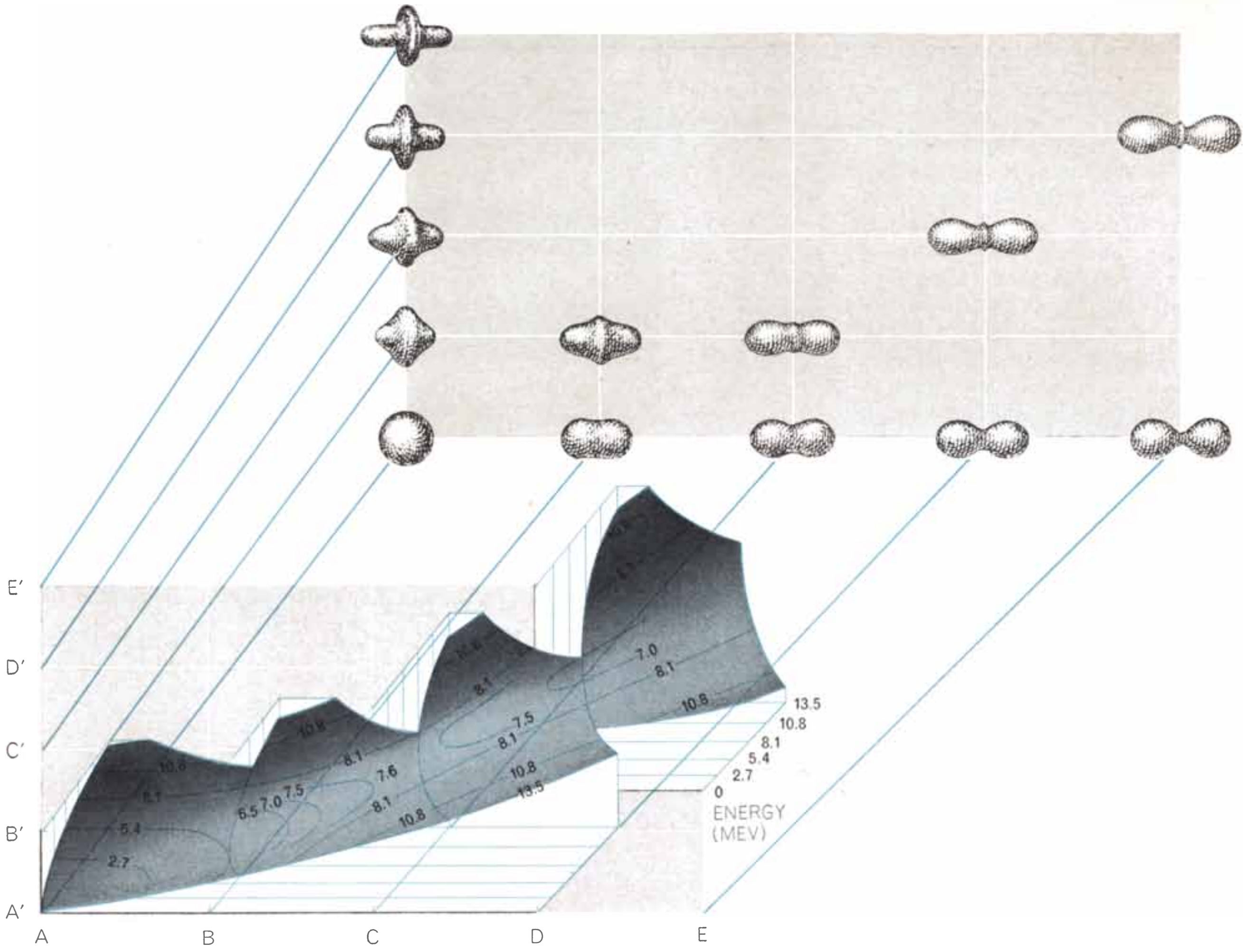
ENERGY RELEASED by the fission of the uranium nucleus into very unequal fragments (*two bars at bottom*) is less than that released by fission into two equal or nearly equal fragments (*two bars at top*). Most of the energy released is in the form of kinetic energy (*dark gray*); a smaller amount is released as internal energy, including energy of deformation, of the fragments (*light gray*). Energy is in millions of electron volts, abbreviated "mev."



ENERGY REQUIRED to deform a uranium nucleus (*top*) increases up to a calculated threshold of about 7.6 mev, where the cohesive effect of surface tension exactly equals the repulsive effect of the charged protons in the two ends of the deformed nucleus. For greater elongations energy is released (*bottom*). At scission, or the moment of fission, a large additional energy, amounting to some 170 mev, becomes available. This is the kinetic energy of the fragments, which results from the repulsive force between the separated fragments.

The Shell Model

If the liquid-drop model successfully predicts the results of bismuth fission, why does it fail in the case of uranium fission? Recent studies suggest an answer. The calculations for the liquid-drop model are based only on two major forms of energy in the nucleus: the electrostatic repulsive energy and the nuclear cohesive, or surface, energy. They neglect, however, the energy involved in the "shell" structure of the nucleus. Both the neutrons and the protons are known to be numbered in shells analogous to the shells of electrons outside the nucleus [see "The Structure of the Nucleus," by Maria G. Mayer; Scientific American, March, 1951]. The energies involved in these shells are comparatively small. They may nonetheless be a significant factor in the fission of the heavy uranium nucleus, where the margin between cohesive energy and repulsive energy is narrower than in the lighter elements. New experimental measurements now indicate that shell energy does indeed play a part in deter-



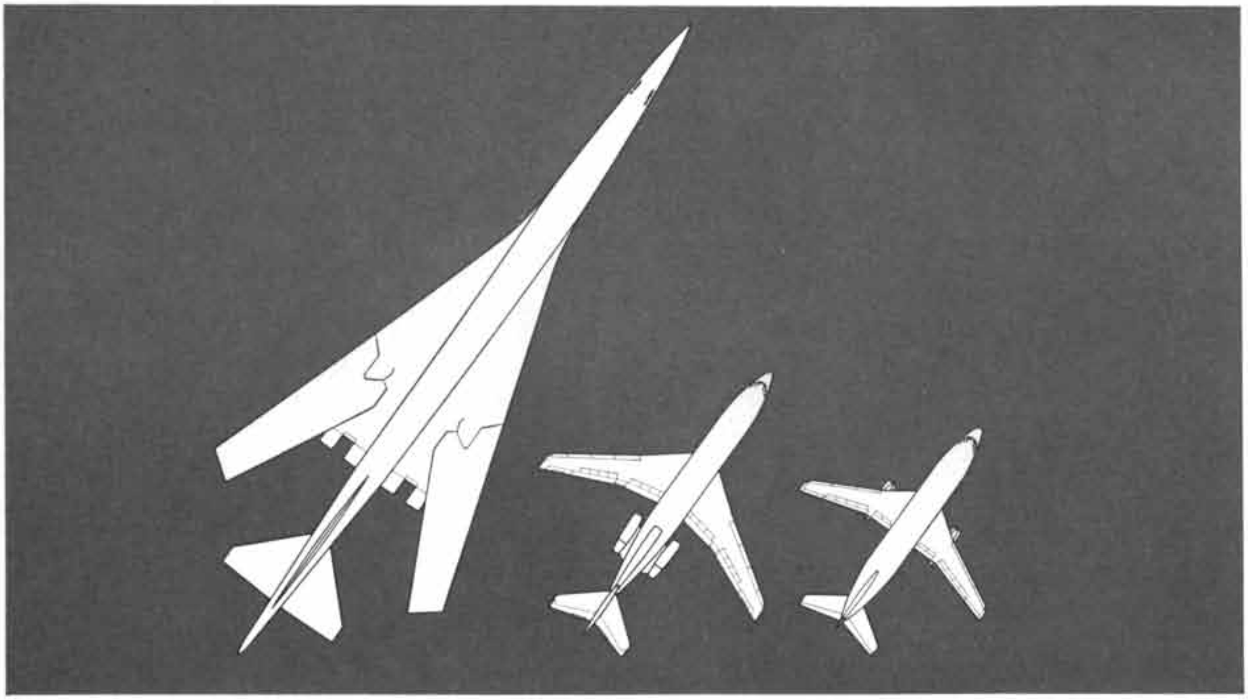
THREE-DIMENSIONAL "ENERGY SURFACE" (*lower left*) **indicates the energies required to deform a uranium nucleus into various shapes. The shapes result from mixing the two basic shapes shown along the axes of the grid at upper right; four specimen shapes resulting from different mixings are depicted. The surface was calculated for the liquid-drop model of the nucleus by Stanley P. Frankel and Nicholas C. Metropolis, then at the University of Chicago. The particular numerical parameters used in these computer calculations resulted in a threshold energy of 7.6 mev** (*colored dot*)**, whereas the actual threshold for uranium has been found to be six mev. More complex calculations mixing 18 basic shapes instead of only two yield essentially the same results.**

mining what products will emerge from the fission of uranium.

Thanks to improved techniques it has become possible not only to record the emission of neutrons from each fission but also to determine the masses of the fragments in an experiment involving millions of fissions. The number of neutrons emitted by a fragment provides a measure of its internal energy. Such measurements have produced a striking finding: the fragments of smallest mass within each of the two groups of fragment masses have very little internal energy. This is indicated by the fact that their later emission of neutrons is minimal. The smallest fragment in the heavy group contains 50 protons plus a complement of neutrons; the smallest fragment of the light group contains 50 neutrons plus a complement of protons. The neutron-emission measurements show that the internal energy of fragments in each group increases steadily with mass. These facts at once present two very interesting implications.

The significance of these results is that the number 50 is one of the "magic" numbers in the shell theory of nuclear structure. Any nucleus with 50 protons or 50 neutrons has a lower than average energy and more than average stability, presumably as a "closed shell" effect analogous to the stability of elements with closed outer shells of electrons. It appears, then, that at some time in the sequence of deformations the nuclear-shell effect influences the shape—and hence ultimately the division—of the uranium nucleus.

The second interesting point is that, although the favored form of fission is division into fragments of unequal size, the fragments finally exhibit approximately equal internal energies. We have seen that these internal energies result from the deformation of the nucleus from a spherical shape; this implies that the paired fragments of the most likely divisions tend to be equally distorted. The simplest picture of this—although we have no assurance that it is the correct picture—is a nucleus just before fission shaped like two spherical balls at opposite ends of a thin, stretched neck. The larger sphere has 50 protons plus neutrons; the smaller, 50 neutrons plus protons. The neck consists of about 26 particles—protons and neutrons. It is reasonable to assume that the neck is thinnest at the midpoint between the spheres, consequently that the nucleus is most likely to break at that point. Each sphere will therefore have an equal portion of the neck material attached to it after fission.



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Position & Duties		
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Position & Duties		

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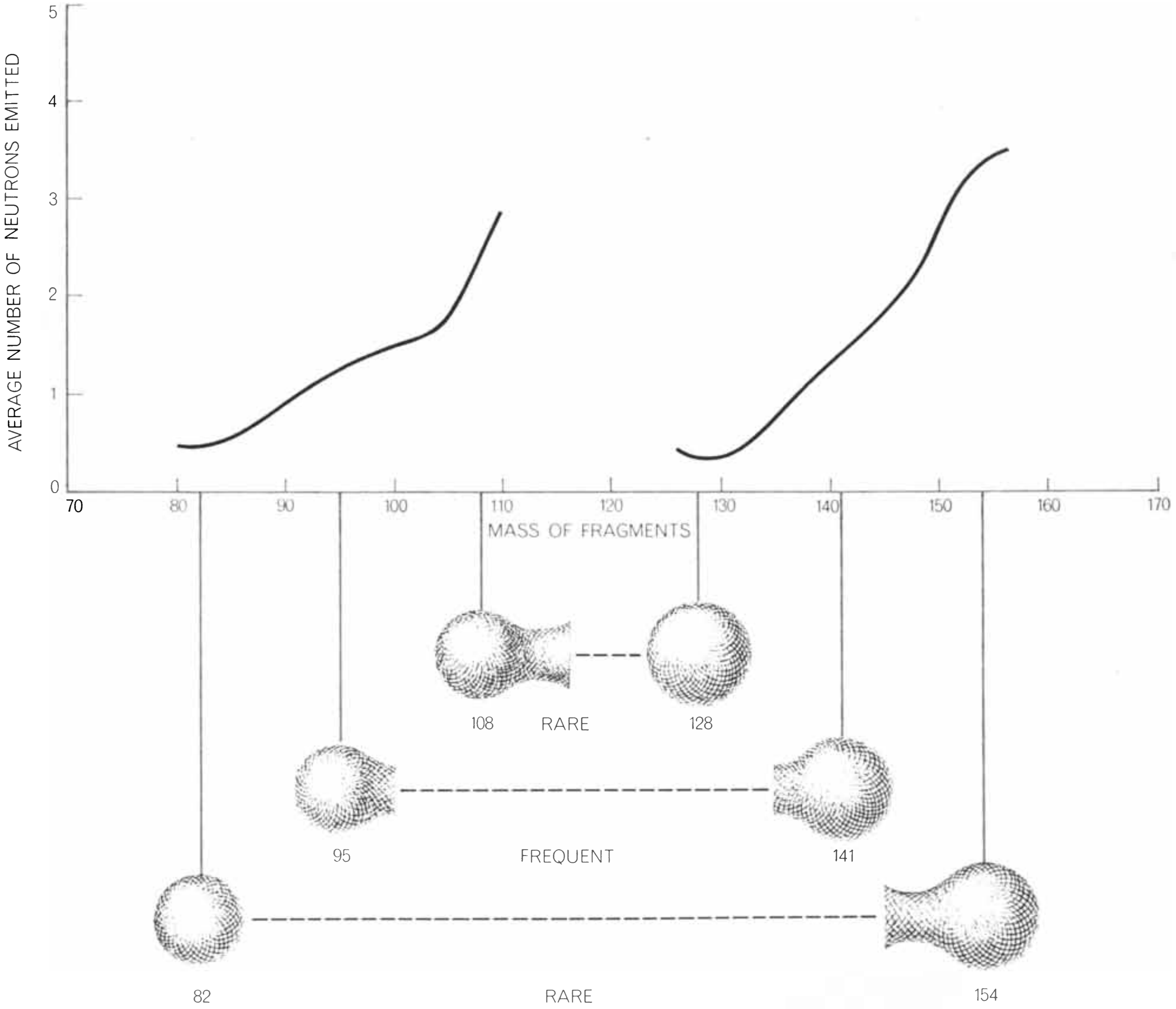
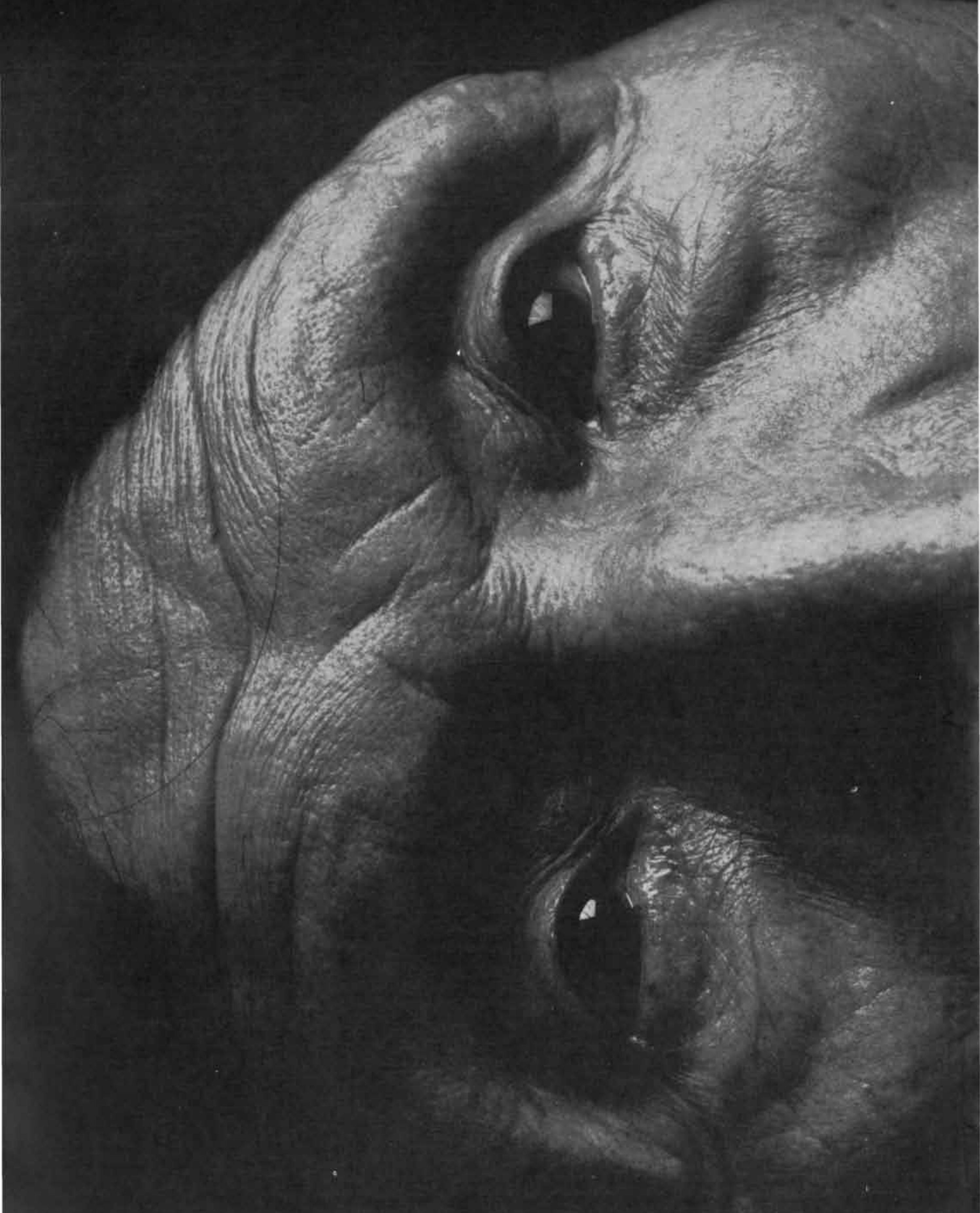
The neck part, being nonspherical, carries energy of deformation, and therefore both fission fragments have equal amounts of internal energy. Occasionally the neck of the stretched uranium nucleus will break not in the middle but close to one of the spheres; in these cases one fragment should have much more internal energy than the other. This pattern—equality of energy between the fragments in most cases but inequality in some—is exactly what one finds in the experimental observations of the products of uranium fission [*see illustration below*].

The model nicely explains the fission of uranium into two fragments of unequal mass, but its shell-number requirements are not satisfied in those very rare instances when the uranium nucleus splits exactly in half, with 46 protons and 72 neutrons in each fragment. Evidently these fissions are rare because the energy advantage of the shells is lacking; 46 protons do not close a shell and 72 neutrons are too far beyond closing a shell. In bismuth fission the shell effect apparently does not operate at all; the fission products cannot have a magic number of protons or neutrons for any reasonable division.

The question of just when and how shell energy influences the deformation of the uranium nucleus that leads to fission is an intriguing subject for further investigation. In many additional respects the process of nuclear fission is rich in possibilities for exploring the properties and organization of the nucleus. The fission process is the only ready means we have for observing atomic nuclei in a highly deformed condition, and it is producing information about nuclear matter that could not be obtained in any other way.



NEUTRONS EMITTED by various fragments of a split uranium nucleus provide a measure for the internal energy of each fragment. Such measurements indicate that the fission of uranium is influenced by two spherical clusters of nucleons, each of which has a minimal internal energy as indicated by its minimal later emission of neutrons. The larger cluster contains 50 protons plus a complement of neutrons (*sphere at top right*); the smaller contains 50 neutrons plus a complement of protons (*sphere at bottom left*). The number 50 is one of the "magic" numbers in the shell theory of nuclear structure: any nucleus with 50 protons or 50 neutrons has lower than average energy and more than average stability, presumably as a "closed shell" effect analogous to the stability of elements with closed outer shells of electrons. The neck between the spheres consists of about 26 nucleons. It provides both the internal energy (in the form of energy of deformation) required for neutron emission and the additional neutrons and protons to give the fragments different masses, depending on whether the split comes at the midpoint of the neck or near one of the spheres. Truncated ends of the neck after scission are schematic; nuclei are expected to result in smoother shapes at breaking point.



The Production of Heat by Fat

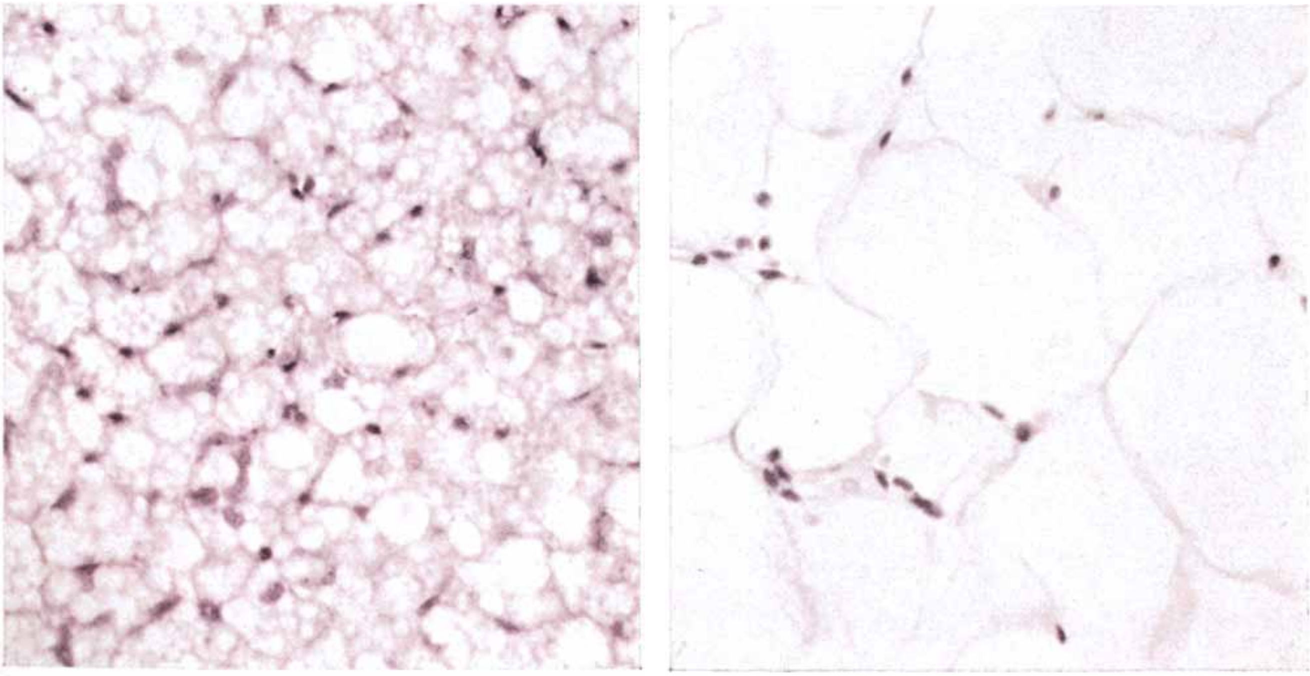
In addition to normal "white" fat, many newborn mammals and adults of hibernating species have "brown" fat deposits. It is metabolism in brown fat cells that increases heat output as a response to cold

by Michael J. R. Dawkins and David Hull

When a warm-blooded animal is exposed to cold, it increases its production of body heat by shivering. Mammals face a cool environment for the first time at birth, however, and many newborn mammals (including human infants) do not shiver. Yet they somehow manage to generate heat in response to a cool environment. The mystery of how this is done has only recently been cleared up. It turns out that the young of many species (and adults of hibernating species as well) are fortified with a special tissue that is exceptionally efficient in producing heat. The tissue in question, long a puzzle to investigators, has become a highly interesting object of physiological and chemical study within the past few years.

Our own interest in it was aroused in 1963 by a chance observation at the Nuffield Institute for Medical Research of the University of Oxford, where we were working in a group studying physiological problems of the newborn. Examining newborn rabbits, we noticed that they had striking pads of brown adipose tissue around the neck and between the shoulder blades. Adipose tissue is a salient feature of all warm-blooded animals. It constitutes the layer of fat underlying the skin over most of the body, and it is known to serve not only as an insulating blanket but also as a storehouse of food and energy. In the adult animal the adipose tissue is almost entirely of the white variety. The large deposits of adipose tissue we saw in the newborn rabbits were in the brown form, and this was a phenomenon that called for explanation.

Looking back through the literature, we found that the brown adipose tissue had mystified investigators for hundreds of years. It was noted as early as 1551 by the Swiss naturalist Konrad von Gesner, who was impressed by the mass of this tissue he observed between the shoulder blades of a marmot. Some observers confused the tissue with the thymus gland, another mysterious structure that had been found to be particularly prominent in newborn ani-



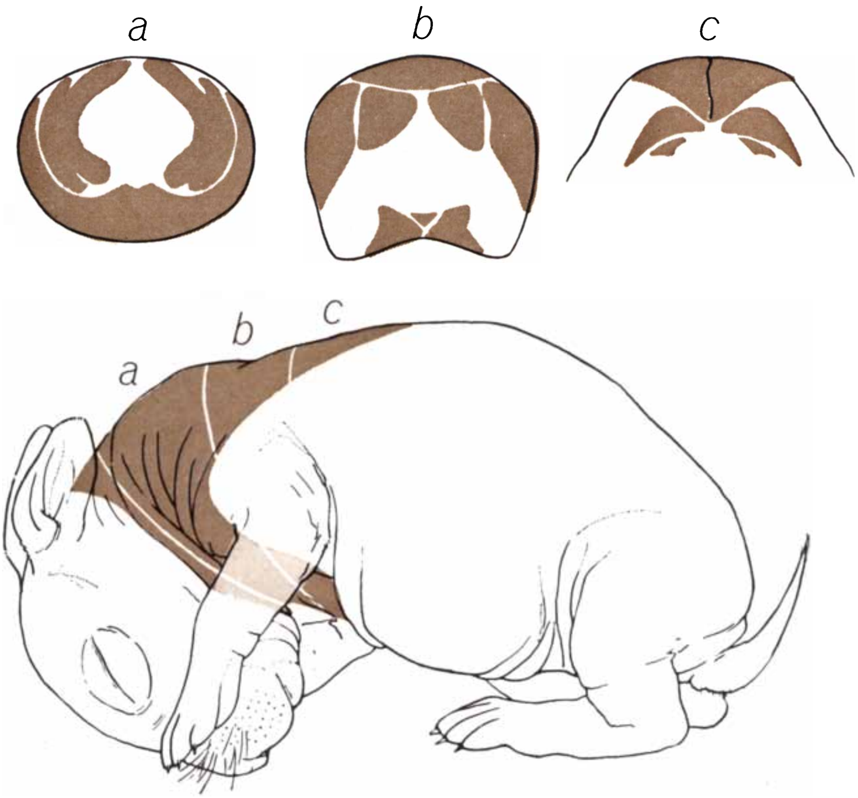
ADIPOSE TISSUE is enlarged 425 diameters in these photomicrographs made by the authors. Brown fat cells (*left*) from between the shoulder blades of a newborn rabbit have numerous small droplets of fat suspended in the stained cytoplasm. White fat cells (*right*) from an adult rabbit have large droplets of fat surrounded by narrow rims of cytoplasm. The stain is hematoxylin and eosin.

mals. Other zoologists, noting that a brown adipose mass was typical of hibernating animals, called it the hibernation gland. In this century more modern theories were advanced. Some physiologists suggested that brown adipose tissue had something to do with the formation of blood cells; others, that it was an endocrine gland. It does, in fact, contain hormones similar to those secreted by the adrenal cortex, but experiments in administering extracts from the tissue failed to show any consistent evidence of hormonal effects.

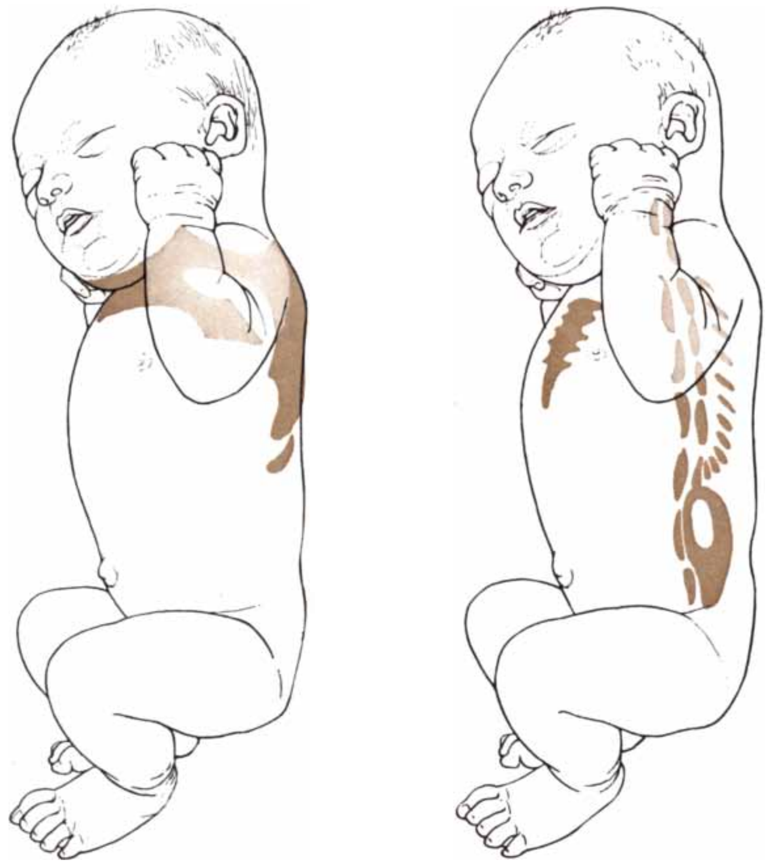
In 1961 two physiologists independently suggested a more plausible hypothesis. George F. Cahill, Jr., of the Harvard Medical School, noting that adipose tissue has an active metabolism that must generate heat as a by-product, proposed that the layer of white fat clothing the body should be regarded "not merely as a simple insulating blanket but perhaps as an electric blanket." And Robert E. Smith of the University of California School of Medicine at Los Angeles specifically called attention to the high heat-producing potentiality of brown adipose tissue, whose oxidative metabolism he had found to be much more active than that of white adipose tissue.

The cells of adipose tissue are characterized by droplets of fat in the cytoplasm (the part of the cell that lies outside the nucleus). In the white adipose cell there is a single large droplet, surrounded by a small amount of cytoplasm. The brown adipose cell, on the other hand, has many small droplets of fat, suspended in a considerably larger amount of cytoplasm. With the electron microscope one can see that the brown fat cells contain many mitochondria, whereas the white fat cells have comparatively few. Mitochondria, the small bodies sometimes called the powerhouses of cells, carry the enzymes needed for oxidative metabolism. What gives the brown fat cells their color is a high concentration of iron-containing cytochrome pigments—an essential part of the oxidizing enzyme apparatus—in the mitochondria.

It is easy to show by experiment that brown fat cells, loaded as they are with mitochondria, have a large capacity for generating energy through oxidation of substrates. Tested, for example, on succinic acid, an intermediate product in the Krebs energy-producing cycle, the brown fat cells of rabbits prove to have a capacity for oxidizing this substance that is 20 times greater than the oxidative capacity of white fat cells



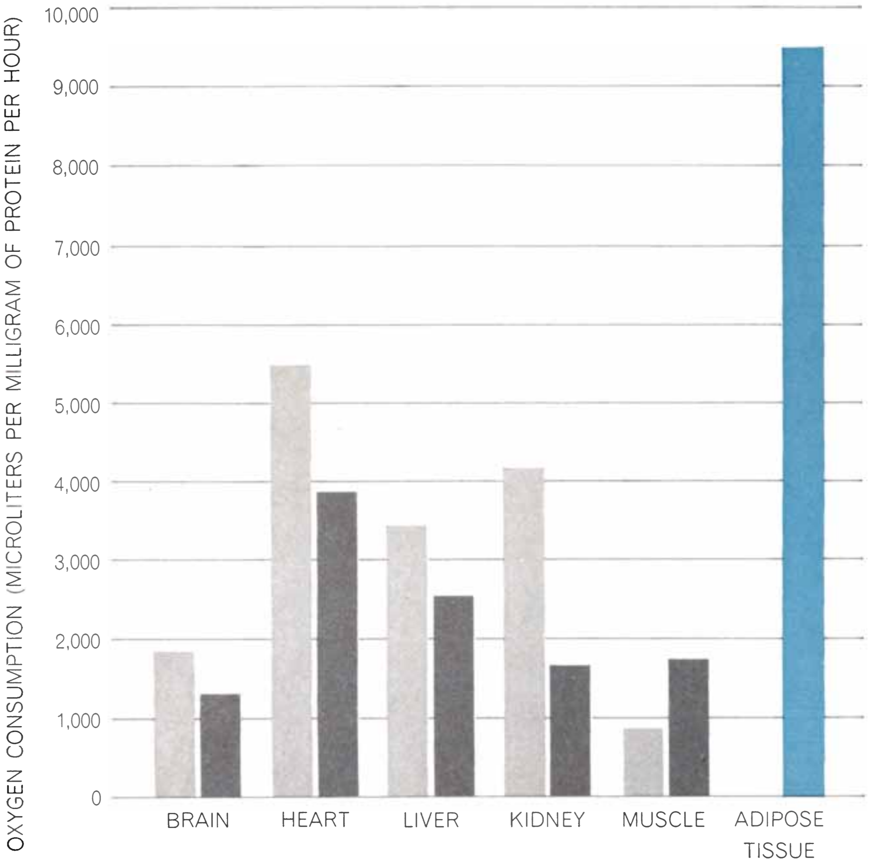
BROWN FAT accounts for 5 or 6 percent of the body weight of the newborn rabbit. It is concentrated, as shown in sections, around the neck and between the shoulder blades.



