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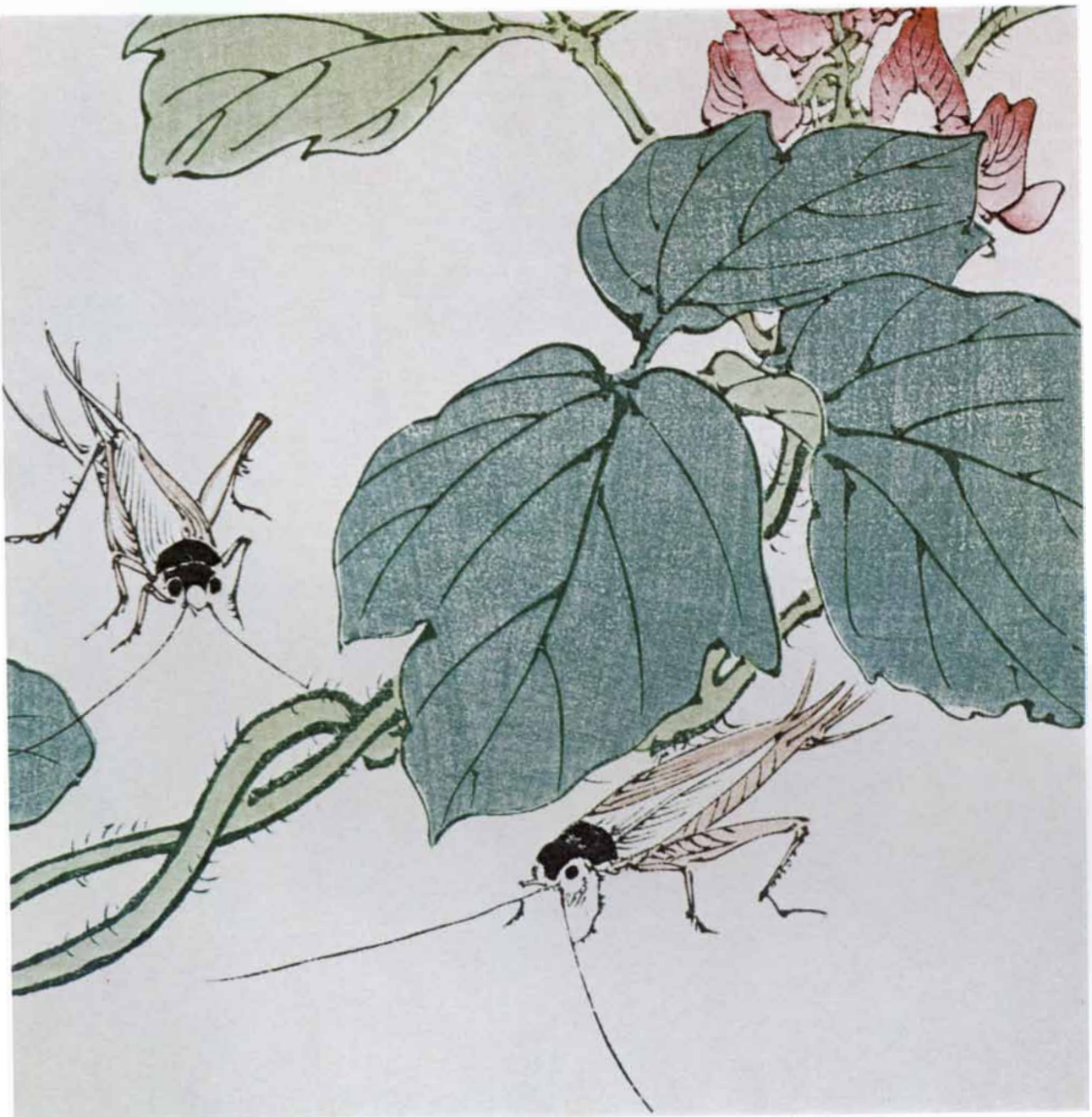

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Offshore oil

A safer, more economical way to get millions of barrels of oil from ship to shore to you.

America imports one-third of its oil. Even with energy from other sources, U S. oil imports will increase for some years Most of that increase will come from the Middle East. Important as that oil is, it may not arrive here nearly as efficiently as it could.

The reason? America is largely inaccessible to the biggest, most economical oil tankers in the world —*supertankers*. This is because at 200,000 tons and up, these ships require much deeper water than is found in almost any U.S. port.

The result is that America must now rely on smaller tankers to supply our energy system. For example, six 70,000-tonners are needed to deliver the same 3 million barrels of oil that a single 400,000-ton supertanker could deliver.

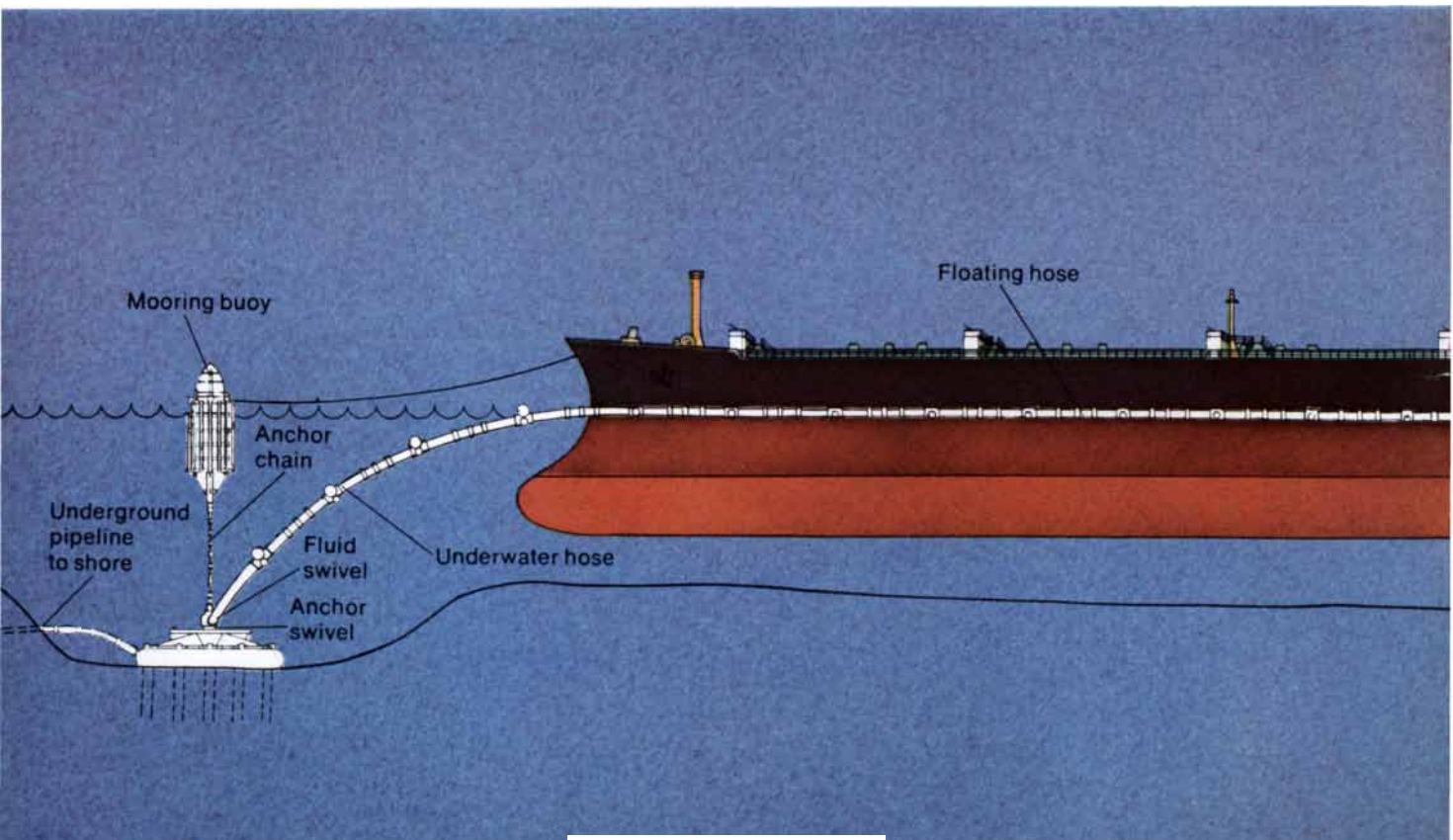
Using fewer but larger ships would reduce harbor congestion, decreasing the chances of collision and spills. Using the big ships also would improve efficiency. For example, moving crude oil from the Middle East to the United States in supertankers would require significantly less fuel than moving the same oil in medium-size tankers.

An offshore answer

One promising solution to the shortage of U.S deepwater harbors is the single buoy mooring, or SBM. Each SBM is anchored well off shore. It is equipped with a swivel which permits the ships to "weathervane" 360 degrees to face into wind, waves and current. Supertankers simply moor to the SBM, hook up to floating cargo hoses and pump off their oil. The oil is transferred via pipelines buried beneath the sea floor—and beneath the ground on land—to storage tanks.

Compared to in-port unloading, it's fast, simple—and safer. Offshore facilities have been used successfully for years by dozens of countries throughout the world.

Now, Exxon and other compa-



terminals.

nies are engaged in design and other studies for the development of the first deepwater offshore oil terminals for the U.S. Of course, permits will be necessary to allow construction to begin.

A giant step in the Gulf

Several offshore oil terminals have been proposed for the Gulf of Mexico. One of these is "Seadock," a facility planned for installation off the coast of Texas by Exxon and a number of other companies. Plans are to locate "Seadock" 32 miles offshore, southeast of Freeport. Conventional underground pipelines would move crude oil from "Seadock" to refineries along the Gulf Coast and in the Midwest.

Another proposed deepwater terminal called LOOP—Louisiana Offshore Oil Port—would be located 20 miles off the Louisiana coast. It would move crude oil, again via underground pipeline, to refineries in Louisiana, Mississippi and the Midwest.

Both "Seadock" and LOOP would accommodate present-day and future supertankers, unloading their cargos at the rate of several million barrels a day.

Exxon and other companies also are looking into the feasibility of similar offshore oil terminals to serve the Northeast, including New York, New Jersey, Pennsylvania, Maryland and Delaware.

Should states and the cities involved desire it, offshore facilities could provide the opportunity for local industrial expansion.

What about the environment?

Offshore oil terminals greatly reduce the effect of tanker operations on the environment. Noise and visual impact would be cut a good deal because the unloading facility cannot be seen from shore and because fewer tankers would be coming to it. Storage tanks, which are needed no matter how oil is delivered, can be located so as to minimize their visual impact on the landscape. But the drop in harbor congestion would be the greatest environmental benefit because it would substantially reduce the chance of collisions and spills.

If you would like more information on oil tankers and offshore terminals, write for our free booklets, "Safer Tankers and Cleaner Seas" and "Reducing Tanker Accidents," Exxon Corporation, P.O. Box 705, Elmsford, New York 10523.

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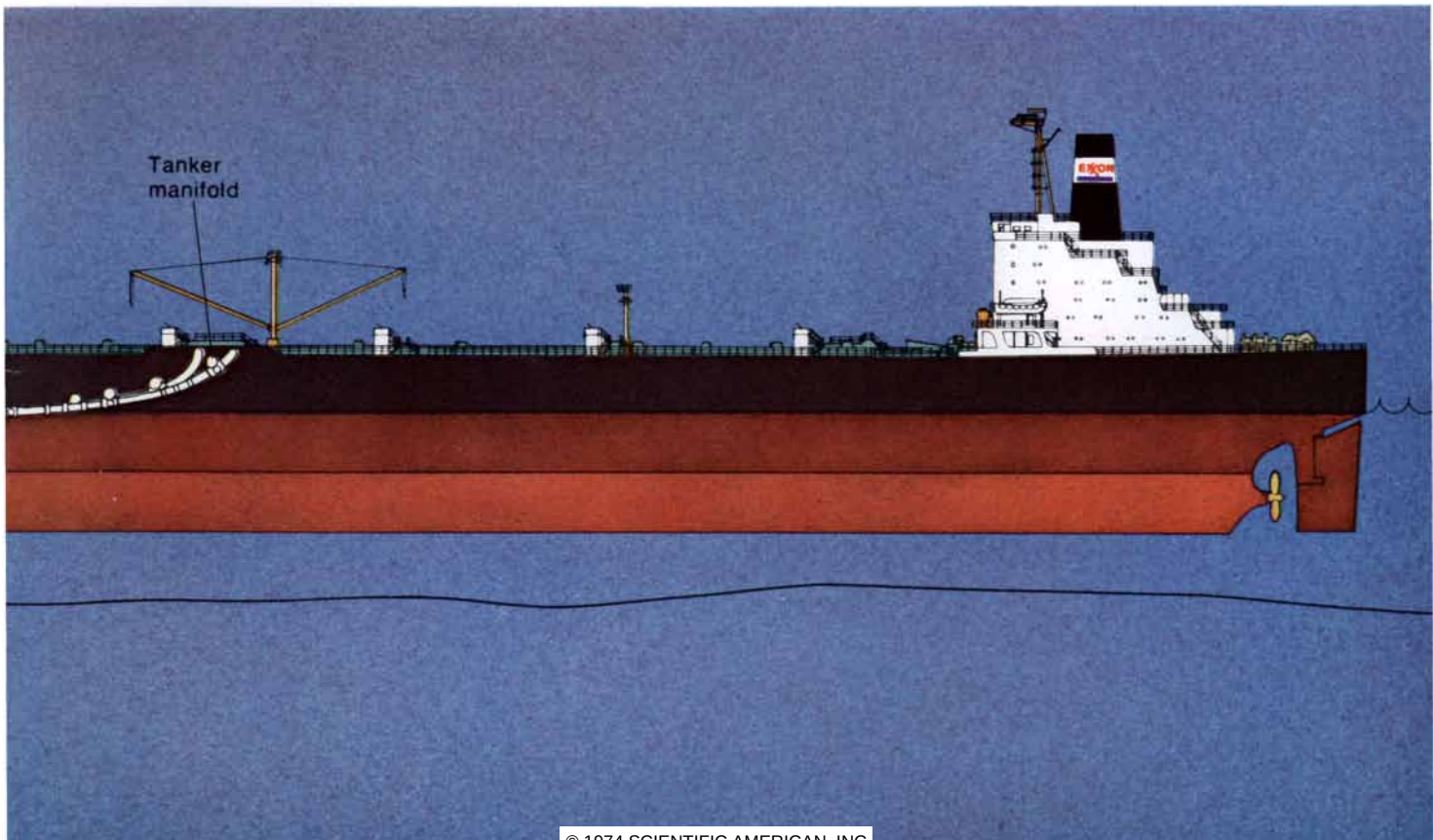

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b. Children near Pavillion Lake, British Columbia.
c. Canada's major West Coast city, Vancouver.
d. A sidewalk cafe in Vancouver's Gastown.

For more information contact British Columbia House, 565-3303 Wilshire Blvd., Los Angeles, California 09910; British Columbia House, Room 400, 100 Bush Street, San Francisco, California 94105, or write The British Columbia Department of Travel Industry, 1019 Wharf Street, Victoria, British Columbia, Canada V8W 2Z2.

Established 1845 **SCIENTIFIC AMERICAN** August 1974 Volume 231 Number 2

ARTICLES

16 **THE DISPOSAL OF WASTE IN THE OCEAN, by Willard Bascom**
Contrary to widely held views, the ocean is the best place to put certain wastes.

26 **THE COSMIC BACKGROUND RADIATION, by Adrian Webster**
The radiation suffusing intergalactic space is a clue to the history of the universe.

34 **THE NEUROBIOLOGY OF CRICKET SONG, by David Bentley and Ronald R. Hoy** This system links genetics, the nervous system and behavior.

53 **THE ORIGINS OF ALIENATION, by Urie Bronfenbrenner**
The estrangement of young people is traced to evolutionary changes in the family.

62 **SUPERHARD MATERIALS, by Francis P. Bundy**
Hardness is determined by the strength and orientation of bonds between atoms.

72 **TRITICALE, by Joseph H. Hulse and David Spurgeon**
This hybrid cereal combines the high yield of wheat and the toughness of rye.

82 **HOW ACTINOMYCIN BINDS TO DNA, by Henry M. Sobell**
The antibiotic blocks the synthesis of protein by binding to DNA's double helix.

92 **THE RISE OF COAL TECHNOLOGY, by John R. Harris**
The antecedents of the Industrial Revolution lie in the earlier uses of coal as fuel.