HUMAN INFANT at birth has a thin sheet of brown adipose tissue between the shoulder blades and around the neck, and small deposits behind the breastbone and along the spine.

tion on opposite page]. The temperature difference persisted for many hours, until the fat stored in the brown tissue was almost completely exhausted.

This clear indication that the brown adipose tissue produced heat was strengthened by an experiment in which the newborn animals were deprived of oxygen, the oxygen content of the air in the experimental chamber being reduced from the normal 21 percent to 5 percent. Deprived of the oxygen required for oxidative metabolism, the brown adipose tissue promptly cooled to the same low temperature as the muscle tissue. When the oxygen concentration in the air was restored to the normal 21 percent, the brown adipose tissue immediately warmed up again, with the muscle tissue and deep-body temperature trailing after it in recovery.



OXIDATIVE CAPACITY of various tissues is compared by measuring their ability to oxidize succinic acid. The light gray bars are for adult rabbit tissues, the dark bars for tissues from newborn rabbits. Newborn brown fat (*color*) is the most active oxidizer by far.

and is even greater than that of the hardworking cells of the heart muscle.

To explore the role of the brown adipose tissue in newborn rabbits we began by measuring the animals' total heat production. An indirect measure of this production is the animal's consumption of oxygen: each milliliter of oxygen consumed is equivalent to about five calories of heat in the body. We found that at an environmental temperature of 35 degrees centigrade (95 degrees Fahrenheit) newborn rabbits produced heat at a minimal rate. When their environment was cooled to 25 degrees C. (77 degrees F.), they trebled their heat output. At 20 degrees C. (68 degrees F.) their heat production reached a peak: 400 calories per kilogram of body weight per minute. If newborn rabbits were as fully protected against heat loss and as large as adults are, this rate of production would be sufficient to maintain their internal body temperature at a normal level even in a cold environment as low as 30 degrees below zero C. A newborn rabbit, however, has little or no fur and a large surface area in relation to its body mass; hence its deep-body temperature falls when the animal is only mildly chilled by the outside air.

The next step was to determine whether or not heat production was concentrated in the brown adipose tissue. In a newborn rabbit this tissue makes up 5 to 6 percent of the total body weight and is localized, as we have noted, around the neck and between the shoulder blades. We inserted a fine thermocouple under the skin next to the brown adipose tissue to measure any change in the temperature of that tissue, and for comparison we inserted a second thermocouple in back-muscle tissue at the same distance from the skin and a third in the colon to record the deep-body temperature. At the neutral environmental temperature of 35 degrees C. the temperatures at all three sites in the body were the same. When the environmental temperature was lowered to 25 degrees C., differences developed: the temperature at the brown adipose tissue then was 2.5 degrees higher than that in muscle tissue in the back and 1.3 degrees higher than the deep-body temperature [*see illustra-*

Is the brown adipose tissue solely responsible for the newborn animal's increase in heat production in response to cold? We examined this question in a series of experiments with Malcolm M. Segall collaborating. The experiments consisted simply in observing the effect of excising most of the brown adipose tissue (amounting to a few grams) from newborn rabbits. When 80 percent of this tissue was removed (by surgery under anesthesia), the animals no longer increased their heat production in response to exposure to cold. In short, removal of the few grams of this specific tissue practically abolished the newborn rabbit's ability to multiply its oxygen consumption threefold and step up its heat production correspondingly. Evidently, then, the brown adipose tissue was entirely, or almost entirely, responsible for this ability.

Our results did not necessarily mean that all the metabolic heat in response to cold was produced within the brown fat cells themselves. Those cells might release fat in some form into the bloodstream for transport to other tissues, where it might be oxidized. Fortunately this question too could be investigated experimentally.

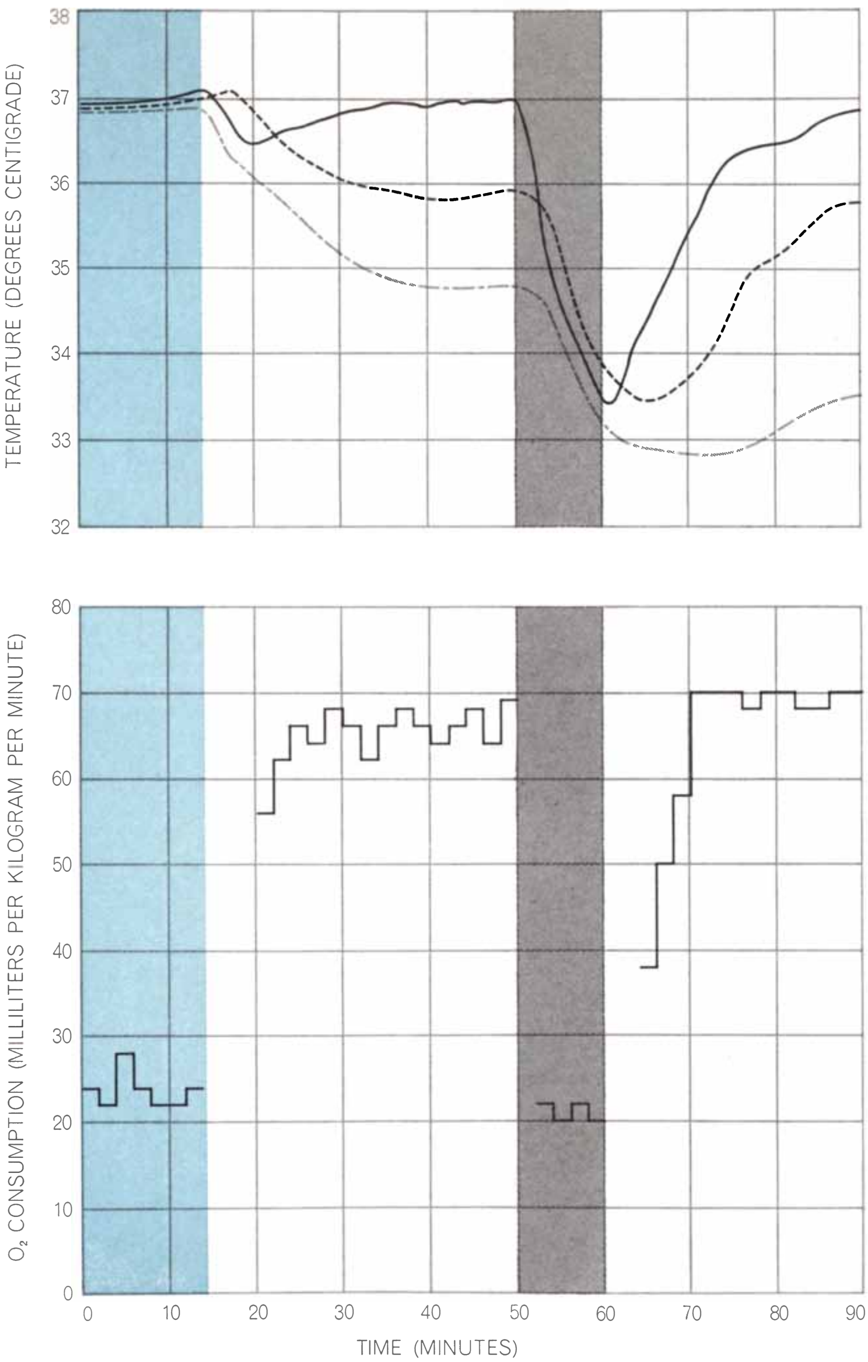
The fat in the droplets in adipose cells is in the form of triglyceride molecules. A triglyceride consists of a glycerol molecule with three long-chain fatty acids attached [*see middle illustration on page 66*]. Before the triglyceride can be oxidized it must be split into smaller, more soluble units—that is, into glycerol and free fatty acids. Glycerol cannot be used for metabolism in a fat cell, because that type of cell does not contain the necessary enzymes. Consequently all the glycerol molecules freed by the splitting of triglycerides in fat cells are discharged into the bloodstream. The glycerol level in the blood therefore provides an index of the rate of breakdown of triglycerides in fat cells. Now, if the level of free fatty acids in the blood corresponds to the glycerol level, we can assume that fatty acids also are released from these cells in substantial amounts for distribution to other tissues.

We examined the blood of newborn rabbits from this point of view. To begin with, at the neutral incubation temperature of 35 degrees C. the level of free fatty acids in the blood was slightly higher than that of glycerol. When the environmental temperature was lowered to 20 degrees, the glycerol level in the blood increased threefold. The concentration of free fatty acids in the blood, however, rose only a little. This showed that most of the fatty acid molecules freed by the splitting of triglycerides in fat cells must have remained in the cells and been metabolized there. Studies of adipose tissue in the test tube indeed demonstrated that less than 10 percent of the freed fatty acid is released from the cell. We can conclude that the brown fat cells are the main site of cold-stimulated heat production.

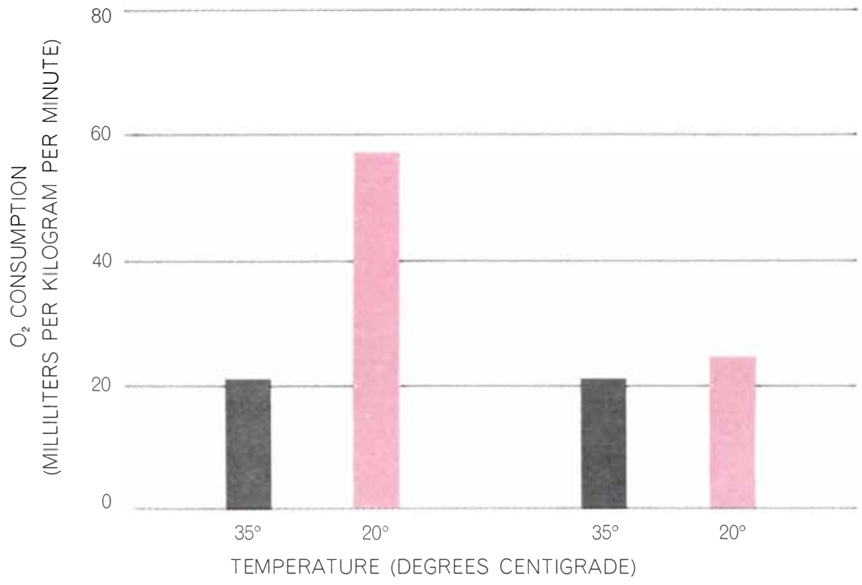
How is the heat produced? Brown fat cells are admirably suited, by virtue of their abundance of mitochondria, for generating heat by means of the oxidation of fatty acids. In this process a key role is played by adenosine triphosphate (ATP), the packaged chemical energy that powers all forms of biological work, from the contraction of muscle to the light of the firefly. The probable cycle of reactions that turns chemical energy into heat in adipose tissue cells is shown in the illustration on page 67.

Triggered by the stimulus of cold, the brown fat cell splits triglyceride molecules into glycerol and fatty acids. The glycerol and a small proportion of the free fatty acids are released into the bloodstream for metabolism by other tissues (probably liver and muscle). More than 90 percent of the fatty acid molecules remain, however, in the fat cell. They combine with coenzyme *A*, the energy for this combination being donated by ATP. Since the donation involves the splitting of high-energy bonds in ATP, with its consequent hydrolysis to adenosine monophosphate (AMP), the cell has to regenerate ATP. This is accomplished by oxidative phosphorylation: the addition of inorganic phosphate to AMP with the simultaneous oxidation of a substrate.

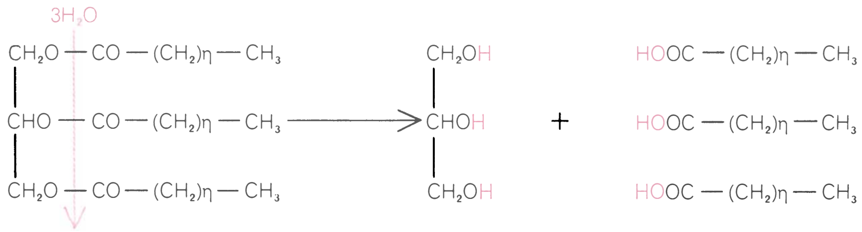
Now, some molecules of the fatty acid–coenzyme *A* compound formed with the help of ATP are oxidized to provide energy for the regeneration of ATP. But most of this complex is reconverted, by combination with alpha-glycerol phosphate, to the original triglyceride. In short, there is an apparently purposeless cycle that breaks triglyceride down to fatty acids only



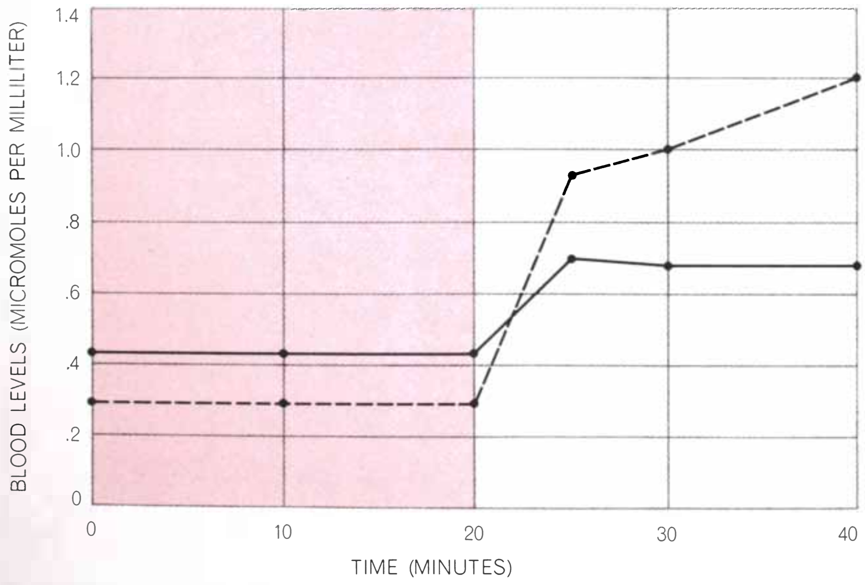
SITE AND OXYGEN DEPENDENCE of heat production are established by data from newborn rabbits subjected to cold and temporarily deprived of oxygen. The top curves are for body temperature measured near brown fat (*solid black line*), in muscle (*broken gray*) and in the colon (*broken black*). The bottom curves trace metabolic activity. In the period covered by the colored band the environmental temperature was 35 degrees centigrade; thereafter it was 25 degrees. The gray band marks a period during which the oxygen concentration was cut from 21 percent to 5 percent. Apparently brown-fat metabolism in the presence of adequate oxygen accounts for a rabbit's ability to respond to a drop in temperature.



REMOVAL OF BROWN FAT by surgery sharply curtails the response to cold. The two bars at the left show the oxygen consumption in intact newborn rabbits at two temperatures. The bars at the right are for rabbits that have had 80 percent of their brown fat removed: metabolism at 35 degrees is unchanged but there is virtually no increase at 20 degrees.



METABOLISM OF BROWN FAT begins with the hydrolysis of the triglyceride molecule (*left*), yielding one molecule of glycerol (*center*) and three of free fatty acid (*right*).



GLYCEROL CONCENTRATION (*broken line*) in the blood of a newborn rabbit rises sharply when the environmental temperature drops from 35 degrees centigrade (*colored area*) to 20 degrees (*white area*). The concentration of fatty acids in the blood rises only slightly, however (*solid line*). Apparently fatty acids are largely metabolized in the cell.

to resynthesize the latter back to triglyceride. Although the cycle seems pointless in chemical terms, it is clearly significant in terms of work. The cycle is, in fact, a device for turning the chemical-bond energy of fatty acids into heat. The energy driving the cycle comes fundamentally from the oxidation of the fatty acids, and the fact that the cycle is exceptionally active in brown adipose tissue is demonstrated by that tissue's high consumption of oxygen. Judging from the proportion of free fatty acids retained by the cells of brown adipose tissue, and from the effects of surgical removal, this tissue accounts for more than 80 percent of the increased body heat produced by a newborn rabbit in the cold.

The heat must of course be distributed to the rest of the body by the bloodstream. The newborn animal's brown adipose tissue has an extremely rich blood supply. During exposure to cold the blood flow through this tissue may increase to several times its normal rate, and indirect calculations suggest that as much as a third of the total cardiac output is directed through the tissue.

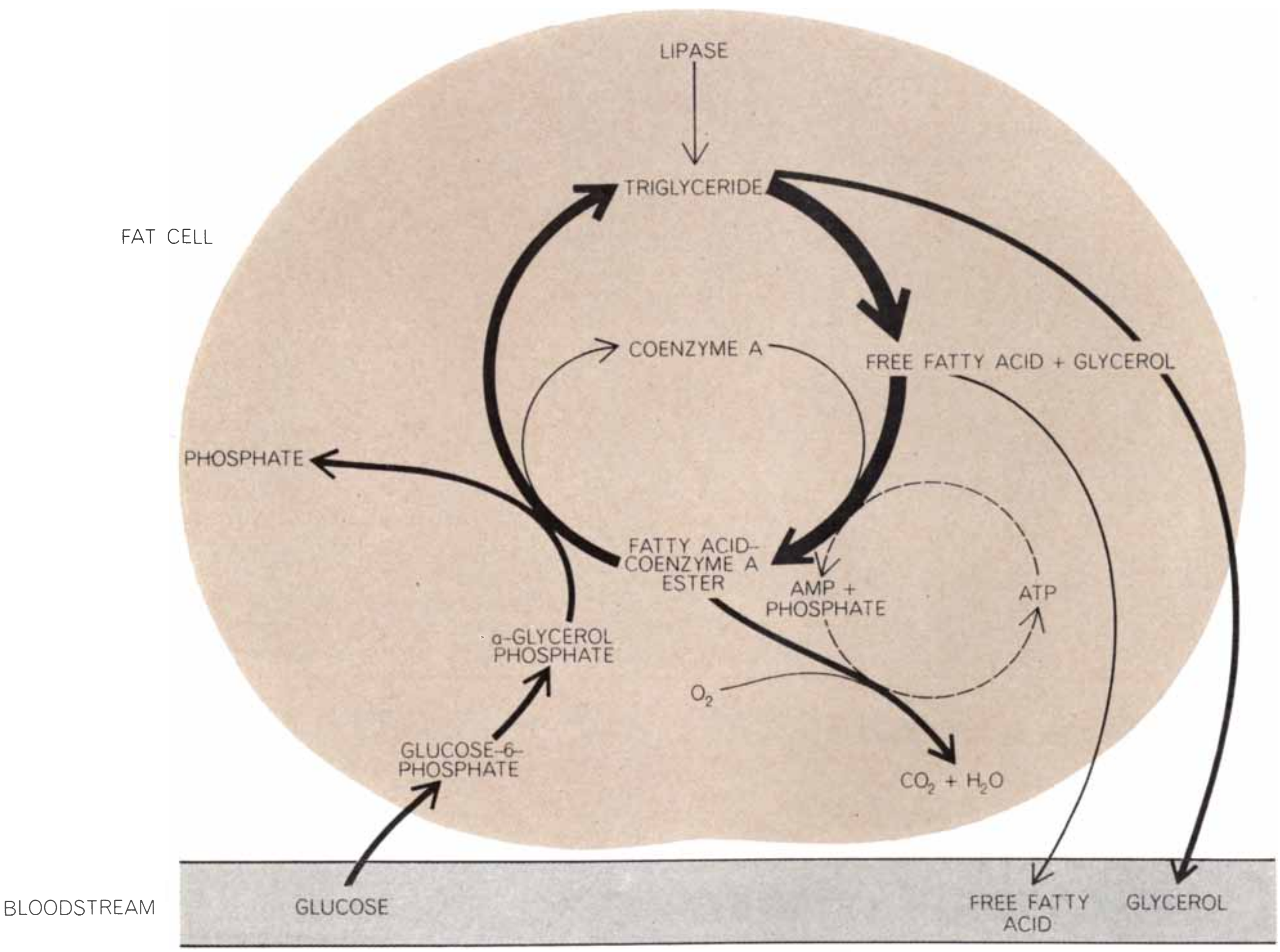
How does cold stimulate the brown adipose tissue to generate heat? There are two possible means by which the body's sensation of cold may be communicated to the tissue: by nerve impulses and by hormones, the chemical "messengers" of the body. We found that the hormone noradrenaline has a specific stimulating effect on the brown adipose tissue. An intravenous infusion of noradrenaline in a newborn rabbit will bring about a large increase in the animal's oxygen consumption and heat production in its brown fat. If the brown fat is removed, the hormone no longer produces any increase in the body's oxygen consumption. The question remains: Is the hormone delivered to the intact tissue by way of the bloodstream or by release at sympathetic nerve endings, which are known to secrete noradrenaline close to cells? Several clues suggest that the nerve endings, rather than the bloodstream, are the agent of delivery. For one thing, the adipose tissue's rapid response to cold indicates that the message travels via the nerves. Second, experiments show that drugs that block the action of noradrenaline circulating in the blood do not block the tissue's response to cold. Third and conclusively, direct electrical stimulation of the sympathetic nerves going to the tissue will cause the brown adipose tissue to produce heat, whereas when the sympathetic nerves are cut, the tissue can no longer burn its fat when the animal is exposed to cold.

Various findings indicate that the overall system controlling the production of heat by brown adipose tissue is probably as follows: The temperature receptors in the skin, on sensing cold, send nerve impulses to the brain. The brain's temperature-regulating center then relays impulses along the sympathetic nerves to the brown adipose tissue, where the nerve endings release noradrenaline. The hormone activates an enzyme that splits triglyceride molecules into glycerol and free fatty acids and thereby triggers the heat-producing cycle. Thus the rate of heat production is controlled by the sympathetic nervous system.

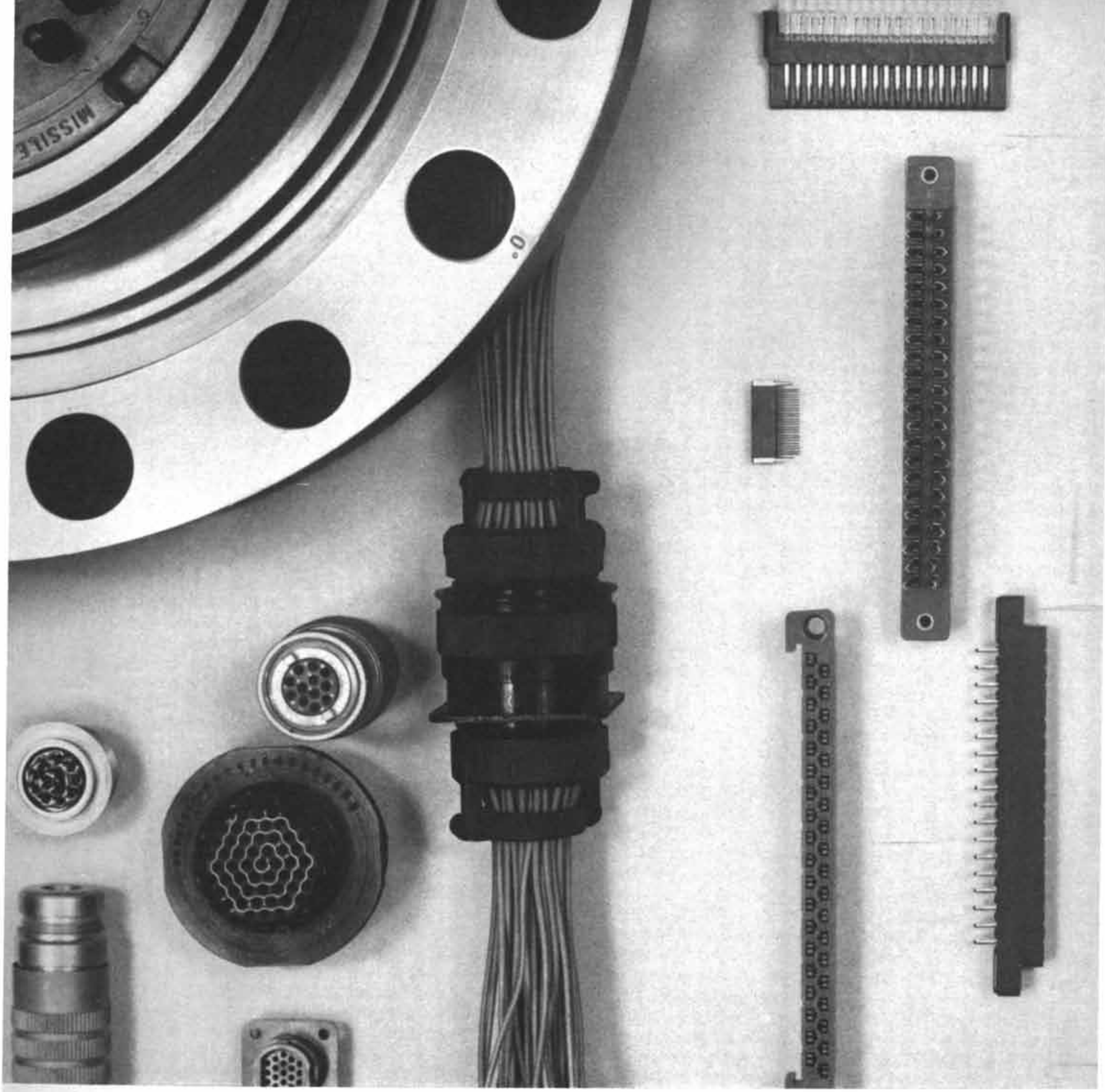
Among the animals that have brown adipose tissue at birth, the amount varies considerably from species to species. As in the rabbit, there are large deposits between the shoulder blades in the newborn guinea pig and the coypu (a water rodent). In the cat, dog and sheep at birth there are sheets of brown adipose tissue between the muscles of the trunk and around the kidneys. The human infant has well-marked deposits of such tissue [*see bottom illustration on page 63*], and recent studies indicate that this tissue is a source of heat for a baby as it is for other newborn animals. When a baby is exposed to cold, its blood shows a small but definite rise in the glycerol level with no significant change in the level of fatty acids; on prolonged exposure to cold the fat in its brown adipose tissue is used up.

In most species of animals born with brown adipose tissue the tissue appears to be largely converted to the white form by the time the animal has reached adulthood. Certain animals retain at least some tissue in the brown form, however. The adult rat, for example, has small amounts of brown adipose tissue in the shoulder blade region and elsewhere. The rat's venous system indicates that there is a rich flow of blood from this region to the plexus of veins around the spinal cord; this suggests that the brown adipose tissue in the adult rat may serve particularly to warm vital structures in the animal's body core during exposure to cold. When a laboratory rat is kept in a cold environment, it develops additional brown adipose tissue and an increased ability to produce heat without shivering.

For hibernating animals brown adipose tissue is an all-important necessity throughout life. These animals possess large amounts of the tissue, and direct studies have now shown that the brown adipose tissue is responsible for the animals' rapid warming and awakening from the torpid hibernating state.



HEAT IS PRODUCED in brown fat cells by the oxidation of fatty acids. In response to cold an enzyme, lipase, splits triglyceride. The glycerol leaves the cell. The fatty acid forms an ester with coenzyme *A*, the reaction acquiring energy from the splitting of adenosine triphosphate (*ATP*) into adenosine monophosphate (*AMP*) and inorganic phosphate. Some of the ester is oxidized to regenerate ATP; the rest goes to resynthesize triglyceride. The effect of the cycle, then, is to turn chemical-bond energy into heat energy.



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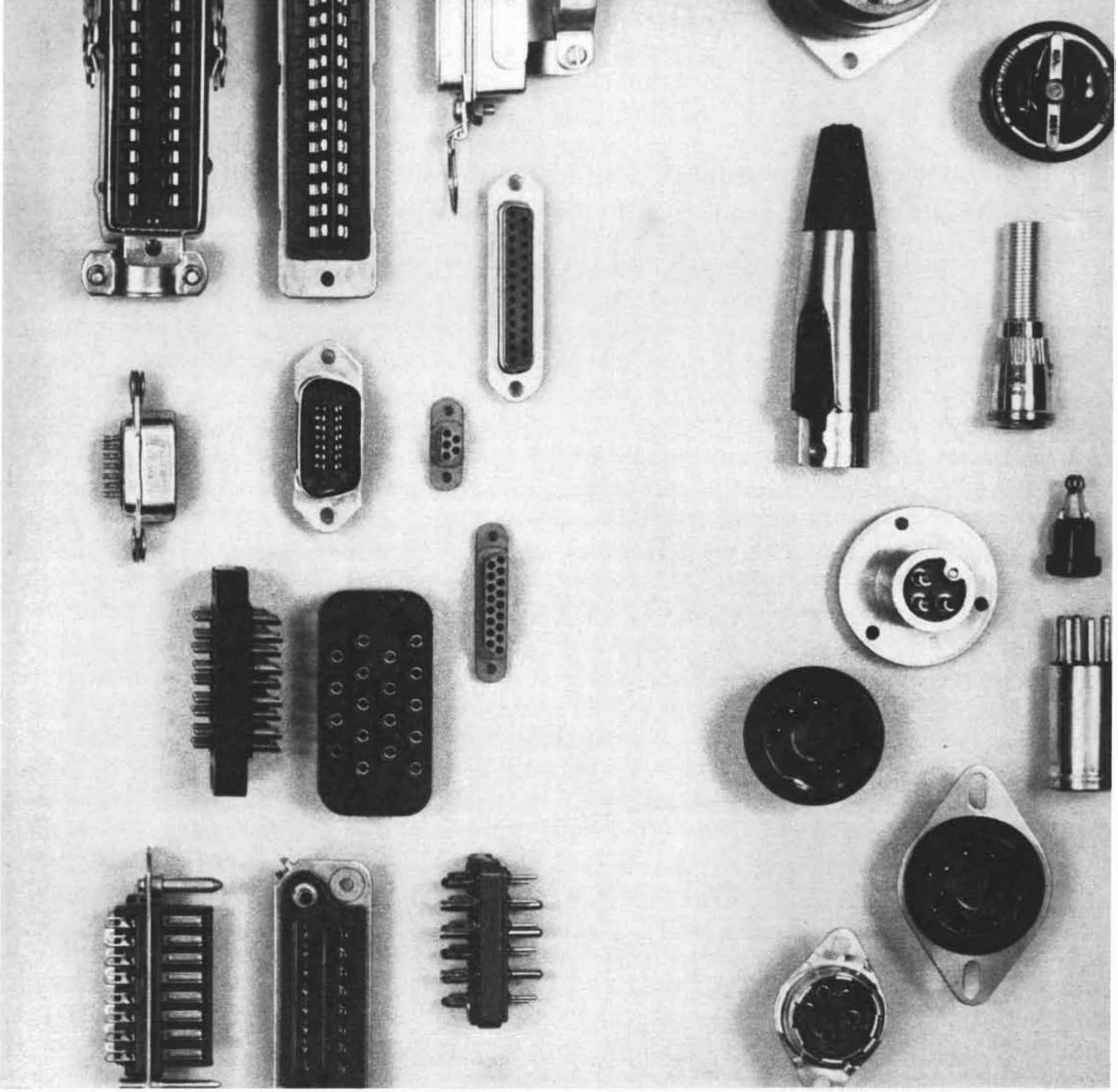

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DENSITY GRADIENTS

Devices incorporating this simple concept have recently found application in fields as diverse as solid-state physics, the manufacture of plastics and the chemistry of the genetic code

by Gerald Oster

The term "density gradient" has a somewhat technical ring, but there is nothing esoteric about the concept. Examples of density gradients will be immediately familiar to the reader. The earth becomes progressively denser toward its center, with a sharp rise in density at a boundary some 1,800 miles below the surface. The density of the air we breathe decreases exponentially with increasing altitude up to about three miles, where fluctuations in temperature caused by the absorption of the sun's ultraviolet radiation disrupt its smooth decline. The density of the water in the oceans increases roughly as a linear function of increasing depth. Within the human body—indeed, in all biological systems—density gradients in the form of gradients in the concentration of various molecules are essential for the distribution of these molecules to their respective sites of action.

In the laboratory, devices that incorporate density gradients are used to measure tiny variations in the density of samples of matter. The standard device of this type, called a density-gradient column, is capable of detecting variations in density as minute as one part in 10 million, and can do so with a sample weighing only a millionth of a gram! The wide utility of this simple device can be appreciated when one considers that virtually every chemical reaction involving solids or liquids is accompanied by a change in density. In addition to serving as a powerful analytical tool, the density-gradient column is employed extensively in both research and industry to separate substances that could be isolated only with great difficulty, if at all, by other techniques. This article deals with the theoretical and practical aspects of the standard density-gradient column and also describes some of its more interesting recent applications in fields as diverse as solid-state physics, the manufacture of plastics and the chemistry of the genetic code.

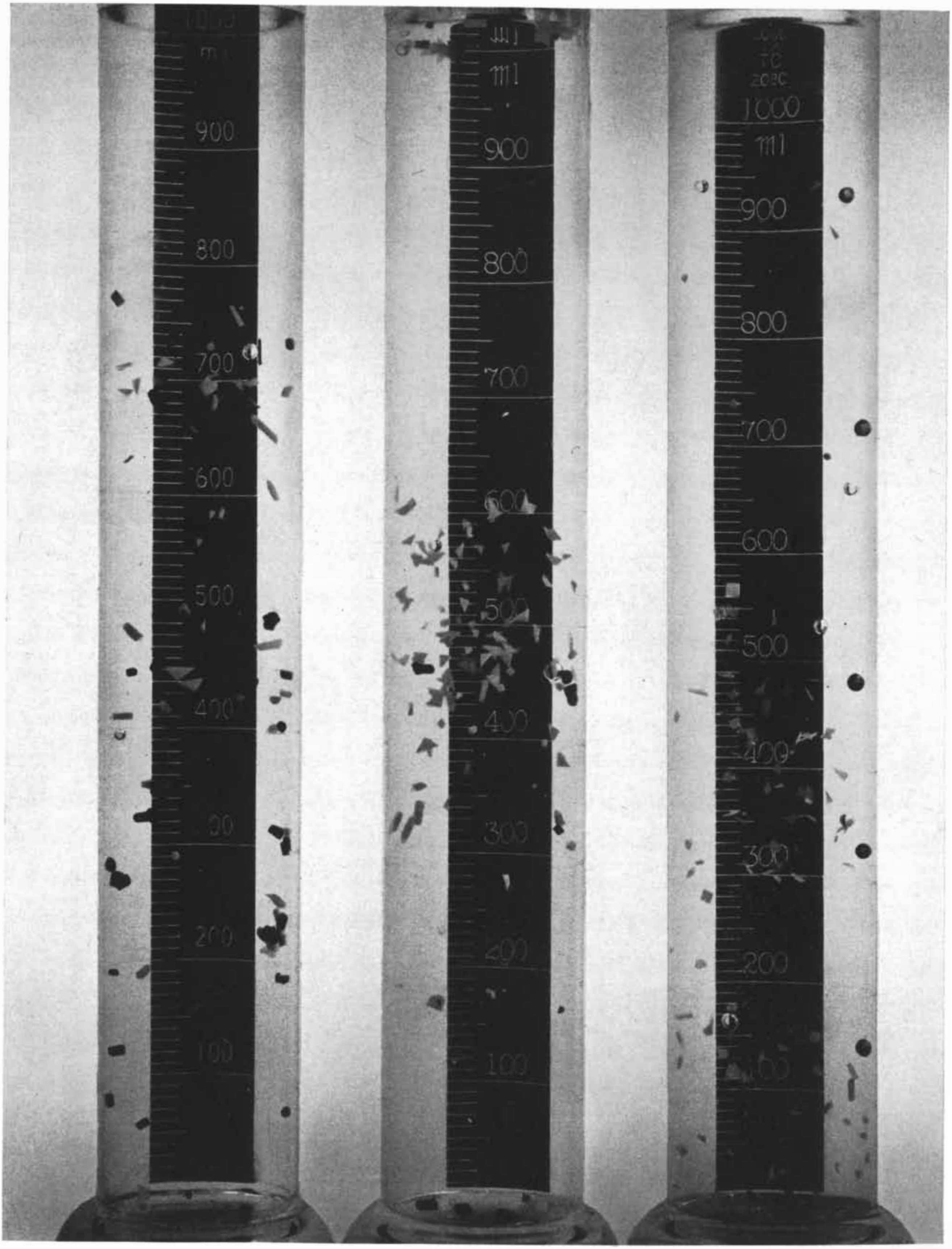
The easiest way to produce a density gradient in the laboratory is to pour a lighter liquid gently over a heavier liquid, as a bartender does in making a many-layered pousse-café [*see illustration at left on page 72*]. At first there is a sharp boundary between the two liquids, but if the liquids are miscible the boundary soon begins to spread out to form a more gradual transition zone. If a sample of matter (either solid or liquid) with a density somewhere between the densities of the two original liquids is now placed in the density-gradient column, the sample will come to rest at a point where the density of the liquid in the column exactly matches its own. By carefully calibrating the column beforehand the density of the sample can be read off with considerable precision.

If a collection of samples with different densities is placed in the density-gradient column, each sample will come to rest at a different height in the column; by successively removing samples at different heights the density-gradient column can be made to serve as a highly reliable separation device. Moreover, such a column is a self-stabilizing device: any object placed in it will return to its proper level after being disturbed.

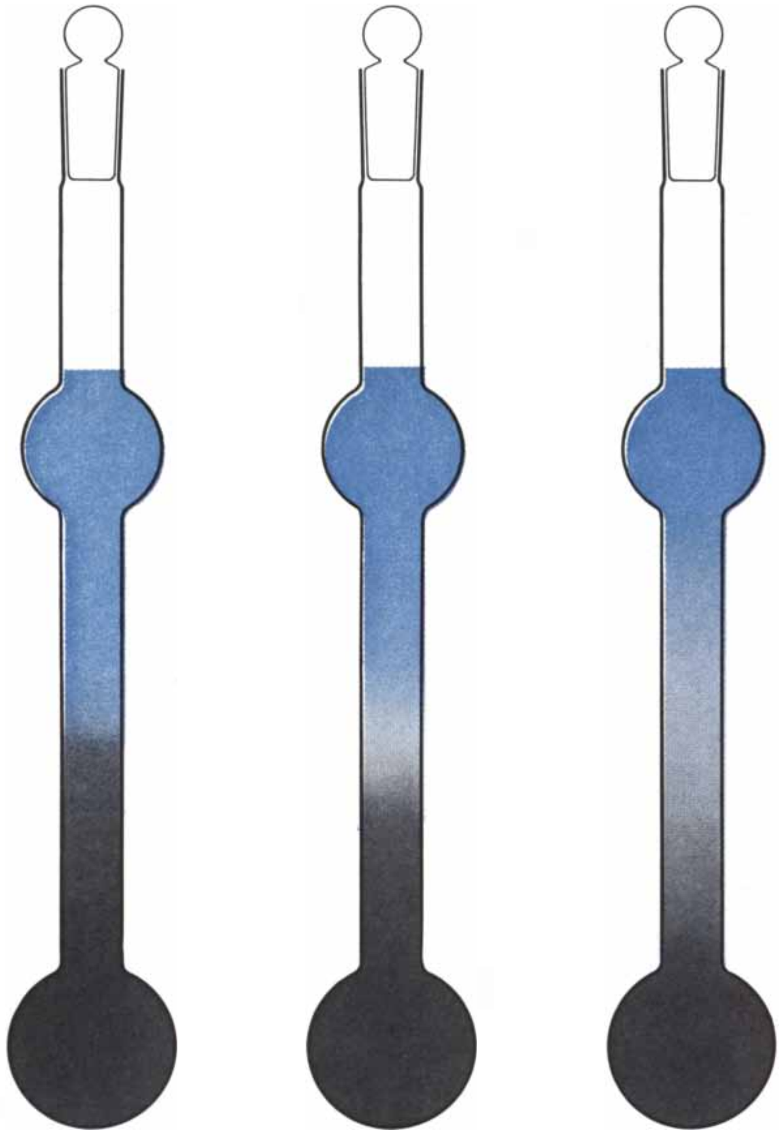
These three important features of a density-gradient column were recognized more than 300 years ago by Galileo Galilei, who described the following experiment in his *Dialogues concerning Two New Sciences:* "In the bottom of a vessel I placed some salt water and on this some fresh water; then I showed them that the ball [of wax] stopped in the middle and that when pushed to the bottom or lifted to the top it would not remain in either of these places but would return to the middle." Noting that a single drop of the sample sufficed for the experiment, Galileo went on to suggest that his invention might have some practical applications, perhaps in medicine.

A density-gradient column constructed by Galileo's method has one serious drawback: normally the interdiffusion of the two liquids proceeds so slowly that it takes days or even weeks to achieve a useful linear gradient, that is, a gradient in which the density varies in direct proportion to the height. The diffusion process can be speeded up, however, by several techniques. One is simply to agitate the boundary region with smooth up-and-down stirring movements of increasing amplitude [*see illustration at right on page 72*]. In order for such a column to be stable for at least a month the ends of the column must be provided with reservoirs of the two liquids whose densities represent the extremes of the density range of the samples to be tested. Since the gradient can be disrupted by fluctuations in temperature, it is also desirable that the entire apparatus be placed in a constant-temperature bath. "Instant" density-gradient columns can be made by pouring the two liquids into the column at controlled rates [*see top illustrations on pages 74 and 75*].

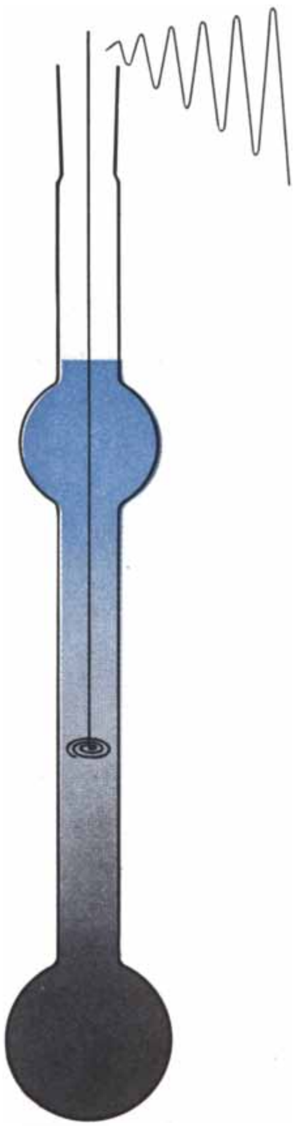
Another way to produce a density gradient is to subject any solution to a substantial centrifugal force. Modern ultracentrifuges rotate at speeds in excess of 1,000 revolutions per second and generate forces enormously greater than gravity. As a result the molecules in solution distribute themselves in the centrifuge cell in such a way that the density is higher the greater the distance from the center of the rotor.



DENSITY-GRADIENT COLUMNS used for measuring the density of samples of polyethylene were photographed at the plastics-manufacturing plant of the W. R. Grace & Co. in Clifton, N.J. The columns contain a mixture of water and isopropyl alcohol, with the water on the bottom. The samples are dropped into the columns from the top one at a time and come to rest at points where their density exactly matches that in the columns. Dark spheres at right and clear spheres elsewhere in the columns are glass floats used for calibrating the density gradients. Many samples from completed tests remain in the columns. Columns are about three feet high.



INTERDIFFUSION of two miscible liquids with different densities is the easiest way to produce a density gradient in the laboratory. The denser liquid (*gray*) is poured into the bottom of the column and is gently overlaid with the less dense liquid (*color*). At first there is a sharp boundary between the two liquids (*left*), but this soon begins to spread out into a more gradual transition zone (*center*). It takes days or even weeks for this method to achieve a linear gradient (*right*), that is, one in which density varies directly with height.



AGITATION of the boundary region between the two miscible liquids at left is one way to speed up the interdiffusion process. To achieve a good linear gradient the mixing loop should make smooth up-and-down movements of increasing amplitude.

A density-gradient column can be calibrated in several ways. One method is to introduce hollow glass floats or liquid droplets of known density into the column. (In the case of liquid droplets it is important that they be immiscible with both liquids in the column.) Another method is to determine the variation in the refractive index of the liquid in the column; this method takes advantage of the fact that light is refracted, or bent, at a larger angle when it passes through a denser medium than when it passes through a less dense medium. In an ultracentrifuge this type of calibration is usually accomplished by means of the "schlieren" optical technique [*see bottom illustration on page 74*]. In a recent series of experiments performed in our laboratory at the Polytechnic Institute of Brooklyn, Yasunori Nishijima and I found that the variation in refractive index with density could be determined far more simply by the use of moiré-pattern gratings [*see bottom illustration on page 75*].

A sensitive density-gradient column, that is, one in which there is a small but constant variation in density over a workable distance, has many applications in research. For example, the column can be used to record the dislocations that occur in certain crystals as a result of ionizing radiation. When potassium chloride crystals, say, which are normally colorless, are treated with X rays, they turn purple; this is because some of the chlorine atoms are pushed out of their positions in the crystal lattice and are replaced by electrons. The change in color is accompanied by a minute decrease in density, which can be observed by placing the irradiated crystals in a density-gradient column consisting of tetrabromoethylene and benzene. Recently I found that if the purple crystals were subsequently illuminated with yellow light, they sank, demonstrating that their original density had been restored.

The density-gradient technique is also capable of detecting extremely small amounts of impurities in a test sample. One area in which this is particularly important is the analysis of crystalline semiconductors, such as those employed in transistor devices. As little as two parts in 10 million of boron in silicon crystals has been detected in this manner.

Density gradients play a role in almost every separation technique used today in research and industry. The traditional unit operations of chemical engineering, in which the components of a mixture are separated in the course of being transferred from one homogeneous phase to another, all involve the action of a density gradient subject to gravity; these operations are gas absorption, distillation, liquid extraction, leaching, crystallization and drying. The same applies to the newer separation techniques, which include zone refining, electrophoretic convection and thermal diffusion. Incidentally, it is quite easy to separate sodium chloride crystals from potassium chloride crystals by the density-gradient technique, a task that is practically impossible by any other means; the density gradient is provided by the interdiffusion of two liquids in which the crystals are insoluble.

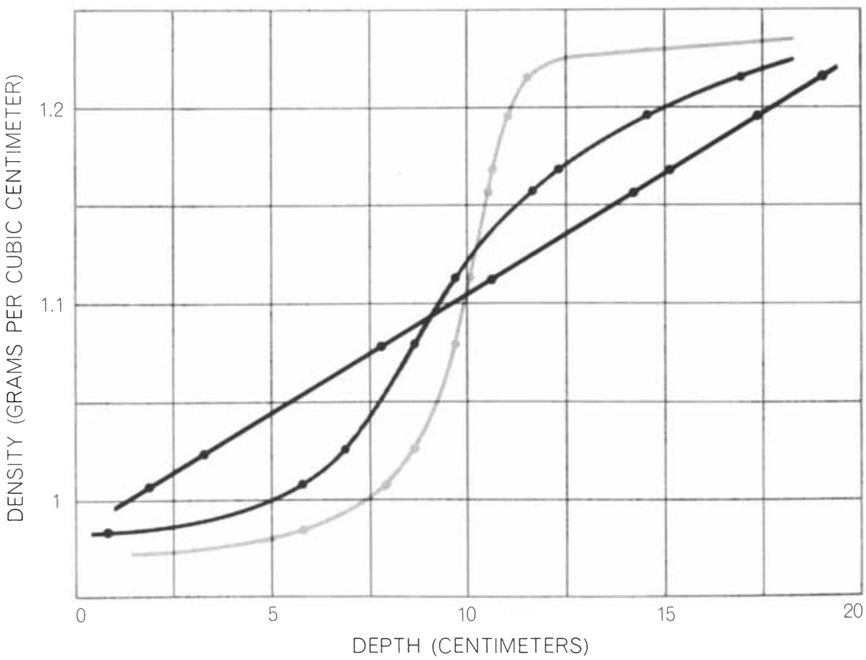
It is now common practice in all polyethylene-manufacturing plants to evaluate samples of the plastic by means of density-gradient columns [*see illustration on page 71*]. The density of a particular sample of polyethylene is directly proportional to its degree of crystallinity. The more linear the long-chain polyethylene molecules are (that is, the less branched they are), the better the chains can pack and hence the more crystalline the sample is. The crystallinity of the plastic in turn determines its gross mechanical properties, such as stiffness and tensile strength. Thus by merely observing where a sample of polyethylene comes to rest in a calibrated density-gradient column one can immediately determine its suitability for a particular end use.

Crystallization in plastics is a rather slow process; for example, if saran is melted and suddenly chilled to room temperature, it remains amorphous for some time. Apparently the alignment of the long-chain molecules proceeds quite slowly, owing to the high viscosity of the plastic and the length of the molecules. When a piece of amorphous saran is placed in a density-gradient column, it gradually sinks as crystallization proceeds; in this way one can conveniently follow the kinetics of crystallization. Another interesting trick is to place in a density-gradient column a piece of Mylar that has been freshly cut at one end with a pair of scissors. The cut end will tip down, presumably as a result of the greater crystallinity brought about by the shearing action of the scissors. In time, however, the sample will become level, thereby indicating the particular "relaxation" time associated with the sample.

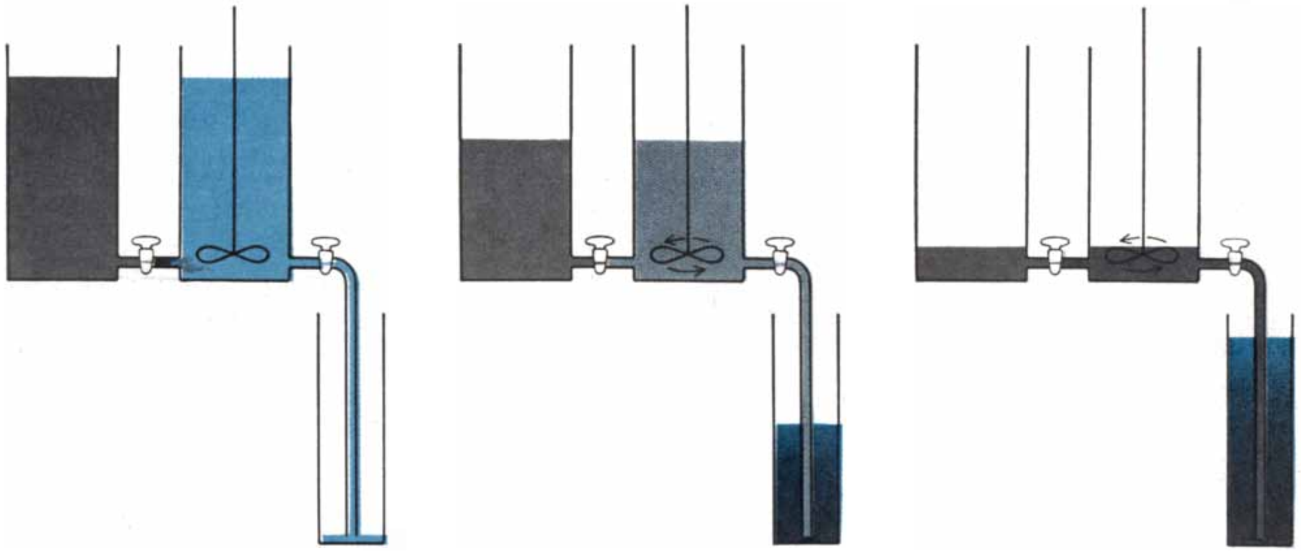
All chemical reactions in solution involve some alteration in the bonding of the reacting molecules and hence in the distribution of electrons in the sample. This in turn almost invariably means that the density of the sample is changed. A rather extreme case of density change occurs in the conversion of a vinyl monomer into a long-chain polymer: the transformation of the double bond of the monomer into the single bond of the polymer results in an increase in density of about 35 percent. Masahide Yamamoto and I recently succeeded in carrying out such a polymerization reaction in a density-gradient column. Acrylamide, a vinyl monomer, in the presence of riboflavin can be made to link into polymer by light; we illuminated a droplet of the monomer in the column and observed the rate of fall of the droplet and thus the rate of polymerization of the sample.

The late Danish investigator Kai U. Linderstrøm-Lang, who invented many ingenious experimental techniques in biochemistry, was the first to apply the density-gradient technique to the study of the process by which proteins are digested in the intestines. When a protein molecule is attacked by digestive enzymes, its chain (or chains) of amino acid subunits is split at certain points, yielding mostly single amino acids or combinations of two amino acids. These comparatively simple units are then ingested into the bloodstream. At one end of each unit is an amino group (NH_2); at the other is a carboxyl group (COOH). Both groups are electrically charged and are capable of causing a considerable increase in the density of water by breaking down its rather open molecular structure—a process known as electrostriction. Linderstrøm-Lang was able to follow the digestion of proteins by periodically placing droplets of protein mixed with digestive juice in a density-gradient column consisting of hexane and nitrobenzene. He found in the case of the milk protein lactoglobulin that the electrostriction was greater than it should have been if only the bonds linking the amino acid subunits in the protein chain had been split. Evidently before the splitting of the bonds some kind of unfolding of the protein chain occurs that also contributes to electrostriction.

Biochemists who work with the cells of living tissues generally use density gradients in conjunction with the centrifuge. When a cell membrane is broken, many cell components—nuclei,



EFFECT OF AGITATION on the formation of a linear density gradient in a column consisting of benzene and bromobenzene is depicted here. The three curves represent the original density distribution (*light gray*), the distribution after 25 strokes with the mixing loop (*dark gray*) and the distribution after 50 strokes and standing for 10 hours (*black*).

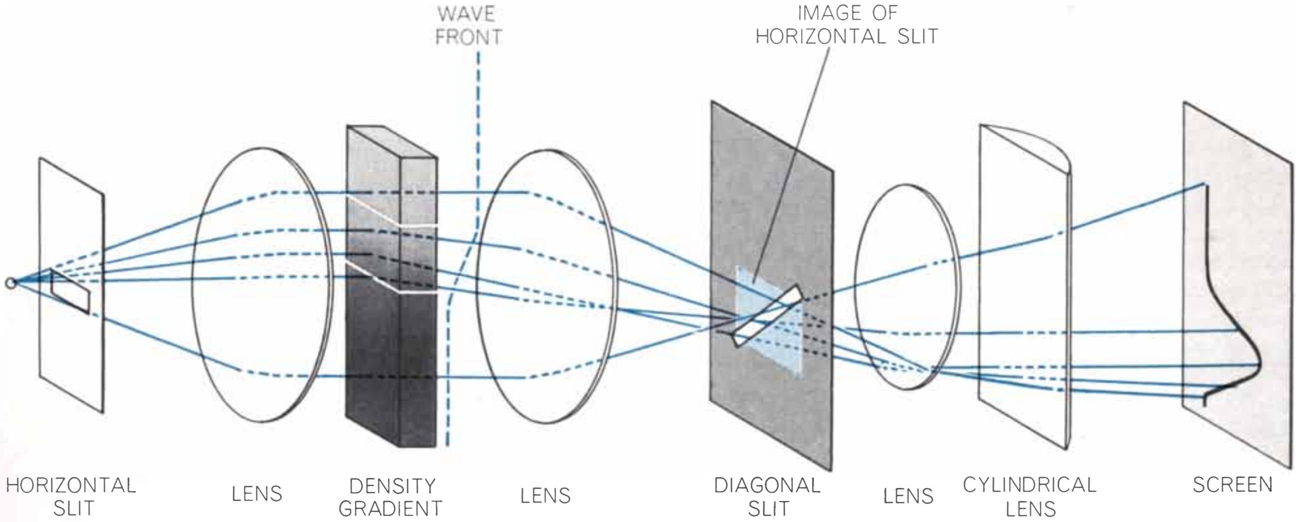


"INSTANT" DENSITY GRADIENT can be set up by the following method: The denser liquid (*gray*) is introduced into the bottom of a vessel containing the less dense liquid (*color*), where the two liquids are mixed by a propeller-like agitator. The resulting mixture flows out of the second vessel through a tube that leads to the bottom of the density-gradient column. If the rate at which the denser liquid flows from the first to the second vessel is exactly half the rate at which the mixture flows out of the second vessel, a linear gradient will be formed in the column, with the denser liquid at the bottom and the less dense liquid at the top.

mitochondria and so on—are released more or less intact. Such particles are too small to settle in a reasonable time in an ordinary gravitational density gradient. Their separation can be accelerated, however, by installing the gradient in a centrifuge. One instrument developed specifically for this purpose by Norman G. Anderson of the Oak Ridge National Laboratory allows the continuous separation of subcellular particles while the machine is operating; the method is particularly suited for collecting viruses and other particles needed in large quantities for research [*see top illustration on page 76*].

The idea of employing a density gradient inside the cell of an ultracentrifuge (a very-high-speed centrifuge) was conceived about 10 years ago by Matthew M. Meselson, Franklin W. Stahl and Jerome R. Vinograd, who were then working at the California Institute of Technology. They dissolved deoxyribonucleic acid (DNA) in a water solution of the salt cesium chloride and proceeded to subject the mixture to centrifugation. At high speeds of rotation the cesium chloride solution forms a density gradient, with the concentration of the salt (and therefore the density of the solution) highest at the outer end of the centrifuge cell. As the centrifugation proceeds the DNA molecules move outward in the cell until they come to rest at a point where their density is exactly matched by the density of the cesium chloride solution. To achieve this condition of equilibrium a rather long period of centrifugation is required, but the process can be considerably accelerated by using a very short centrifuge cell.

This technique was utilized by Meselson and Stahl to perform an ex-

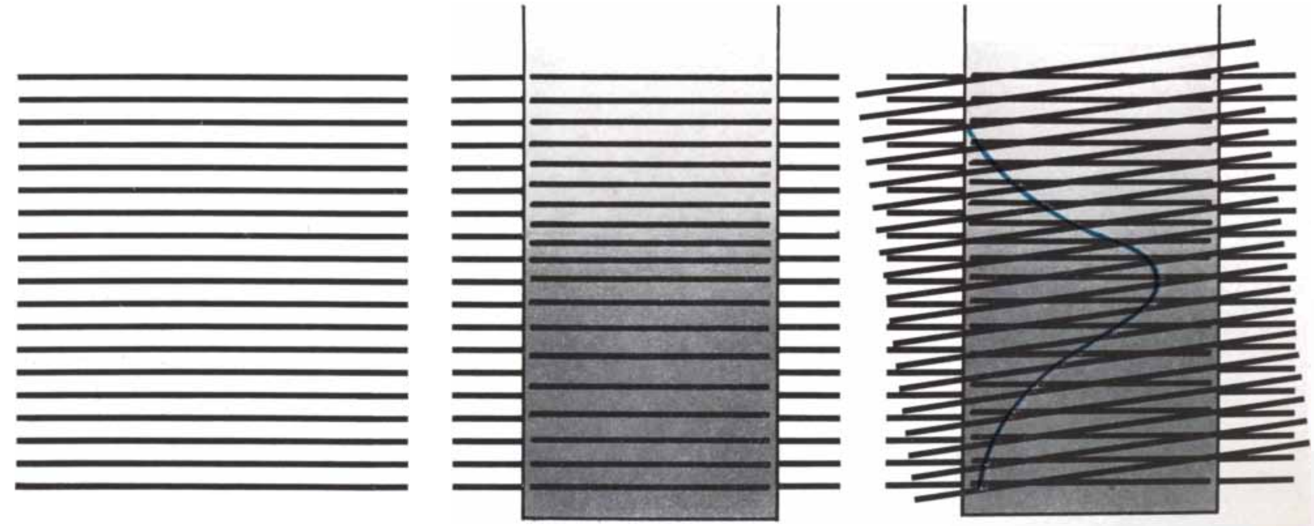


"SCHLIEREN" TECHNIQUE can be used to calibrate a density-gradient column by determining the variation in the refractive index of the liquid in the column. This method takes advantage of the fact that light is refracted, or bent, at a larger angle when it passes through a denser medium than when it passes through a less dense medium. The essential optical parts of the system are shown.

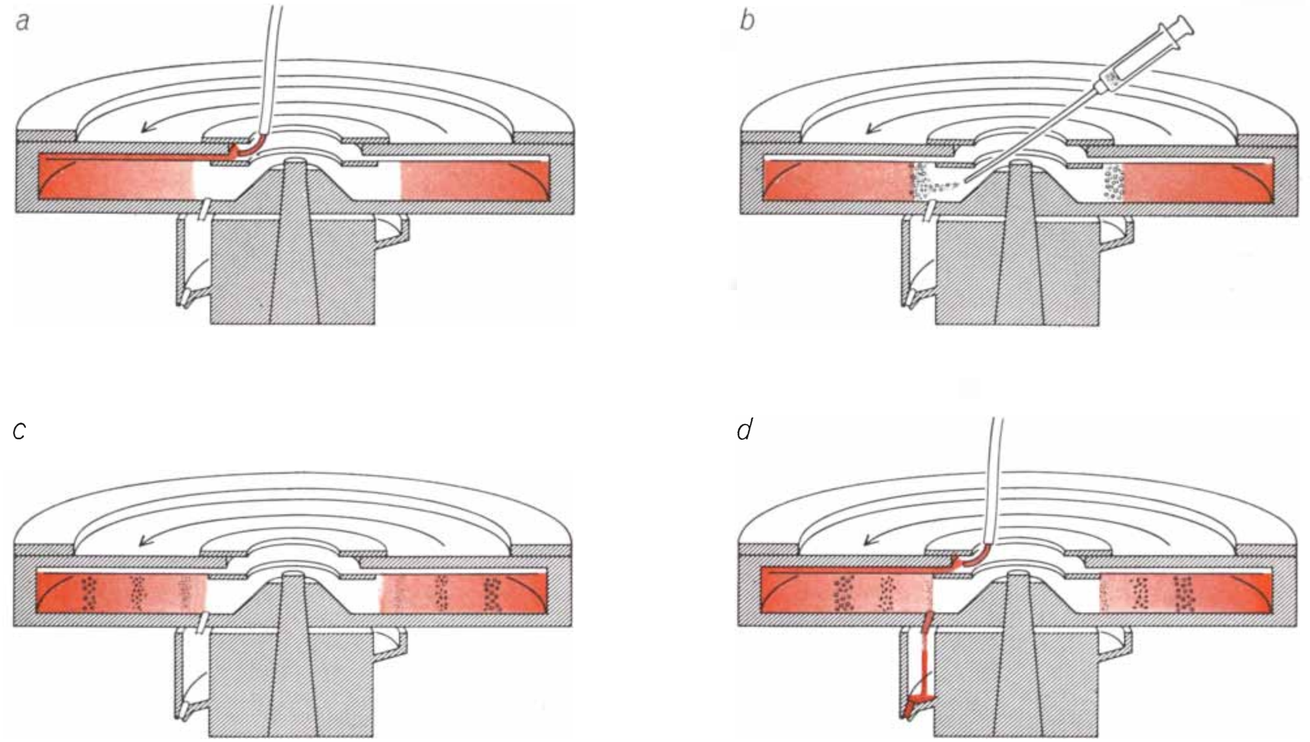
ANOTHER METHOD by which a linear density gradient can be set up almost instantaneously is to introduce the two liquids simultaneously into the column at controlled rates of flow. The flow of the less dense liquid begins at a maximum and decreases to a minimum, whereas the flow of the denser liquid begins at a minimum and increases to a maximum. The total flow at any time remains constant. One way to control the flow of the two liquids is to use syringes whose pistons are operated by helical cams of variable pitch. Vessels containing the liquids can also be suspended on a pulley that raises one at the same rate at which it lowers the other.

periment of great importance to biology. They set out to test the hypothesis, put forward by James D. Watson and F. H. C. Crick in 1953, that the molecule of DNA is a double-strand helix that replicates itself by becoming untwisted and providing two separate templates for the formation of two new complementary strands. Meselson and Stahl began by growing bacteria in a medium containing the heavy isotope of nitrogen (N-15); the heavy nitrogen was incorporated into the bacteria's DNA. The heavy-nitrogen bacteria were then placed in a medium containing the lighter common isotope of nitrogen (N-14). Shortly thereafter samples of DNA were extracted from the growing bacterial population and placed in the density-gradient ultracentrifuge. Three types of DNA were separated in the centrifuge cell: (1) molecules containing only N-14, (2) molecules containing only N-15 and (3) molecules containing both N-14 and N-15. The isotopes in the last category were equally divided, suggesting that the replication of DNA in the bacteria involves two continuous molecular units. Meselson and Stahl also found that when the hybrid DNA was heated, it split into two pure samples respectively containing only N-14 and only N-15, thus demonstrating the presence of two separable units of the original genetic material. These results provided strong support for the Watson-Crick hypothesis.

Much further work has been done on DNA with the density-gradient ultracentrifuge. For example, the technique has demonstrated that the density of a DNA molecule varies with the proportion of its subunit "bases" (specifically with the ratio of, on the one hand, the paired bases adenine and thymine and,



MOIRÉ TECHNIQUE also measures the density of the liquid in the column by determining the variation in refractive index. The distortion in the image of a regular grating seen through the liquid is magnified by viewing it through a slightly rotated, identical grating. The resulting moiré pattern (*right*) contains a curve (*color*) that indicates directly the variation of refractive index with density.