DEPARTMENTS

10 LETTERS

12 50 AND 100 YEARS AGO

14 THE AUTHORS

46 SCIENCE AND THE CITIZEN

98 MATHEMATICAL GAMES

104 THE AMATEUR SCIENTIST

111 BOOKS

116 BIBLIOGRAPHY

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THE COVER

The picture on the cover is a Japanese print featuring two crickets. The songs of crickets have recently been found to provide an unusually good means of examining the relations among genetic information, behavior and the structure and function of the nervous system (see "The Neurobiology of Cricket Song," by David Bentley and Ronald R. Hoy, page 34). The print, which is in the collection of the East Asiatic Library of the University of California at Berkeley, is of a watercolor made by Toko Morimoto. The animals appear to be crickets of the subfamily Gryllinae in the family Grillidae.

THE ILLUSTRATIONS

Cover painting courtesy of East Asiatic Library, University of California at Berkeley

Page	Source
17–18	National Aeronautics and Space Administration and U.S. Army Corps of Engineers
19–24	Alan D. Iselin
25	Harry Pecorelli, Los Angeles Department of Public Works
27	Mullard Radio Astronomy Observatory, Cavendish Laboratory, University of Cambridge
28–33	Allen Beechel
35–36	Bunji Tagawa
37–38	David Bentley, University of California at Berkeley
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92–97	New York Public Library
98	Ilil Arbel
99	Milford Small, E. A. Poe Ivory Tangram, Manuscripts & Archives Division, New York Public Library, Astor, Lenox and Tilden Foundations
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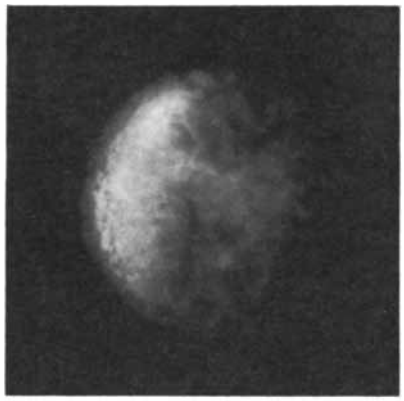
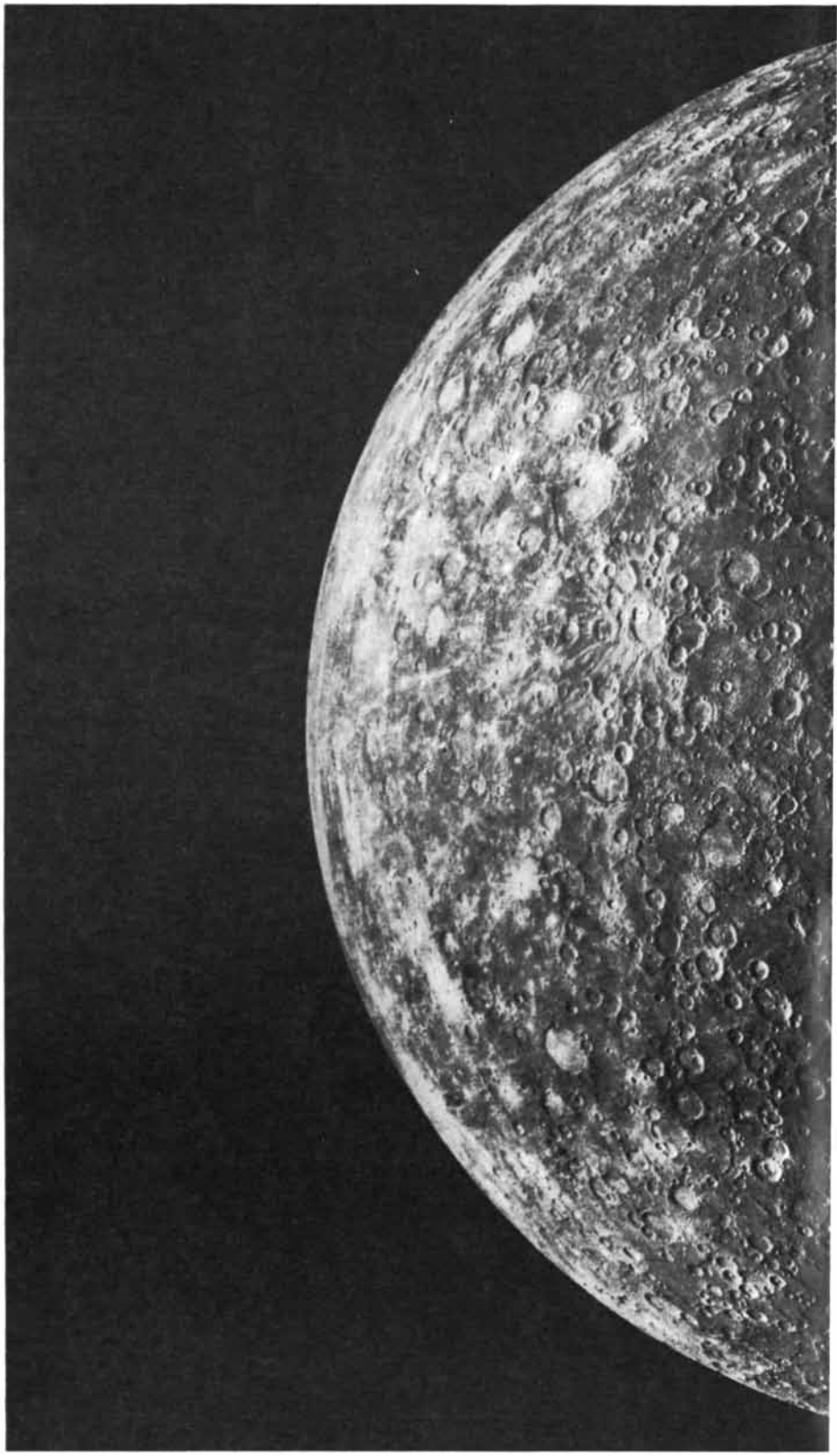
The very best of telescopic sightings have shown Mercury as a fuzzy ball, marked by faint shadows. The primary problem is that the planet is generally positioned against the sun and is visible only before sunrise and just after sunset.



There has been general agreement that Mercury was a well-burned husk, with only traces of an atmosphere and that it was lashed by heat five times as intense as that upon Earth. But it wasn't until 1965 that radar observation disclosed that the Mercurian day is 58.6 Earth-days long, rather than 88 days as previously thought.

On November 3, 1973 NASA launched the Mariner 10 spacecraft from the Kennedy Space Center. The assignment: a 160-day photographic and testing mission to confirm what Venus and Mercury are like. This was one of the most hostile environments any spacecraft had entered. Mariner 10 came closer to the sun than any craft launched by man. In addition, Mariner 10 used Venus as a gravitational springboard to reach Mercury — the first time another planet had been used in this manner.

Another critical aspect of the mission was that the spacecraft had to make three separate maneuvers in flight in order to be on target for the observation work on Mercury. With Mariner



Once a hazy mystery, planet

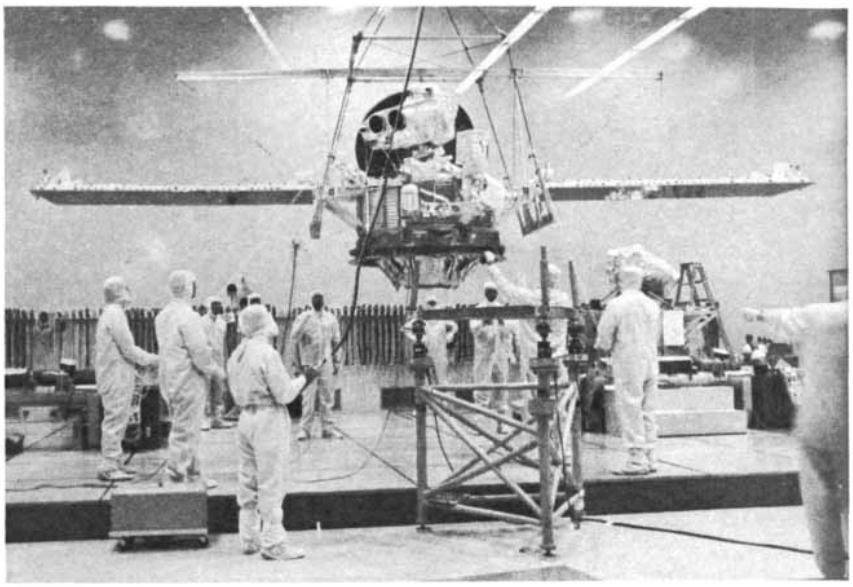
10 flying hundreds of millions of miles on its journey, there wasn't room for even an infinitesimal error.

Boeing built the spacecraft under the direction of the Jet Propulsion Laboratory and outfitted it with science instruments. Throughout all planning, Boeing engineers were constantly evaluating requirements vs. costs. Working with NASA, changes to the original specifications were made that allowed the spacecraft to do its job at a lower cost without detracting from its science effectiveness. Actually, the project came in about $1 million under budget.

The basic structure of the spacecraft was a compact 54½" x 18" octagon. Solar panels 106" long and a 20' long magnetometer boom extended from the craft. Launch weight of the spacecraft was only 1,108 pounds, including 66 pounds of propellant and 122 pounds of science instruments.

The fly-by of Mercury took only a few short hours. But it took five months and millions of miles to get there.

Then, as the Boeing spacecraft moved to within 460 miles of Mercury, it began supplying an unprecedented store of scientific data. This was the beginning of the greatest volume of information for a single flight of a Mariner probe. By comparison, Mariner 10 supplied 780 "bits" of information per dollar investment while Mariner 9 had 305 "bits" per dollar.



The spacecraft reported the Mercurian atmosphere was very thin and tenuous.

Photographs showed Mercury resembles the moon on the outside in some respects, but other instruments reported data that indicate the interior of the planet to be much like Earth with a heavy iron core. This could be a clue to how the inner planets of the solar system were formed.

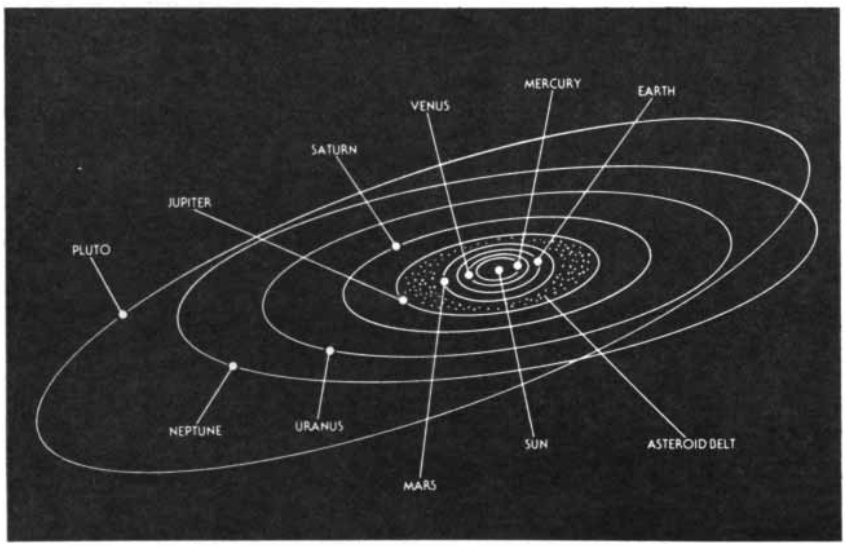
The spacecraft also picked up an unexpected magnetic field. Scientists figure the magnetism might be generated by some interaction between the intense "wind" of charged particles from the nearby sun. However, it also could be the result of an internal iron core much like Earth's—only substantially weaker.

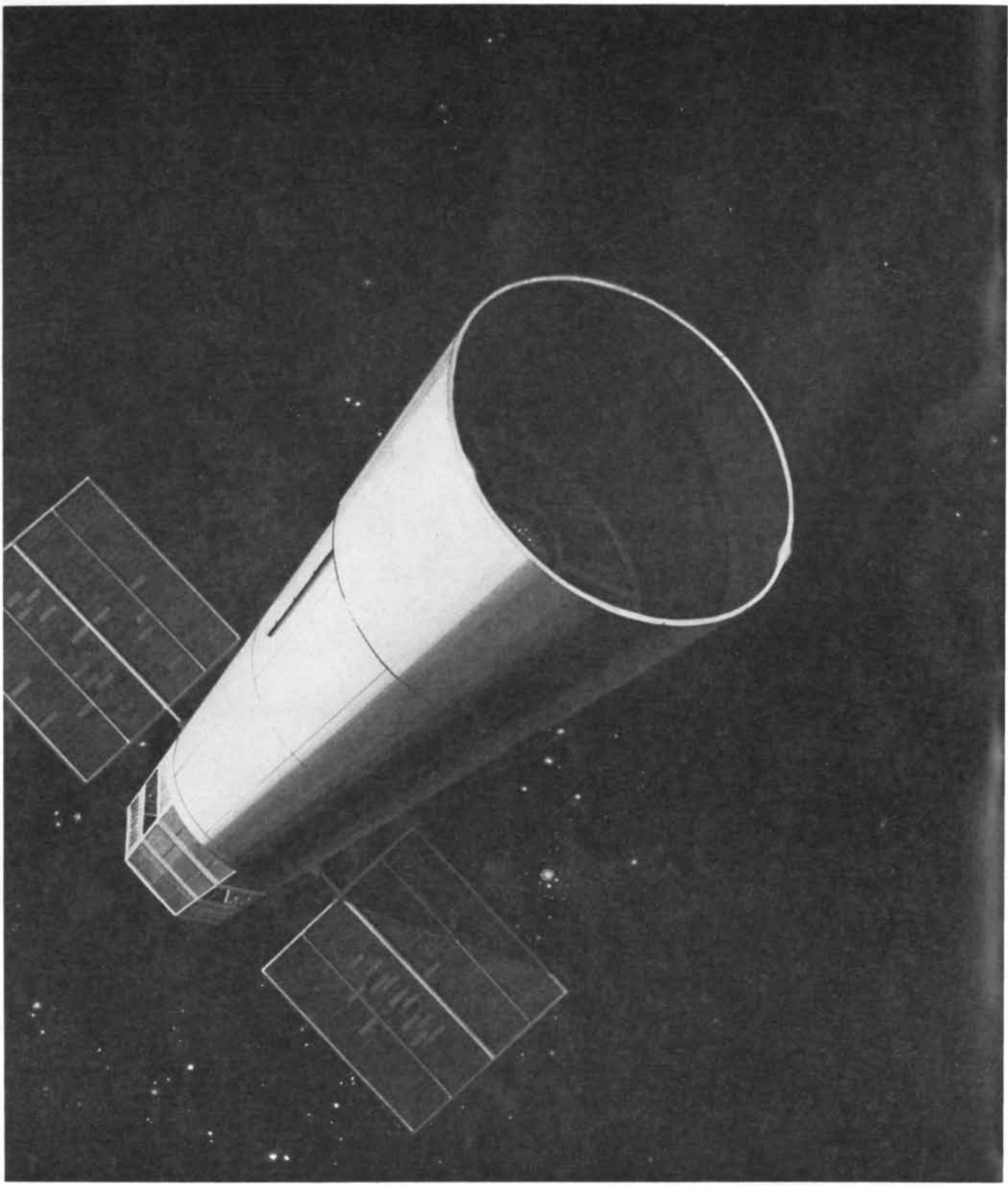
The spacecraft has completed its primary mission. Now scientists are piecing together more answers to the puzzle of the universe. The result will be a better understanding of our solar system and planet Earth.

In the last few years our knowledge of the inner planets has accelerated tremendously. Still, we have merely penetrated many of the mysteries of space. Where we go from here is very critical. To curtail space exploration now would be like asking Columbus to turn back the ships as soon as he sighted land.

Now Boeing is being considered for another important space project – the Large Space Telescope.

Please turn the page.





We're about to stretch our space know

NASA will launch the Large Space Telescope (LST) into orbit in the 1980's. It's just one more important Space Shuttle mission —a program that will allow man to observe the universe unhindered by Earth's atmosphere.

LST is a tremendous reach into space.

To put it into perspective—the Hale telescope at Mount Palomar allows us to dimly see an estimated two billion light years or about 12 billion trillion miles into space. The LST can provide clear pictures of space even beyond this distance.

Scientists expect a lot from the LST. A few of its missions will be: (1) study of energy processes that occur in the center of galaxies; (2) study of early stages in the formation of stars and planets; (3) observation of such stellar objects as quasars and pulsars; (4) advanced studies related to the origin of the universe.

Within our solar system, the LST will be able to provide long-term monitoring of atmospheric phenomena on Venus, Mars, Jupiter and Saturn. This can assist in a better understanding of our own atmosphere.

How will the LST perform?

The guidance system will be capable of holding onto a target for extended periods within 0.005 seconds of arc. This is equivalent to locking into a single strand of hair at a distance of two miles. The telescope will be unmanned because studies show that a human heartbeat would destroy its pointing precision in the zero-gravity, no-atmosphere condition of space.

The LST is a complex but compact package. It'll weigh about 21,000 pounds. Plans call for it to be 65 feet long and about 12 feet wide. The most important optical element will be a diffraction-limited mirror 10 feet in diameter.