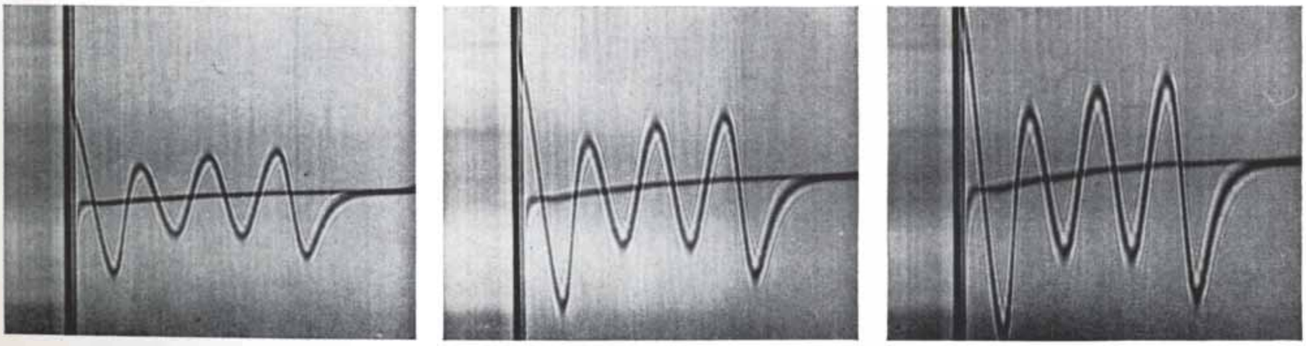


DENSITY-GRADIENT ULTRACENTRIFUGE developed by Norman G. Anderson of the Oak Ridge National Laboratory allows continuous separation of subcellular particles while the machine is operating. The gradient liquid flows into the spinning rotor from the center through small tubes to the rotor's outer edge, where it builds up a density gradient with the densest liquid outermost (*a*). The cell fragments are then injected into the inner, least dense edge of the gradient (*b*). After more spinning the particles are separated (*c*) and then removed by introducing a dense solution to outer edge of rotor, pushing gradient out of an inner drain tube (*d*).

on the other, the paired bases guanine and cytosine). This observation has been particularly interesting to workers engaged in deciphering the genetic code. Chemists who work with synthetic long-chain polymers have also found a use for the density-gradient ultracentrifuge: it is now possible to separate polymers that differ in chemical composition, degree of branching or general three-dimensional geometry.

The stabilizing action of a density-gradient column can be used to great advantage in the separation of substances by the technique of electrophoresis. In the conventional electrophoresis apparatus a mixture of substances in solution—proteins, say—is placed in a tube and subjected to the influence of an electric field. If the molecules of one of the substances have a characteristic charge, they will migrate through the tube at a characteristic rate and form a band that is separate from the rest of the mixture. The leading edge of the band is denser than the liquid behind it, which gives rise to some ambiguity in observation. If the entire process is carried out in a preformed density gradient of sugar and water, however, the band is much sharper. The Swedish investigator Harry Svensson has shown that density-gradient electrophoresis yields much finer resolution of the proteins in blood serum than had ever been thought possible. Work along these lines could lead to the discovery of new blood proteins and, it is hoped, to a more precise diagnosis and analysis of certain diseases.

In an age of increasingly complicated instrumentation it is refreshing to know that such a simple concept as the density gradient continues to find new uses in so many fields of investigation.

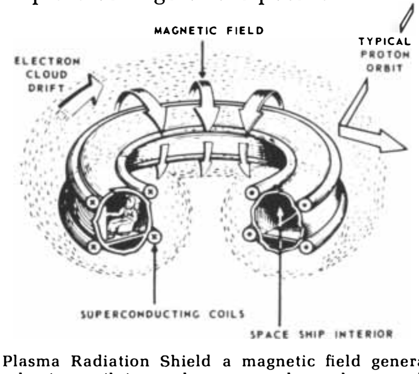


SCHLIEREN PHOTOGRAPHS of a density gradient consisting of four copolymers of styrene and iodostyrene were made by J. J. Hermans and H. A. Ende of the Chemstrand Research Center in Durham, N.C. The gradient was produced in an ultracentrifuge; the dark vertical line at the left in each photograph is the meniscus, or surface, of the liquid. The four cycles in the curve indicate the variation in refractive index for each of the copolymers, which differ in their percentage of iodine and hence in their density.

RESEARCH REPORT

Plasma Radiation Shielding for Astronauts

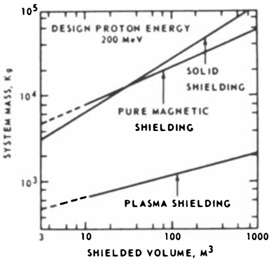
The environment in deep space is never more hostile than after a large flare erupts on the surface of the sun. For the next day or two the solar system is filled with penetrating radiation in the form of very energetic protons (30-1000 MeV). On earth we are shielded from this hazard by our magnetic field and by our atmosphere. In space some substitute shield has to be found. Magnetic or solid shielding could be used, but very large weights are involved. The only other approach that has been advanced involves charging the space vehicle to a large positive electrostatic potential (typically 200-million volts) relative to space. This scheme suffers from the defect that the vehicle would attract electrons from the surrounding space at an entirely unacceptable rate. It would require thousands of megawatts to prevent the rapid discharge of the potential.



In the Plasma Radiation Shield a magnetic field generated by a superconducting coil is used to suspend an electron cloud near a spacecraft charged to a high voltage. Protons from the sun enter the electron cloud but slow down as they reach regions of higher potential and are repelled.

1. Levy, R. H. and Janes, G. S., Avco-Everett Research Laboratory Research Report 192 (Sept. 1964); also, AIAA J. 2, 1835-38 (Oct. 1964).
2. Janes, G. S., Avco-Everett Research Laboratory AMP 165 (June 1965).

A new approach to electrostatic shielding called "Plasma Radiation Shielding," has been put forward[1] and is being studied under NASA sponsorship. The heart of this idea is the use of the magnetic field of a superconducting coil to suspend a cloud of electrons in the vicinity of the space vehicle. The cloud acts as the negative terminal of a capacitor while the space vehicle itself is the positive terminal. The electrons find themselves in crossed electric and magnetic fields and, as in the Philips' ionization gauge or the microwave magnetron, drift in a direction perpendicular to both the electric and magnetic fields. The electron trajectories do not intersect a wall and consequently a high charge can be maintained. Protons from the sun would penetrate the electron cloud, slowing down as they reached regions of higher potential. If their kinetic energy is less than the voltage of the space vehicle, they never reach the vehicle. With the spacecraft charged to a high enough potential, the number of protons which reach the vehicle is tolerable. Since only a moderate magnetic field is required to control the electron cloud, it is estimated that a Plasma Radiation Shield would be 20 times lighter than the more conventional shields.



Comparative weights for different shielding systems.

As in other devices for containing charged particles, stability may be a serious problem. Thus far, electron containment and injection experiments[2] at low voltage (~10KV) have been successful and in agreement with theoretical predictions. We have been unable to identify any insuperable problems standing in the way of achievement of the required high voltages.

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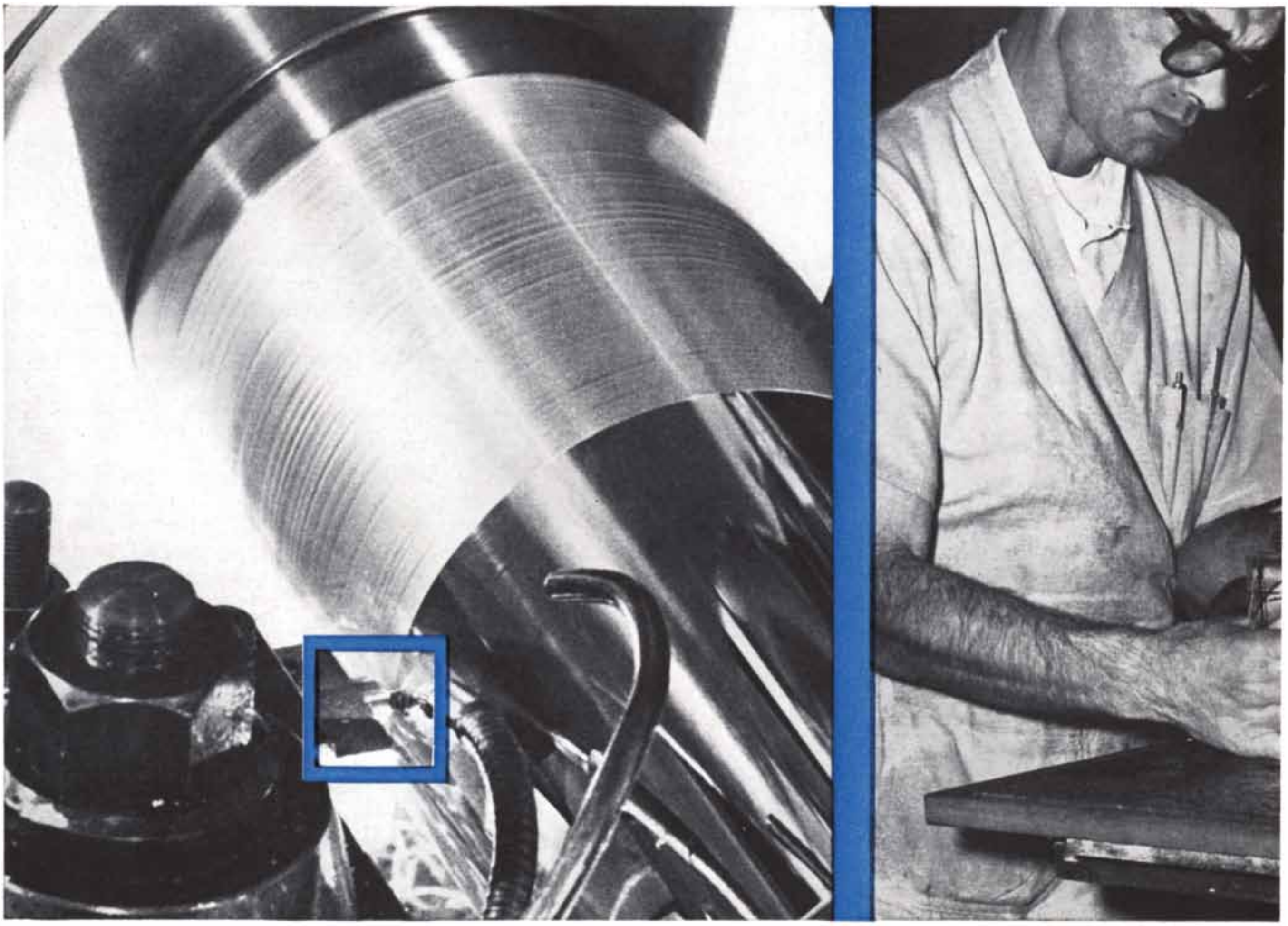

FINISHING ELECTROSTATIC DRUM

Natural-diamond tool produces mirror finish on aluminum office copier drums at Xerox Corporation, Rochester, N. Y. Tolerances on final finish are held to four microinches rms (root mean square). Such close tolerances are necessary to allow absolute uniformity in the deposition of the selenium coating used in the company's copying machines.

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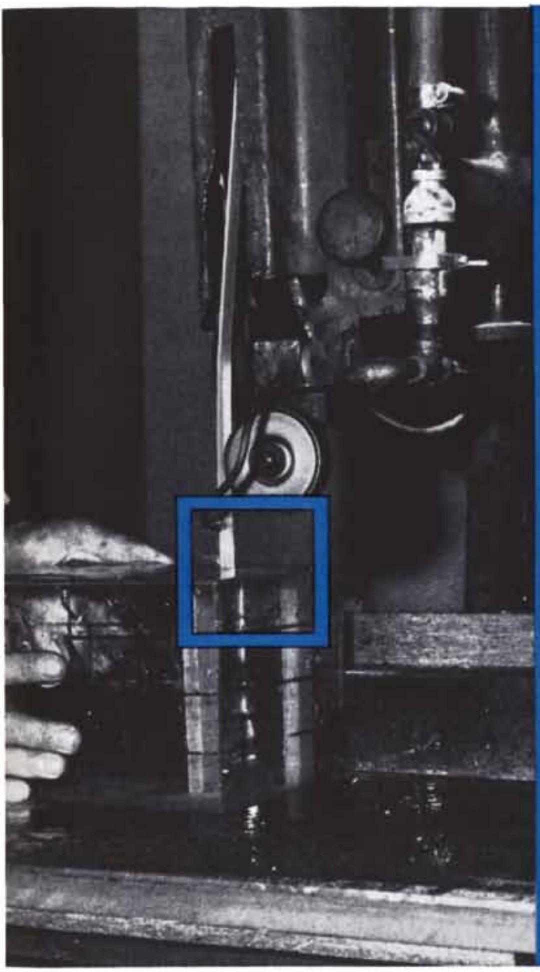
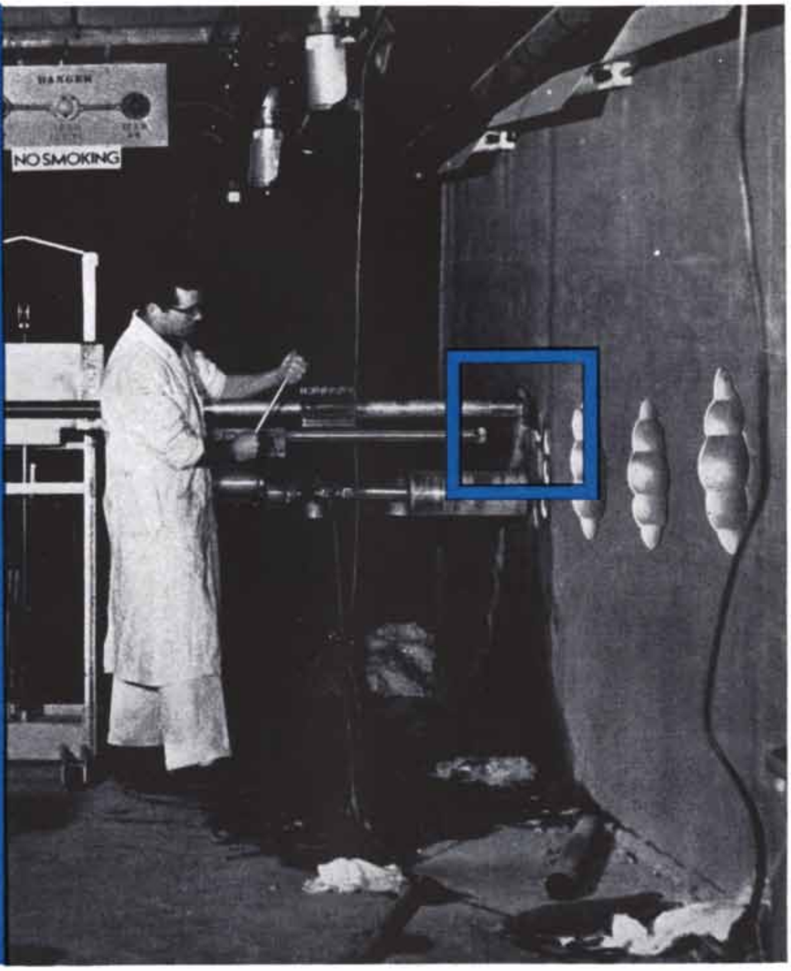


CUTTING BARIUM GLASS

Solid block of hard barium-content glass is cut into 1½-inch-thick sections with diamond-edged bandsaw blades. Unusual sawing job, performed at Dia-Chrome Company, Glendale, Calif., was the only practical method of obtaining usable blanks. A blade speed of 1000 s.f.m. was employed.



ADAPTING A CYCLOTRON

The cyclotron at Washington University required holes cut into the walls to permit installation of storage tubes for radioactive material. A cluttered ceiling and a sloping floor called for horizontal bracing of the Truco Model "B" portable drilling machine. Diamond drills reduced job time by 90% over similar drilling job performed with jackhammers.

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The Swimming Energetics of Salmon

These fish perform a mighty metabolic feat when they swim hundreds of miles upstream without food to spawn. Experiments in the field and in the laboratory help to clarify how the feat is accomplished

by J. R. Brett

Man has far surpassed the flight of birds in the air, but he has yet to match the hydrodynamic feats of a fish in the water. The swimming of fishes and whales shows an efficiency of propulsion, in terms of the energy expended, that is much beyond anything human designers have been able to create. Indeed, the efficiency of the aquatic vertebrates is so remarkable that it has been called "Gray's paradox," after the British zoologist who has stimulated an intensive study of it [see "How Fishes Swim," by Sir James Gray; SCIENTIFIC AMERICAN, August, 1957].

MIGRATION of sockeye salmon up the Fraser River from the Pacific to the spawning stream above Stuart Lake covers some 700 miles. It is one of the longer migrations.

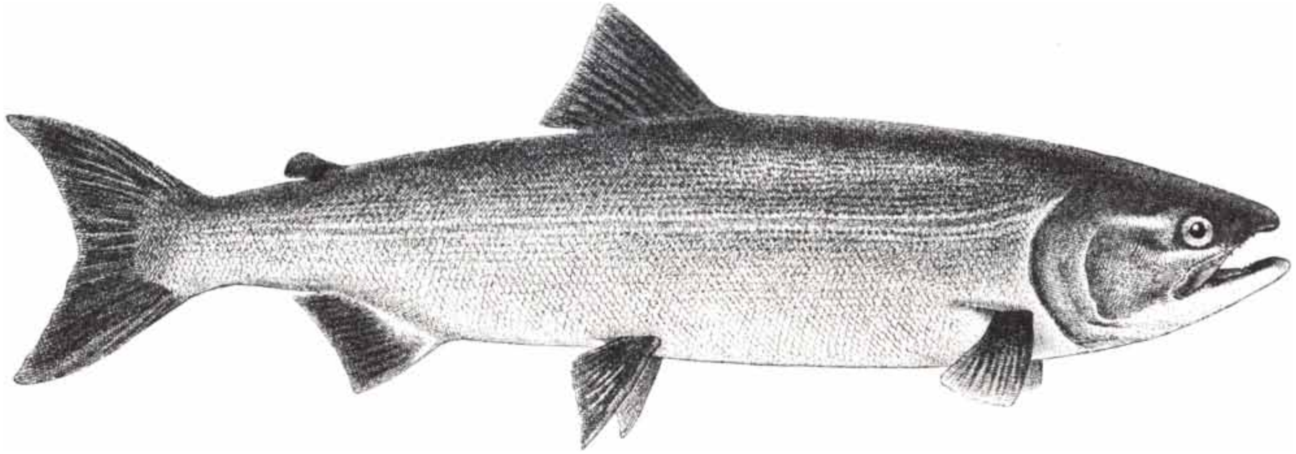
Among the most spectacular fish performances are those of the homing salmon of the Pacific Ocean. These renowned swimmers are born in the headwaters of rivers flowing into the Pacific, migrate down to the ocean to spend the major portion of their lives and eventually swim back to their birthplace to spawn. They frequently make their way upriver on journeys of 500 to 1,000 miles, against strong currents, over rapids and waterfalls and past artificial obstacles, such as dams and locks, that man has erected in these rivers. Except when they are blocked by a difficult passage the salmon swim steadily day and night without rest and without food. With their magnificent sense for hydrodynamic advantage, they complete the journey by the thousands with dramatic success.

Part of the story of how the salmon accomplish this can now be told. Because industrial development along the rivers threatens extermination of the salmon, a food resource that man cannot afford to sacrifice, systematic studies have been undertaken to determine what conditions are necessary to ensure the animal's survival. Exactly how much energy does the migrating salmon expend? What is the metabolic basis of its extraordinary performance and endurance? How is its ability to complete its marathon affected by temperature, its size and other factors? How fast can it swim? What is the secret of its hydrodynamic efficiency? Some of these questions, incidentally, are exactly those a naval architect must consider in designing a ship: the cruising range, the top speed, the most economical speed, maintenance problems, the nature of the waters to be traversed and so on.

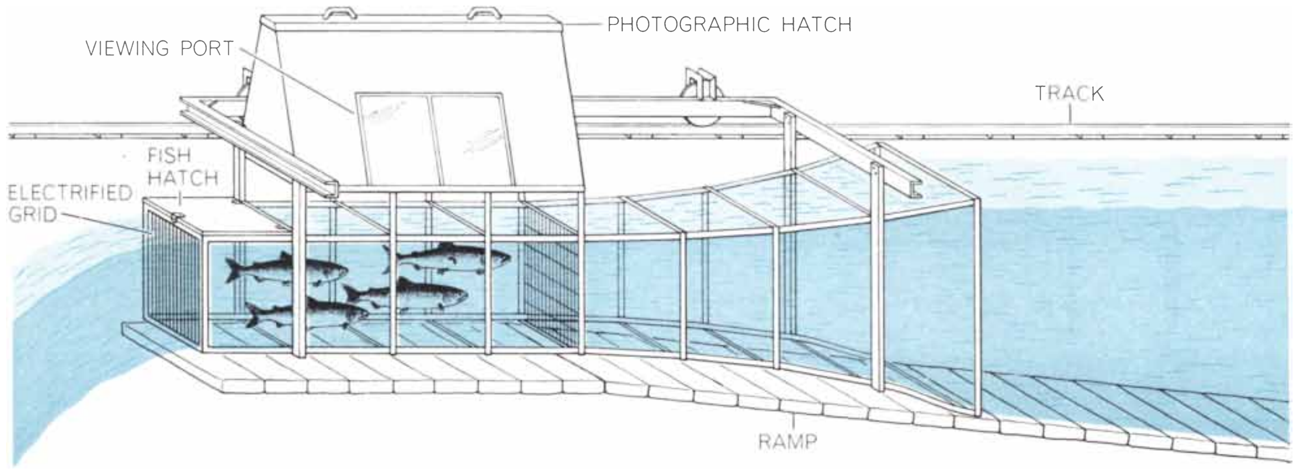
In pursuit of answers to the questions about the salmon my colleagues and I made field studies of the fish in rivers and also measurements of its performance under strictly controlled conditions in the laboratory. The laboratory experiments were conducted at the Biological Station of the Fisheries Research Board of Canada at Nanaimo in British Columbia. For the experiments we developed two special kinds of apparatus. One is a respirometer: a water tunnel in which the fish's consumption of oxygen, indicating its rate of metabolism, can be measured while it is forced to swim at a given speed and at a given temperature of the water [*see top illustration on pages 82 and 83*]. The swimming speed is controlled by the water flow through the tube, against which the fish has to swim upstream; if it fails to match the velocity of the flow, it is forced back against a charged screen and receives a slight electric shock. The salmon quickly learned to avoid the shock and would swim at the enforced speed until they were exhausted. Measurements of a fish's rate of consumption of oxygen during a test can be obtained at intervals by shutting off new water temporarily and recirculating the enclosed water so that the depletion of its oxygen can be ascertained.

The second apparatus is an exercise cage, placed in a funnel-shaped structure, in which the fish can be made to swim at speeds up to 5.4 feet per second, or 3.7 miles per hour [*see lower illustration on opposite page*]. This device was employed mainly to observe the effects on the fish of sustained swimming for long periods under various conditions.

The experiments gave two independent measurements of the energy expended by salmon in swimming. One



ADULT MALE SOCKEYE is portrayed as it looks at about the time it begins its upriver migration. Such a fish may be about two feet long and weigh about five pounds. In its almost ceaseless effort to migrate from the ocean to its birthplace to spawn an adult bound for Stuart Lake progresses upstream at an average rate of about 1.33 miles per hour; its sustained speed must be about 2.65 m.p.h. because of the current. Sockeye salmon were the principal subjects of experiments conducted by author and his colleagues.

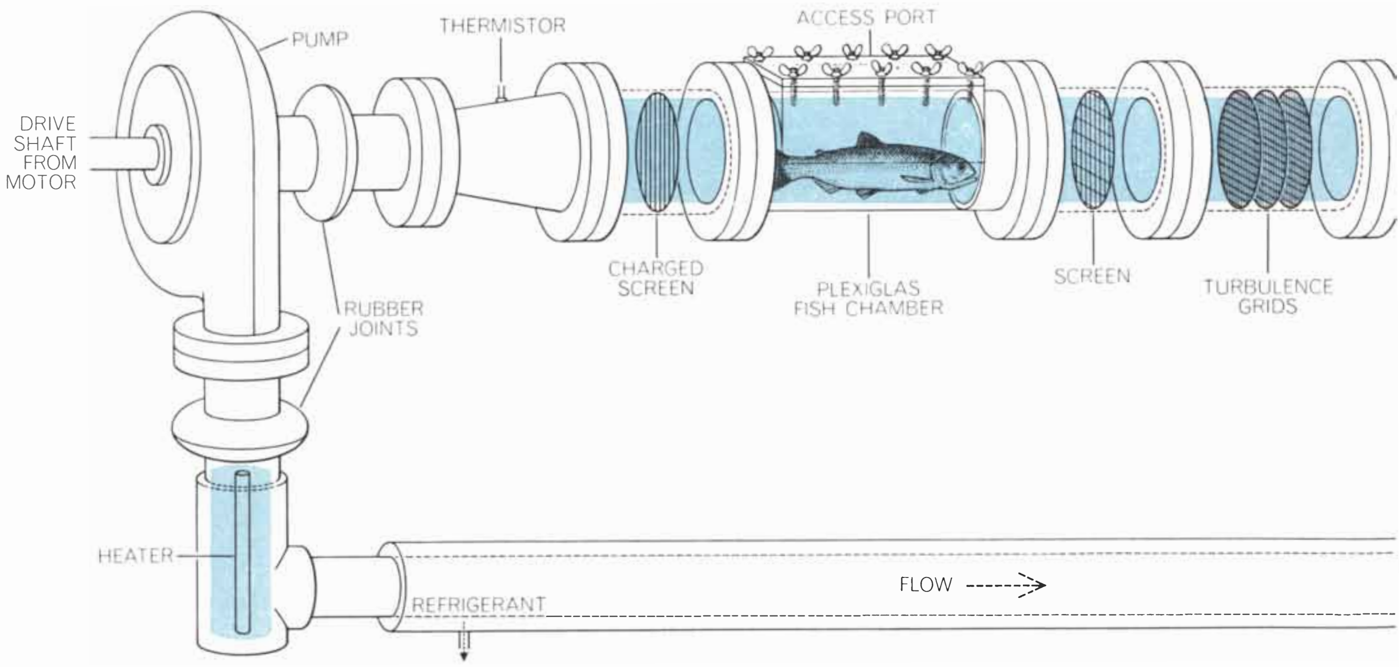


EXERCISE CAGE was devised by the author and his colleagues to observe the effect of long periods of swimming, comparable to the upriver migration for spawning. The fish's effective speed is determined by the velocity of the water, which can be controlled by moving the entire apparatus forward or backward on the ramp. As depicted here the cage is in the position for maximum velocity. Salmon are induced to swim by the electrically charged screen behind them; they receive a mild shock if they touch it.

measure was oxygen consumption, showing the rate at which the fish generated energy through its metabolism. The other measure was the fish's consumption of stored body fuels; this was determined by measuring the depletion of its body fat and protein at the end of a prolonged period of swimming during which it ate no food. The program of studies was designed to obtain quantitative information in four specific areas: (1) how the salmon's metabolic rate varies with its swimming speed, its size and the water temperature; (2) how much stored energy, in the form of fat and protein, a fish burns up in a long session of swimming at a given speed and temperature; (3) what speeds can be sustained by young and adult salmon over a long period, and (4) the total amount of energy, in terms of depletion of body fuels, that is actually expended by salmon of various sizes in their long homing journey up a river, the object in this case being to learn also how the river's characteristics influence the energy requirement. In addition to these four points, our program sought to learn something about the hydrodynamic properties that make the salmon's swimming feats possible.

To investigate the first point, we began by testing young sockeye salmon of a certain size (about 20 centimeters, or eight inches) in the respirometer. The fish were not fed for 36 hours beforehand so that none of their energy would be spent in digesting or absorbing food. At rest and in an unexcited state the young salmon had a certain basal metabolic rate. When the fish was forced to swim in the respirometer, the metabolic rate rose; with further increase in the swimming speed the metabolic rate mounted like a compound-interest curve, each gain in speed calling for a greater proportional increase in output of energy [*see illustration at left at bottom of next page*]. Ultimately the curve peaked where the fish reached its maximum rate of oxygen consumption. This peak, called the active metabolic rate, represents the top speed the fish can sustain. It can swim faster by going into oxygen debt, but any such higher speed is limited to short bursts. The experiments showed that at low swimming speeds an excited or overactive fish uses more oxygen than a fish not under stress, but at high speeds the energy output of the excited fish is about the same as that of the unexcited one.

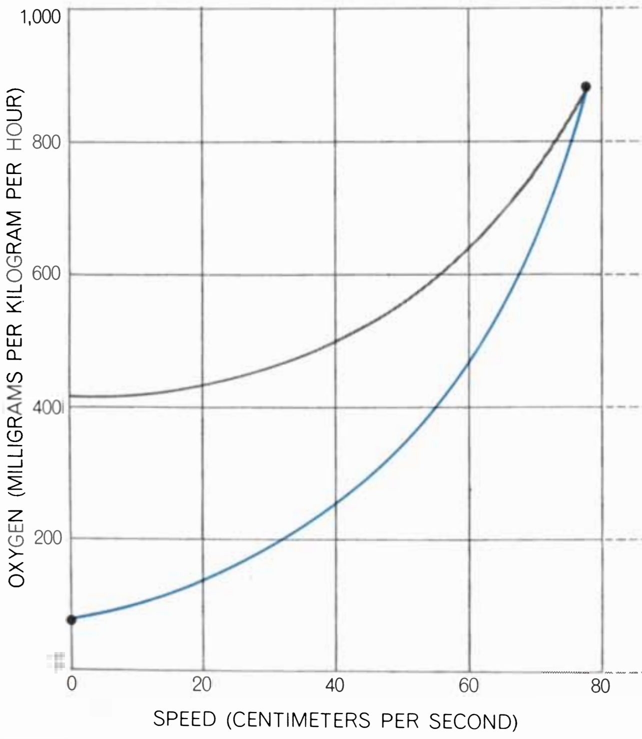
In these first tests the temperature of



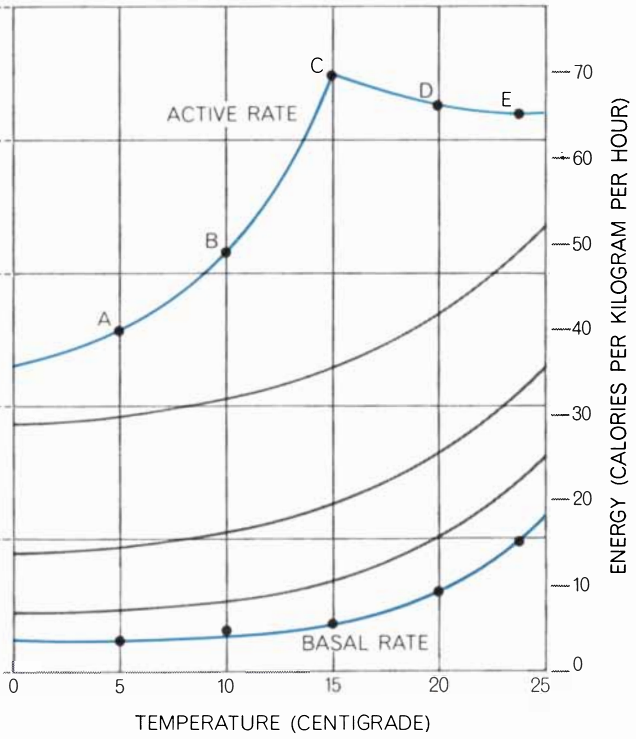
RESPIROMETER APPARATUS is used to determine the metabolic rate of a salmon by measuring its oxygen consumption. The amount of energy required by the fish depends on the velocity of the water through the fish chamber. Water temperature, which

the water was set at 15 degrees centigrade (59 degrees Fahrenheit), which is about the average summer temperature of many of the rivers the salmon ascend. To what extent is the fish's expenditure of energy affected by temperature? Clearly there must be an effect. Rising temperature causes the chemical machinery of a cold-blooded vertebrate to turn faster, either at rest or under a work load. Moreover, a fish is compelled to put forth more effort to obtain oxygen at elevated temperatures, because water then holds less dissolved oxygen. To obtain enough oxygen the fish must flush more water through its gills, just as a mountain climber must breathe harder to obtain sufficient oxygen from the rarefied air at high altitudes.

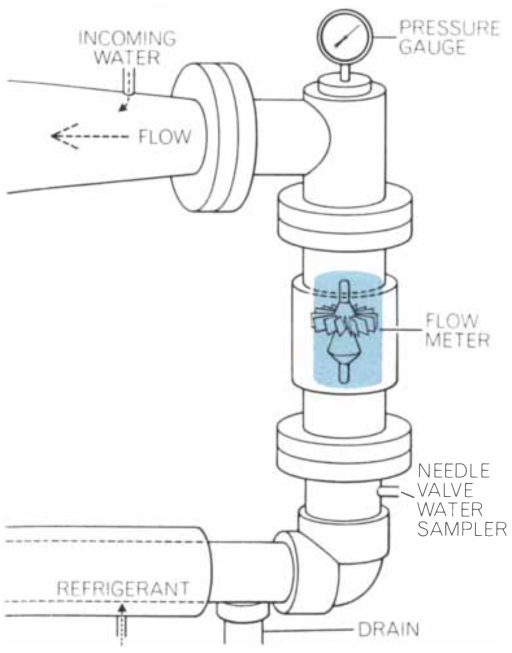
Our young sockeye salmon were sub-



SPEED of fish affects metabolic rate. Curves represent yearling salmon in normal (*color*) and excited (*gray*) conditions. Lower dot shows basal metabolism of resting salmon; upper dot, maximum rate.