A number of science instruments will cluster at the focus of the telescope. One will break light into spectra to explore energy levels and material content of objects seen. Others will measure light intensity and polarization, and perform additional specialized experiments.

The Space Shuttle will place the LST into orbit at an altitude of 280 nautical miles at an inclination of 28.5 degrees. Then from time to time the Space Shuttle will be used to return to the LST for service and refurbishment.

Boeing has been working on large orbital telescopes since 1965. And just recently, the Marshall Space Flight Center, which will direct the LST project, awarded Boeing a contract to design and test the prototype of a structure that can be used to stabilize the LST mirrors.

The Boeing work on Mariner 10, the three Lunar Rover vehicles, five Lunar Orbiters, the Saturn booster rockets for Apollo missions and the Minuteman program give Boeing the right kind of background for an assignment of this magnitude. Specifically, Boeing's scientific research and product development activities match extremely well with the requirements necessary to build the LST's support systems module and to integrate the optics, instrument and spacecraft portions of the LST.

This program of exploring the unknown can have enormous benefits to mankind. Perhaps we can use the energies at work in the universe in the same manner that we now employ electricity. Or the basic workings of the universe may help us to understand the subnuclear processes, leading to breakthroughs comparable to the development of atomic power.

The people at Boeing believe this could be the most exciting venture into the unknown that man has ever taken. We are pleased to have a part in the preliminary work on the LST.

ledge beyond 12 billion trillion miles.

Boeing plans to be there.

LETTERS

Sirs:

I wonder whether Professor Guillery ["Visual Pathways in Albinos," by R. W. Guillery; SCIENTIFIC AMERICAN, May] has considered the possibility that some cases of crossed eyes in humans may be caused by abnormal layering of the lateral geniculate nuclei. This hypothesis is attractive for several reasons. First, although the relationship between albinism and the odd structure of the lateral geniculate has been clearly demonstrated, there is no evidence to suggest that this type of abnormal geniculate development is related only to albinism. Thus it would be instructive to look at the brain of normally pigmented, cross-eyed mammals, particularly humans. Second, cross-eyed cadavers should be easier to locate than albino cadavers for the obvious reason that strabismus is more common than albinism. Third, the cure for crossed eyes in man has been attempted typically by peripheral intervention, but this method is often a failure. One explanation for the failure would implicate a central cause of the abnormality. Finally, in some unpublished (and incomplete) research Dennis Wright and I studied rapid eye movements (REM) of highly cross-eyed subjects during a night of normal sleep (to test R. J. Berger's theory linking REM to the development and maintenance of orderly conjugate eye movements when awake). We have found, in the three subjects studied, that their eye movements were abnormal (that is, they showed many instances of nonconjugate movements) even during REM. One hypothesis this finding suggests is that the abnormal movements in cross-eyed individuals are under the control of central mechanisms.

ALVIN G. GOLDSTEIN

Department of Psychology
University of Missouri
Columbia

Sirs:

The brief answer to Professor Goldstein's interesting letter is yes. I have considered the possibility he mentions, and am keen to see further studies of human brains. The laminar pattern will not be as easily analyzed as in cats and tigers, since in the normal human lateral geniculate nucleus there are complex interdigitations of the layers. However, a careful comparison between normal and abnormal nuclei could prove instructive. My inclination would be to define the laminar pattern in an albino brain first and then to look for a comparable abnormality in others in whom a well-defined strabismus had no known cause. In view of the scarcity of albino brains Professor Goldstein's strategy may be more practical.

R. W. GUILLERY

Bardeen Medical Laboratories
University of Wisconsin
Madison

Sirs:

The "50 and 100 Years Ago" column in your June issue, by virtue of its quoting without comment, revives the myth of the Paleozoic flowering plant. The column refers to the report of a J. H. Hoskins (in the June 1923 *Botanical Gazette*) of a coal age (Carboniferous) Paleozoic angiosperm, which was named *Angiospermophyton americanum* and which was presumed to be the stem of a

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NAME

NEW ADDRESS

OLD ADDRESS

monocotyledon. This report is one of the classical blunders in paleobotany and is an excellent example of interpretation based on inadequate background, hasty thinking and superficial similarities. Within the year of Hoskins' report his fossil was conclusively shown to be the petiole of *Medullosa*, a seed fern and gymnospermous plant quite unrelated to the flowering plants. Actually the flowering plants do not turn up in the fossil record until the early Cretaceous, some 200 million years after the Hoskins fossil. All pre-Cretaceous records of the flowering plants are very suspect, and the oldest of these is only of Triassic age, which is still some 100 million years more recent than the Hoskins plant.

RUDOLF SCHMID

Department of Botany
University of California
Berkeley

Sirs:

As a scholar of New College, I was interested in Professor Fromkin's remarks about Warden Spooner ["Slips of the Tongue," by Victoria A. Fromkin; SCIENTIFIC AMERICAN, December, 1973]. The "spoonerisms" she quotes are definitely apocryphal, as she indicates. According to New College tradition, most if not all of the genuine ones were made in the chapel. (I wonder what Freud's explanation would have been?) For example, it seems certain that he announced the hymn "Conquering Kings Their Titles Take" as "Kinquering Congs Their Tatles Tike." However, one of the nicest transpositions was not in the technical sense a spoonerism at all. The story was told to me in 1944 by the (late) Reverend E. Bleiben, himself a scholar of the college and at that time rector of Headington Quarry parish, Oxford. He remembered both Spooner and the incident well. Apparently Dr. Spooner preached a sermon on Aristotle one Sunday in New College Chapel. Even the learned dons found it difficult to follow, but they were patient because Dr. Spooner after all was one of the best scholars in Oxford. He finished his sermon, sat down in his stall, but jumped to his feet as the choir began the anthem and announced, "Did I say Aristotle? I meant of course St. Paul!"

C. L. WALE

Lecturer in Chemistry
Mander College
Bedford, England

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1924: "An important achievement in the communication art was recently demonstrated by the American Telephone & Telegraph Company and the Western Electric Company. This was the transmission of pictures over telephone lines. On the afternoon of May 19 photographs taken in Cleveland were transmitted to New York and reproduced almost immediately. The actual time required to transmit a picture five by seven inches was less than five minutes. An ordinary positive film is used for transmission. A special apparatus makes an exact electrical copy of each element or area of the picture and transmits it over an ordinary telephone line. This electrical copy passes through the coils and vacuum-tube repeaters in the line just as ordinary speech does, and at the receiving end other apparatus reconstructs the picture. At the transmitter the film is rolled up into the form of a cylinder and is rotated under an intense beam of light. The light passing through the film varies in intensity according to the amount of blackening on the film, and a photoelectric cell placed in the path of the beam causes variations in an electric current. At the receiving end an unexposed piece of film is passed under a light beam controlled by the current transmitted over the telephone circuit."

"Some years back, even before the beginning of the World War, there was conceived the possibility of flying aircraft from and onto ships. The idea was not given much publicity at the time, both because nothing concrete was developed and because the world at large would probably have ridiculed the idea as a useless risk to human life. The first U.S. airplane carrier, as such ships are called, is now sailing. It is the U.S.S. *Langley*, and it presents a most fascinating departure from the commonplace. The *Langley* was named for Professor Samuel Pierpont Langley, one of the pioneers in his conceptions of the possibility of aviation. It is 540 feet long and 65 feet wide. The flying deck extends nearly the full length of the ship and is supported by lattice-work steel towers on each side. When an airplane is to be launched from the ship, the pilot signals when all is ready, and men nearby release a hook that has been holding the plane to the deck. The plane speeds along the deck and into the air before it is halfway to the bow. When a plane returns to the ship, it glides gracefully to the deck, slows down and is held there in the strong grip of the 'arresting gear' (the details of which are confidential) after a remarkably short travel."

SCIENTIFIC AMERICAN

AUGUST, 1874: "The celebrated German physicist Helmholtz has made some modifications in the hypothesis by which he accounts for the functions of our organs of hearing. It will be remembered that the sound waves of the air are communicated to the fluid contents of the inner ear and thence to the nervous surface that transmits to the brain the sensation of sound. To understand the theory by which Professor Helmholtz explains this phenomenon it is necessary to consider the oscillations of a pendulum. Suppose a number of pendulums of different length are arranged in regular succession in the same vertical plane. Imagine that an experimenter strikes all these pendulums at the same time in some particular rhythm. It is evident that those pendulums whose times of vibration are equal to the interval between two blows, or to a submultiple of the interval, will oscillate; all others will be stopped. Suppose in the internal ear a great number of nervous fibers exist; if the liquid vibrates at a certain rate, all the fibers having a corresponding time of oscillation will be set in motion. A combination of impressions will result, peculiar to a given vibration and different from any other."

"There was a large gathering of American scientists at Northumberland, Pa., on July 31 to celebrate the 100th anniversary of the discovery of oxygen by Joseph Priestley. Priestley's discoveries, embracing at least two-thirds of the now known gases, showed conclusively the compound structure of the air. Although himself the founder of a new school of chemistry, he adhered firmly to the old philosophy and died the last defender of phlogiston."

"The natural history of the diamond is one of the puzzles of geology, and until recently the place of its origin was as great a mystery as the manner of its formation. Happily the first part of the problem has been solved: the diamond has been tracked home. Diamonds are found under two very dissimilar conditions: first, as pebbles associated with pebbles of quartz, agate, zoolite and other minerals, and second in circumscribed pits or shafts filled with a chalky or clayey earth, more or less hardened. The shafts are surrounded by a rim of rock; inside the rim, or 'reef,' as the miners call it, the diamonds are found at home and untraveled, whereas outside they occur only in layers of gravel or other products of running water. That the gems within the shaft have rested undisturbed since their formation is attested by the nature of their matrix, which at one South African shaft has been mined to a depth of 200 feet without any apparent decrease in the richness of the yield."

"The visitation of locusts in Minnesota has proved to be a serious calamity. The total damage thus far done consists in a loss of about a twelfth of the usual crop. The plague extends over a tenth of the cultivated area of the state. The locusts that have appeared in Minnesota are, when full-grown, about an inch and a quarter in length and a dusky grayish color. When the insects are hatched, they feed on the nearest vegetation and then take flight in vast clouds, seeking other pastures. A Minnesota settler who has suffered severely from their ravages describes a throng of the locusts as resembling a huge snow cloud."

"Chicago was visited, on July 14th, by a second great fire, which devastated about 18 blocks. Although falling far short of the conflagration of 1871 in its disastrous effects, this visitation has rendered thousands of people homeless. Other cities invite the fate of Chicago. Buildings are being run up to heights to which water cannot be thrown by the fire engines. There are wooden structures in close proximity to some of the grandest edifices. There are blocks on blocks of tenements filled with people, the majority of whom, from poverty, must use kerosene in place of gas, and in which a great fire, once started, would work terrible ravages."

"The high rates of taxation and exorbitant rents in New York City have virtually banished a large number of persons to the adjacent suburban districts. As a result village after village has sprung into existence on Long Island, in New Jersey and at every point within a radius of 40 miles of the metropolis."

What would you do with a Statistics and Number-Crunching Computer that starts at $7,100,* has 16K Hardwired Basic Language and 28 Major Peripherals?

Plenty!

The new Wang System 2200 is a System. It gives you the raw power and the peripherals you must have for a wide range of problem solving. For under $7,200 you get a CPU with 16K bytes of BASIC language instructions hardwired into the electronics . . . plus a 4K operating memory. You also get a big 16 lines (of 64 characters each) CRT display, a console mag tape drive and your choice of either alpha or BASIC Keyword keyboards.

Some Words About Language: The hardwired MOS ROM language in your System 2200 finally ends your dollar tradeoffs . . . economy systems that are costly to program or very expensive systems that are relatively easy to program. Many, if not most, of your people already know BASIC. They'll be solving problems the day your system is delivered (and, we can deliver in about two weeks). Most of your budget will go into problem solving; not system support.

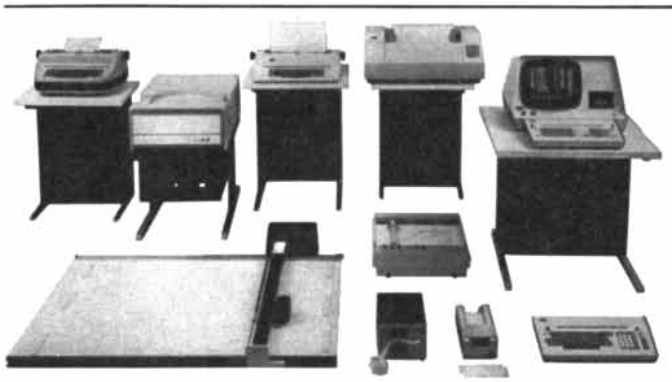
Try To Out-Grow It: Main memory is field expandable in 4K increments (at $1,500 per 4K). Up to 32K. You can choose from three kinds (and 7 price ranges) of printers . . . one even has a stepping motor for very precise 4-quadrant incremental plotting. Speaking of plots, we have a new, very large flatbed (31" × 42") for only $7,500 or a smaller one if you plot small. Both print alphanumerics and plot under full program control. Been appalled lately by disk prices? Starting at just $4,000, we offer you our new "floppy" disk in single, double and triple disk configurations (.25, .50 and .75 MB's). For big disk power, you can have 1, 2 or 5 megabyte fixed/removable disk systems. All peripherals, including punched or mark sense hopper card readers, paper tape readers and on- line BCD or ASCII controllers are easily added-on in the field so your System 2200 will grow with your needs.

The Wise Terminal: If you are now or may soon be getting into terminals, we have several new products that will instantly upgrade your System 2200 for telecommunications with any other System 2200 or a mainframe computer. And, you still have a powerful stand-alone system. Another approach, of course, is to justify it as a powerful terminal and get a "free" stand-alone computer. Wise?

We Do A Lot For You: System 2200 is backed by over 250 factory-trained Wang Service Technicians in 105 U.S. cities. Naturally, we guarantee or warranty everything you buy from us. If you want, there are free programming/operating schools here in Tewksbury, Massachusetts, almost every week. We have a growing program library on a wide range of statistics and math/science applications. Our user group (with the unlikely name of "SWAP") could help you cut programming costs even further. We do a lot for you.

* All prices U.S. List. If you're the entrepreneur type, we've just announced a new 7-module Basic Accounting System software package for the business end of your business like payroll, invoicing, inventory, receivables and some really fancy management reports.

WANG



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THE AUTHORS

WILLARD BASCOM ("The Disposal of Waste in the Ocean") is director of the Southern California Coastal Water Research Project, which is sponsored by five local governments and the U.S. Environmental Protection Agency. The project's objective is to determine the effects of discharging various materials into the ocean. Bascom began his career as a mining engineer but switched to oceanography in 1945 as a research engineer for the University of California, first at Berkeley and later at the Scripps Institution of Oceanography. For several years beginning in 1954 he was a member of the staff of the National Academy of Sciences. He has been associated with such projects as the first deep-ocean drilling and the search for undersea diamonds off the coast of southwest Africa.

ADRIAN WEBSTER ("The Cosmic Background Radiation") is at the Mullard Radio Astronomy Observatory of the University of Cambridge as a Research Fellow of the Royal Commission of the Exhibition of 1851 and a Research Fellow of Clare Hall. He obtained his bachelor's degree in theoretical physics at Cambridge in 1967 and his Ph.D. (in radio astronomy) there in 1972. For the two academic years beginning in 1971 he was a research fellow at the Miller Institute for Basic Research in Science at the University of California at Berkeley. "My outside interests," he writes, "include squash racquets and combining hiking with photography."

DAVID BENTLEY and RONALD R. HOY ("The Neurobiology of Cricket Song") are respectively at the University of California at Berkeley and Cornell University; Bentley is associate professor of zoology and vice-chairman of the department of zoology and Hoy is assistant professor in the division of biological sciences. Bentley writes: "I grew up in Michigan and received my undergraduate education at Williams College. After returning to Michigan for my doctorate I spent two delightful years in postdoctoral study, the first at Cologne and the second at Stanford, where I became quite addicted to the Bay Area. I enjoy mountain walking with my family and playing stringed instruments such as acoustic guitars and squash racquets. My notion of an idyllic interlude from research is canoeing in the boreal forest wilderness as far north as possible. I am an avid supporter of zero population growth, the Sierra Club and like-minded organizations." Hoy received his bachelor's degree (in zoology) at Washington State University and his Ph.D. (in biology) from Stanford University. He was a postdoctoral fellow in Bentley's laboratory at Berkeley and then worked for three years in the biology department of the State University of New York at Stony Brook. "My recreational activities," he writes, "include photography and going for late-night cricket walks with my wife, Peggy."

URIE BRONFENBRENNER ("The Origins of Alienation") is professor of Human Development and Family Studies and of psychology at Cornell University. He was graduated from Cornell in 1938, obtaining his master's degree (in education) at Harvard University in 1940 and his Ph.D. (in psychology) from the University of Michigan in 1942. He joined the Cornell faculty in 1948 after teaching at Michigan for two years. Born in Russia, Bronfenbrenner was brought to the U.S. by his parents at the age of six, when his father became research pathologist at Letchworth Village, a New York State institution for the mentally retarded. Bronfenbrenner worked as an attendant there while he was in high school.

FRANCIS P. BUNDY ("Superhard Materials") is a physicist at the General Electric Research and Development Center in Schenectady, N.Y., working in the inorganic and structures branch of the Physical Chemistry Laboratory. He was graduated from Otterbein College in Ohio in 1931 and received his Ph.D. from Ohio State University in 1937. He taught physics at Ohio University from 1937 to 1942 and then spent the war years at the Underwater Sound Laboratory of Harvard University and the U.S. Navy's Underwater Sound Laboratory in New London, Conn. He went to General Electric in 1946. His memberships in the Adirondack Mountain Club, the Mohawk Soaring Club and the Soaring Society of America reflect several of his outside interests, which he lists as "camping, canoeing, gliding and soaring and gardening." He is a glider instructor and has been designated by the Federal Aviation Administration as an examiner of glider pilots.

JOSEPH H. HULSE and DAVID SPURGEON ("Triticale") are at the International Development Research Centre in Ottawa; Hulse is director of the division of agriculture, food and nutrition sciences and Spurgeon is director of publications. Hulse, who is a member of the United Nations Protein Advisory Group, served as assistant director of the nutrition division of the Food and Agriculture Organization, director of research of Maple Leaf Mills in Toronto and head of food and nutrition research with the Defence Research Board of Canada before taking his present position. His principal hobby is music; as a student he supported himself running dance bands, and he was a church organist and choirmaster for several years. He writes that he played rugby football until he became "too creaky in the joints" and that his athletic activities "now are confined to swimming, cycling and walking." Spurgeon was a reporter with the Toronto *Globe and Mail* for 19 years before he joined the International Development Research Centre. He is a founder and former president of the Canadian Science Writers' Association. He is also a founder and the editor of *Science Forum*, a Canadian publication concerned with the relations between science and society.

HENRY M. SOBELL ("How Actinomycin Binds to DNA") is professor of chemistry, radiation biology and biophysics at the University of Rochester. He received his bachelor's degree at Columbia College in 1956 and his M.D. at the University of Virginia Medical School in 1960. Instead of going on to clinical training in medicine he went to the Massachusetts Institute of Technology for further training in basic science. "During my college years," he writes, "I studied the violin seriously and considered a career in music. I still occasionally find the time to take out my violin for a string quartet or a violin-piano sonata." He adds that his other activities include "tennis and swimming and spending many hectic hours with my wife and five children."

JOHN R. HARRIS ("The Rise of Coal Technology") is professor of economic history and head of the department of economic and social history at the University of Birmingham. He was graduated from the University of Manchester, where he also obtained his master's degree and his Ph.D. in 1950 and 1952 respectively. Before he went to Birmingham in 1970 he taught at the University of Liverpool for 17 years. He has worked and published in the fields of urban and regional history, and he played a part in the founding of the journal *Business History* and in encouraging the early development of industrial archaeology.

SCIENCE/SCOPE

The F-14 Tomcat's AWG-9 system and Phoenix missile were praised in a recent report of the House Armed Services Committee for having demonstrated capabilities "unprecedented in the annals of aviation." Major accomplishments cited in the report: longest-range fighter detection of fighter-size targets; longest-range fighter-launched air-to-air missile firing; first fighter to demonstrate automatic detection and tracking of multiple targets; and first fighter to demonstrate multiple, near-simultaneous firing of missiles against multiple airborne targets. The AWG-9 weapon control system and the Phoenix missile are built by Hughes for the U.S. Navy.

The National Society of Professional Engineers has chosen ERTS (Earth Resources Technology Satellite) as one of the top ten engineering achievements of 1973, based on benefit to mankind, creative significance, and contribution to technology. The multispectral scanner system aboard ERTS, developed for NASA by Hughes and its subsidiary, Santa Barbara Research Center, records solar energy reflected from Earth to produce photos which indicate the health of fields, forests, rivers, and lakes. ERTS was launched in 1972 by NASA's Goddard Space Flight Center and is still operating. It circles Earth every 103 minutes in a polar orbit.

A fiber optic data link carrying aircraft flight control signals from cockpit to controls was successfully flight tested for the first time by the U.S. Air Force recently. The test was part of a program to evaluate various electromagnetic-integration-resistant transmission media for carrying multiplexed signals in a fly-by-wire flight control system. Of particular concern was the potentially catastrophic effect of lightning and other forms of electromagnetic interference on the conventional twisted-pair-wire bus now used to carry primary flight control signals. The two-way multi-port fiber optic data bus was integrated with F-DADS (fault-tolerant digital airborne data system) equipment. Both were developed by Hughes.

39 scientists will provide the experiments aboard the two Pioneer spacecraft NASA will send to Venus in 1978. They were selected from among the 162 who submitted proposals. Primary objective of the twin missions is a detailed investigation of Venus's atmosphere and clouds. One of the spacecraft will orbit Venus in a highly elliptical trajectory, transmitting data for a full Venus year (eight Earth months). The other will launch one large and three small probes before it enters Venus's hot, dense atmosphere. The probes will transmit data to Earth during their hour-long descent to the planet's surface. Hughes will build the two spacecraft.

Laser communications specialists: our Space & Communications Group has immediate openings for well-qualified professionals with experience in: systems analysis/systems engineering (PhD in engineering, 10 years experience); control system design (BS or MS in engineering, 5 years experience); or optical systems design (BS or MS in engineering physics or physics, 5 years experience). U.S. citizenship required. Please send your resume to: D.T. Stewart, Hughes Aircraft Co., P.O. Box 92919, Los Angeles, CA 90009. An equal opportunity M/F employer.

Commercial products from Hughes: a high-power X-band multipactor for high-resolution radar systems; it provides front-end protection for radar receivers and is capable of RF pulse forming and switching....a new version of the Conographic(tm) graphic display terminal, featuring desk-top packaging with integrated keyboard and CRT screen; it displays curvilinear information from significantly less data than required with x-y plotting....three new series of waveguide components for the 26.5 to 110 GHz range -- E- and H-plane bends, tapered transitions, and 45° and 90° bends -- designed for transmission lines and waveguide assemblies.

Creating a new world with electronics

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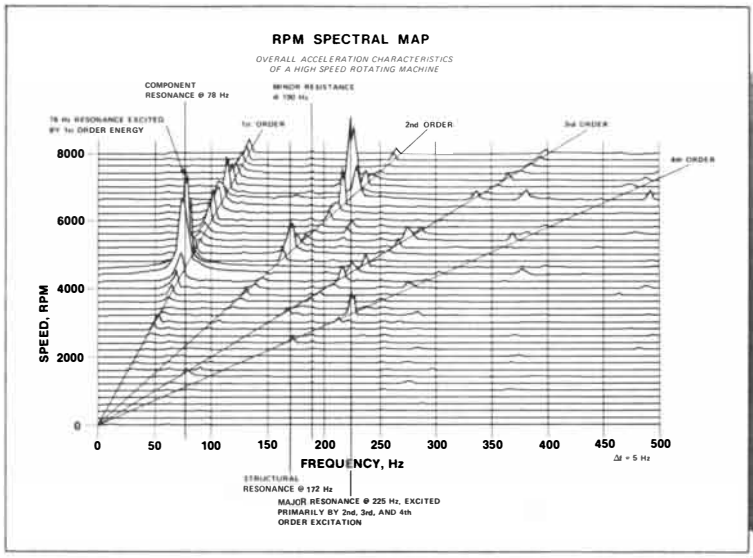

Find out how to keep machines from breaking.

Good Model T mechanics were among the first practitioners of signature analysis. They knew the normal sounds and vibrations of the car—its signature—and were able to detect slight deviations just by listening to it. Through experience and intuition, they could often relate these changes to a broken gear tooth, a scored drive shaft, a worn bearing—and repair the problem before it put the car out of commission.

This kind of intuitive signature analysis has all but passed from the scene as our machines have become more and more complex. In recent years, however, the computer has rehabilitated this powerful diagnostic tool for design analysis, production testing, and preventive maintenance of all kinds of rotating machinery from lawnmowers to jumbo jets.

With the introduction of the new HP Signature Analysis System, the technique has in fact become more revealing, more accurate, and easier to use than ever before.

Here's how it works. Using appropriate transducers, the system measures the complex pattern of vibrations or noise produced by the machine under test as it operates through its range of speeds, and faithfully records the test data on a magnetic disc.

Although these raw time-domain measurements yield little useful information about the machine, the HP system can extract from them a complete set of six frequency-domain analyses—the machine's signature.

Push a button on the system console, for example, and get an *rpm spectral map*, an overall qualitative picture of the machine's dynamic characteristics (one of these is shown). From this three-dimensional isometric plot of signal level *vs* frequency *vs* rpm, you can spot structural resonances and order-related problems at various machine speeds.

Want to take a detailed quantitative look at a resonance problem? Push another button and the system will produce a *spectrum analysis* (signal level *vs* frequency) at the troublesome speed, without retesting—because the original data is always available for further processing. If you suspect an order-related problem with one of the machine components, another pushbutton will get you an *order-tracking* plot (track any specified component and record its vibration as a function of speed). From this frequency-domain analysis, you can easily see the contribution of the suspected component to overall machine noise or vibration.

Three other frequency-domain analyses are available at the touch of a button: *order ratio* analysis, a convenient way to compare order-related component noise or vibration at different machine speeds; *composite power spectrum*, from which you can easily pinpoint the machine speeds that generate the most noise or vibration in a particular band of frequencies; and *time spectral map*, a three-dimensional plot that clearly shows all time-related noise and vibration.

The HP system consists of a minicomputer-based 5451B Fourier Analyzer plus an option package of hardware and a complete set of dedicated application software. Fourier Analyzer prices start at $45,500*; the Signature Analysis Option Package costs $10,750*. Total system price depends on other options and peripherals.

Automatic data acquisition: a calculator-based solution.

We know the many virtues of computer-based measurement and test systems. We should: we're a leading manufacturer and user of them. We also know that many scientists and engineers with low-volume requirements still spend a great deal of time doing the job manually, because their particular application doesn't economically justify a computer system.

For this reason, we are pleased to introduce our new calculator-based Model 3050A Data Acquisition System. The 3050A provides the benefits of an automatic system while meeting the important criteria for low-volume applications in laboratories as well as on the production line, at a commensurate price.

The basic system costs only $13,875* for five channels and can be expanded to 100 channels for a total cost of $19,050*.

It does the complete job, completely automatically. It *acquires* data from a variety of physical sensors (pH meter, thermocouple, pressure transducer—any sensor with ac or dc volt or ohm output) at up to four readings per second; it does *real-time calculations* to convert the raw data into meaningful scientific units (e.g., it linearizes and compensates thermocouple emf outputs and converts them to temperature); it *controls* all system instruments and scanner, without any form of operator intervention; it performs *off-line calculations* (e.g., statistical or trend analysis of results); it *logs, prints, or displays* the results.

And it's easy to use. Programming is done on an HP 9820, 9821A, or 9830A Calculator, in a natural algebraic or HP BASIC language; and the calculator's error detection and flexible editing features make it easy to debug and modify your programs as you write them. To make it easier still, the calculator automatically takes care of the details of controlling the instruments and scanner, through a plug-in Read-Only-Memory and a control program provided with the system.

Of the calculator-based systems available, ours is uniquely flexible, thanks to the new HP interface system which allows a number of instruments to communicate with each other and with the calculator under calculator control. With this new interface system, you can connect instruments in the system to meet your individual requirements. And when you've finished the task, you can re-configure the system for a different task, or return the instrument and the calculator to normal bench use. (The HP interface system is described in the October 1972 *Hewlett-Packard Journal*, available on request.)

The 3050A System works so well that we're using it in an environment monitoring and control system at one of our manufacturing plants. It monitors the pH of the plant effluent holding tank, and sounds an alarm if the pH gets dangerously high. The system also monitors and logs temperature and humidity in critical areas within the plant; the conductivity and flow rate of deionizer water; boiler pressures; and plant electrical load.

Perhaps this versatile system can go to work for your data acquisition requirements, too.

For more information on these products write to us. Hewlett-Packard, 1503 Page Mill Road, Palo Alto, California 94304.

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The Disposal of Waste in the Ocean

Contrary to some widely held views, the ocean is the plausible place for man to dispose of some of his wastes. If the process is thoughtfully controlled, it will do no damage to marine life

by Willard Bascom

No one would dispute the wisdom of protecting the sea and its life against harm from man's wastes. An argument can be made, however, that some of the laws the U.S. and the coastal states have adopted in recent years to regulate the wastes that can be put into the oceans are based on inadequate knowledge of the sea. It is possible that a great effort will be made to comply with laws that will do little to make the ocean cleaner.

This discussion of waste disposal will be limited to disposal in the ocean; it will not take up disposal in lakes, rivers, estuaries, harbors and landlocked bays. Indeed, part of the problem is that insufficient distinction has been drawn between the ocean and the other bodies of water, whose chemistry, circulation, biota and utilization differ from those of the ocean in many ways. It is not sensible to try to write one set of water-quality specifications that will cover all bodies of water. My concern here is only with the quality of ocean water and marine life along the U.S. Atlantic, Gulf and Pacific coasts. The scientific findings in those areas apply, however, to nearly any other coastal waters that are exposed to ocean waves and currents.

Some of the changes that human activities have wrought in the ocean environment are already irreversible. For example, rivers have been dammed, so that they release much smaller quantities of fresh water and sediment. Ports have been built at the mouth of estuaries, changing patterns of flow and altering habitats. On the other hand, certain abuses of the ocean have already been stopped almost completely by the U.S. Nuclear tests are no longer conducted in the atmosphere, so that radioactive material is no longer distributed over the land and the sea; the massive dumping of DDT has been halted, and the reckless development of coastal lands has been restrained by laws calling for detailed consideration of the impact on the environment.

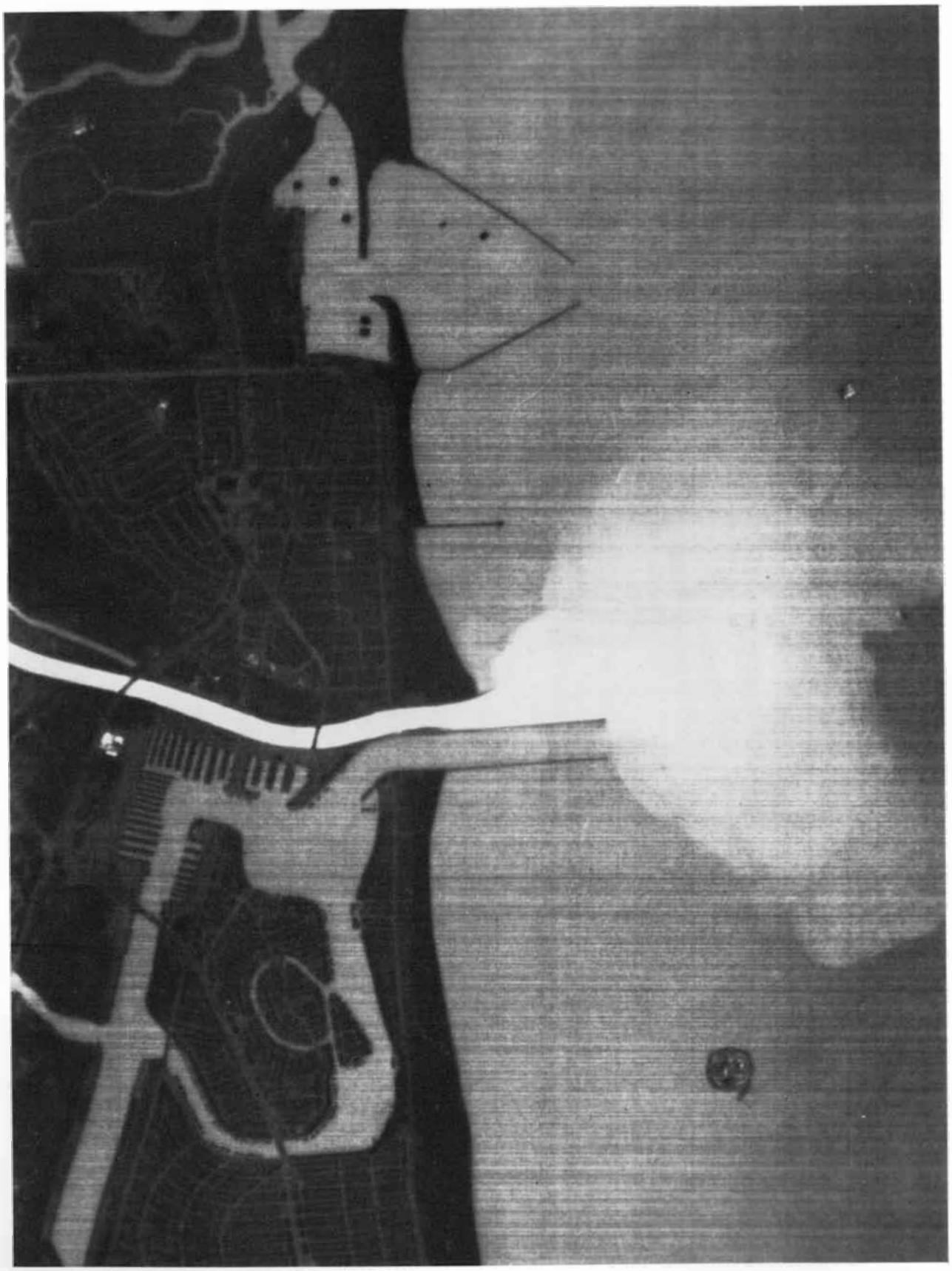
Between these extremes is a broad realm of uncertainty. Exactly how clean should the ocean be? How unchanged should man try to keep an environment that nature is changing anyway? The problem is to decide what is in the best interest of the community and to achieve the objective at some acceptable cost. At the same time it is necessary to guard against the danger that excessive demands made in the name of preserving ecosystems will lead to action that is both useless and expensive.