TEMPERATURE of water affects metabolism. Curves represent conditions from rest (*bottom*) to top sustained speeds (*A–E*). Peak performance at upper temperatures is limited by oxygen availability.



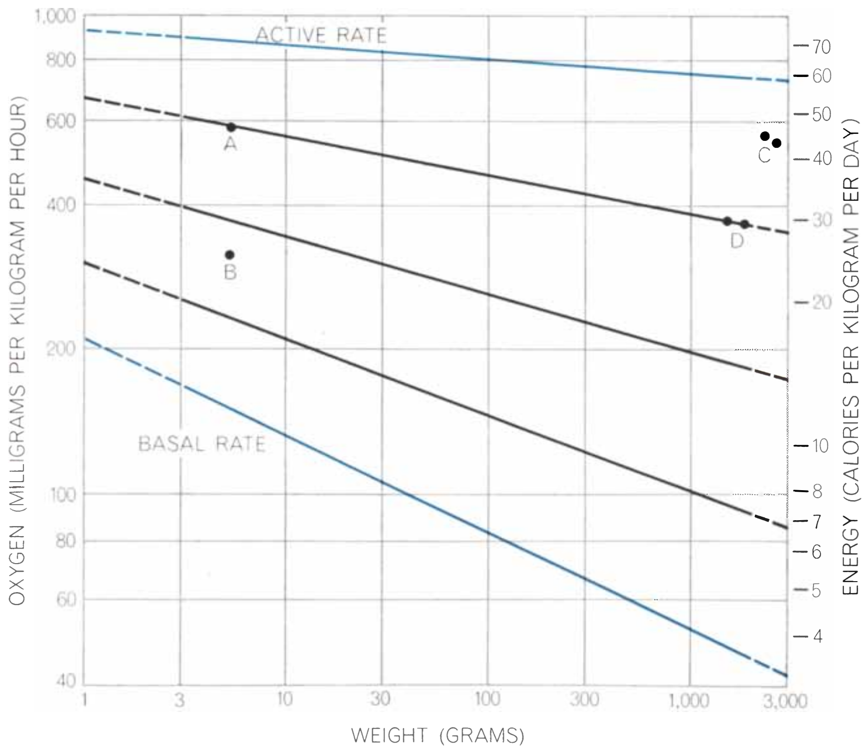
affects metabolism, can be controlled. Part of apparatus appears on cover of this issue.

jected in the respirometer to various temperatures from near zero degrees C. to 24 degrees (75 degrees F.), the highest the salmon can tolerate. Their basal metabolic rate was six times higher at 24 degrees C. than at five degrees. To put it another way, at 24 degrees a young salmon at rest burned as much oxygen as it did while swimming at about a mile an hour at five degrees. The effort required for swimming at the salmon's top sustained speed was a great deal higher at 15 degrees than at five degrees [*see illustration at right at bottom of opposite page*]. It is apparent on the basis of temperature alone that the salmon's migration from the ocean up comparatively warm rivers must be a costly business.

When one considers the combined effect of temperature and the speed required to swim up these rivers, the salmon's accomplishment becomes impressive indeed. The young salmon proved to be capable of increasing their energy output more than twentyfold in attaining their top sustained speed at optimum temperatures. This performance is comparable to that of some mammals; it had not been realized that a fish is capable of such metabolic increase. The salmon can truly be placed in a class with the racehorse.

In order to determine the relation of the metabolic cost to the size of the salmon, sockeye salmon of a wide range of sizes, from five-gram smolts to 1,500-gram (three-pound) adults, were tested in the respirometer with the temperature held constant at 15 degrees C. These measurements showed that with increasing size the salmon's metabolic rate slows down. This comparative metabolic economy becomes less and less, however, as the fish swims at higher speeds; at the top sustained speed the metabolic rate of the adult salmon is almost as high (per unit of weight) as that of the tiny smolt.

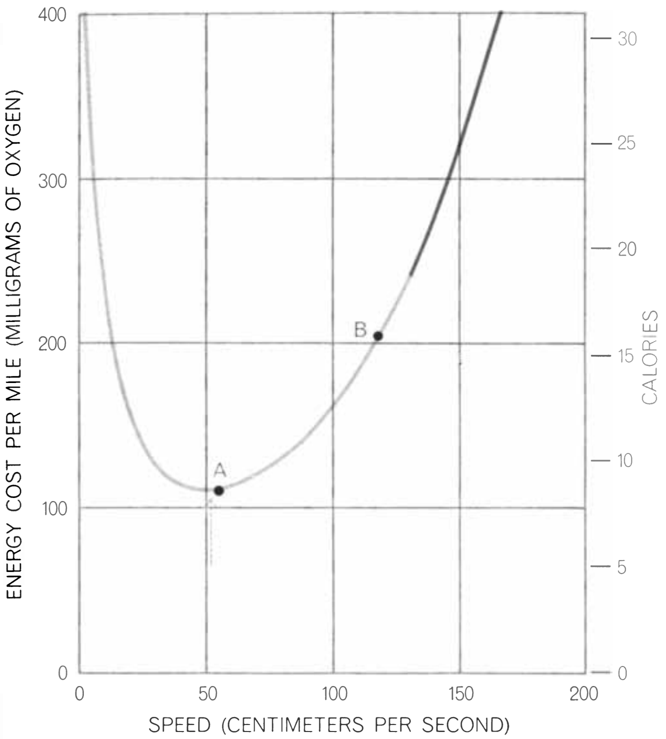
To relate the laboratory findings to the performance of salmon of various sizes in their actual upriver migrations it was necessary to determine how the top sustained speed varies with size. This matter was examined by means of endurance tests in the laboratory, the small fish being tested in the respirometer and the larger ones in the exercise cage, where they had more room for swimming. A large fish can of course swim faster than a small one. The tests showed, however, that the performance does not increase in proportion to the increase in size [*see illustration at left below*]. An eight-inch sockeye salmon, for example, can maintain a speed of 4.1 times its length per second, but a 24-inch salmon has a maximum sustained speed of only 2.5 times its length per second. The adult fish's relative performance is not as good as that of the smaller fish, although its absolute speed is considerably higher.



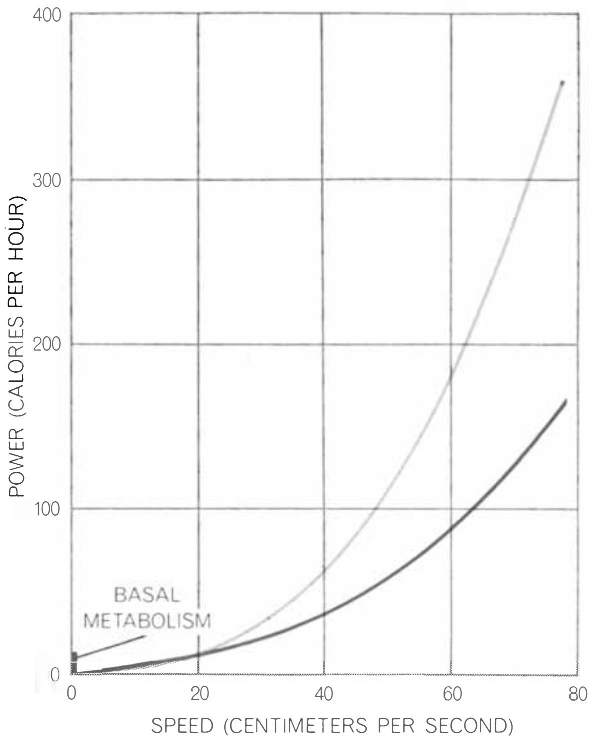
FISH WEIGHT is related to metabolic rates. Bottom curve represents resting fish; top, peak sustained speed; gray, intermediate speeds (all at 15 degrees C.). *A* and *B* represent yearlings migrating downstream; *C*, adults migrating upstream; *D*, adults in exercise cage.

What is a salmon's total energy expenditure in its journey from the ocean upriver to its spawning ground? For an accurate answer to this question the most reasonable direct approach was to measure the fish's consumption of its store of body fuels. Two methods of measurement were pursued, one in the laboratory, the other in the field.

For the laboratory study adult sockeye salmon beginning their upriver migration were trapped in the river and taken to our laboratory. They were divided into an experimental group, which was to be put through a long swim in the exercise cage, and a control group, which was killed and quick-frozen immediately so that its content of stored fuel (fat and protein) could later be compared with that of the salmon depleted by swimming. The living salmon were made to swim in the cage at 1.83 miles per hour for 12.7 days, the equivalent of covering a distance of 560 miles. At the end of this "journey" their remaining content of fat and protein was measured; the difference between this and the original amount, as indicated by the control group, gave a measure of the metabolic price the swimmers had paid for their swim. How much energy did this consumption of fuel represent? Calculations were made on the basis of the known en-



ENERGY-EFFICIENCY CURVE for salmon shows ratio between energy expended and speed attained. Arrow indicates optimum efficiency, nearly achieved *(A)* by ocean migrant; river migrant is indicated at *B*. Dark color shows burst speeds, producing oxygen debt.



POWER REQUIREMENT to overcome frictional drag of dead fish *(light curve)* is compared with that of a swimming fish. Basal metabolism is deducted in latter case because test concerns propulsion energy. This chart uses gram calories; others, kilogram calories.

ergy yields from oxidation of fats and proteins by mammals. Although differences occur in the fish's metabolic products, the use of these assumptions proved to be valid when the results were compared with the rates of energy expenditure by salmon in the respirometer.

The field data on the same question came from intensive studies of the migration of sockeye salmon up the Fraser River in British Columbia, made by the Fisheries Research Board of Canada and the International Pacific Salmon Fisheries Commission. In 1959 D. R. Idler and W. A. Clemens followed a "wave" of sockeye salmon that journeyed up the river to Stuart Lake, about 640 miles from the ocean. These fish, most of them four years old, make the 640-mile trip in approximately 20 days. Their average rate of progress for the total journey therefore amounts to 1.33 miles per hour. To achieve that upriver movement they obviously must swim a great deal faster than 1.33 m.p.h. By conservative estimates the mean velocity of the Fraser River is about three miles an hour. If the salmon breasted this river velocity, to cover the 640 miles to Stuart Lake in 20 days they would have to swim at an average speed of 4.4 m.p.h.! A sustained speed of that order is impossible for the salmon. It must seek out paths in the turbulent river where the downstream flow offers less resistance. Considering the devious route the salmon must follow, there is no way to estimate its true speed or swimming effort from the physical statistics of its journey. The biological data collected by Idler and Clemens, however, make it possible to do so.

By the end of its journey, after it has laid its eggs in a stream above Stuart Lake, the female sockeye salmon has consumed 96 percent of its body fat and 53 percent of its protein reserves. Part of the female's energy has been spent in development of its large ovary. Idler and Clemens were able to establish, however, that the average daily output of energy by male and female salmon in swimming up the Fraser was 43 calories per kilogram of body weight. When we plot this output on the chart showing the results of tests of a full-grown salmon's capabilities, it becomes apparent that the Fraser River migrants were spending energy at nearly 80 percent of the maximum rate they could maintain, leaving little margin for any emergency demands on them. Their rate of energy expenditure corresponds to swimming at an average speed of 2.65 m.p.h. Since swimming straight against the current in the Fraser would call for a speed of 4.4 m.p.h., this means that by skillful maneuvering the salmon reduced the requirement by about 1.7 m.p.h.

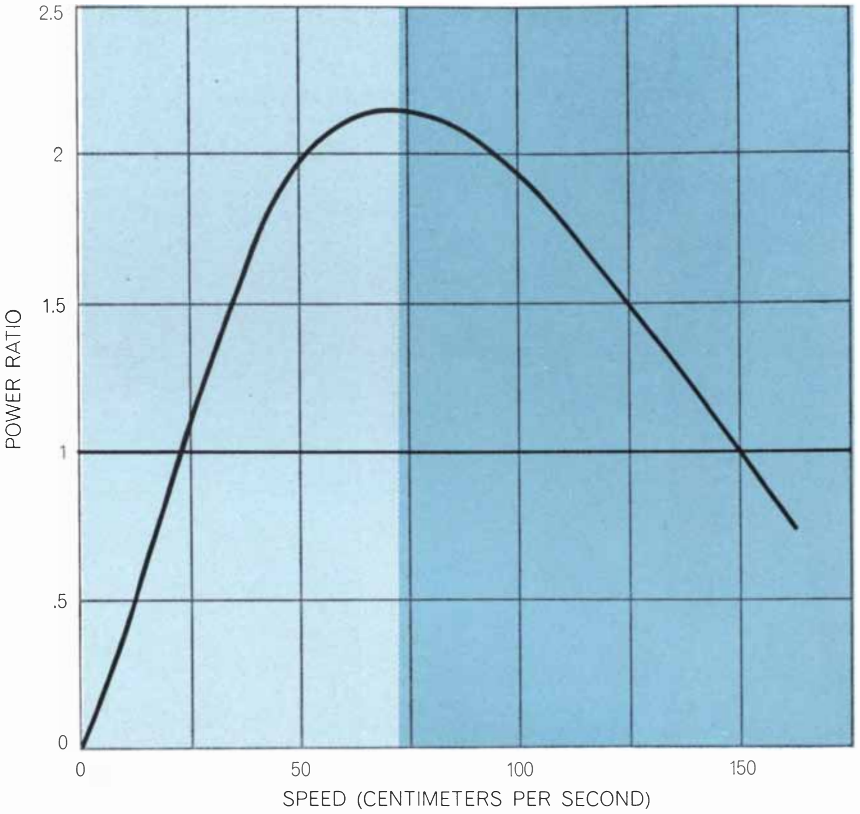
According to computations based on the performance of salmon in the respirometer, the most efficient swimming speed for a typical adult sockeye salmon is 1.1 m.p.h.; at this velocity the ratio of the speed obtained to the energy spent is optimal. At sea tagged salmon migrating toward shore have been found to travel an average of 30 miles per day. Assuming that they swim in the same general direction for most of the 24 hours, this indicates that in the ocean they would be swimming at somewhere near the most efficient speed. To make their way upriver against the river currents, however, the salmon must swim at higher, less efficient speeds. At an average of 2.65 m.p.h.—the speed maintained by the migrants up the Fraser River—the adult salmon must sacrifice nearly half of the possible efficiency in use of energy [*see illustration at left above*].

Having explored the metabolic aspects, we went on to look into the hydrodynamic attributes that help to account for the salmon's remarkable swimming feats and endurance. The first step was to measure the drag force on the streamlined shape of the fish in the water. For this measurement the model was a freshly killed salmon that was held at the end of a thin rod in the flowing water in the respirometer, like a model in a wind tunnel. The drag force, measured by a spring connected to the rod, was found to vary with velocity according to standard hydrodynamic relations. This procedure made it possible to express the drag in terms of the power required to overcome it at a given velocity, and therefore the drag on the dead model could be compared with that on a live fish swimming at the same speed.

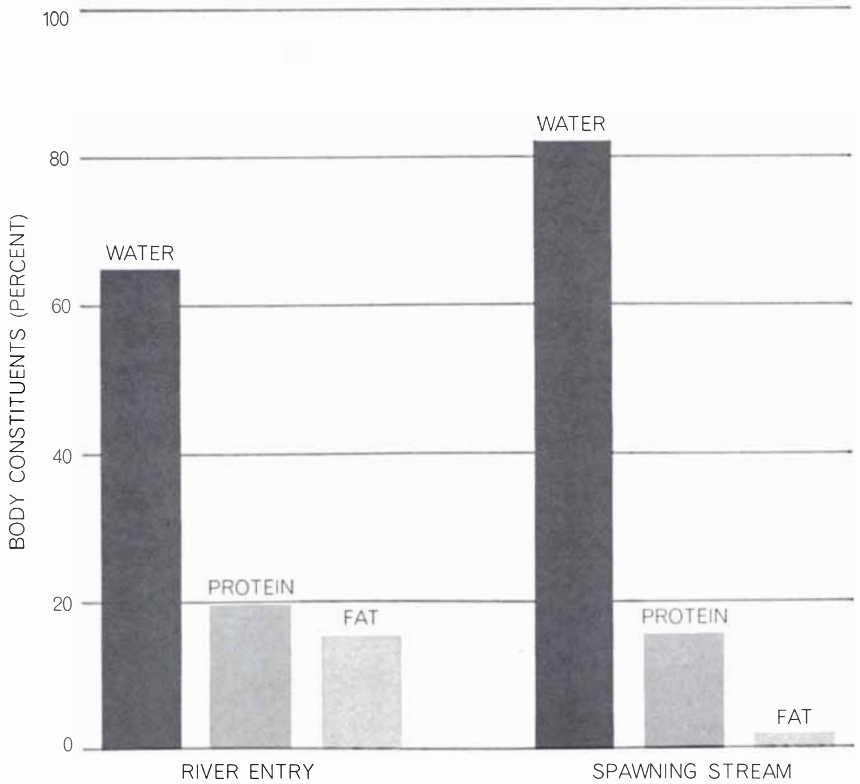
A swimming fish, propelling itself by undulating movements of its body, of course is a different object from a fixed, motionless model as far as drag is concerned. The swimmer leaves remarkably little turbulence in its wake, which indicates that the flow around its body is more laminar, or smoother, than that around a nonoscillating body of the same streamlined shape. Our measurements showed that the drag on the swimming salmon was indeed considerably less than that on the dead model, except at low velocities. The difference increased right up to the maximum sustained speed, where the power required for a swimming fish to overcome drag was less than half that for the dead model [*see illustration at right on opposite page*]. At speeds beyond the maximum that the fish could sustain—that is, at speeds attainable only in short bursts—the swimming fish lost its hydrodynamic advantage.

In short, the salmon's hydrodynamic efficiency is greatest at its top sustainable speed. This helps to counteract the high metabolic cost of swimming at that speed. Evidently the evolution of the salmon has endowed it with a hydrodynamic perfection that tends to minimize the energy it must spend for its extraordinary swimming performance. It appears that the best prospects for further improvement of the performance lie in the evolution of increased efficiency in the salmon's metabolic yield of energy.

Evolution has carried the salmon very far. It remains for man to take pains to avoid destroying the fish's chances of surviving and flourishing. By unraveling the secrets of the salmon's hydrodynamic efficiency man may also learn some lessons of benefit to his marine technology.



HYDRODYNAMIC EFFICIENCIES are compared. The "power ratio" is that of the power required for overcoming drag on a dead fish to that required by yearling sockeye swimming at the same velocity. The light color represents sustained speeds; the dark color, burst speeds. Optimum hydrodynamic efficiency occurs at the level of maximum sustained speed.



EFFECT OF SPAWNING MIGRATION on stored body fuels of sockeye salmon is indicated according to data obtained by D. R. Idler and W. A. Clemens for the International Pacific Salmon Fisheries Commission. Total change in weight is fairly small because the large increase in the water content of the fish compensates for the losses of protein and fat.

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```
                        NUMBER = 2+2
101. =                  NUMBER=          4
101. -READY