Waste disposal automatically suggests pollution, which is a highly charged word meaning different things to different people. A definition is needed for evaluating accidental and deliberate inputs into the ocean. Athelstan F. Spilhaus of the National Oceanic and Atmospheric Administration, who has written extensively on pollution, defines it as "anything animate or inanimate that by its excess reduces the quality of living." The key word is excess, because most of the substances that are called pollutants are already in the ocean in vast quantities: sediments, salts, dissolved metals and all kinds of organic material. The ocean can tolerate more of them; the question is how much more it can tolerate without damage.

One approach to the question was suggested by the National Water Commission in its report of June, 1973, to the President and Congress: "Water is polluted if it is not of sufficiently high quality to be suitable for the highest uses people wish to make of it at present or in the future." What are "the highest uses" that can be foreseen for ocean waters, particularly those near the shore? They are probably water-contact sports, the production of seafood and the preservation of marine life.

Water-contact sports are occasionally

MONTEREY BAY in California appears in a deliberately overexposed aerial photograph on the opposite page. The overexposure through a filter is a technique that shows details of turbidity in the water caused by mud, organisms or waste. At bottom right a harbor projects into the bay. The light spot of water along the shore above and slightly to the left of the harbor is a sewage outfall. The dark brown spots are beds of kelp, and the reddish purple is a "red tide" consisting of large numbers of the marine organism *Gonyaulax*.



THERMAL EFFLUENT from generating plants of the Southern California Edison Co. and the Los Angeles Department of Water and Power appears in a thermograph of the San Gabriel River, which is the white strip at center, and San Pedro Bay. The intake temperature of cooling water from the bay was 18.9 degrees Celsius. On discharge into the river it was 26.7 degrees C. At the point where the river enters the bay the water temperature was 24.4 degrees C. The two plants jointly generate 900 megawatts of power.

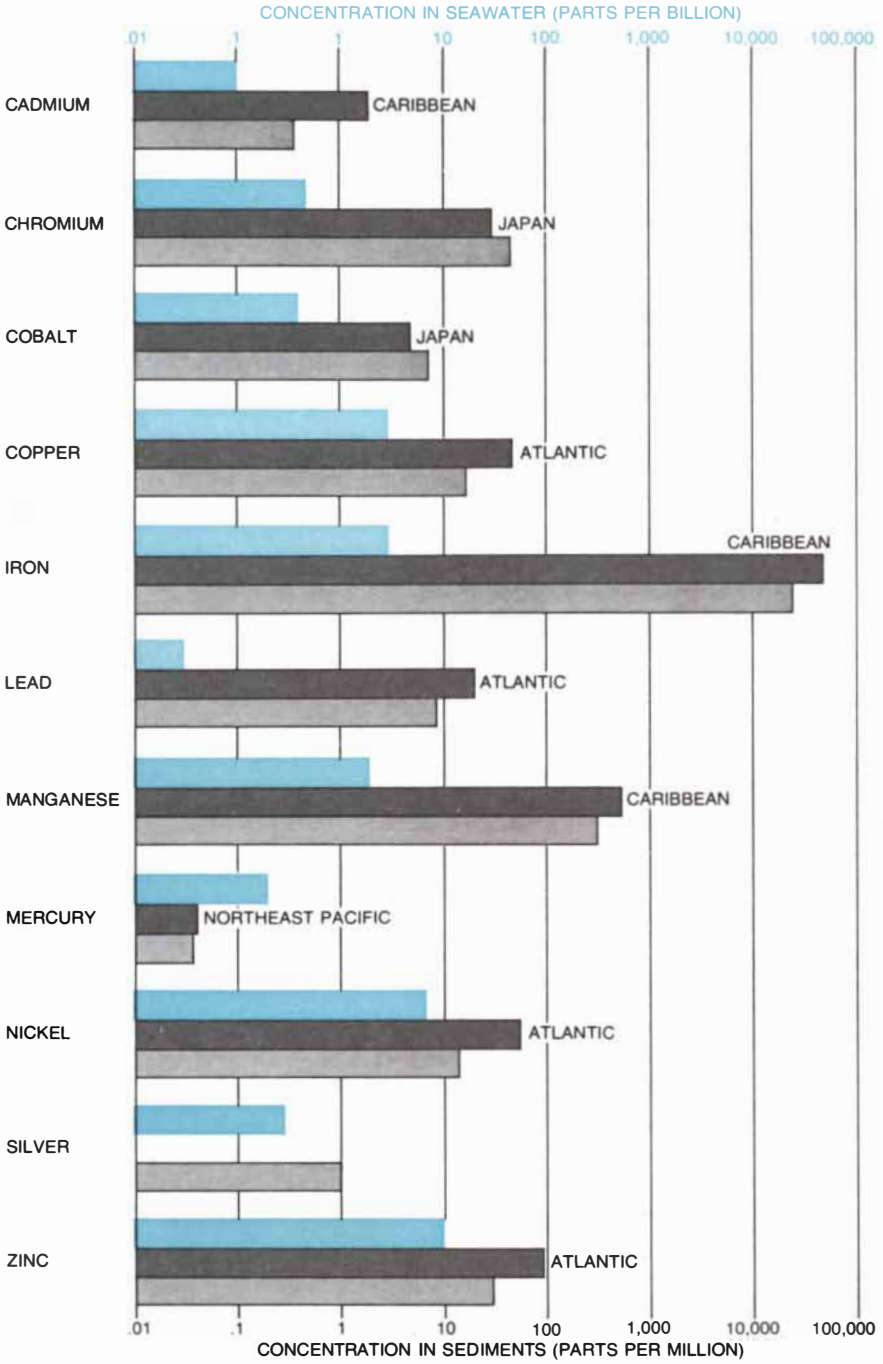
inhibited by pollutants on the seacoasts of the U.S. Where such conditions exist they should be corrected at once. Even where coastal waters are clean the community must be alert to keep them so.

To maintain the ocean waters at an acceptable level of quality it is necessary to consider the main inputs of possible pollutants resulting from human activity. One of them is fecal waste (75 grams dry weight of solids per person per day), which after various degrees of treatment ends up in the ocean as "municipal effluent." Wastes also flow from a host of industrial activities. They are usually processed for the removal of the constituents that are most likely to be harmful, and the remaining effluent is discharged through pipes into the ocean. Dumping from barges into deep water offshore is a means of disposing of dredged materials, sewage sludge and chemical wastes. Thermal wastes include the warmed water from coastal power plants and cooled water from terminals where ships carrying liquid natural gas are berthed. In addition ships heave trash and garbage overboard and pump oily waste from their ballast tanks and bilges.

Such are the intentional discharges, but pollutants reach the ocean in other ways. Aerial fallout brings minute globules of pesticide sprayed on crops, particles of soot from chimneys and the residue of the exhaust of automobiles and airplanes. Painted boat bottoms exude small amounts of toxicants intended to discourage the growth of algae and barnacles. Forest fires put huge amounts of carbon and metallic oxides into the air and thence into the sea. Oil spills from ship collisions and blowouts during underwater drilling operations add an entire class of compounds.

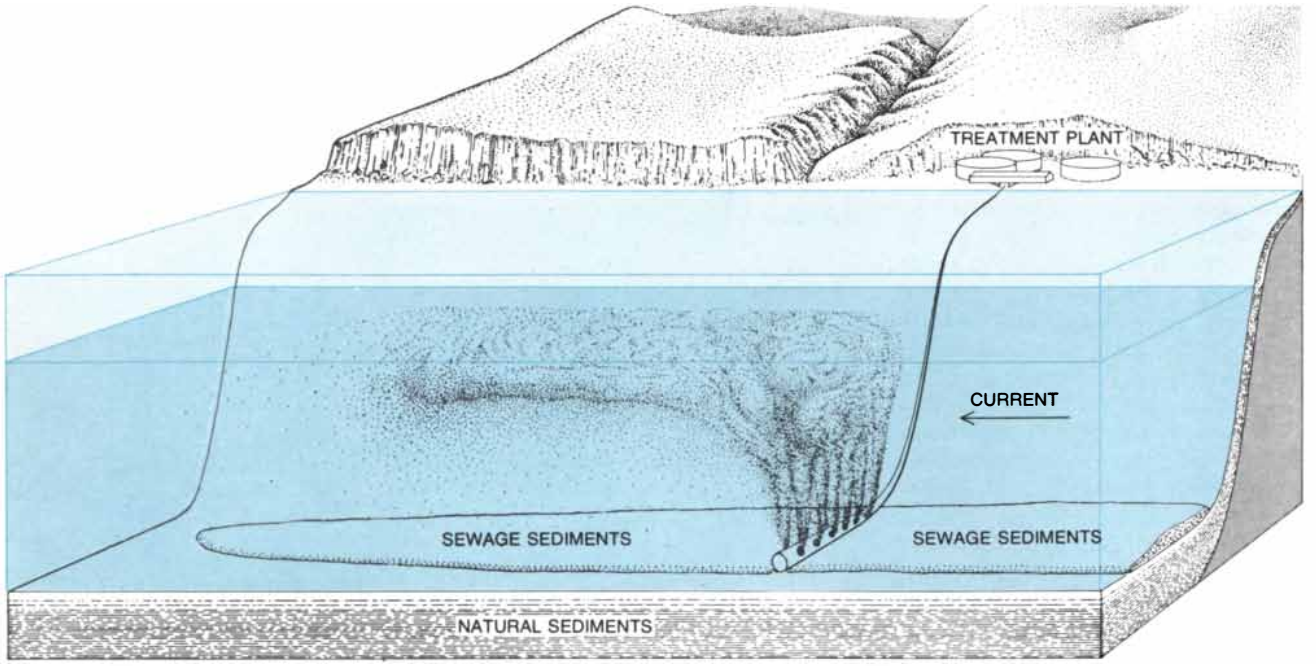
Moreover, natural processes contribute things to the sea that would be called pollutants if man put them there. Streams add fresh water, which is damaging to marine organisms such as coral, and they also bring pollutants washed by rain from trees and land. Volcanic eruptions add large quantities of heavy metals, heat and new rock. Oil has seeped from the bottom since long before man arrived.

Finally, the ocean is neither "pure" nor the same everywhere. It already contains vast amounts of nearly everything, including a substantial burden of metals at low concentration and oxygen at relatively high concentration, plus all kinds of nutrients and chemicals. It has hot and cold layers, well stratified by the thermocline (the boundary between the warm, oxygen-rich upper layer and the cold, oxygen-poor depths). Waves and currents keep the water constantly in motion. It is against this complex background that man must measure the effects of his own discharges.

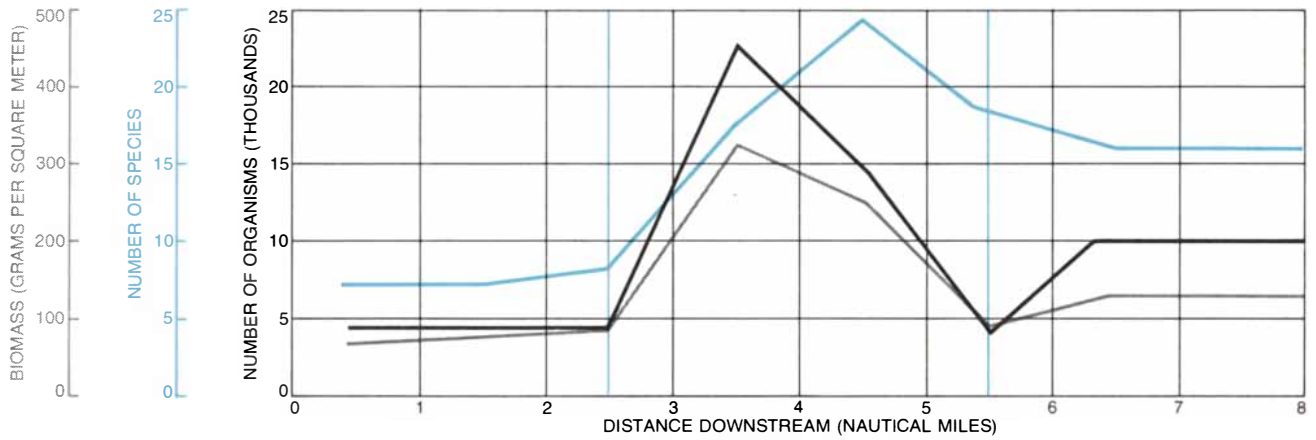


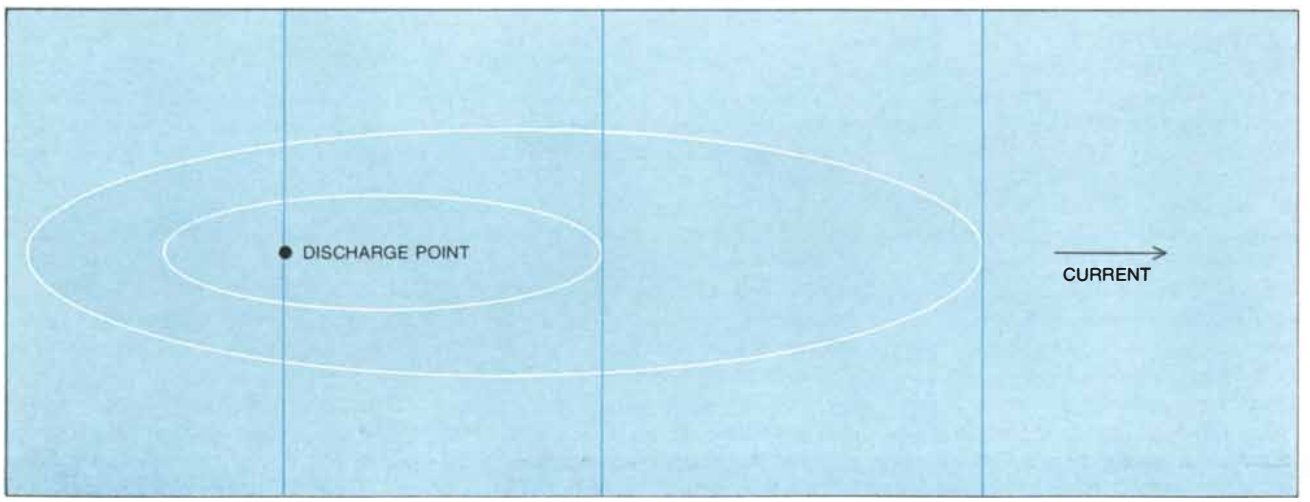
TRACE METALS in seawater (*color*) and top 10 centimeters of sediment (*gray*) are charted. Seawater figures are a worldwide average. The darker gray bars show concentrations at several sampling sites and the lighter bars the average from five sites along California coast.

Even if there were no people living on seacoasts, it would be impossible to predict accurately the kind and quality of marine life because of the natural variability of the ocean. The biota shifts constantly because the temperature and the currents change. Great "blooms" of plankton develop rapidly when conditions have become exactly right and then die off in a few days, depleting the oxygen in the water on both occasions. Within a single year the population of such organisms as salps, copepods and euphausids can change by a factor of 10. When the waters off California become warmer as the current structure shifts, red "crabs" (which look more like small lobsters and are of the genus *Pleuroncodes*) float by in fantastic numbers, fol-



OCEANIC DISPOSAL of waste from a sewage-treatment plant is portrayed. The system is for a plant with a capacity of about 100 million gallons per day. Effluent from the plant flows a distance of from two to five miles through an outfall pipe that is from six to 12 feet in diameter. For about a quarter of a mile at its end the pipe has dozens of six-inch discharge ports. The mostly liquid material it discharges rises to the thermocline, which is the boundary between deep, cool water and the warmer surface layer. Prevailing current mixes material and moves it to one side or the other, depending on wind and tide. Some solid particles settle on the bottom.





EFFECT OF OUTFALL on a community of polychaete worms is depicted. For about three miles downstream from the outfall the worm population is reduced. For the next three miles it is above normal. Thereafter it is about the same as in uninfluenced seabed.

lowed by large populations of bonito and swordfish. They came in 1973 as they did in 1958 and 1963, but the water soon turned cold again and the fish departed, leaving windrows of dead *Pleuroncodes* along the beaches.

The investigator's problem is to learn enough about the major natural changes so that he can tell whether or not human activities have any effect, either positive or negative. It is a signal-to-noise problem; here the changes one is trying to detect are often only a tenth of the natural biological and oceanic background variations. Both types of variation are hard to quantify.

In the case of the sardine, however, a record of the natural changes has been preserved below the floor of the Santa Barbara Basin off the coast of southern California. The bottom of the basin is anaerobic, that is, lacking in oxygen and so supporting little life. The particles that sift down to form sediments are undisturbed by burrowing creatures and therefore remain exactly as they land, in thin strata, layer on layer, one per year. The years can be counted backward, and the count can be confirmed with the lead-210 dating technique.

Some years ago John D. Isaacs of the Scripps Institution of Oceanography, who is also director of the California Marine Life Program, discovered in work with Andrew Soutar that each layer contains identifiable fish scales. Each layer showed a more or less constant number of anchovy and hake scales, but the sardine scales were present erratically, indicating major changes in the population. When the sardines disappeared about 1950, human activities were blamed. The geologic record clearly shows, however, that the sardines had come and gone many times before man arrived. Someday they will return.

It is obvious that some of man's wastes can be damaging to sea life; indeed, products such as DDT, chlorine and ship-bottom paint have been specifically designed to protect man against insects, bacteria and barnacles. Ionic solutions of certain metals are also known to be toxic at some level, as are numerous other substances. The problem is to determine what level is harmful, remembering that some of the substances are actually required for life processes. For example, copper is beneficial or essential for a number of organisms, including crabs, mollusks and oyster larvae. Other marine animals seem to require nickel, cobalt, vanadium and zinc.

Oceanographers would like to be able to demonstrate cause and effect in the ocean, that is, to show that some specific level of a metal does not harm marine life. Proving the absence of damage, however, including long-term and genetic effects, is difficult. Only on fairly rare occasions has it been possible to directly link a specific oceanic pollutant with biological damage. Examples include the finding by Robert Risebrough of the University of California at Berkeley that the decline of the brown pelican off California was attributable to DDT, which inhibits the metabolism of calcium and so makes the shells of the eggs so thin that the mother pelican breaks her own eggs by sitting on them. After patient scientific detective work the source was found to be a single chemical plant in the Los Angeles area. As a result of the work the plant was required to stop discharging DDT wastes into the ocean, and the brown pelican is now returning to California.

From what I have said so far it can be seen that the question of what is a pollutant or what amount of a substance represents pollution is not always easy to answer. Let me now try to put the main kinds of waste in proper perspective.

Municipal sewage containing human fecal material is the type of waste one usually thinks of first. It is certainly a natural substance; indeed, as "night soil" it has long been in demand as a fertilizer in many countries. Since it is not appreciably different from the fecal material discharged by marine animals, is there any reason to think it will be damaging to the ocean, even without treatment? Isaacs has pointed out that the six million metric tons of anchovies off southern California produce as much fecal material as 90 million people, that is, 10 times as much as the population of Los Angeles, and the anchovies of course comprise only one of hundreds of species of marine life.

Two aspects of municipal sewage do require attention. One of them is disease microorganisms. Human waste contains vast numbers of coliform bacteria; they are not themselves harmful, and they die rapidly in seawater (90 percent of them in the first two hours), but they are routinely sampled along public beaches because they indicate the level of disease microorganisms. When there are no endemic diseases in the city discharging the waste (the normal condition in the U.S.), there will be none in the water. It should be noted, however, that the assumption that disease microorganisms die off at the same rate as coliform bacteria is being questioned. It is necessary to guard against the possibility that such organisms will survive in bottom muds long enough to be stirred up by a major storm.

The usual way of reducing the bacterial count is to add chlorine to waste water that is about to be discharged. This approach seems reasonable, since chlorine is commonly added to drinking water and swimming pools to kill bacteria and algae. The trick is to add just the right amount, so that the chlorine exactly neutralizes the bacteria and no excess of either enters the ocean.

The other problem with sewage is one of aesthetics. People do not like to look at discolored water or oily films. A greater effort to reduce effluent "floatables" (tiny particles of plastic, wood, wax and grease) will help to reduce such effects. It will also reduce the number of bacteria reaching the shore, since many of them are attached to the particles.

Petroleum products are perhaps the most controversial marine pollutants. They are seen as small, tarlike lumps far out to sea and on beaches, as great slicks and as brown froth. From two to five million metric tons of oil enter the ocean annually. At least half of it is from land-based sources such as petroleum-refinery wastes and flushings from service stations. Significant quantities of oil enter the marine environment from airborne hydrocarbons. A considerable amount of oil must enter the ocean as natural seepage from the bottom, but it is obviously difficult to estimate how much.

Oil pollution from ships is the most serious problem. Oceangoing vessels shed oil in three ways: by accidents such as collisions; during loading and unloading, and by intentional discharge, which includes the pumping of bilges, the discharge of ballast by tankers and the cleaning of oil tanks by tankers. The ballast component is the worst.

After a tanker unloads its cargo of oil it takes on seawater (about 40 percent of the full load of oil) so that it will not ride too high in the water and be unmanageable. Any oil that remains in the tanks mixes with the water and is discharged with it when the ballast is pumped out in preparation for reloading the vessel with oil. The discharge of oil can be reduced in two ways. One is to wash the tank with water and stow the water aboard in a "slop tank," where the oil slowly separates from it. Then the water is discharged and the next load of oil is put on top of the oil that remains in the slop tank. This practice, which is described as being 80 percent effective, is followed in tankers carrying about 80 percent of the oil now transported at sea. The other stratagem is to build segre-

gated ballast spaces into the double bottoms of new tankers, which reduces the discharge by 95 percent.

A system of international controls could virtually eliminate such discharges. There is an extra incentive for international controls because wherever oil is discharged, and by whatever ship, there is no telling to what shore it will be carried by winds, waves and currents. Substantial progress toward this kind of agreement has been made recently.

Ships are also responsible for most of the littering of the ocean and its shores. Waste consisting of paper, plastics, wood, metal, glass and garbage is customarily thrown overboard. The heavier material sinks quickly, littering the bottom; paper products disintegrate or become waterlogged and sink slowly, and the foods are soon consumed by marine scavengers. The wood, sealed containers and light plastics float ashore.

The estimated yearly litter from ships is about three million metric tons, much of which seems to come from the fishing fleets. The litter that Americans see and are annoyed by comes mostly from the land by way of streams or is thrown into harbors or tossed overboard from pleasure craft. Littering is an aesthetic problem rather than an ecological one, but it certainly reduces the quality of living. It can be curbed by the force of public opinion.

Dumping is a word with a specific meaning; it should not be confused with littering or with discharges from pipes. Dumping means carrying waste out to sea and discharging it at a designated site. Barges carrying solids simply open bottom doors and drop their cargo. Barges carrying liquids generally pump the material out through a submerged pipe into the turbulent wake of the vessel. Still other barges dump wastes enclosed in steel drums or other containers.

Much of the material is dredge spoil sucked up from harbor bottoms by hopper dredges to deepen ship channels. Some 28 million tons of this material were dumped into the Atlantic in 1968. Next in quantity in the New York area is relatively clean material removed from excavations for buildings; then comes sewage sludge, and finally industrial waste such as acids and other chemicals.

The amount of sludge dumped annually into New York Bight is about 4.6 million tons. Much of it is sewage sludge, which is a slurry of solid waste formed by sedimentation in primary sewage treatment or by secondary treatment in the activated-sludge process. For ocean discharge the material is thickened by settling or centrifuging to from 3 to 8 percent solids. Much of the solid material is silt, but complex organic materials and heavy metals are also present.

In some parts of the country the sludge is not dumped but is discharged into the ocean through special pipes. In others it is buried in landfill or spread as fertilizer, although the metals it contains may cause problems later. A broad spectrum of industrial effluents (solvents from pharmaceutical production, waste acid from the titanium-pigment industry, caustic solutions from oil refineries, metallic sodium and calcium, filter cake, salts and chlorinated hydrocarbons) are dumped intermittently at certain sites under Government license.

What damage is done to marine organisms by materials of this kind? The turbidity created by dumping is usually dispersed within a day. Dumped dredge spoil buries bottom-dwelling animals under a thin blanket of sediment, but many of them dig out and the others are replaced by recolonization in about a year. Sewage sludge is high in heavy metals, which may be toxic, particularly when they combine with organic materials to create a reducing (oxygen-poor) environment in which few animals can live. Sludge can also have a high bacterial count. It is clear that much industrial waste could be harmful to marine life and should not be dumped into the sea.

The entire matter of dumping needs more study. With reliable data it will be possible to retain the option of disposal at sea for some materials, such as dredge spoil, and to reject it for others, such as chemicals. Deep-water sites could be set aside for dumping on the same logic that applies to city dumps, namely that it is a suitable use for space of low value where few animals could be harmed.

Thermal waste is discharged into the sea by power plants because the sea is a convenient source of cooling water. The temperature of the water on discharge is typically 10 degrees Celsius higher than it was on intake. The difference is within the range of natural temperature variations and so is not harmful to most adult marine animals. The eggs, larvae and young animals that live in coastal waters, however, are sucked through the power plant with the cooling water. They are subjected to a sudden rise in temperature and decrease in pressure that is likely to be fatal. For this reason and others it would seem logical to put new power plants offshore. There they could draw deeper and cooler water from a level that is not rich in living organisms. For a nuclear plant the hazards of a nuclear accident would be reduced; for an oil- or coal-fired plant fuel could be delivered directly by ship, and the shoreline could be reserved for nonindustrial purposes.

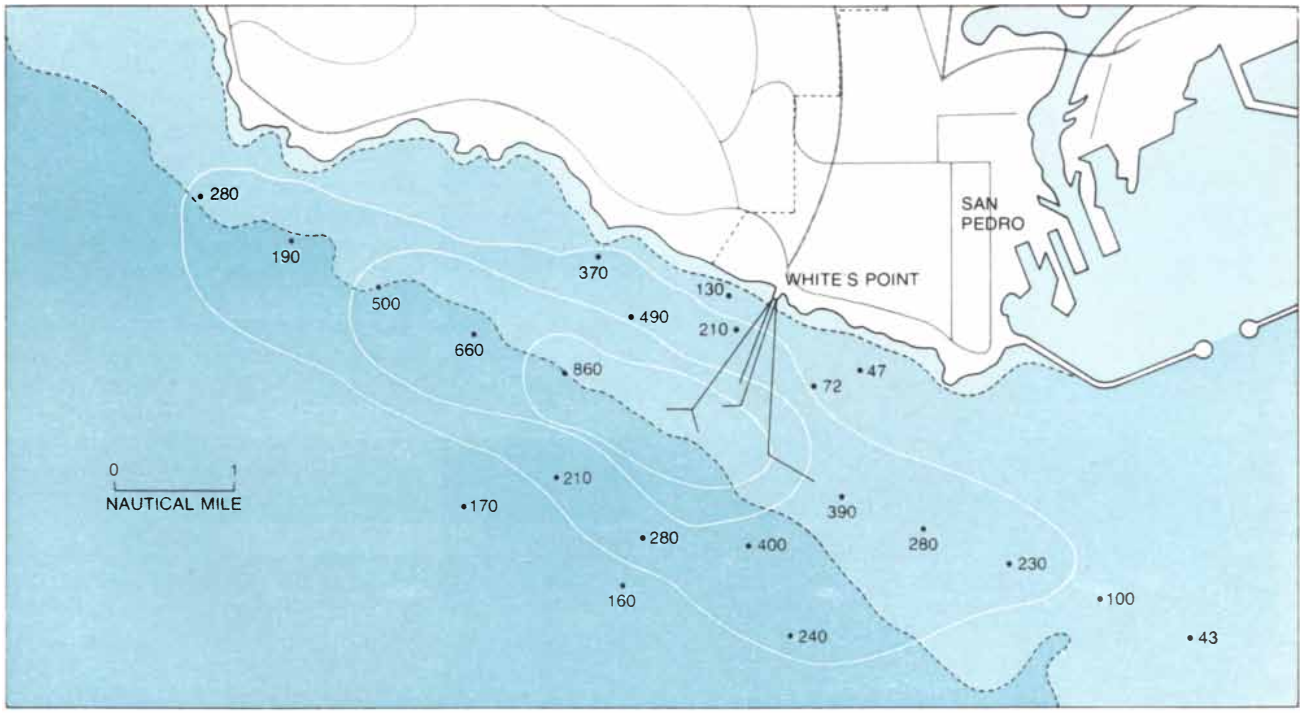
Some industries discharge substantial quantities of heavy metals and complex organic compounds into municipal waste-water systems whose effluent reaches the ocean. Certain of the metals (mercury, chromium, lead, zinc, cadmium, copper, nickel and silver) are notably toxic and so are subject to stringent regulation. The most dangerous substances, however, are synthetic organic compounds such as DDT and polychlorinated biphenyls. The discharge of these substances as well as the heavy metals must be prevented. The best way to do so is by "source control," meaning the prevention of discharge into the sewer system. Each plant must be held responsible for removing and disposing of its own pollutants.

Other waste substances that generate controversy are those with nutrient value. Since they are decomposed by bacteria, oxygen is required. This biological oxygen demand is commonly measured in units that express how much oxygen (in milligrams per liter) will be required in a five-day period.

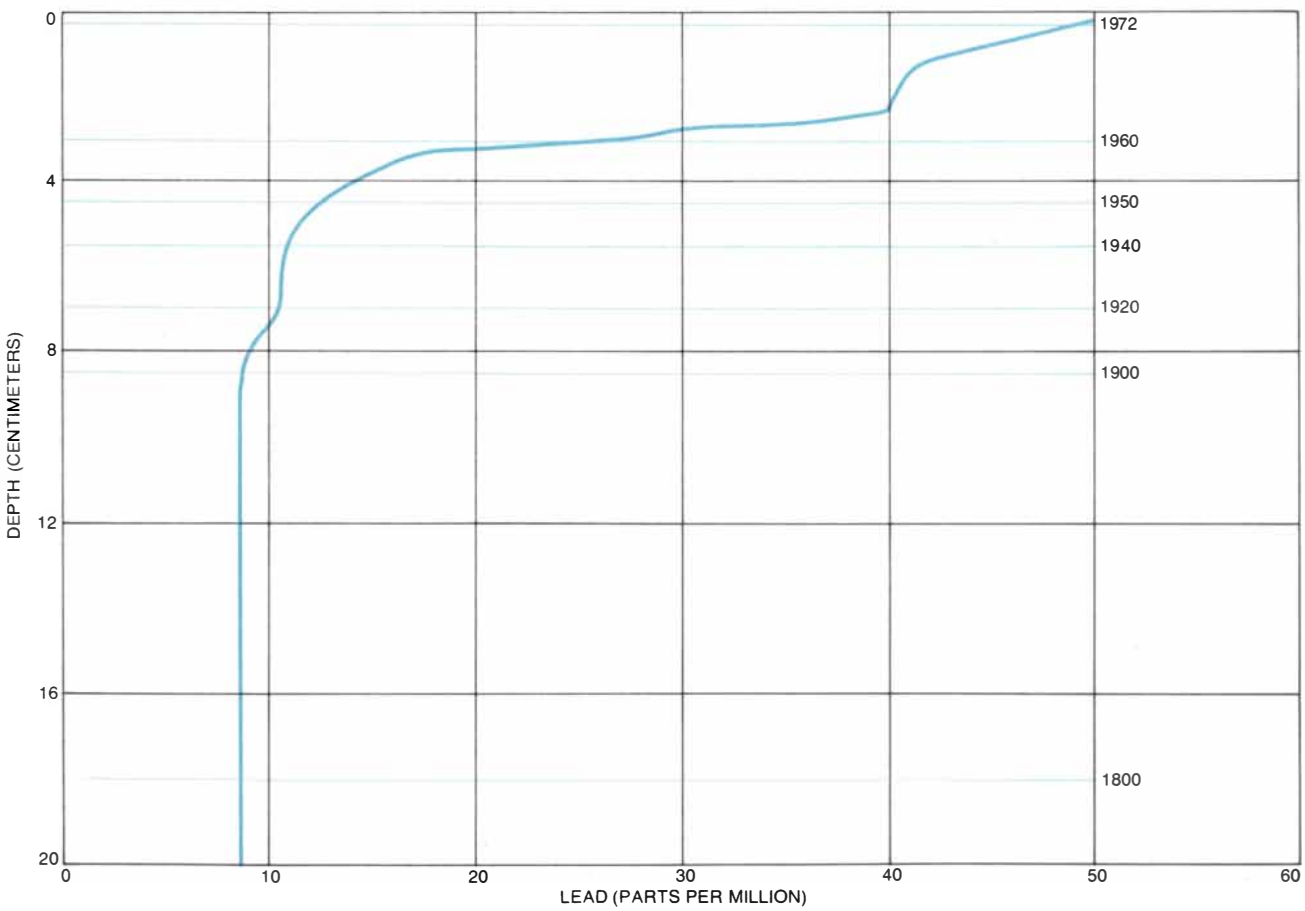
There is good reason to restrict the amount of nutrient material that is discharged into lakes and rivers, where oxygen is limited and a reducing environment can be created. The ocean is another matter. It is an essentially unlimited reservoir of dissolved oxygen, which is kept in motion by currents and is constantly being replenished by natural mechanisms.