                        NUMBER = 12/2
101. =                  NUMBER=          6
101. -READY

                        N = SQRT(64.)
101. =                  N=          8
101. -READY

101. -READY             PROGRAM(SAMPLE)
102. +READY             DIMENSION ZPLOT(52), TABLE(500)
103. +READY             X=0
104. +READY             Y=1.
105. +READY             I=1
106. +READY             READ 101, DELX,CHAR,ZPLOT
107. +READY 101         FORMAT (F7.4, 53A1)
108. +READY             PRINT 102
109. +READY 102         FORMAT (5X,1HX,7X,1HY)
110. +READY     2       TABLE (I) = X
111. +READY             TABLE (I+1) =Y
112. +READY     1       PRINT 103,X,Y
113. +READY 103         FORMAT(2X,F7.4,F8.5)
114. +READY             IF (X-1.) 5,3,3
115. +READY     5       I=I+2
116. +READY             X=X+DELX
117. +READY             DELY =X*Y*DELX
118. +READY             Y=Y+DELY
119. +READY             GOAT 2
119. +ERROR         STATEMENT NOT IN LANGUAGE
119. +READY             GO TO 2
120. +READY     3       DO 4  J= 1,I,2
121. +READY             X= TABLE(J)
122. +READY             K=1. +((TABLE(J+1)-TABLE(2))/(TABLE (I+1)-TABLE (2))*50.)
123. +READY             ZPLOT(K) = CHAR
124. +READY             PRINT 101, X, ZPLOT
125. +READY     4       ZPLOT (K)=ZPLOT (K+1)
126. +READY             STOP77
127. +READY             END
```

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THE ROYAL HEMOPHILIA

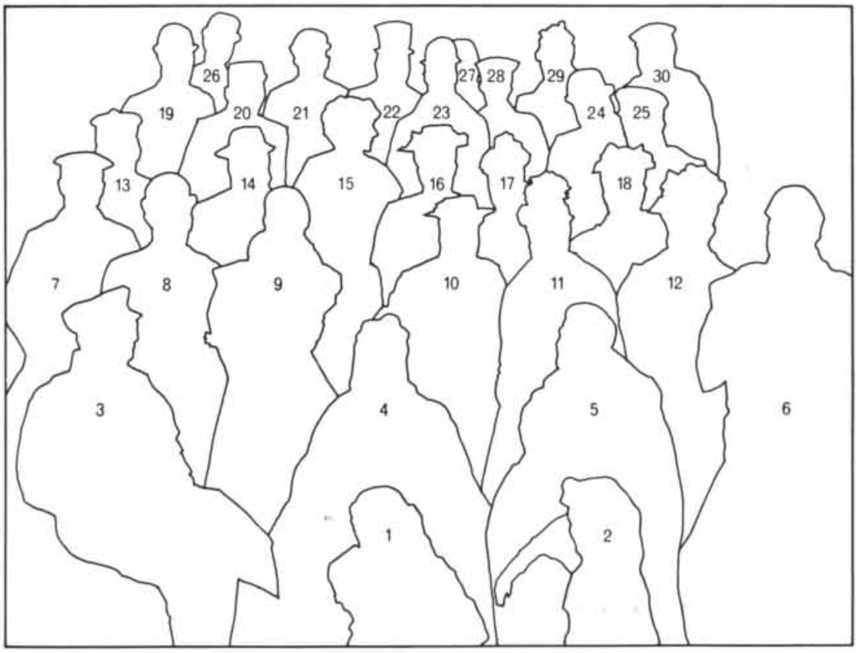
A disease caused by the inheritance of a defective *X* chromosome, it has plagued European royalty for three generations. Queen Victoria was the first carrier of the mutation, which may not yet be extinct

by Victor A. McKusick

On April 7, 1853, Queen Victoria of England gave birth to the eighth of her nine children. From the beginning the infant Leopold was sickly; his baptism was postponed for almost three months. It may be that the trauma of birth had resulted in hemorrhages. In any event it soon became evident that he had an unusual tendency to bleed even from trivial injuries; Prince Leopold suffered from hemophilia. His birth made medical history for quite a different reason: at the confinement Victoria received chloroform, the anesthetic introduced by James Young Simpson of Edinburgh only six years earlier. Many were quick to see a connection between hemophilia in the newborn prince and the use of an anesthetic; a bitter controversy occupied the press and the church of Victorian England. Painless childbirth was viewed by some as a defiance of the Scriptural admonition that "in sorrow thou shalt bring forth children."

Hemophilia is a disease caused by a genetic defect; an individual who suffers from it bleeds too freely because he cannot produce a factor in the blood that causes the plasma to coagulate. It is a sex-linked, recessive defect originally resulting from the mutation of a gene in the *X* chromosome of a germ cell—either the sperm of the father or the egg of the mother [*see illustration on page 92*]. If the child is a male, he will be hemophilic; if a female, she will be a carrier of the disease (although she will rarely suffer from it), and the chances are one out of two that her sons will be hemophilic and her daughters carriers. The sons of a hemophilic father will carry no trace of the hereditary defect, since they receive his *Y* (and not his *X*) chromosome. All his daughters, however, will be carriers.

The pattern in which hemophilia is inherited was understood more than 30 years before the birth of Prince Leopold. It had been described in 1803 by John Conrad Otto, a young Philadelphia physician; his observations were confirmed in 1813 by John Hay, a physician of Reading, Mass. In 1820 Christian Friedrich Nasse, professor of medicine in Bonn, described the same pattern of inheritance, and it became known as Nasse's law. The historical record does not tell us whether or not Queen Victoria ever understood the hereditary pattern of the disease she carried. When one of her grandchildren died in childhood, however, she did write in her journal: "Our poor family seems persecuted by this awful disease, the worst I know." Even with the benefit of modern knowledge one of Victoria's living grandchildren—Victoria Eugénie, the former queen of Spain—is evidently convinced that the hemophilia that beset her own sons and her cousin's son stemmed from their common German great-grand-



ASSEMBLED ROYALTY, including four of Queen Victoria's nine children and six of her 34 grandchildren, posed for a group portrait surrounding the Queen on the occasion of a family wedding in 1894. Three of the female carriers of the Queen's hemophilia-producing mutant gene are present: her youngest daughter, Beatrice (*No. 14 in key above*), and two granddaughters (children of Alice), Princess Alix (*No. 9*), who stands to the left of her future husband (*No. 8*), then Czarevitch but soon to be Czar Nicholas II of Russia, and Princess Irene (*No. 11*), the bride of Prince Henry of Prussia (*No. 28*). Other children of Queen Victoria present are Edward, Prince of Wales (*No. 13*), Arthur, Duke of Connaught

father, thus ignoring the fact that her grandmother, her mother and her aunt were the carriers. The hemophilia of Queen Victoria's family is a classic case; of her nine children two daughters were carriers, one son was a victim and a third daughter was a possible carrier. Three (or possibly four) out of nine is not exactly one out of two, but it is a reasonable approximation.

Throughout his lifetime Prince Leopold suffered from repeated episodes of bleeding. The *British Medical Journal* took note of two of the episodes; the reports provide some clinical details. In 1868, when Leopold was 15, the following was recorded: "His Royal Highness..., who has previously been in full health and activity, has been suffering during the last week from severe accidental haemorrhage. The Prince was reduced to a state of extreme and dangerous exhaustion by the loss of blood, but has since greatly recovered, and has regained strength so that Dr. Jenner [Sir William, who was not closely related to Edward, the originator of vaccination] and Mr. Paget, who were summoned to Osborne and remained for some days in permanent attendance,

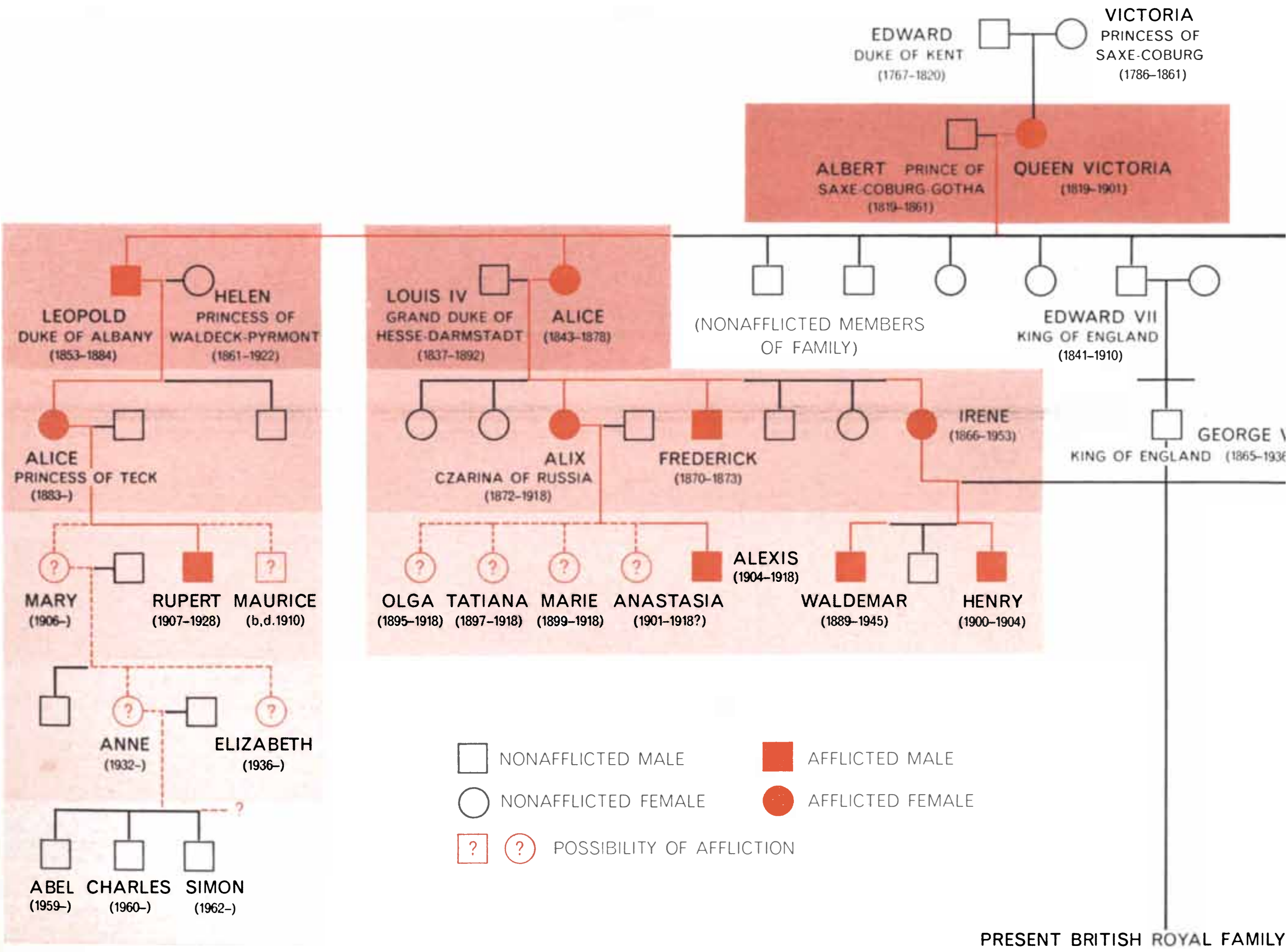
(*No. 25*), and Victoria, Empress of Germany (*No. 5*). The four other grandchildren are Kaiser Wilhelm II of Germany (*No. 3*), Marie, the future Queen of Romania (*No. 27*), Elizabeth, bride of Grand Duke Serge of Russia (*No. 29*), and Victoria, bride of Prince Louis of Battenberg (*No. 10*). None of them inherited the mutation. Others in the royal party are (*from the bottom*) Princess Beatrice of Saxe-Coburg-Gotha (*No. 1*), Princess Feodore of Saxe-Meiningen (*No. 2*), Queen Victoria (*No. 4*), Prince Alfred of Saxe-Coburg-Gotha (*No. 7*), the Duchess of Saxe-Coburg-Gotha (*No. 6*), Princess Philip (*No. 15*) and Princess Alexandra (*No. 16*), both of Saxe-Coburg-Gotha, the Princess of Saxe-Meiningen (*No. 17*), the Duchess of Connaught (*No. 18*), Prince Louis (*No. 19*) and Prince Henry (*No. 20*), both of Battenberg, Prince Ferdinand of Romania (*No. 21*), Count Mensdorff (*No. 22*), Grand Duke Serge (*No. 23*), Grand Duke Vladimir (*No. 24*) and Grand Duke Paul (*No. 26*), all of Russia, and the Duke of Saxe-Coburg-Gotha (*No. 30*).

have returned to town." In 1875 the same journal noted: "Haemorrhage after typhoid fever is always one of the most serious complications. In this case, the attack of fever was slight, but the peculiar liability of the Prince to severe haemorrhage, from which he has always been a sufferer, gives a special aspect of gravity to his condition. It is essentially a case for vigilant medical attendance and most careful nursing, and as these have before now saved Prince Leopold from urgent conditions of peril, so we may now hope that they will triumph over the present difficulties. He is in the hands of those who have watched him from the cradle, and who are armed by the special experience of his constitution, as well as the most ample command of professional resources."

In 1879 Victoria wrote her prime minister Benjamin Disraeli (using the regal third person) that she could not send Leopold to Sydney to represent her at the first Australian international exposition: "She cannot bring herself to consent to send her very delicate son, who has been *four or five times at death's door,* who is *never* hardly a *few* months without being laid up, to a great *distance,* to a climate to which he is a stranger and to expose him to dangers which he may not be able to avert. Even if he did *not* suffer, the terrible anxiety which the Queen would undergo would unfit her for her duties at home and might undermine her health."

In 1882 Leopold, then 29 years old, married the German princess Helen of Waldeck. His mother noted that at the wedding he was "lame and shaky." The shakiness may not have been attributable to his hemophilia, but the lameness is another matter: rheumatism from bleeding into the joints is often a crippling feature of the disease. In 1883 Leopold's bride bore him a daughter, Alice; as the daughter of a hemophilic father she was inescapably a carrier of the mutated *X*-chromosome gene. Helen was pregnant a second time when, in March of 1884, Leopold visited Cannes for his health. He fell; a minor blow on the head resulted in a brain hemorrhage and convulsions. He died on March 28 at the age of 31; his second child, born a few months after his death, was a son and therefore exempt from the hereditary defect [*see illustration below*].

If the *X* chromosome of the fertilized egg that was destined to become Prince Leopold had been the site of the gene mutation that caused his hemophilia, then among all Queen Victoria's children and grandchildren Leopold and



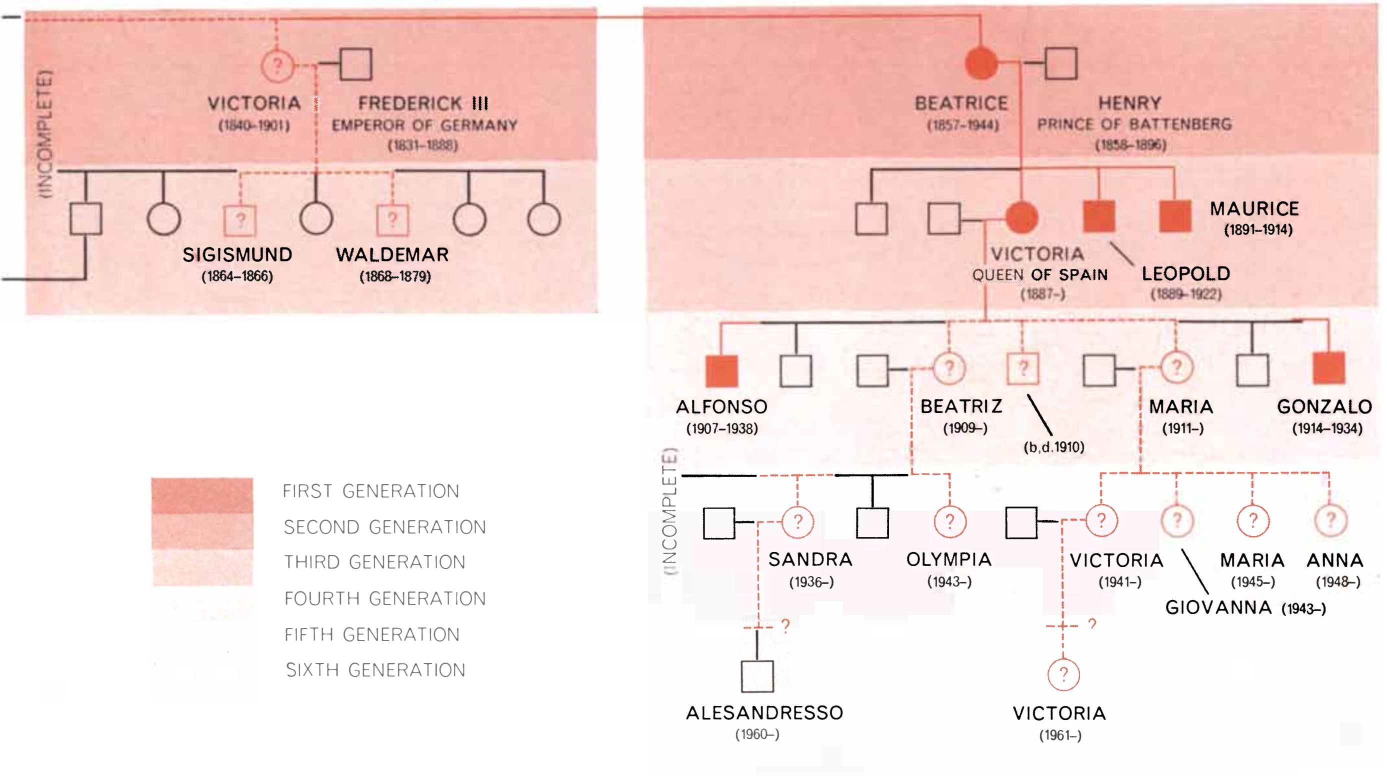
SIX-GENERATION RECORD of known and possible hemophilia among the descendants of Queen Victoria shows how the genetic defect was inherited by various children and grandchildren of her afflicted son, Prince Leopold, and her daughters Alice (the Grand Duchess of Hesse) and Beatrice (Princess Henry of Battenberg). The untimely death of two sons of Victoria (Empress Frederick III

his descendants alone would have been subject to the disease. Actually it is clear that the mutation had taken place in the preceding generation and that all Victoria's germ cells contained a defective *X* chromosome. Victoria herself was almost certainly the first to carry the new mutation; that is, the mutation had occurred in an *X* chromosome of one of the germ cells that made her. Victoria was an only child. Late in life her father, Edward, Duke of Kent (together with his brothers, the Duke of Clarence and the Duke of Cambridge) married in order to ensure a succession to the throne after the principal heir, Princess Charlotte, had died in childbirth. Edward was 52 when Victoria was born in 1819; he died the following year. It has been shown that mutations are more likely to occur in the germ cells of older fathers; it can therefore be conjectured that Edward's *X* chromosome was the site of the mutation.

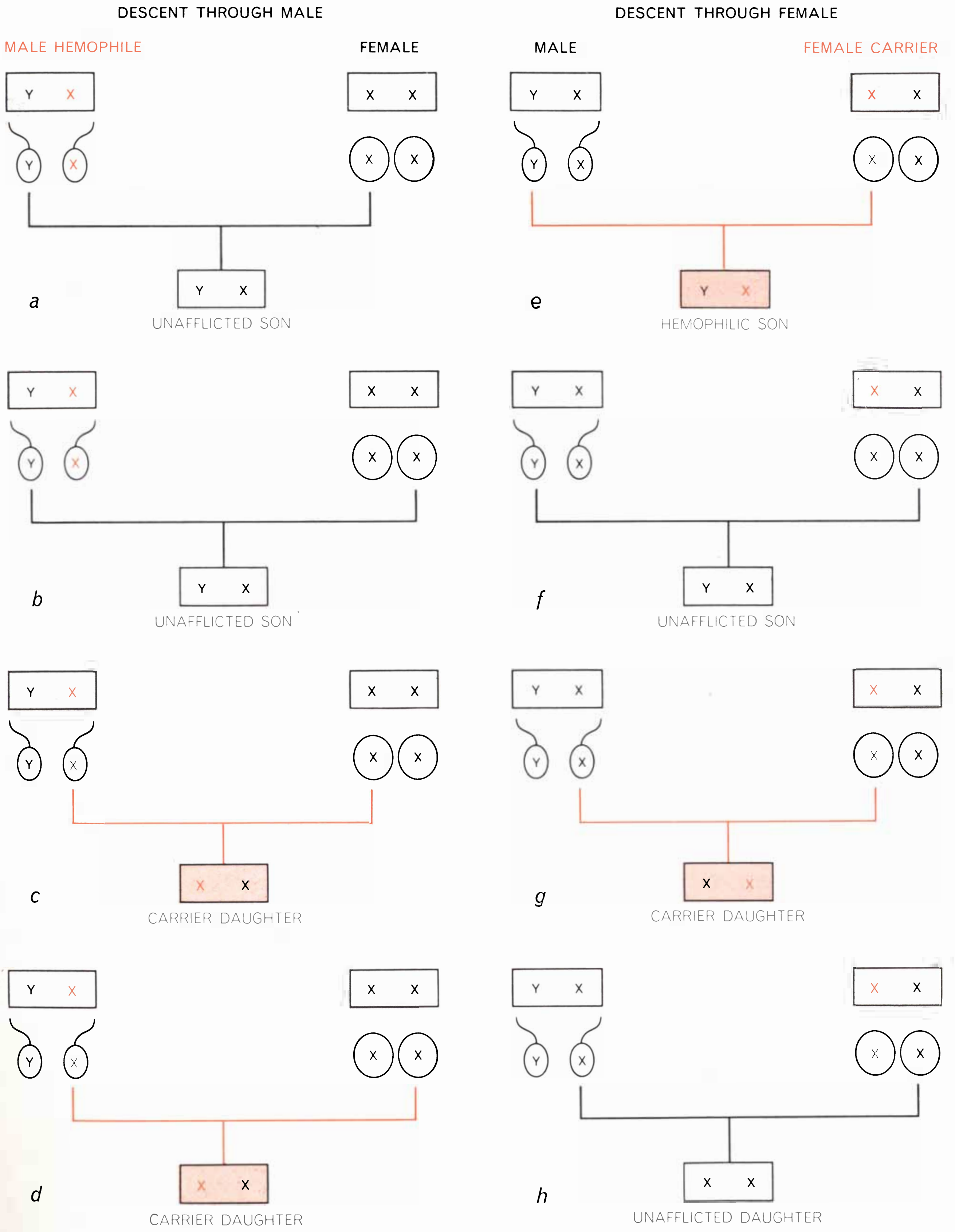
Of Queen Victoria's four sons, only Leopold was hemophilic; of her five daughters, four had children and two of them definitely proved to be carriers. All of this is clear enough in retrospect, but proof that Queen Victoria had passed the mutation to at least one of her daughters, and was thus herself a carrier, was actually available a full 10 years before her son Leopold died of the disease.

This proof was provided by Victoria's third child, Alice, who was born in 1843. In 1862 Alice married Louis IV, Grand Duke of Hesse. Of her seven children, three—two daughters and a son—received the mutant gene [*see illustration below*]. The son's early death from hemophilic hemorrhage demonstrated that another of Queen Victoria's children carried the defect. The boy was named Frederick William; "Frittie," as he was called, was delicate from birth and his hemophilia soon became evident. At the age of two, for example, he bled for several days from a small cut on the ear. At three Frittie and his older brother Ernst came romping into their mother's room one morning while she was still in bed. The windows, which reached nearly to the floor, were open; in the course of playing Frittie fell out of a window onto a stone terrace 20 feet below. None of his bones were broken, and at first it was hoped that all would be well, but bleeding in the brain had been initiated. By evening the child was dead.

Irene, the elder of Alice's two daughters who were carriers, married her cousin, Prince Henry of Prussia. As in her mother's case, the chance was one in two that her children would inherit the mutant gene; in fact, she bore three



of Germany) led to the popular belief that she too was a carrier, but this is contrary to available medical evidence. In the Hesse line, the execution of the Russian Imperial family and the death of the two afflicted Prussian princes has evidently brought about extinction of the disease. Females of the English (*left*) and the Spanish (*right*) lines, however, may still be carriers of the mutant gene.



INHERITANCE PATTERN of hemophilia depends on whether the father's or the mother's germ cell contains the defective *X* chromosome that is the cause of the disease. In the case of a father (*left column*), all sons escape the disease because only the normal *Y* chromosomes of the father ("*a*" *and* "*b*") are involved in the conception of male children. All daughters, however, inevitably receive a defective *X* chromosome ("*c*" *and* "*d*") and thus become carriers of the disease. Such carrier mothers (*right column*) run a 50 percent chance ("*e*" *versus* "*f*") that any son they bear will be hemophilic and any daughter will carry the defect ("*g*" *versus* "*h*").

sons and two of them were hemophilic. Prince Waldemar of Prussia (1889–1945) survived for 56 years, setting a record for longevity among the hemophilic descendants of Queen Victoria; he left no children. Prince Henry of Prussia died at the age of four in 1904; his short, unhappy life was carefully concealed, apparently for political reasons. He is not listed, for example, in such genealogical works as *Burke's Peerage* or the *Almanach de Gotha*. The third son, Sigismund, escaped the fatal heritage; he now lives in Costa Rica and his children and grandchildren are normal.

Alice's sixth child, the other carrier, was born in 1872 and was named Alix; Alice explained to Queen Victoria, "Alice they pronounce too dreadfully in German." Of all Victoria's granddaughters Alix had the most melodramatic life. She was courted by Nicholas II of Russia, then the Czarevitch [*see illustration on page* 89], and married him at the age of 22 in 1894, thus bringing the mutant gene into the Romanov line. On her marriage she assumed the Russian name Alexandra and embraced the Russian Orthodox faith. Alexandra bore Czar Nicholas four daughters in succession; the fifth child, a son, was born in 1904 and was christened Alexis. The Czarevitch proved to be hemophilic.

The failure of conventional medicine to turn the sickly Alexis into a robust infant made the Czar and Czarina seek help from the lunatic fringe. One M. Philippe, a spiritualist from Lyons, was the first healer in whom the imperial parents put their confidence. The fanatic monk Rasputin was the last. The story is a familiar one: During one of the Czarevitch's bleeding episodes, in 1907, Rasputin was summoned at the urging of one of Alexandra's ladies-in-waiting. After three days and nights, during which the monk maintained a prayerful vigil, the bleeding stopped. Asked if he could continue to keep the child from danger, Rasputin replied: "He will live as long as I am there to watch him."

The prediction was partly correct; Alexis outlived Rasputin by more than two years. A group of noblemen murdered the monk in the winter of 1916; Alexis and the rest of his family were shot in a cellar in Ekaterinburg in July, 1918. This bloody end, together with the Prussian Prince Waldemar's more placid death in 1945, apparently completed the extinction of Victoria's mutant gene in the line of her daughter Alice, Grand Duchess of Hesse.

As has become widely known in recent years, in 1928 a certain Anastasia Tschaikovsky advanced the claim that she was actually the youngest Romanov princess, Anastasia. She said that she had been rescued from the Ekaterinburg executions by one of the soldiers, who had smuggled her away; together they had made a long journey, largely by sled, from Siberia to Romania. This claim has been the subject of prolonged controversy. The alleged Princess Anastasia still lives in a village in southern Germany; her only child, a son sired by her presumed rescuer, was supposedly left in a convent in Romania years ago and has since vanished from sight. There is a one-in-two chance that any of Alexandra's four daughters was herself a carrier of hemophilia; if the alleged son of the alleged Princess Anastasia were hemophilic, the case for the mother's royal identity would be strengthened. At present it remains an open question.

Beatrice, Queen Victoria's ninth and youngest child, was born in 1857; she too proved to be a carrier. In 1885 she married Prince Henry of Battenberg, a first cousin of her sister Alice's husband, the Grand Duke of Hesse. Prince Henry moved to England and became a British subject. During World War I, at the urging of King George V, the family translated its name from the German Battenberg to the English Mountbatten. Beatrice bore her husband four children; two of her three sons were hemophilic and her daughter was a carrier.

Both of Beatrice's hemophilic sons served in World War I in spite of their disability. The elder—Leopold, Earl Mountbatten—was too frail to do more than fill a staff position; he died at the age of 33 following surgery in 1922. His brother Maurice served in the King's Royal Fusiliers; he was killed in action near Ypres in October, 1914. Neither left any children.

Beatrice's daughter, Victoria Eugénie, was born in 1887; she married Alfonso XIII, King of Spain, at the age of 19 and bore him five sons and two daughters. One of the sons died at birth; it is quite likely that he was hemophilic. Of the other four, the eldest (Alfonso) and the youngest (Gonzalo) were both hemophilic. There is no evidence that either of Victoria Eugénie's daughters—Beatriz (who has a son and a grandson) or Maria (who has four daughters)—is a carrier of the defect.

In 1934, three years after his father had abdicated the throne, Gonzalo was motoring with his sister Beatriz in Austria. Beatriz swerved to avoid a bicyclist and hit a wall; her brother received an insignificant injury but died a few days later, aged 20. His elder brother Alfonso survived him by four years. Estranged from his family—particularly from his mother, whom he castigated for having given him hemophilia—Alfonso went to the Americas in 1935 and spent the remaining years of his life in Cuba and the U.S. For several months he suffered from an abscess in the muscle of the right buttock that had developed from an intramuscular injection. In Cuba the abscess was opened and packed. When blood continued to ooze from the wound, a treatment then considered helpful in hemophilia was instituted: Alfonso received a series of blood transfusions from individuals whose spleen had been removed. (The rationale is based on the observation that the blood of such splenectomized patients coagulates rapidly.) In spite of the treatment, or perhaps because of the normal antihemophilic component of the transfused blood, he did stop bleeding.

In the early hours of September 5, 1938, Alfonso was motoring with a night club entertainer in Miami; the young woman swerved to avoid a truck and crashed into a telephone pole. She suffered minor bruises; Alfonso received several cuts and bruises and broke a leg. He died of hemorrhage within a few hours, aged 31 and childless. His death, as far as positive evidence is concerned, may well have completed the extinction of the mutant gene in the line of Victoria's daughter Beatrice.

The question remains of whether or not Queen Victoria's namesake daughter, later the wife of Frederick III, Emperor of Germany, was also a carrier.

PRINCESS ALICE was Queen Victoria's third child. Alice bore seven children; a son was hemophilic and two daughters were carriers of defective *X* chromosomes.

PRINCE LEOPOLD was Queen Victoria's eighth child and a hemophile. The father of two children, he passed his genetic defect on to his daughter but sired a normal son.

PRINCESS BEATRICE was the last of Queen Victoria's nine children. Her only daughter was a carrier of the mutant gene and two of her three sons were hemophilic.

She bore her husband four sons: Wilhelm (the Kaiser of World War I), Henry (the Prince of Prussia who married his cousin, Irene of Hesse), Sigismund (who died at two) and Waldemar (who died at 11). Neither Wilhelm nor Henry was hemophilic. The late J. B. S. Haldane reported a Dutch physician's conclusion that Sigismund and Waldemar were almost certainly not hemophilic.

Has Queen Victoria's mutant gene therefore finally become extinct? The question cannot yet be answered with certainty. In addition to the two daughters of Victoria Eugénie—the Spanish princesses Beatriz and Maria—there survives a descendant of Prince Leopold: Lady Mary Abel Smith, the daughter of his daughter Princess Alice, who had married Alexander, Earl of Athlone. Princess Alice, the daughter of a hemophilic father, was inescapably a carrier. Of her two sons, one died in infancy, apparently not as a result of hemophilia. The other—Rupert, Viscount Trematon—was hemophilic and met the same kind of unhappy end as his cousins Gonzalo and Alfonso did; he died at the age of 20 of a brain hemorrhage following an automobile accident.

Hence there remain among the many living descendants of Queen Victoria three—the two princesses of the Spanish branch and Lady Mary—who have a 50 percent chance of being hemophilia carriers like their mothers. I have mentioned that the son and grandson of Princess Beatriz are apparently not afflicted; this is also true of Lady Mary's only son and of her daughter's sons as well. The possibility nonetheless remains that the gene may have gone underground; it may still exist in the heterozygous carrier state in the female descendants of both lines.

Just as half of the sons born to a hemophilia carrier can be expected to be hemophilic, so a quarter of the grandsons produced by the carrier's daughters can be expected to inherit the mutant gene. Among Queen Victoria's descendants, eight of the 25 male issue who were sons of daughters of carriers were afflicted—somewhat more than one in four. In turn, the chance that Lady Mary and the Spanish princesses are *not* carriers of hemophilia is $(1/2)^3$, or one in eight. It appears possible, therefore, that at least one of the three is a carrier. The prospect that hemophilia will reappear among some of Queen Victoria's distant male descendants remains a real one.

MATHEMATICAL GAMES

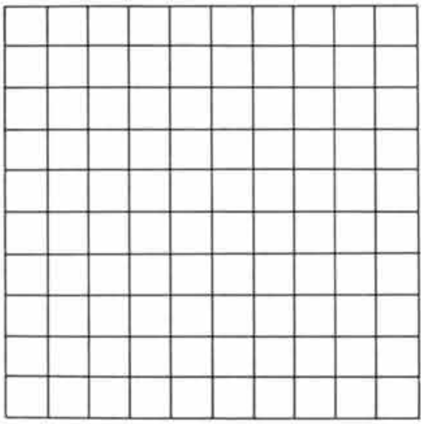
Thoughts on the task of communication with intelligent organisms on other worlds

by Martin Gardner

Across the gulf of space, minds that are to our minds as ours are to those of the beasts that perish, intellects vast and cool and unsympathetic, regarded this earth with envious eyes, and slowly and surely drew their plans against us.
—H. G. WELLS, *The War of the Worlds*

In 1898, when Wells's novel was first published, a number of distinguished astronomers seriously believed Mars was inhabited by creatures with "intellects vast and cool" and superior to our own. The Italian astronomer Giovanni Schiaparelli (the uncle of the dress designer Elsa Schiaparelli) had reported in 1877 that he saw fine lines crisscrossing the red planet. A wealthy Bostonian, Percival Lowell, became so excited by Schiaparelli's continued disclosures that he decided to abandon Oriental studies and become an astronomer. In 1894, when Mars was unusually close to the earth, Lowell established his own observatory on "Mars Hill" in Flagstaff, Ariz.

Lowell too saw the lines Schiaparelli had called "canali." (The word, which means "channels," had been subtly mistranslated "canals.") Indeed, he saw them in fantastic profusion; eventually he mapped more than 500. In three books—*Mars* (1895), *Mars and Its Canals* (1906) and *Mars as the Abode of Life* (1908)—Lowell argued that the lines he saw were wide bands of vegetation bordering enormous irrigation ditches constructed to bring water from melting polar caps to the dry Martian deserts. "That Mars is inhabited by beings of some sort or other," he wrote, "we may consider as certain as it is uncertain what those forms may be." Lowell's Mars books had an enormous influence on early science fiction; the canals turned up everywhere, from Wells's 1897 short story "The Crystal Egg" to the later Martian romances of Edgar Rice Burroughs.



10-by-10 scanning matrix

There is no doubt about Lowell's competence as an astronomer. Calculations he made in 1915 led to the discovery of Pluto by Clyde W. Tombaugh in 1930—at the Lowell Observatory. ("Pluto" was chosen as the planet's name because its first two letters are Lowell's initials and its last two the beginning letters of Tombaugh; Pluto's symbol, ♇, combines *P* and *L*.) But as Jonathan Norton Leonard observes in his book *Flight into Space,* Lowell's temperament was closer to that of his sister Amy, the cigar-smoking poet, than to that of his cautious, conservative brother Abbott Lawrence, who became president of Harvard. Although some astronomers enthusiastically confirmed Lowell's observations of Martian canals, others with better telescopes and better eyes could see no canals at all. Even in today's best telescopes Mars is a tiny, jiggling spot of light, and in those rare, fleeting moments when the image holds still, one's mind can play strange tricks. Photographs are no help because the earth's turbulent atmosphere blurs the image.

The consensus among astronomers today is that Schiaparelli, Lowell and their followers were the victims of optical illusions induced by irregular splotches on the red planet and elaborated by astigmatism and psychological self-deception.

Among the few living scientists who continue to take Lowell's speculations seriously the most vocal is Wells Alan Webb, a California chemist. In his book *Mars, the New Frontier: Lowell's Hypothesis* (1956) and in many magazine articles and lectures he has reported on an interesting topological analysis of canal drawings made by Lowell and by one of his leading supporters, Robert J. Trumpler. Considering the maps of these two astronomers as geometrical networks, Webb determined the percentage of vertices at which three, four, five, six, seven and eight rays came together. On the maps drawn by both men vertices of order 4 (four lines meeting at a point) predominate: they constitute about 43 percent of the vertices on Trumpler's maps and about 55 percent on Lowell's. A similar analysis of networks found in nature—mud cracks, shrinkage cracks of glazed chinaware, cracks in ancient lava beds, rivers and so on—showed order-3 vertices leading their percentage list. Only in networks constructed by living things, such as spider webs and animal trails, did Webb find the order-4 points predominating. The networks that are topologically most like the Lowell-Trumpler maps are such man-made ones as railroad lines and air travel routes. Thus does topology, Webb argues, back up Lowell's intuitive conviction that the canals must have been the work of high-order intellects.

Webb's arguments assume, of course, a correspondence between the Martian surface and the Lowell-Trumpler maps. But if these maps are no more than doodles of what Lowell and Trumpler imagined they saw, their topological similarity to railroad lines is easily understood. At this writing the first television pictures of Mars are being received from *Mariner IV*, but they have not yet established whether or not there are lines on the planet. Certainly few astronomers expect the pictures to show anything like Lowell's cobwebs; if they do, the great canal controversy will surely break out again.

From 1880 to 1925, when interest in Martian canals was high, all sorts of proposals were put forward for establishing contact with Martians. Two frequent suggestions were that a powerful searchlight be built that would blink a code message, or that a chain of bright lights be stretched across a vast area to make a diagram, visible in Martian telescopes, of the Pythagorean theo-

1. A. B. C. D. E. F. G. H. I. J. K. L. M. N. P. Q. R. S. T. U. V. W. Y. Z.

2. A A, B; A A A, C; A A A A, D; A A A A A, E; A A A A A A, F; A A A A A A A, G; A A A A A A A A, H; A A A A A A A A A. I; A A A A A A A A A A, J.

3. A K A L B; A K A K A L C; A K A K A K A L D. A K A L B; B K A L C; C K A L D; D K A L E. B K E L G; G L E K B. F K D L J; J L F K D.

4. C M A L B; D M A L C; I M G L B.

5. C K N L C; H K N L H. D M D L N; E M E L N.

6. J L AN; J K A L AA; J K B L AB; AA K A L AB. J K J L BN; J K J K J L CN. FN K G L FG.

7. B P C L F; E P B L J; F P J L FN.

8. F Q B L C; J Q B L E; FN Q F L J.

9. C R B L I; B R E L CB.

10. J P J L J R B L S L ANN; J P J P J L J R C L T L ANNN. J P S L T; J P T L J R D.

11. A Q J L U; U Q J L A Q S L V.

12. U L WA; U P B L WB; AWD M A L WD L D P U. V L WNA; V P C L WNC. V Q J L WNNA; V Q S L WNNNA. J P EWFGH L EFWGH; S P EWFGH L EFGWH.

13. GIWIH Y HN; T K C Y T. Z Y CWADAF.

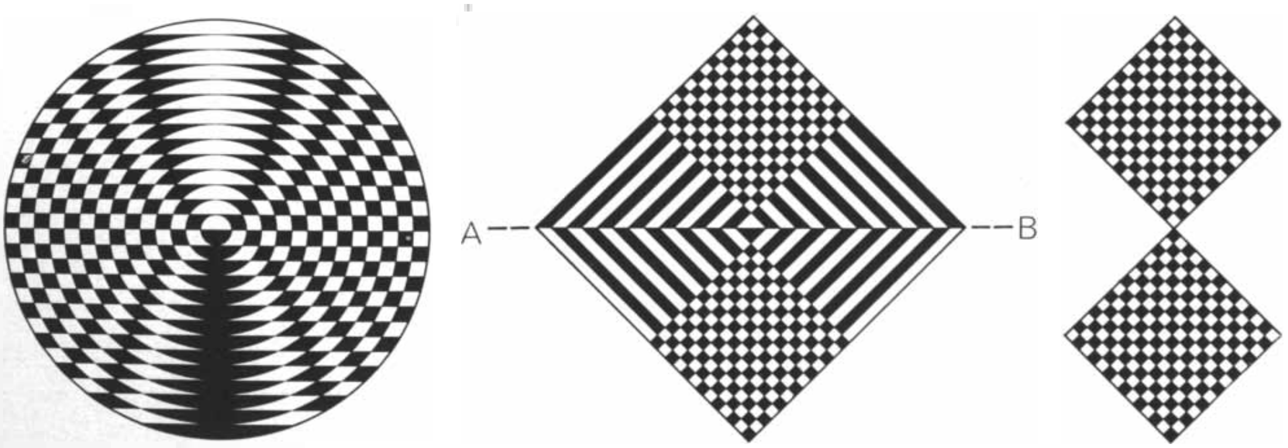
14. D P Z P WNNIB R C Q C.

Ivan Bell's interplanetary message

rem. There was much discussion about radio contacts: sending a series of beeps to represent the counting numbers (beep; beep, beep; beep, beep, beep; . . .) or such arithmetical trivia as two plus two equals four. In 1900 Nikola Tesla declared that he had received radio signals from intelligent beings on Mars. Twenty-one years later Guglielmo Marconi made a similar announcement. Spiritualists too were in frequent contact with minds on the red planet. The most remarkable was Hélène Smith, a Swiss medium, whose strange story is told in the book *From India to the Planet Mars: A Study of a Case of Somnambulism with Glossolalia* (1900) by the Swiss psychologist Théodore Flournoy. In her trances Hélène seemed to be under Martian control, speaking and writing a complex Martian language, complete with its own alphabet.

Now that we are close to landing exploratory robots on Mars and are expecting to find, at the most, only a low-grade vegetation, interest in extraterrestrial communication has shifted to planets in other solar systems. In 1960 Project Ozma failed to detect any radio messages from outer space after several months of listening near the frequency at which free hydrogen radiates. (For various reasons this frequency, with its wavelength of 21 centimeters, seems to be the ideal frequency for interstellar communication.) Nevertheless, interest both in sending and in searching for such messages continues, and much abstruse work is being done on the best methods of exchanging information with an alien culture once contact is established. It is a fascinating problem, almost the exact opposite of devising wartime codes. The purpose of a code is to transmit information in such a way as to make it as difficult as possible for anyone not knowing the key to understand the message. The purpose of an interstellar code is to communicate with minds that know nothing of our language, and in such a way as to make it as *easy* as possible for them to understand.

Many of the papers in *Interstellar Communication*, edited by A. G. W. Cameron (1963), are concerned with this task. All experts agree that messages had best start with simple arithmetic. One assumes that units can be counted by any type of intelligent creature, and that arithmetical laws are uniform throughout the galaxy. Of course one cannot assume that any given method of symbolizing numbers—such as our positional notation based on 10—would be universal. It would be foolish, for example, to try to get extraterrestrial attention by transmitting a decimal ex-