It is nonetheless possible to overwhelm a local area of the ocean with a huge discharge of nutrient material that may form a deposit on the sea floor if the local conditions are not carefully considered. The materials must be presented to the ocean in the right places and at reasonable rates. Among the ways of achieving that objective are the use of discharge pipes that lead well offshore and have many small diffuser ports and, if the volume of discharge is exceptionally large, the distribution of the effluent through several widely dispersed pipes.

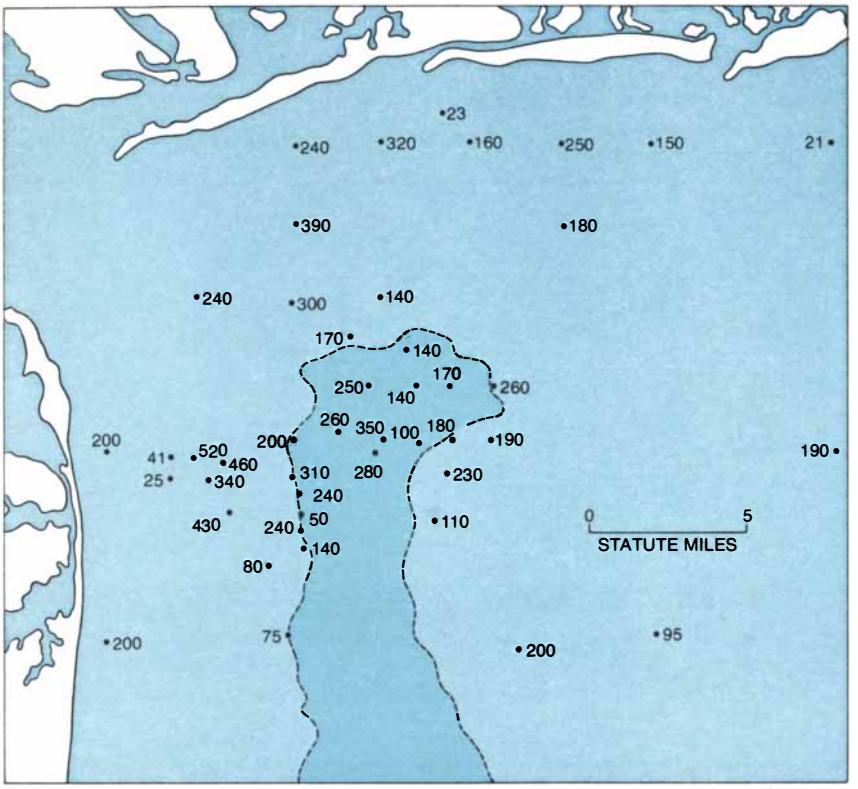
Problems caused by the addition of nitrogen and phosphate to inland waters, which they overfertilize, do not apply to the ocean. There they could be helpful by producing the equivalent of upwelling, the natural process that brings nutrients from deep water to the surface waters where most marine organisms are found. As Isaacs has pointed out, "the sea is *starved* for the basic plant nutrients, and it is a mystery to me why



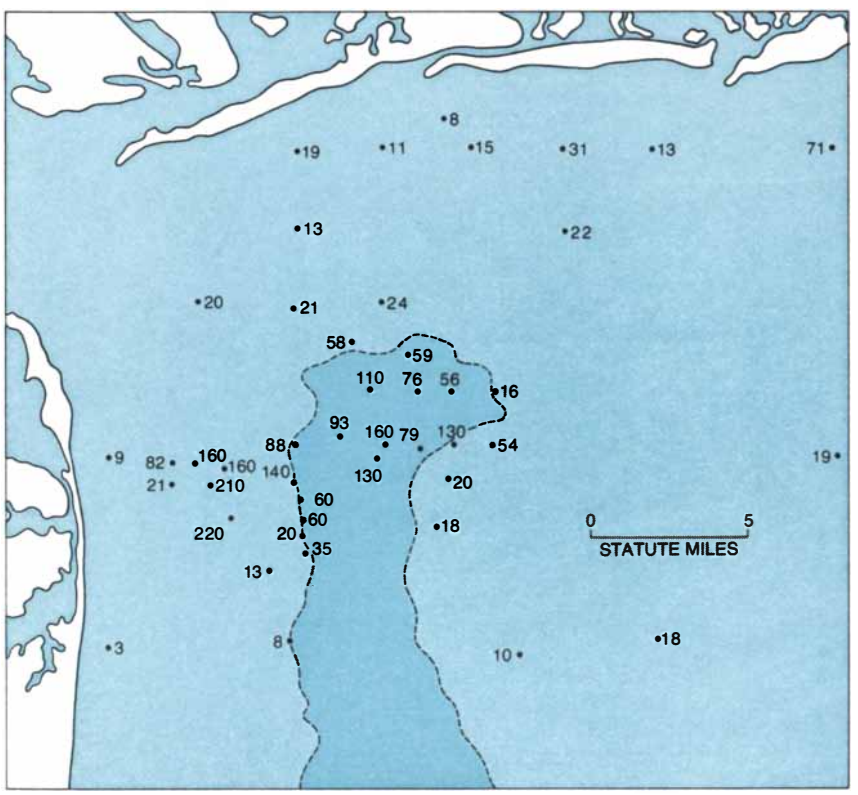
CONCENTRATION OF CHROMIUM in the upper sediments adjacent to a major industrial outfall off San Pedro, Calif., is charted in parts per million. Four outfall lines enter the sea from White's Point. The smallest area surrounded by an elliptical contour line is the area where the concentration is 800 parts per million or more, and the larger contoured areas have concentrations above 500 and 200 parts per million respectively. A depth of three fathoms is shown by the broken line close to shore. Farther out is a 50-fathom line. Other heavy metals discharged into the ocean make similar patterns based on current structure and the slope of the bottom.



CONCENTRATION OF LEAD in the sediments of the San Pedro Basin shows an increase in recent years because of airborne lead that originates mainly from automobile emissions. The figures are based on samples of the sediments obtained by means of coring.



EFFECT OF DUMPING on sediments of the New York Bight is indicated by the concentration of chromium in parts per million in and around the dumping area. A bight is an open bay formed by a bend in a coast. Material transported to the bight to be dumped includes sewage sludge and rubble. The broken contour line represents a depth of 30 meters.



COPPER CONCENTRATION in sediments of the dumping area of the New York Bight is shown in parts per million. Data on chromium and copper in the New York Bight are based on work by Grant Gross of the oceanography section of the National Science Foundation.

we should be concerned with their thoughtful introduction into coastal seas in any quantity that man can generate in the foreseeable future."

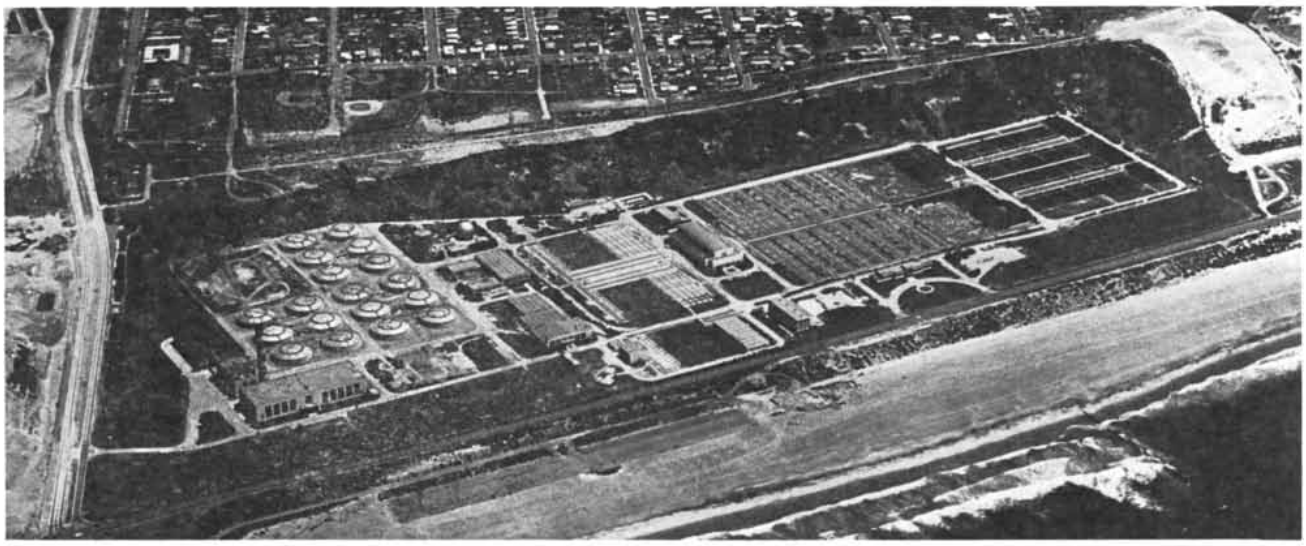
Once possible pollutants reach the ocean it is necessary to keep track of where they go, the extent to which they are altered or diluted and what animals they affect. In order to obtain this information many of the techniques of oceanography are brought into play. Currents are measured above and below the thermocline; other instruments measure the temperature, salinity and dissolved oxygen. Water is sampled at various depths, and so are bottom sediments. It is also useful to directly monitor any changes in plant and animal communities with divers or television cameras.

A good indicator of change is the response of the polychaete worms in the bottom mud. Close to an effluent-discharge point the number of species may be as low as from four to 10 per sample and the total weight of worms as low as 50 grams per square meter. A short distance away the number of species may be 40 or more and the total weight 700 grams per square meter. At greater distances the figures drop off to normal: about 25 species and 300 grams per square meter. This local enrichment shows that worms thrive at some optimum level of organic material. Laboratory tests by Donald Reish and Jack Word of California State University at Long Beach show that worms have a similar optimum for toxic metals such as zinc and copper.

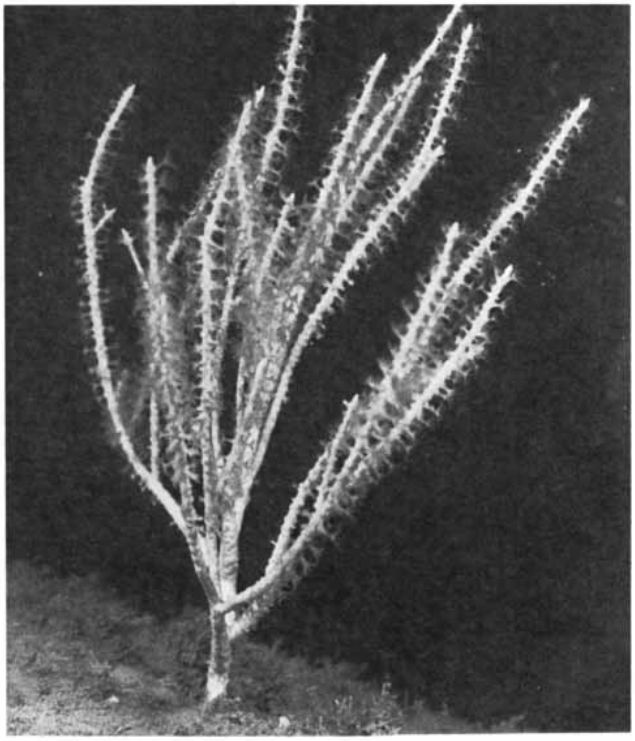
Man must do something with his wastes, and the ocean is a logical place for some of them. No single solution will be sensible for all kinds of waste or all locations, but the following suggestions may help to protect both the land and the sea in the long run. (1) Clearly define what is ocean, separating it from inland freshwaters and from harbors and shallow bays, and make laws that are appropriate for each environment. (2) Avoid the assumption that anything added to the ocean is necessarily harmful and consider instead what substances might cause damage and eliminate excesses of them. (3) Rigorously prohibit the disposal in the ocean of all man-made radioactive materials, halogenated hydrocarbons (such as DDT and polychlorinated biphenyls) and other synthetic organic materials that are toxic and against which marine organisms have no natural defenses. (4) Set standards based on water quality (after reasonable mixing) that are compatible with what is known about the threshold of

damage to marine life, providing a safety factor of at least 10. (5) Work to obtain international cooperation in prohibiting ships from disposing of litter or oil and from pumping bilges. (6) Set aside ocean areas of deep water and slow current where certain materials can be dumped with minimal damage. (7) Require each discharger to make studies to demonstrate how his specific effluent will influence the adjacent ocean. (8) Support additional research on the effect of pollutants on the ocean and its life. (9) Anticipate pollutants that may become serious as technology produces new chemical compounds in greater quantities.

A more rational basis is needed for making decisions about how to treat wastes and where to put them. No oceanographer wants damaging waste in the ocean where he works or on land where he lives. Since the waste must go to one place or the other, however, one would prefer the choice to be based on a knowledge of all the factors. Unemotional consideration of which materials can be introduced into the sea without serious damage to marine life will result in both an unpolluted ocean and a large saving of national resources.



SEWAGE-TREATMENT PLANT serves the City of Los Angeles, discharging into the Pacific Ocean about 235 million gallons per day of primary treated effluent and 100 million gallons per day of secondary effluent. The discharge pipe is 12 feet in diameter and nearly five miles long. At the discharge end it is in 197 feet of water. The plant separately discharges sludge, consisting of about 1 percent solids, through a seven-mile pipe to a depth of more than 300 feet. The sludge is discharged at the brink of a marine canyon.



MARINE ORGANISMS grow on the outfall pipe from the Los Angeles sewage-treatment plant. At left are anemones about three feet high and at right is a gorgonian. The location is near the discharge point of the outfall pipe at a depth of approximately 200 feet.

The Cosmic Background Radiation

The space between the galaxies is filled with radiation ranging from radio waves to gamma rays. The radiation has been generated by various processes, some of which are traced to the "big bang"

by Adrian Webster

No part of the universe is empty. The space between the planets contains the "wind" of ionized gas expelled by the sun and the dust that is seen from the earth as the zodiacal light. The space between the stars contains a variety of materials, ranging from the hydrogen whose emission and absorption at the wavelength of 21 centimeters is studied by radio astronomers to the dust that weakens and reddens the light of distant stars. Even on the largest scale of all, the vast reaches of space between the galaxies are not empty. To be sure, no gas or dust or any other form of matter has been detected there, but it is quite clear that the whole of that space is permeated by a uniform background of electromagnetic radiation. This cosmic background radiation has now been detected across most of the electromagnetic spectrum, from radio waves at a wavelength of 300 meters to gamma rays at a wavelength of 10^{-14} meter. It provides a wealth of information on the history of the universe back to its origin in the "big bang."

The cosmic background radiation has been measured only within the past decade, but interest in the subject goes back two and a half centuries. Early in the 18th century Edmund Halley asked: "Why is the sky dark at night?" This apparently naïve question is not easy to answer, because if the universe had the simplest imaginable structure on the largest possible scale, the background radiation of the sky would be intense. Imagine a static infinite universe, that is, a universe of infinite size in which the stars and galaxies are stationary with respect to one another. A line of sight in any direction will ultimately cross the surface of a star, and the sky should appear to be made up of overlapping stellar disks. The apparent brightness of a star's surface is independent of its distance, so that everywhere the sky should be as bright as the surface of an average star. Since the sun is an average star, the entire sky, day and night, should be about as bright as the surface of the sun. The fact that it is not was later characterized as Olbers' paradox (after the 18th-century German astronomer Heinrich Olbers). The paradox applies not only to starlight but also to all other regions of the electromagnetic spectrum. It indicates that there is something fundamentally wrong with the model of a static infinite universe, but it does not specify what.