Answer to last month's topology problem

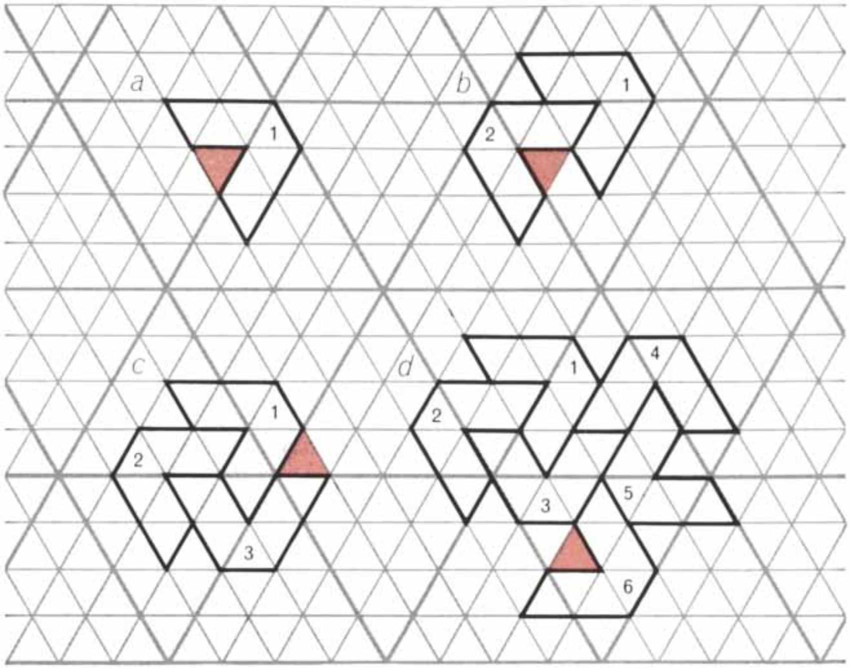
pansion of pi; the aliens might use a different base system and our pi would seem at first to be no more than a series of random symbols. Hans Freudenthal, a Dutch mathematician, has invented an elaborate artificial language he calls Lincos (for "lingua cosmica") that starts out with arithmetic and simple logic, proceeds to more advanced mathematics and ultimately is capable of communicating all human knowledge. The first volume of his work, *Lincos: Design of a Language for Cosmic Intercourse,* was published in the Netherlands in 1960.

Most of Freudenthal's efforts may prove to be irrelevant because of the great ease with which pictures can be sent by a simple code of two symbols. This does not require that beings receiving such a code have eyes sensitive to light but only that they have some means of mapping the shape of things; our visual pictures could be translated by them into whatever sensory technique provides *their* best way of observing the world. Perhaps the simplest way to transmit a shape is by a two-symbol message giving directions for scanning a rectangular matrix of cells, one symbol indicating that a cell is filled and the other that it is empty. Indeed, this is the technique by which pictures are now transmitted by radio as well as the basis of television-screen scanning. Consider the following 100-symbol message:

0000000111
1111111101
1110000111
1010000000
0000000000
1010110101
1010100101
1100110111
1010100010
1010110010

The 100 symbols suggest the 10-by-10 matrix shown on page 96. If the reader will scan the cells from left to right, top to bottom, darkening every cell indicated by 1, he will produce a picture of a familiar object and the English word for it. It is easy to see that once the principle of picture scanning is grasped, ease in communication advances by leaps and bounds.

Since it might take hundreds or thousands of years for a message to travel from the earth to a planet in another solar family, it obviously is impossible to chat back and forth the way one does on a telephone. Messages would have to open with something designed to catch attention—the counting numbers or a series of primes—followed by simple arithmetic leading quickly to picture scanning, then on to encyclopedic transfers of information. But what sort of information should be sent first? Here we come up against a curious situation. One might suppose that the simplest knowledge to send would be about things physicists call "observables"—information derived from our senses, often aided by relatively simple observational devices such as telescopes and microscopes. But suppose the minds on Planet X have as their most highly developed sense some method of mapping the world that evolution here has failed to exploit, say by magnetic forces or some type of radiation not yet known to us. Our pictures of the world, derived from our observables, might have less meaning on Planet X than information about such "unobservables" as electrons, protons and neutrons. If so, the inhabitants of Planet X might understand a description of the periodic table of elements more readily than a description of a house or tree. From one point of view the colors, shapes and sounds of our world are the bedrock facts and the electron a shadowy abstraction. The problems arising here suggest the opposite. The mathematical structure of a helium atom may be more universally understood than the color, smell, taste and shape of an apple, not just because apples are unlikely to grow on other planets but because other minds may map their worlds with senses that have little in common with sight, smell, taste and touch. Inferred entities such as particles and electromagnetic fields might be easier for extraterrestrials to understand than the familiar sights and sounds of our world.



Proof that the V-heptiamond will not tile the plane

In 1960 Ivan Bell, an Englishman teaching English in Tokyo, read about the plans for Project Ozma. To amuse his friends he devised a simple interplanetary message of 24 symbols. It was printed in *The Japan Times* of January 22, 1960, and readers were asked if they could decipher it. Four complete solutions were received. One was from Mrs. Richard T. Field, now living in Bridgeton, N.J., who last year sent me a photocopy of Bell's article.

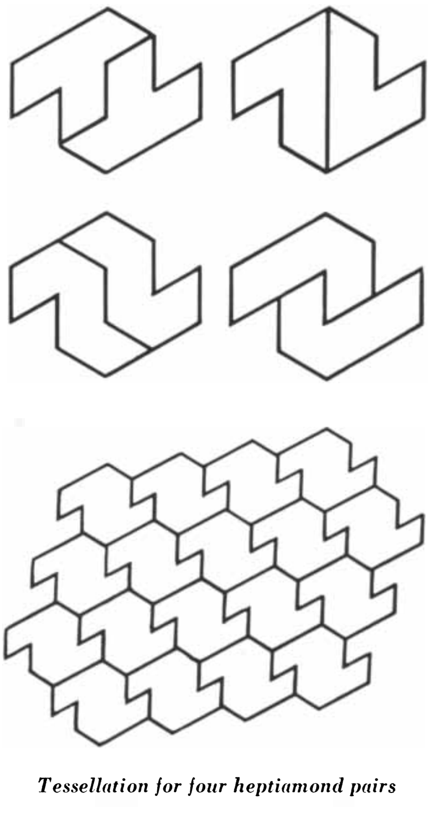
Bell's message is reproduced at the top of the opposite page. It is much easier to decipher than it looks, and readers are urged to try it. Letters from *A* through *Z* (omitting *O* and *X*) provide the 24 symbols. (Each symbol is presumably radioed by a combination of beeps, but we need not be concerned with those details.) The punctuation marks are not part of the message but indications of time lapses. Adjacent letters are sent with short pauses between them. A space between letters means a longer pause. Commas, semicolons and periods represent progressively longer pauses. The longest time lapses come between paragraphs, which are numbered for the reader's convenience; the numbers are not part of the message. To minds in any solar system the message should be crystal clear except for the last paragraph, which is somewhat ambiguous; even if properly deciphered, it could be understood fully only by inhabitants of one of our solar system's planets. (Mrs. Field wrote her answer in the same code and signed off by saying—in the code—that she lived on Jupiter.) The key to Bell's message and a complete translation will be given next month.

Readers were asked last month to make one straight cut across a circular Op pattern [*see figure at left in bottom illustration on page 98*] so as to divide the pattern into two parts, each topologically equivalent to a square checkerboard. That the pattern itself cannot be continuously distorted to produce a checkerboard is evident from the fact that the number of its cells, 392, is not a square. Note also that the two cells inside the bull's-eye are each three-sided; any distortion that turns one of these cells into a square would turn the other into a nonconvex figure. It is therefore necessary that the cut separate these two cells. The only straight cut that does this is one along the horizontal diameter of the large circle. The figure in the middle is topologically the same as the one at the left. It is easy to see that a single cut along *AB* produces two halves, each of which is topologically the same as a square checkerboard 14 cells on a side [*figure at right in bottom illustration on page 98*].

The only heptiamond that will not tile the plane is the V-shaped figure shown at *a* in the illustration on the preceding page. The proof, by Gregory J. Bishop, an electrical engineering student at Northeastern University, is simple. A second piece can fill the colored triangular concavity of the first one only as shown at *b*. (We ignore a mirror reversal of the second piece.) The colored triangle of the second piece can now be filled only by placing a third piece as shown at *c*. The colored triangle of this figure must in turn be filled by placing a fourth piece as shown [*d*], and there is a similar lack of choice in positioning pieces *5* and *6*. Now we are stuck. There is no way to fill the colored triangle associated with piece *6*.

Space does not allow showing sample tessellations for the other 23 heptiamonds depicted last month. The reader may have discovered the useful trick of pairing two pieces to form a pattern that periodically tiles the plane. For example, four different heptiamonds [*at top of illustration below*] can be paired to fit the same periodic tessellation [*bottom*]. It is conjectured that any geometrical shape, *if* it can tile the plane, will also form a finite pattern (of two or more replicas) that will repeat periodically to cover the plane. Bishop has also established that each of the 66 octiamonds will tile the plane, and that all but four of the 108 heptominoes will do so.

The paradox of the heptagon tessellation was taken from Hugo Steinhaus' *One Hundred Problems in Elementary Mathematics* (Basic Books, 1964). The paradox arises from the fact that a rearrangement of terms in an infinite series can lead to a different calculation of the average term. Steinhaus gives as an example the series 1, 0, 1, 0, 1, 0... for which 1/2 is the average. But the two infinite sets of ones and zeroes can also be arranged 1, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1...(where successive sets of zeroes have cardinal numbers that are squares of 1, 2, 3...), in which case the average is 0. It is easy to form other arrangements to make the average any desired integral value between 0 and 1. In the heptagon pattern two different arrangements of two infinite sets of angles are considered, and there is no reason why the calculation of an average angle should be the same in each.



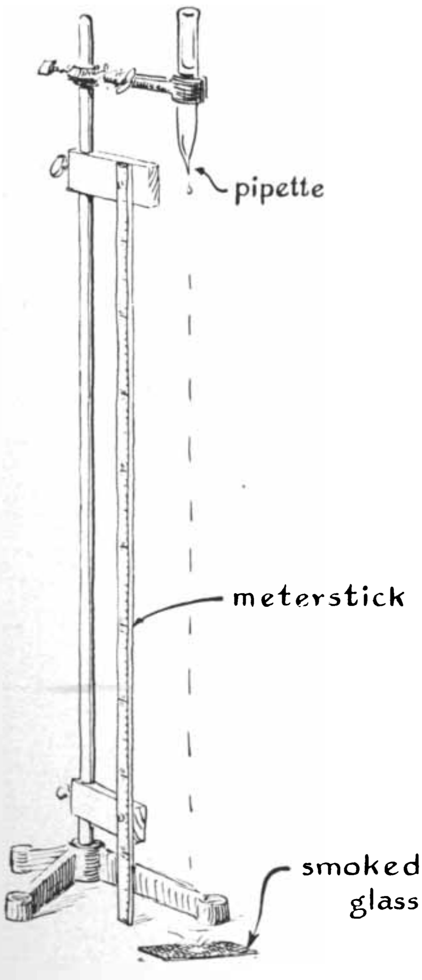
Tessellation for four heptiamond pairs

THE AMATEUR SCIENTIST

How to measure raindrops, make snowflakes and simulate subatomic particle scattering

Conducted by C. L. Stong

A full explanation of why rain falls would obviously be of considerable interest. Such an explanation would in turn require two kinds of information not now available: information on a satisfactory way to measure the diameter of a raindrop and on a satisfactory way to grow a snowflake. It is known that water vapor in the air condenses on suspended particles to form clouds and that certain droplets grow at the expense of others until they become heavy enough to fall. Under certain circumstances the water vapor precipitates as ice crystals that may grow into snowflakes, melt and continue to grow as drops of water that merge with smaller drops on the way down. What mechanism triggers the initial precipitation and what conditions favor the growth of certain drops?



Apparatus for creating splash patterns

The investigation of these questions requires the statistical analysis of drop sizes as a rainstorm develops. It also requires an intimate knowledge of the mechanisms responsible for the growth of snowflakes. Recently Norman J. Wilder of Corvallis, Ore., and Richard W. Wahl of Golden, Colo., respectively chose the problems of gauging raindrops and growing snowflakes as projects for their Junior Research Fellowship in the Atmospheric Physics Program at the University of Nevada. They worked under the supervision of Vincent J. Schaefer.

The program provided only limited time for experimentation. For this reason the procedures devised by Wilder and Wahl require additional work before they can be evaluated. Even so, the experiments demonstrate that some of the more fascinating aspects of weather can be studied indoors and with modest facilities.

Several techniques have been used for measuring the diameter of drops. In one a flat plate coated with oil or a similar substance that resists water is exposed to the drops as an airplane flies through a cloud. Some of the drops stick to the plate and are promptly photographed. The resulting images are later measured. The procedure is not altogether satisfactory. Large drops tend to break up on impact with the plate. Moreover, the airstream separates at obstructions such as flat plates. The smallest drops are therefore diverted, and many do not come in contact with the oil. Hence the collection efficiency of the plate declines in proportion to the diameter of the drops. Finally, the smallest drops evaporate quickly and may disappear before they can be photographed. For these reasons the observations are biased in favor of the larger drops.

An indirect technique has been used to measure drop sizes in supercooled clouds when icing conditions exist. It is based on the fact that the thickness of the ice that forms on a cylinder exposed for a certain time to freezing drops of a certain size varies with the diameter of the cylinder. When cylinders of assorted diameters are exposed to freezing drops, the ice collected by each cylinder varies with the distribution of drop sizes in the cloud. The distribution is calculated by melting the ice and weighing the water that is recovered from each cylinder. Still other methods, such as direct photography, have been tried, but none is entirely satisfactory.

In the method devised by Wilder drop diameter is indicated by the size and character of splash patterns made when drops strike a sheet of smoked glass. His experiments were done indoors; the method has not yet been tested in a natural rain cloud. The equipment consists of an apparatus stand with a scale for determining the height from which a drop of water of predetermined size falls on a sheet of smoked glass below [*see illustration on this page*]. The drops are released by a pipette attached to the vertical rod of the apparatus stand. The resulting splash patterns are examined with a microscope and measured by a calibrated reticle in the eyepiece.

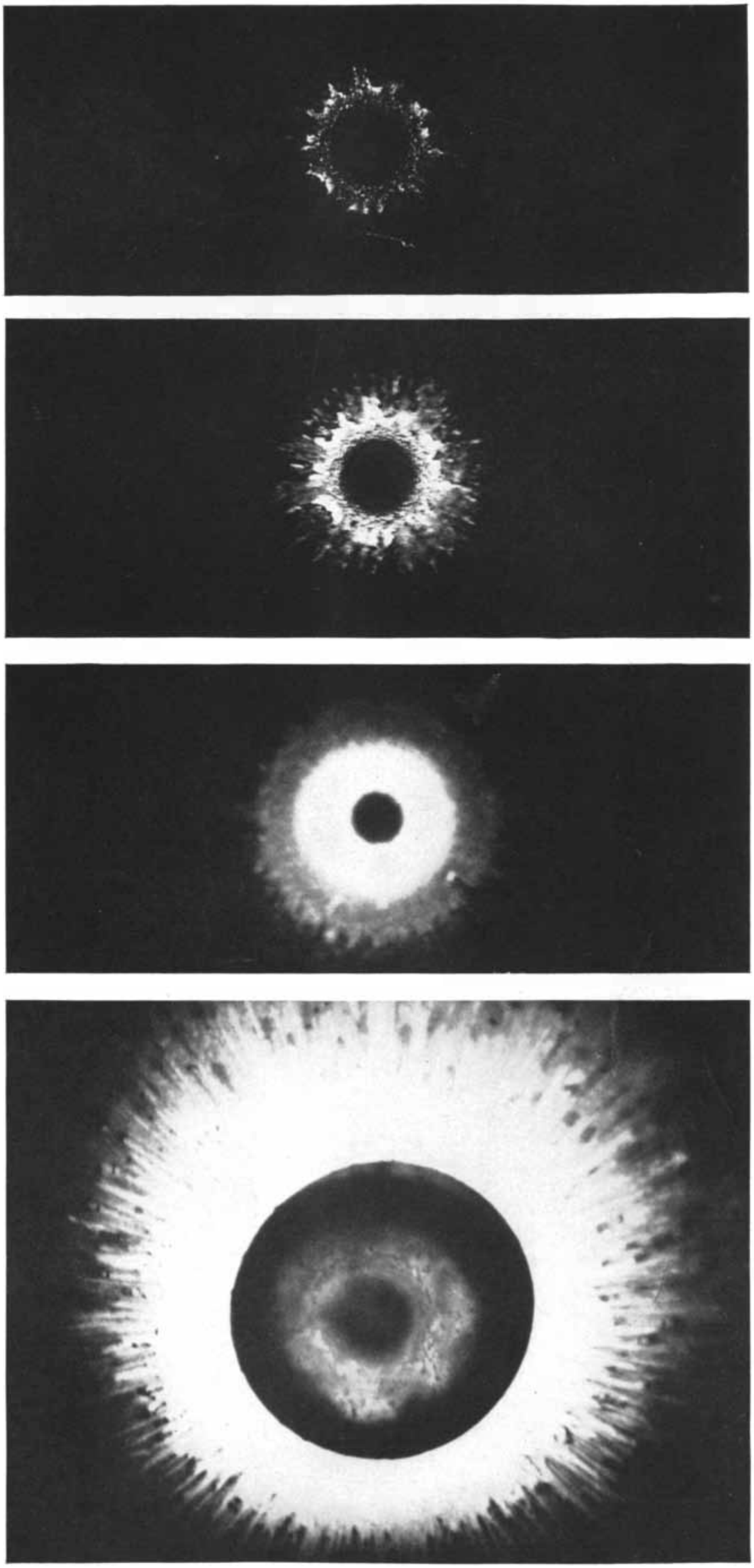
Pipettes of polyethylene are available in a range of nozzle diameters for releasing drops of a desired size. Droppers can also be made easily by heating a narrow section of glass tubing approximately eight millimeters in diameter until the glass softens; one then pulls the ends apart quickly and breaks the tube at its thinnest point to form two pipettes of identical nozzle diameter. When the glass is pulled to about the diameter of a human hair, drops less than a millimeter in diameter are released if the pipette is filled with distilled water. Drops of maximum uniformity are released if the nozzle is coated with a film of silicone grease. Tubes for releasing proportionately larger drops can be made by breaking off the capillary at points of larger diameter. To make a pipette for releasing drops of maximum diameter hold the end of a length of six-millimeter tubing in a gas flame until it softens and almost closes. Attach to the opposite end of the tubing a rubber squeeze bulb for releasing the drops.

Wilder found that the most distinctive splash patterns are formed on glass that has been treated with a nonwetting agent such as ferric stearate prior to the application of soot. The ferric radical clings to the surface and causes the stearate to clump as a water-resistant film. Wilder places three or four small grains of the compound on a microscope slide and heats the glass until the grains melt. The resulting film is spread evenly with a piece of paper toweling folded into a small square. When the slide has cooled, the glass is buffed with a soft cloth until the waxy streaks made by the stearate disappear. The prepared face of the slide is then smoked by passing the glass back and forth through a yellow gas flame.

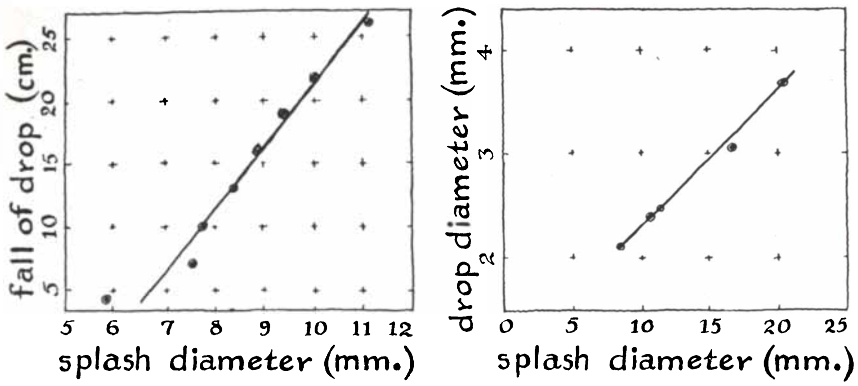
During the operation the glass can be held by a pair of tweezers or by a fixture improvised from wire. Reasonably uniform coats of soot can be applied by passing the slide back and forth completely through the flame at the rate of about two strokes a second. This motion, which should be continuous, will also cause the slide to heat uniformly and so prevent the glass from cracking.

A thickness gauge is automatically built into the carbon layer. Any thinly coated slide, when held almost parallel to the rays of a light, reflects one or more bands of iridescent color, depending on the uniformity of the film. The appearance of many bands indicates either that the slide is not being moved through the flame quickly enough or that the flame is too luminous. To correct the latter condition open the air adjustment of the burner. The colors will begin to fade as the thickness of the film increases. The best thickness for making splash patterns is reached when the color just disappears.

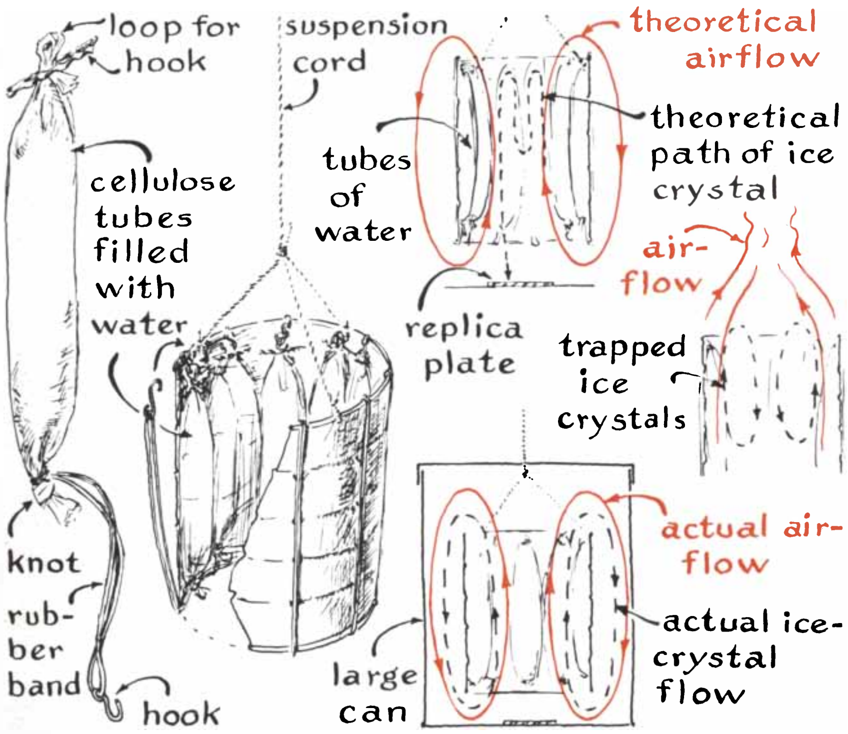
Both the height from which the drop



Photomicrographs of splash patterns



Graphs of the splash patterns



Wind tunnel for growing snowflakes

is released and the diameter of the drop influence the size of splash patterns. "One day," Wilder writes, "I noticed that the clear inner ring of a pattern made by a drop that fell from a height of 1.5 meters was larger than one made by a drop that fell only 25 centimeters, indicating that the size of the center ring varies with the terminal velocity of the drop. Twenty runs were then made from various heights but the results were meaningless. The outer diameter of the patterns also appeared to increase uniformly with height. A series of runs was then made to check the relation. This dimension, when plotted against the height from which the drops fell, resulted in a straight graph for falls between 10 and 25 centimeters [*see top illustration above*]. Below five centimeters the diameter decreased disproportionately. There was not enough time to investigate the effect at heights greater than 25 centimeters.

"Similarly, both the diameter of splash patterns and their overall configuration vary with the diameter of drops released from a predetermined height. In other words, the size and configuration of splash patterns bear a direct relation to drop diameter. A test made by releasing from a height of one meter drops that ranged in diameter from two to four millimeters resulted in a linear graph that included the diameter of substantially every drop. Drops of a given size always made similar patterns. I have had no opportunity to check the procedure with cloud droplets."

While Wilder was investigating splash patterns, Wahl developed a miniature wind tunnel for the production of snowflakes. Essentially his device consists of an open-end cylinder lined with cellulose tubes containing water. The assembly is suspended vertically in a chamber maintained at freezing temperature. The temperature difference between the water and the air generates an updraft through the cylinder. Evaporation from the permeable cellulose tubes causes a supercooled cloud to form in the cylinder.

This cloud can be "seeded" with particles of dry ice, just as natural clouds are seeded to trigger the precipitation of rain. The resulting crystals of ice are carried upward by the convection current and grow into snowflakes. Heavy flakes fall to the bottom of the cold chamber, where they can be collected in a shallow dish that contains a film of Formvar solution diluted with chloroform. When the film solidifies, impressions of the snowflakes remain. They can be examined at room temperature.

The cylinder consists of a tin can at least 10 centimeters in diameter and as tall as it is wide. The inner wall of the can is lined with closely spaced casings of the kind used by meat packers for making sausages [*see lower illustration at left*]. If sausage casings are not available, similar tubes can be made of sheet cellulose by joining the side edges of a sheet to form a tube; the edges are held together with plastic adhesive tape that resists water.

Wahl designed the assembly so that the cellulose tubes could be easily dismantled for replacing water lost by evaporation. He tied the bottom of each tube shut with a rubber band to which was attached a wire hook. When the tube is filled, the top is folded over and clamped shut with a bobby pin. After the filled casing has been placed in the assembly the rubber band is stretched around the outside of the can and attached by the wire hook to the loop of cellulose made by the top fold. The completed tunnel is suspended in the cold chamber by a sling of three wires attached to the upper rim of the can.

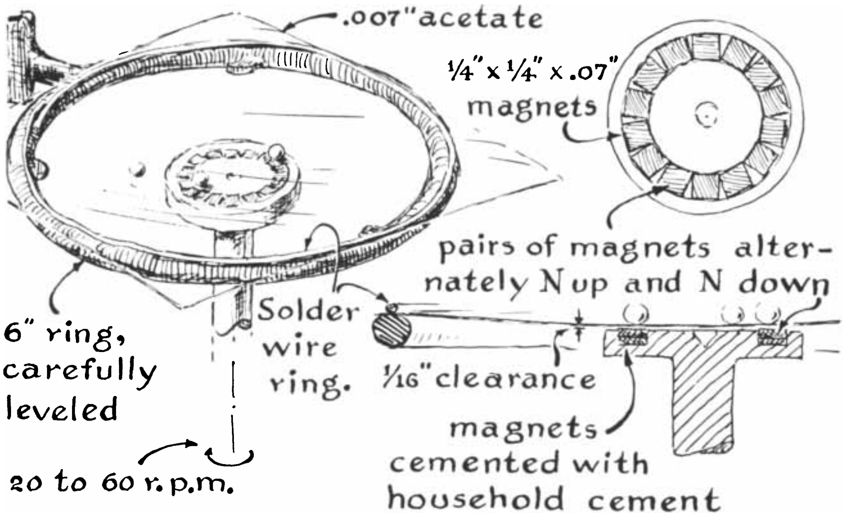
A cold chamber can be made of a pair of boxes—an outer one that is well insulated and an inner one, preferably of metal, that transmits heat readily. The chamber can be refrigerated by filling the space between the boxes with dry ice. The temperature need not be lower than 10 degrees Fahrenheit. The outer box can be inexpensively insulated with rock wool or with foam plastic of the kind used as packing material.

At subzero temperature on the Fahrenheit scale the apparatus operates for only short periods. At 10 degrees below zero ice forms on the casings in 15 minutes, and the water freezes solid within 25 minutes. The freezing could be prevented by inserting a short length of nickel-alloy resistance wire in each casing and applying enough electric current to maintain the water above 32 degrees F. This would allow longer cycles of operation and the production of larger snowflakes.

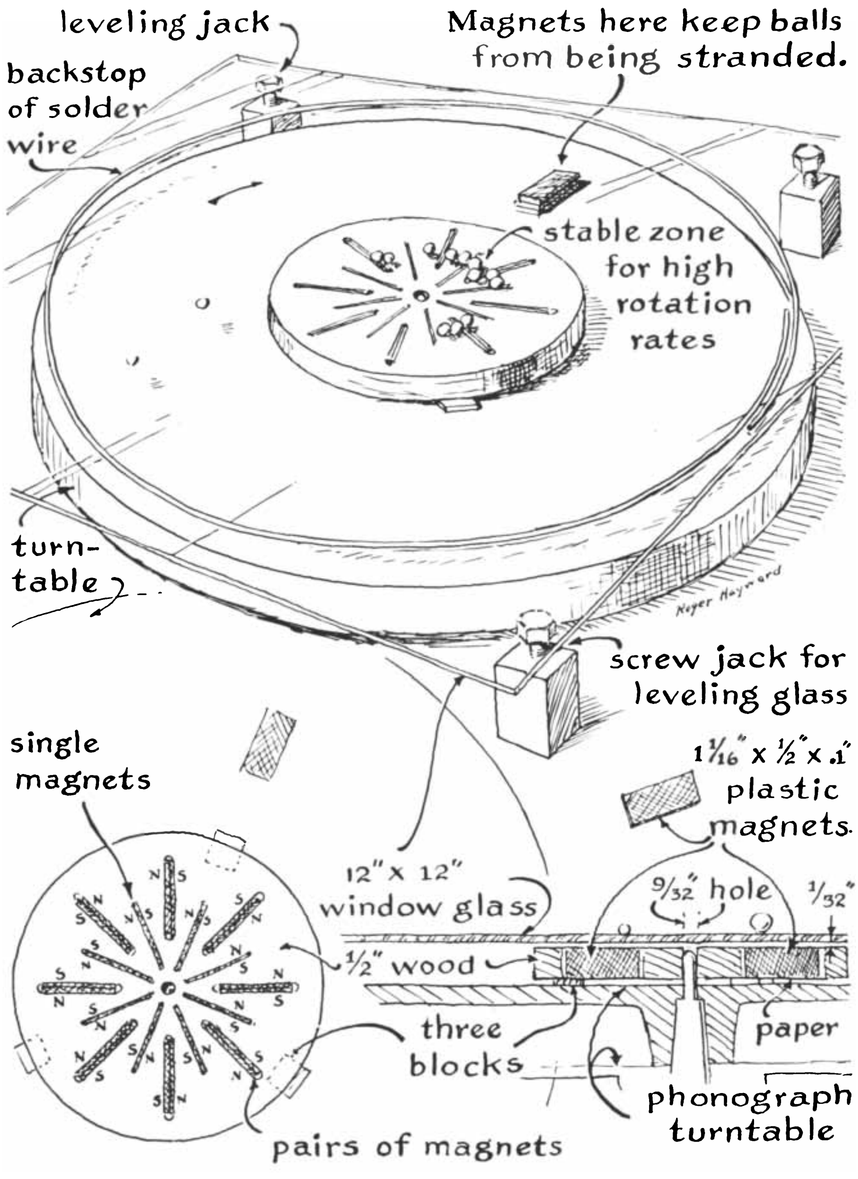
None of the snowflakes grown by Wahl were larger than one millimeter in diameter. "In repeated cold-chamber experiments," he writes, "many different shapes and sizes of crystals were observed. Most were typically hexagonal, some were nearly triangular and on several occasions nearly all were rectangular. Although the temperature of the chamber could not be regulated, exceptionally large crystals appeared when the temperature of the air was just below the freezing point.

"I observed that the convection current tended to blow the crystals up out of the cloud and over the sides of the chamber. Some crystals were swept back into the updraft at the bottom of the tunnel and made a second trip through the cloud, growing larger en route. This recirculation was obviously desirable in such an experiment. Several schemes were tried in an effort to establish continuous recirculation, but without much success. First a small polyethylene bag with a little hole in the top for seeding was tied over the top of the apparatus. Vapor condensed on the plastic, heat accumulated and the air became stagnant. A second tunnel was then fitted with a cylindrical extension at its upper end. I had hoped that the convection current would lose enough velocity in the extension to prevent the escape of crystals. This arrangement did not work either. Next a funnel extension was tried with substantially the same result.

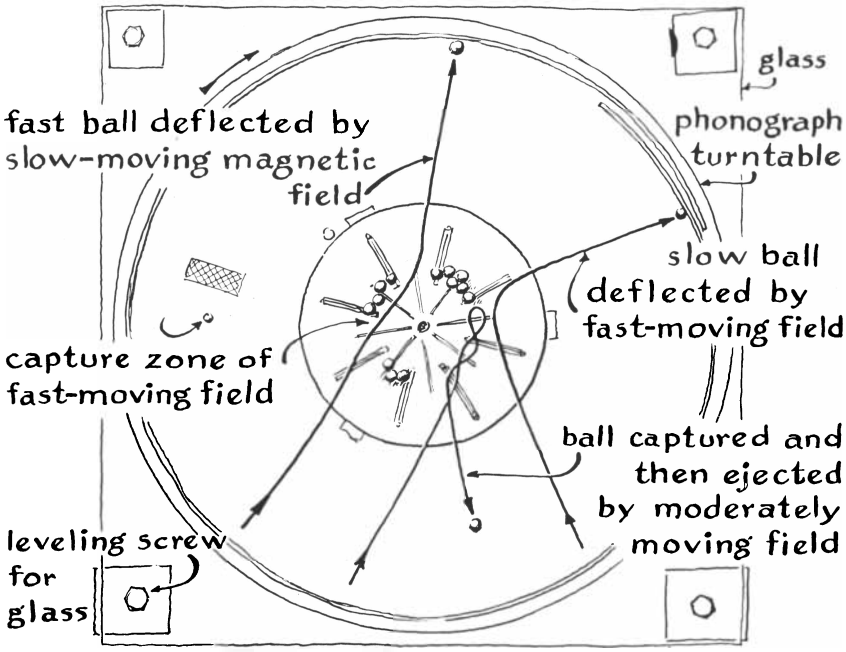
"Because of limited time I did not have an opportunity to try another idea—the use of an electric field to control the movement of the flakes. Most crystals of ice carry an electric charge that might possibly be used to control their movement. A boxlike arrangement could be improvised with electrodes in the form of wire screening at the top



Small model of the scattering apparatus



Larger apparatus for simulating nuclear scattering



Typical trajectories of scattered balls

and bottom. This apparatus would be placed in the cloud. A potential difference applied across the screens could be adjusted experimentally to balance the force of gravity as the ice crystals gain weight. With this arrangement it should be possible to grow snowflakes of any desired size."

Roger Hayward, whose illustrations regularly appear in this department, has devised a unique model that simulates the scattering of subatomic particles by a nucleus. "About nine months ago," he writes, "I bought a number of magnetic blocks that appear to be made of finely divided iron particles embedded in plastic. The larger units measure 1 1/16 inches long and 1/2 inch wide; the smaller ones are 1/4 inch square. All are about 3/32 inch thick. I understand that the units are commonly used for clamping papers to bulletin boards made of sheet iron. My objective was to construct a dynamic model for demonstrating some of the properties of a single atom of gas by setting up a rotating multipole magnetic field that would act on a set of steel balls 3/16 inch in diameter. The balls are supported just above the magnets by a level sheet of glass.

"My first model consisted of 14 pairs of 1/4-inch magnets, cemented in an annular groove machined in a disk of clear plastic [*see top illustration on preceding page*]. The stacks were arranged so that the magnetic poles faced alternately up and down. A hole was drilled in the center of the disk to fit a vertical spindle on which the assembly could be rotated. The speed of rotation could be varied continuously from about 10 to 100 revolutions per minute. The steel balls rolled on a thin sheet of plastic, and the plastic was in turn held in place by the ring support of an apparatus stand.

"The arrangement works quite well when the magnets are rotating in the range from 20 to 40 r.p.m. Balls launched squarely across the magnetic field are either captured or deflected in random directions. Balls can be launched in a desired direction at constant and reproducible speeds by means of a small inclined track.

"I next constructed a similar model equipped with the larger magnets, which were rotated by means of a nonmagnetic phonograph turntable [*see bottom illustration on preceding page*]. The disk that supported the magnets was cut from 1/2-inch plywood and was slotted radially to take 24 magnets. The poles of these magnets appear on the large faces of the rubber strips. Eight radial grooves, which terminate near the center of the disk, each hold an array of magnets assembled so that the north pole of each magnet faces the south pole of its neighbor.

"A second set of radial grooves was cut midway between the first set and spaced about half an inch farther from the center than the first set. Each of these grooves holds two magnets with opposite poles in contact. The combined field of these magnets points in the same direction as that of the inner set of magnets.

"The center of the disk was drilled to make a snug fit with the spindle of the phonograph. I think that the spindle is steel and that there may be a friction clutch of steel under the aluminum turntable. If so, these parts do not appear to distort the magnetic field significantly. I blocked a 12-inch square of window glass over the turntable so that it cleared the top of the magnets by about 1/32 inch. Incidentally, most window glass is slightly concave on one side and slightly convex on the other. The manufacturer's label is usually fixed to the convex side. The glass should be placed over the magnets with the concave side upward. Both the turntable and the glass were leveled to within about .005 inch by means of jacks improvised by threading a set of small blocks to accommodate cap screws. When the balls are placed on the leveled glass, they do not roll unless started, and once they are started they seem to roll equally well in all directions.

"In one sense this model is more limited than the first one because the speed of rotation is restricted to 33⅓, 45 and 78 r.p.m. On the other hand, the larger size presents a more attractive display. The accompanying illustration [*opposite page*] depicts the typical deflection path of a 'particle' that penetrates the 'nucleus,' the capture and subsequent emission of a particle and the trajectory of a sharply deflected particle. When the field is rotated at 78 r.p.m., a large number of balls are captured. The balls seem to become sufficiently magnetized to attract each other. At 45 r.p.m. the mass becomes unstable and a few balls escape. When the speed is reduced to 33⅓ revolutions, the mass becomes very unstable, and within seconds balls are scattering in all directions.

"Balls occasionally enter the capture zone and are immediately ejected. One would be hard put to show a statistical relation between the trajectory of the balls and the nature and size of the magnetic array. I suppose it would be possible to demonstrate some effective diameter of the nucleus by a statistical analysis of the trajectories. The stack of three magnets that appears in the illustration at the half-radius point merely creates activity when there are a number of balls on the glass. These magnets might represent another near atom that would be expected to deflect free particles."

BOOKS

Is it possible for anyone to "understand" physics?

by Max Black

BEYOND THE EDGE OF CERTAINTY: ESSAYS IN CONTEMPORARY SCIENCE AND PHILOSOPHY, edited by Robert G. Colodny. Prentice-Hall, Inc. ($8.75).

Not to understand modern science is to be in a certain sense illiterate, excluded like the tone-deaf from a whole realm of intellectual and imaginative insight. But to say this is merely to raise some perplexing questions. What is it to *understand* modern physics, for instance, short of being a qualified physicist? What kind of grasp of fundamental theory is feasible for a nonspecialist? How does understanding differ, if at all, from the power to handle mathematical algorithms?

Some light might be thrown on these important and nagging questions by examining this collection of essays on physics and its philosophy (originally composed as lectures for delivery at the University of Pittsburgh). All the distinguished authors are engaged, with varying degrees of success, in trying to make sense of physics, not only for nonspecialists but also for the high practitioners themselves.

Only an alliance between history and logical analysis can be of much help. The antiseptic presentation of fundamental theory in contemporary textbooks, where all the rough edges have been trimmed away, too often yields a specious and deadening pseudo-clarity. It is often highly instructive, even for specialists who want chiefly to use the theory, to return to the gropings of the first discoverers. In one way or another many of the present authors follow the path of what might be called idealized history; they seek, more or less consciously, to reconstruct what the history of an idea would have been had its evolution been unimpeded by confusion and false starts.

The obvious risks in amalgamating historical narrative with logical criticism are well illustrated in Norwood Russell Hanson's provocative essay "Newton's First Law: A Philosopher's Door into Natural Philosophy." I was taken aback at the outset by Hanson's flat statement that "Newton's first law of motion reads: EVERY BODY FREE OF IMPRESSED FORCES EITHER PERSEVERES IN A STATE OF REST OR IN UNIFORM RECTILINEAR MOTION *AD INFINITUM*." (The capitals and italics are Hanson's.) The generally accepted rendering of Newton's Latin text runs as follows: "Every body continues in its state of rest, or of uniform motion in a right [that is, straight] line, unless it is compelled to change that state by forces impressed upon it."

Why does Hanson, with the Latin text before him (it is reproduced in his first footnote), gratuitously import the reference to infinity, with all its notorious philosophical difficulties? The answer may be that Hanson has a preconceived idea that the first law cannot be construed as a straightforward generalization from accessible experience. No doubt Hanson is right, but it is another matter to saddle Newton with the insight of Ernst Mach or some other late commentator. Newton's own comment on the first law—with its reference to the observable motions of projectiles, tops, planets and comets—suggests that he himself thought of the law as arising from observation more directly than Hanson and others would accept. (That scientific theory involves some measure of idealization can surely be taken for granted.) Newton's philosophy of science may have been inadequate, but it is a violation of elementary historical method to think of him as an early Ludwig Wittgenstein.

Hanson wants to argue that Newton's first law does not refer to "certain demonstrable facts," that it ought, indeed, to be construed as a "counterfactual conditional," asserting what *would* happen if—as is never the case—a body were found free of any impressed forces. Unlike Hanson, I do not think that this is the "logically most transparent form" of the law, if only because similar logical transformations would allow too many generalizations that are soundly supported by observations to appear to be just as dubiously "counterfactual." For instance, the generalization "All hot bodies attract one another" can be transformed by contraposition into the counterfactual form "Bodies that did not attract one another would not be hot," which is hardly an improvement. I would suppose that Hanson's counterfactual rendering is a consequence of the law rather than an accurate analysis.

Hanson's main conclusion about the first law is that it is "really a *family* of schemata" (his italics). He means, in part, that we are largely free to adopt some of the law's constituent terms as being primary and then to define the others by means of them; we can choose "different semantical platforms" to which we can attach the fundamental laws, and their logical status will vary correspondingly.

I wonder about that "really" in Hanson's verdict. That we have a considerable degree of freedom in the choice of the primitive terms of an axiomatized theory has been well known ever since alternative axiom systems of Euclidean geometry were first constructed. But that the logical character of the resulting propositions is altered by such choices needs more argument than Hanson provides. I think Hanson exaggerates the difficulties in attaching a clear meaning to Newton's principles. It is surely an overstatement to maintain that "*every law* within physics is a cornucopia of philosophical perplexities and conceptual excitement." I cannot get very excited about Boyle's law.

Brian Ellis' analysis of Newton's principles, in which he pays special attention to Newton's second law (concerning the measurement of the "impressed forces" in terms of communicated changes in momentum), is a good deal cooler and more lucid than Hanson's. Ellis' conclusion that the second law "has a variety of different roles" is close to Hanson's own position. The implied relativity of the fundamental concepts comes out clearly in Ellis' judgment that "forces exist only because we choose to regard certain changes or states as natural and others as unnatural."

This sounds illuminating until one perceives it to be as good as platitudinous. A "natural" motion, by definition, is one that a body performs "on its own," that is, without the participation or interference of other bodies or media. If so, external forces must, of course, be invoked to explain any deviation from such free or natural motions. But it is going pretty far to suggest that we can "choose" to consider any motions we please as being "natural." For one thing, the notion of a force is closely linked, at any rate in prescientific thought, with the concept of a material source, whether a body or a field—common sense cannot tolerate the notion of free-floating forces exerted by *nothing* substantial. Some invocations of forces to explain "unnatural" motions will violate this condition; others will violate essential features of causal concepts. (Consider Newton's own qualms about "action at a distance.") It is a weakness of Ellis' often imaginative discussion that he does not pursue such topics.

Altogether I think that Hanson and Ellis overemphasize the degree to which Newton's laws and Galileo's imperfect anticipation of them express conceptual connections rather than generalizations from observations. Hanson makes much of Galileo's use of the *Gedankenexperiment,* or thought experiment. But the very term *Gedankenexperiment,* which Mach managed to establish as part of the working vocabulary of the philosophy of science, invites romantic confusion.

Take one famous example. According to the Aristotelian law of free fall, heavier bodies should descend faster than lighter ones. Galileo, by a brilliant stroke, imagines a heavier stone bound to a lighter one, so that the two fall together as one. He then argues that the heavier body, which according to the Aristotelian view would move faster if it could, must drag the lighter stone forward; the lighter stone must similarly hold its partner back. Therefore the resultant velocity must be intermediate between those that the two bodies would have if they fell separately. This means that the combined body, which is heavier than either of the parts, must in fact fall with a velocity less than that of one of its parts!

At first one might easily gain the illusory impression that Galileo has here established, by reasoning and imagination alone, a result that must necessarily be confirmed by experience. (There is evidence that Galileo sometimes thought this way himself.) But the label "thought experiment" is misleading if it suggests that imagination alone can inform us as to what must as a matter of fact happen in the real world. Mach has illuminating things to say on this point in a neglected paper on the *Gedankenexperiment* (in his *Erkkentnis und Irrtum,* second edition, 1906). A thought experiment, he points out, is basically a redeployment of concepts themselves based on correct or partly erroneous previous experience; it is a telescoped and vivid equivalent, we might say, of a piece of formal reasoning. Thus Galileo's tour de force of the combined falling stones could easily enough—and to some advantage—be represented as a strict argument. There is evidence in Galileo's *Dialogues concerning Two New Sciences* that he conducted fairly elaborate experiments on inclined planes and pendulums. Galileo's genius shows in his ability to wed experiment and theoretical construction; it does him less than justice to stress one of these at the expense of the other.

The difficulties of making sense out of classical physics, formidable as they can be made to seem, are dwarfed by those of understanding quantum physics. The acceptance of *discontinuous* transitions ("quantum jumps") in interactions of matter and radiation, initiated by Albert Einstein and Max Planck and necessitated by the occurrence of phenomena that classical physics was helpless to explain, might have been assimilated readily enough were it not for the simultaneous need to use mathematical formalisms and physical models based on the acceptance of *continuous* interaction and transmission of energy ("waves"). These two radically opposed types of explanation, each powerfully supported by success in predicting experimental results, have never been successfully reconciled. In the effort to make the particle and the wave lie down together, philosophically minded physicists have sometimes resorted to extraordinary expedients, involving the drastic rejection of accepted ideas about causation, spatiotemporal location, material identity and much more. (An onlooker might be forgiven for thinking that no price in philosophical absurdity has seemed too high to pay for the elimination of apparent contradiction.) Many of these interpretations of the mathematical symbolism were too fantastic to satisfy even their own inventors for long; it is therefore not surprising that many physicists have seized with relief on the "Copenhagen interpretation" advocated by, among others, Niels Bohr. This can be described very roughly as a program for treating the basic terms of quantum physics as "theoretical fictions," symbols that lend deductive power within the mathematical framework of the theory but that stand for no entities or processes with independent reality. On this view, talking about the "position" or "momentum" of an elementary particle or a photon is no more than a reference to an auxiliary symbol that facilitates prediction, in favorable cases, of information wholly describable in classical terms (tracks in a bubble chamber, specks in a photographic emulsion and so on).

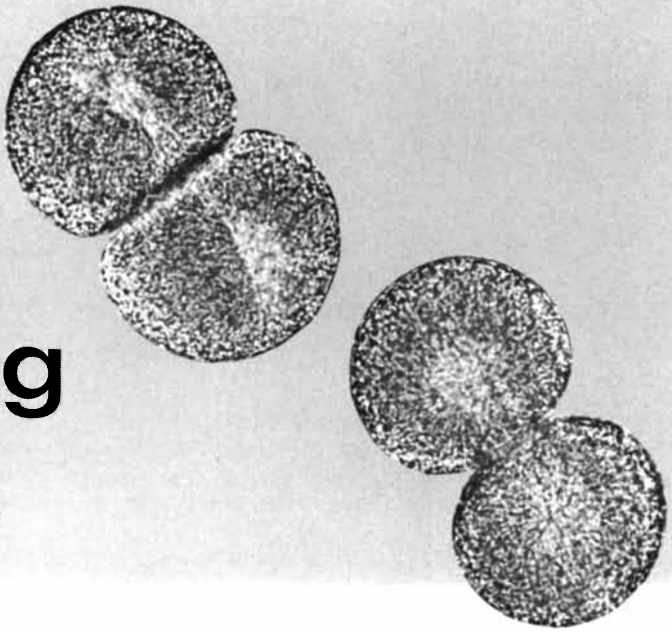
In practice this radically instrumental view of the situation has rarely been advocated. Writers such as Bohr and Werner Heisenberg are more likely to waver between a positivistic and a sporadically realistic attitude; this shows up, for example, in confusing but all too popular talk about "measurement *creating* position." The advantages of positivism are obvious: it seems to bypass the baffling ontological questions and allows the theorist the peace of mind that comes from accepting the formula that whatever works is conceptually respectable. Rigidly adhered to, this kind of approach would leave the impressive structure of post-Newtonian physics looking like a series of mysterious mathematical dodges, whose success in predicting phenomena—often startlingly novel ones—has to be regarded as an ultimate datum for which no further explanation is possible. Although few of the great physical innovators of our century have been content to take this extreme position, their attempts to gloss mathematical physics, to explain how the "theoretical fictions" or "auxiliary symbols" might fit into a rational conception of the universe, have remained extremely confusing.

Hilary Putnam's lecture on this thicket of unresolved problems ("A Philosopher Looks at Quantum Mechanics") seems to me—in originality, clarity and insight—one of the best things I have read on the subject during the past decade. For one thing, I find helpful his strategy of distinguishing among three distinct ways, all historically influential, of interpreting the mathematical symbolism of quantum physics. First we have what Putnam calls "the De Broglie interpretation of quantum mechanics," the view, in brief, that

Announcing the publication of

The Living Cell

readings from SCIENTIFIC AMERICAN



Introductions by Donald Kennedy, Stanford University

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CLIFFORD GROBSTEIN, University of California, San Diego

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University of Georgia

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________THE LIVING CELL

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"physical systems *are* sets of waves." Somewhat later in the history of the modern philosophy of physics we get the early form of the Copenhagen interpretation (Putnam calls it the "Born interpretation"), the view that elementary particles are point masses in the classical sense, having determinate positions and velocities, whereas the corresponding "waves" represent not some indeterminate condition of the physical world itself but rather our necessarily incomplete knowledge of the states of the particles. Finally, we have the full-fledged Copenhagen interpretation that "says, in a nutshell,... that 'observables,' such as position, *exist* only when a suitable measurement is actually being made."

To me Putnam's argument that none of these popular approaches will ultimately work is convincing. The De Broglie view comes to grief in trying to cope with what happens when a measurement is made. Anybody who insists that the quantum "waves" have objective reality will have to swallow the idea that observation is always accompanied by the sudden concentration of the "wave" at the place of observation, as if it obligingly collapsed almost everywhere else in order to make precise and localized measurement possible (the "reduction of the wave packet"). Putnam shows restraint when he says that this would have to count as "very strange behavior." It would not be unfair to say that such behavior, if we still wanted to call it such, would be unintelligible in the absence of further explanation.

The Born interpretation takes this kind of difficulty in stride. What "collapses" or "contracts" at the moment of observation is a certain distribution of knowledge, indeed, a knowledge of probabilities; before the measurement only probabilities can be assigned to the particle's possible positions, whereas afterward its location can be determined with relative precision. This is, on the face of it, no more surprising than the transition from probability to certainty after a die has been cast. Unfortunately this attractive way out goes too far in denying the reality of waves; the famous "two-slit experiment," much discussed in the literature, seems to show that the interference patterns produced can be reasonably explained only if we attribute some kind of causal influence to the waves. In general it is discouragingly hard to understand how "probability waves" could be considered to have genuine physical effects.

Putnam's objections to the full Copenhagen position are too detailed to be summarized adequately. He makes much of the point that the Copenhagen view is committed to holding that "macro-observables," which can be directly measured by classical instruments in the laboratory, have to be assumed to be "sharp," or precise, at all times, and that the "micro-observables" alone (the individual properties of elementary particles, for instance) have sharp values only when measured. An obvious objection is that it is often possible to trigger macroscopic events by microscopic ones, as in the familiar case of the click of a Geiger counter, or the more picturesque example of "Schrödinger's cat," which is electrocuted when a photon manages to pass through a half-silvered mirror. On the Copenhagen view it is hard to avoid the absurdity of saying that the cat is neither dead nor alive until it is observed.

The resourceful defenders of the Copenhagen view may be able to find convincing answers to the difficulties Putnam has sharply raised against them. One unusual merit of his discussion is the pains he has taken to bring into the open the assumptions he is making or those he attributes to the targets of his criticism. This is a promising path to further clarity. It is much to be hoped, for example, that some pro-Copenhagian will someday take the time to explain in detail precisely to what theory of measurement that approach is committed.

Of the remaining articles, the most remarkable is a jumbo-sized essay by Paul K. Feyerabend ("Problems of Empiricism"), the 73 pages of which are supplemented by notes occupying an additional 42 pages. If this piece does not contain the proverbial kitchen sink (as I am reasonably sure), it compensates by reproducing three large pictures of rhinoceroses (with a long quotation from Ernst Gombrich's well-known *Art and Illusion*). Feyerabend, in this as in other of his copious writings, has interesting and suggestive criticisms to make against certain simplified but still influential forms of empiricism. But he spoils a good case, for one reader at least, by a certain stridency.

Philip Morrison's essay "The Physics of the Large" oscillates between a rehearsal of what might by now be taken to be familiar (photographs of galaxies, for instance) and all too brief references to such sophisticated matters as "Hubble times" and the Robertson-Walker form for local interval in relativity. It is hard to imagine the reader for whom this is intended. David Hawkins ("The Thermodynamics of Purpose") engages in speculation about what he calls "natural teleologies" that roves across almost every branch of science, and Nicholas Rescher's discussion "The Ethical Dimension of Scientific Research" ends with hardly more than is obvious (scientists must choose research goals, decide how much credit to claim in cooperative enterprises and so on). One obligation Rescher does not discuss is that of trying to make the great conceptual advances of science more intelligible to the common reader.

Short Reviews

JANE'S ALL THE WORLD'S AIRCRAFT, 1964–65, compiled and edited by John W. R. Taylor; JANE'S FIGHTING SHIPS, 1964–65, edited by Raymond V. B. Blackman. The McGraw-Hill Book Company ($42.50 each). During the past several years Jane's annuals have had an increasingly lugubrious tone as they reviewed the trials and tribulations of the world's fleets of aircraft and fighting ships. No matter what portions of various national treasuries are lavished on these fauna, *Jane's* always seems to feel the amounts are inadequate. *Jane's Aircraft* this year observes that never in its 55 years of publication has the future looked "more full of foreboding" for large sections of the aircraft industry. The gloom is supported by such circumstances as the uncertain fate of the Anglo-Concorde supersonic airliner, the "tragic and confused life story" of the XB-70A ("a bomber that will never carry a bomb," on which the U.S. has spent $1.5 billion), the resistance of commercial airlines to buying the Super VC-10, and so on. Still, there are many new developments the editor feels are worth celebrating. Among interesting possibilities for the future he suggests the use of monorail coaches to transport passengers from large cities to airports; on arrival the coaches would be attached to the bellies of flying cranes for quick flights to other cities.

Jane's Fighting Ships is, for a change, reasonably cheerful as evidence accumulates that not only the Royal Navy, which had suffered a "massive run down" from its wartime strength, but also several other nations are determined "to use the sea as never before" in deterring miscreants and maintaining blissful peace in the world. Included in the foreword is a quotation from the U.S. Chief of Naval Operations, who suggests that in order to meet "the whole spectrum of possible aggression" the U.S. Navy, in spite of the "limited" funds available to it, will have to continue to build new ships, engender new concepts, develop nuclear propulsion and at the same time maintain every war canoe now in being—suitably modernized. Both annuals add hundreds of new illustrations.

MENTAL HEALTH FOR THE POOR: NEW TREATMENT APPROACHES FOR LOW INCOME PEOPLE, edited by Frank Riessman, Jerome Cohen and Arthur Pearl. The Free Press of Glencoe ($9.95). The lives of the poor reflect a special subculture; this subculture renders its members unable to use the modern individual psychotherapy, which takes time and money and is adapted to the intellectual mind. The poor are not easily persuaded to seek psychotherapy; when they do, they are often rejected as unsuitable subjects or drop out before the therapy is well advanced. The poor, say the editors of this book, differ from the better-to-do in that their primary motivation is to seek security rather than status. They are practical and anti-intellectual. They regard the world as unpredictable; they believe in luck. They are easily angry on behalf of the underdog, ready for excitement and action, centered on persons and objects, not on ideas and abstractions. Therapeutic self-analysis lies outside their thing-centered natures, yet they need help with their mental difficulties and illnesses. How are they to get it?

Society has now become deeply interested in the problem, and this book, which reprints 57 excerpts from articles by 67 authors, undertakes to clarify the problem and describe the proposals for making mental therapy available to the poor with respect to time, money and motivation. First, psychotherapy for the poor needs to be shortened and rendered more accessible by giving it over to brief sessions with the general practitioner in his ordinary practice. For this the general practitioner needs to have had special psychotherapeutic training. He must learn to offer in his practice total help—physical and mental. In this process psychotherapy must be deintellectualized; a common man's practical total therapy must be formulated. Since the common man is thing-oriented, the general practitioner will meet his faith in pills and needles by supportive use of tranquilizers, sedatives, stimulants, hormones and vitamins, which may function well in actuality or as placebos. Such therapy inevitably becomes "directive"; the insecure, practical anti-intellectual wants to be cured, not merely led to understand how to cure himself.

There is also a sociotherapy for the poor. Let the patient identify himself with a movement, so adding faith to medicine. Let him join neighborhood committees, the Negro movement, the youth movement. Negro crime diminished in Montgomery when the boycott was on. Joining the Black Muslims may reduce drug addiction. The new general practitioner who treats the whole person of the poor will not be able to shrug off delinquency as beyond his province. The delinquent is not well; he too needs help.

This is a big book—full of facts, opinions, experiments and people, but it has no index of topics or names. This omission sharply curtails its usefulness.

A DICTIONARY OF MODERN ENGLISH USAGE, by H. W. Fowler, revised and edited by Sir Ernest Gowers. Oxford University Press ($5). For anyone who loves the English language there has never been a better companion and a more delightful guide than Fowler's elegant, fastidious and idiosyncratic handbook. It is a work of character, a mirror of the moral and intellectual excellence of its creator. It is the happiest of circumstances that Sir Ernest Gowers was available and was selected by the Oxford University Press to revise the book. This he has done with fine feeling, leaving all the Fowleresque flavor. He has trimmed—as Fowler himself wistfully remarked in his dedication he might himself have done—some of the "prolixities," pruned some of the illustrative quotations, omitted a few superfluous entries, rearranged for convenience, added items here and there and carefully modified judgments that have suffered with time and usage. No one will want to get rid of his old Fowler and no one will want to do without the new; they belong together on the literate person's bookshelf.

KEPLER'S DREAM, with an introduction by John Lear. University of California Press ($5). A first translation into English (by Patricia Frueh Kirkwood) of Kepler's *Somnium, Sive Astronomia Lunaris,* a fanciful moon journey and a guide to lunar geography. The text is prefaced by Lear's 80-page introduction and interpretation (garlanded by 183 footnotes), which attempts to show that Kepler's dream is a "serious scientific work" and is somehow related to the ordeal of Kepler's mother when she was accused of witchcraft. Except for parts of the introduction, which are of antiquarian interest, the book is something of a bore. Kepler's dream could safely have been allowed to remain in the dustbin of oblivion.

LISTEN TO LEADERS IN SCIENCE, edited by Albert Love and James Saxon Childers. David McKay Company ($5.50). This is a curious volume devoid of any distinct character. It presents a series of essays—obviously tape-recorded and edited—by a number of leading scientists, who attempt to explain their own specialties, why they got into them and where future opportunities for research lie. One supposes the book is addressed either to older teen-agers or to their parents or both. The end product, in spite of the high competence of the contributors—including George Gaylord Simpson, George Wald, George W. Beadle, J. Robert Oppenheimer and George A. Miller—is vague, aimless, chummy and altogether unsatisfactory.

THE FUSION OF PSYCHIATRY AND SOCIAL SCIENCE, by Harry Stack Sullivan. Introduction and commentaries by Helen Swick Perry. W. W. Norton & Company, Inc. ($7.50). This is a collection of papers by Harry Stack Sullivan, the influential psychiatrist who died in 1949. Together with *Schizophrenia as a Human Process,* published in 1962, these essays and lectures form a fairly complete record of Sullivan's professional career. Particularly noteworthy are the two lectures "The Illusion of Personal Individuality" and "The Meaning of Anxiety in Psychiatry and in Life." In them Sullivan sets forth more persuasively, eloquently and clearly than in his other writings his notion of interpersonal relations: how the individual sees others, how he makes them into the image of his desire, what he seeks to find in them and how by this process he both helps and deprives himself, shapes his life and personality and theirs. Like Freud, Sullivan is much more effective in his own words—although they are often groping and involved—than in the words of his disciples.

THE EXPULSION OF THE TRIUMPHANT BEAST, translated and edited by Arthur D. Imerti. Rutgers University Press ($7.50). An English translation of Giordano Bruno's celebrated allegorical and polemical work that attacked the social evils of his day and sniped at prevailing religious orthodoxies. It was perhaps the single most influential factor in bringing about Bruno's condemnation for heresy by the Inquisition and his consignment to the flames. A long introduction contributed by the editor discusses Bruno's life and ideas and vividly describes his trial.

HANDBOOK OF CHEMISTRY AND PHYSICS, edited by Robert C. Weast and others. The Chemical Rubber Publishing Company ($15). The 45th edition of this well-known reference embodies one radical change and a number of revisions and enlargements. In place of the squat, corpulent volume so familiar to more than a generation of technical workers the handbook has now acquired a much larger format. Only in this way has it been possible to keep the work within a single volume and allow for future growth. New data have been added to many tables; some of the older tables have been eliminated.

THE DEVELOPMENT OF MODERN CHEMISTRY, by Aaron J. Ihde. Harper & Row ($13.50). A scholarly and well-written history of chemistry from the time of Lavoisier that deals both with experimental and theoretical advances and with their impact on industry, military affairs, biology, agriculture and medicine. Some attention is also given to the relation between chemistry and social, political and economic circumstances. There are valuable annotated bibliographies for each period and topic and abundant illustrations.

MATHEMATICS: ITS CONTENT, METHODS AND MEANING, edited by A. D. Aleksandrov, A. N. Kolmogorov and M. A. Lavrent'ev. The M.I.T. Press ($30). The first volume of this work was published by the American Mathematical Society and was reviewed in these columns early last year. The set is now complete and includes sections on such topics as partial differential equations, the calculus of variations, prime numbers, probability theory, approximation methods, computers, topology, non-Euclidean geometry and group theory. As the earlier notice stated, the survey is well suited to the needs of advanced students and teachers.

TERRITORY IN BIRD LIFE, by Eliot Howard. Atheneum ($1.75). A reissue in soft covers of a literate and scientifically valuable monograph on the territorial factor in the life of birds, first published in 1920 by the late Henry Eliot Howard. Sir Julian Huxley and James Fisher contribute to this edition a foreword that summarizes the past 40 years of work on the subject of bird territoriality. The foreword characterizes Howard's book, which stimulated further researches as well as healthy disputes, as a milestone in the history of ornithology.

SELECTED PAPERS OF NORBERT WIENER, with contributions by Y. W. Lee, N. Levinson and W. T. Martin. The M.I.T. Press ($12.50). This volume was originally intended to honor Norbert Wiener's 70th birthday, which fell some seven months after his death last year. It brings together several of his major mathematical and technical writings that had previously appeared only in journals, including two very long works: *Generalized Harmonic Analysis* and *Tauberian Theorems.* Included is a fine portrait of Wiener.

BROOKLYN BRIDGE, by Alan Trachtenberg. Oxford University Press ($5.75). The Brooklyn Bridge is more than a great and beautiful piece of engineering; it was in its time a symbol of national destiny and culture, an expression of ambition and optimism. It was also, in some respects, a betrayal of Utopian visions, in the sense that it contributed, as would other bridges, tunnels and roads yet to come, to the growth of multitudinous evils that emerged from the expansion of cities and industries. This is the theme Trachtenberg takes up in an essay that, although it occasionally gets lost in poetic labyrinths, is sensitive, intelligent and firmly shaped.

PREHISTORIC TECHNOLOGY, by S. A. Semenov. Translated by M. W. Thompson. Barnes and Noble ($12.50). A translation from the Russian of a monograph that first appeared in 1957 in a Soviet series on researches in archaeology. The most interesting aspect of Semenov's book is a careful analysis by microscopic and other techniques of the uses of stone and bone tools, a reconstruction made possible by a study of the abrasions and other markings on the tools themselves. The book is illustrated with many photographs and diagrams that show specifically how the tools were held and applied.

QUASI-STELLAR SOURCES AND GRAVITATIONAL COLLAPSE, edited by Ivor Robinson, Alfred Schild and E. L. Schucking. The University of Chicago Press ($10). GRAVITATION THEORY AND GRAVITATIONAL COLLAPSE, by B. Kent Harrison, Kip S. Thorne, Masami Wakano and John Archibald Wheeler. The University of Chicago Press ($6.50). These two volumes include the proceedings of a symposium on relativistic astrophysics held in Dallas in 1953. The main addresses on the important subject of the quasi-stellar radio sources are contained in the first volume. An expanded version of the paper by Wheeler and others suggesting that a portion of the collapsing matter of a neutron star disappears from existence is contained in the second.

Notes

SICK CITIES, PSYCHOLOGY AND PATHOLOGY OF AMERICAN URBAN LIFE, by Mitchell Gordon. Penguin Books ($2.25). An effective survey of the ills of American urban life: the stinking air the inhabitants have to breathe, the traffic constipation, the rat-infested, firetrap schools and the wretched buildings in which men have to live. Paperback reissue.

HISTORY OF THE EXPEDITION UNDER THE COMMAND OF LEWIS AND CLARK, edited by Elliott Coues. Dover Publications, Inc. ($6.75). An attractive, unabridged three-volume paperback reprint of the four-volume Coues edition (1893) of the superb and fascinating journals of Lewis and Clark. Engravings, facsimile letters and maps.

THE MOSSES OF MICHIGAN, by Henry T. Darlington. Cranbrook Institute of Science ($12). A delicately illustrated treatise on the 43 families, 125 genera and 377 species of the mosses of Michigan.

POPULATION PROBLEMS, by Warren Thompson and David T. Lewis. McGraw-Hill Book Company ($8.95). This fifth edition of a study of essential facts relating to population has been almost entirely rewritten.

THEORIES OF THE UNIVERSE, edited by Milton K. Munitz. The Free Press ($2.45). Munitz' collection of cosmological speculations from Babylonian myth to modern science is here reissued in soft covers.

ADVANCES IN GERONTOLOGICAL RESEARCH, edited by Bernard Strehler. Academic Press ($13.50). The first volume of a series intended to provide coverage of various specialized areas of research on aging.

STRUCTURE OF MATTER, by Wolfgang Finkelnburg. Academic Press ($14.50). An English translation of the 10th edition of a German monograph, primarily addressed to students, dealing with our present knowledge of the structure of matter from elementary particles to solids.

PROGRESS IN OCEANOGRAPHY: VOLUME II, edited by Mary Sears. The Macmillan Company ($12). The second volume in this series includes articles on the major deep-sea expeditions between 1873 and 1960, the distribution of zooplankton in the sea, the distribution of phosphorus and oxygen in the Atlantic Ocean. Illustrations.

TEXTBOOK OF ALGEBRA, by George Chrystal. Chelsea Publishing Company ($4.70). Chrystal's text, first published in the 1880's and many times revised, is here issued in a two-volume softcover edition.

ATMOSPHERIC RADIATION, by R. M. Goody. Oxford University Press ($8). The first of two volumes concerned with the interaction of solar electromagnetic energy and the earth's atmosphere, the subsequent redistribution of this energy and its ultimate return to space in the form of low-energy radiation.

BIOGRAPHICAL MEMOIRS OF FELLOWS OF THE ROYAL SOCIETY: VOLUME X. The Royal Society ($6). These memoirs include obituaries of Gerhard Domagk, Herbert S. Gasser, David MacDonald, Otto Struve, E. C. Titchmarsh, Øjvind Winge and Sidney Wooldridge. Portraits and bibliographies.

KIRK-OTHMER ENCYCLOPEDIA OF CHEMICAL TECHNOLOGY: SECOND EDITION, VOLUME V, edited by Anthony Standen and others. John Wiley & Sons, Inc. ($45). The articles in this volume run from chlorine through colors for foods, drugs and cosmetics.

WEATHER EYES IN THE SKY, by J. Gordon Vaeth. The Ronald Press Company ($5). The story of weather satellites told for the general reader. Numerous illustrations.

THE CLIMATE NEAR THE GROUND, by Rudolf Geiger. Harvard University Press ($11.50). A revised version, translated from the fourth German edition, of an authoritative text on micrometeorology.

THE ARCHAEOLOGY AND GEOMORPHOLOGY OF NORTHERN ASIA: SELECTED WORKS, edited by Henry N. Michael. University of Toronto Press ($6.50). This volume consists of 18 articles translated from Soviet sources.

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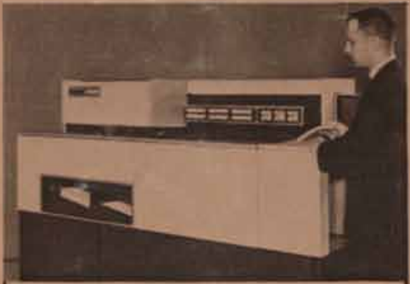

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