Olbers' paradox was resolved in 1929, when Edwin P. Hubble showed that the universe is not static but is uniformly expanding. The galaxies are all receding from one another, and the velocity of recession, as it is perceived on the earth, is directly proportional to the galaxy's distance. The velocity of recession has a strong effect on the light traveling from the galaxy to the earth. First of all, with each passing moment the successive photons (quanta of light) emitted by the stars in the galaxy have farther to go in order to reach the earth, so that their rate of arrival is lower than it would have been if the galaxy had been stationary. Second, the Doppler effect shifts the photons to lower frequencies, so that they have less energy.

Together these two effects weaken the light from the stars in a distant galaxy over and above the dimming due to the galaxy's distance. Both effects become particularly strong when the speed of the galaxy is a substantial fraction of the speed of light, because at that point the special theory of relativity must be taken into account. The result of all these weakening effects is that the energy density of starlight does not reach enormous values and cause the sky to be as bright as the sun. The same argument applies to photons of all other wavelengths.

At this writing the background radiation has been observed in four regions of the electromagnetic spectrum: the radio region, the microwave region, the X-ray region and the gamma-ray region. The background radiation at each of the different wavelengths provides a different kind of information on the history of the universe, so that I shall deal with each region separately, starting at the long wavelengths and continuing toward the short.

The cosmic background radiation in the radio region is detected between the frequencies of one megahertz (million cycles per second) and 500 MHz, corresponding to the wavelengths between 300 meters and 60 centimeters. This radiation is somewhat difficult to detect and measure because our galaxy is itself a source of radio waves. The background flux of radio power from all directions is dominated by this foreground of galactic radiation. Measurements of the brightness of the radio sky at the frequency of 20 MHz in the direction of the Large Cloud of Magellan have shown, however, that some of the radio power comes from outside our galaxy. Within the Large Magellanic Cloud, which is one of two small galaxies close to ours, is a cloud of ionized gas that absorbs radio waves at the frequency of 20 MHz. C. A. Shain of the Commonwealth Scientific and Industrial Research Organization in Australia has found that in the direction of this cloud of ionized gas, designated 30 Doradus, there is a decrease in the radio brightness of the sky. His observations show clearly that the ionized gas of 30 Doradus is absorbing radiation, so that there must be radiation coming from a distance greater than that of the Large Magellanic Cloud and therefore coming from well outside our galaxy.

To study the background radiation over a wide range of frequencies in the radio region a technique developed by radio astronomers at the University of Cambridge is used. Accurate maps of the radio sky are made at a variety of wavelengths and are compared with one another. The background radiation does not vary appreciably in strength between one direction and another, and so it has the effect of increasing all the measurements at one wavelength on any map by a constant amount; the zero level to which the brightness is referred on each map is established by the background radiation. The way in which the zero level varies from map to map at various wavelengths gives the strength of the background radiation at each wavelength.

This mapping technique has revealed that the intensity, or energy density, of the radio background drops off as the spectral frequency increases. That is, the amount of energy at shorter wavelengths is less than that at longer ones. This type of spectrum is commonly encountered in radio astronomy; it is called a nonthermal spectrum to distinguish it from the thermal radiation of a hot gas, where the relation between intensity and frequency is totally different. The nonthermal radiation is believed to be generated by the synchrotron process, in which high-energy charged particles spiraling along the lines of force in a magnetic field emit energy at radio wavelengths.

The origin of the radio background is

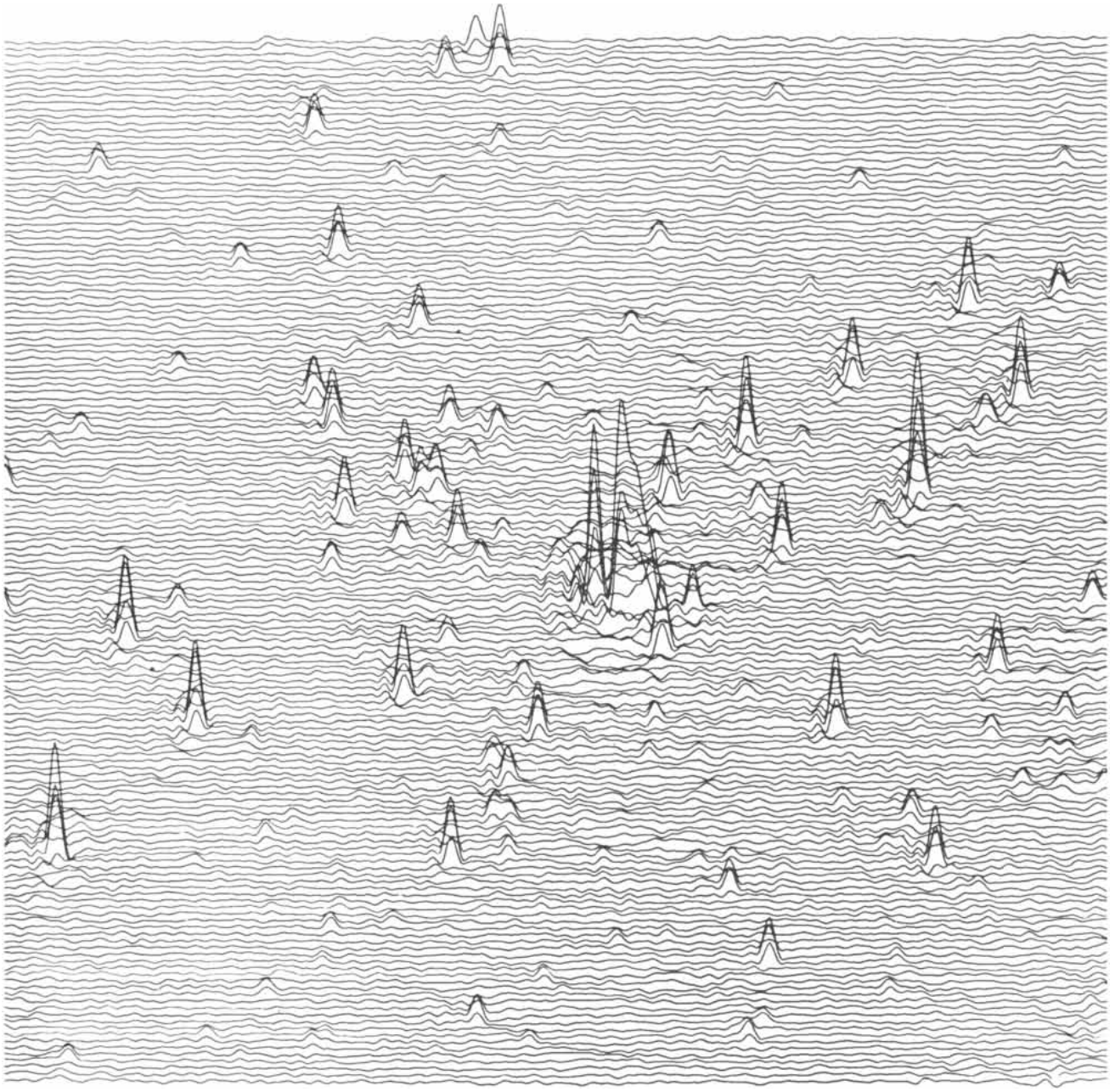
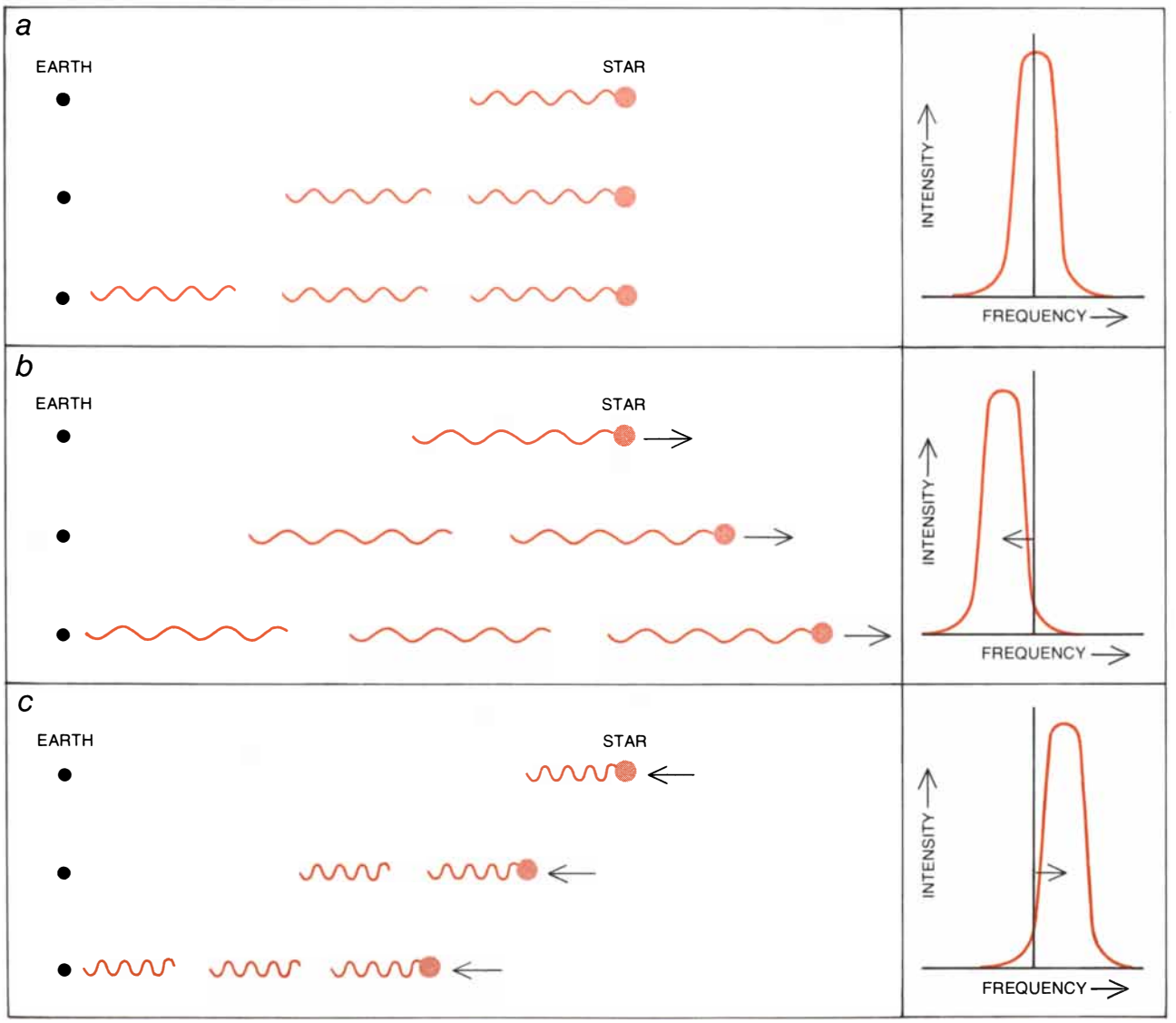


CHART OF THE RADIO SOURCES in a small patch of the sky was made by the three dishes of the One Mile Telescope at the University of Cambridge, which are arranged as an interferometer. Each set of peaks on the chart is a radio galaxy or a quasar. Charts such as this one show that there are more faint celestial radio sources than one would expect from the number of bright ones. It is believed that the cosmic background radiation in the radio region of the spectrum is due to all the radio sources in the sky added together. The faint sources are actually powerful sources at great distances, seen now as they were in the distant past because of the time taken for the signals to reach the earth. Such observations indicate sources were more numerous in the past than they are now.

well understood: it is the emission of all the radio sources in the universe added together. These sources, such as radio galaxies and quasars, have nonthermal spectra of just the same kind as the background radiation. It is possible to count enough radio sources on maps made with radio telescopes of the highest sensitivity to infer that the radiation from all of them, including sources too faint to detect individually, adds up to the strength of the radio background. By analyzing the radio background one can study all at once many more radio sources than one could ever hope to detect and examine individually. A great deal of useful information has emerged from such analysis.

For example, the radio background has confirmed evidence from surveys of individual radio sources that there were many more radio galaxies and quasars in the recent cosmic past than there are now. The reason is that if one were to calculate the strength of the background from the present number of radio galaxies and quasars, the result would be much smaller than the observed strength. Allowing for a greater number of these objects in the past makes the calculations agree with the observations. Such confirmation is of vital importance to modern cosmology because it shows, among other things, that the steady-state theory of the universe is quite wrong. The steady-state theory posits that any one part of the universe is on the average much the same as any other part, and that at present the universe is much the same as it always was and ever will be. One consequence of the steady-state theory is that it calls for the continuous creation of matter to counteract the decrease in density caused by the universe's expansion. The steady-state theory neatly sidesteps all problems about the origin of the universe and the beginning of time by stating that there need not have been a beginning. It is clear, however, that since there were many more radio sources in the past than there are now, the universe was not the same then, and that the fundamental postulate of the steady-state theory is false.



DOPPLER SHIFT of the light from a moving star can be used to determine both the velocity and the direction of the star with respect to the earth. If the star is stationary (*a*), its light will be unaffected, and each of the lines in its spectrum will be at the "rest" frequency (*indicated by the vertical line in the spectrum at right*). If the star is moving away from the earth (*b*), its light will be shifted toward longer (redder) wavelengths and will also be dimmed because fewer photons (*wavy line segments*) emitted by the star will reach the earth within a given time interval than if the star were at rest. Conversely, if the star is moving toward the earth (*c*), its light will be shifted toward shorter (bluer) wavelengths and the photons will be arriving at the earth with greater frequency.

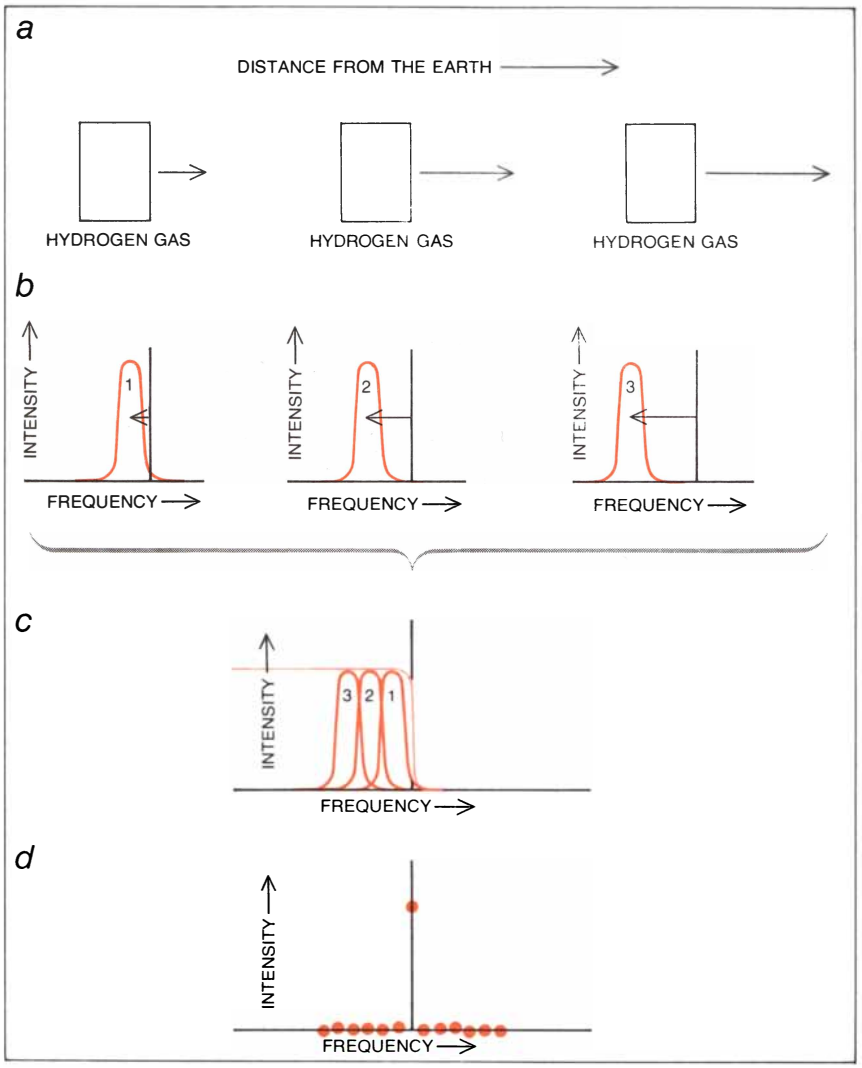
The alternative hypothesis to the steady-state theory is the big-bang theory. This theory states that at the beginning of time all the matter in the universe exploded out of a superdense kernel. The observations of the radio background are easy enough to fit into the big-bang theory: the era from about a quarter of the age of the universe up to the present was the era of radio galaxies and quasars. That era is apparently coming to an end, so that there are few of these objects left. In the future there may well be none at all.

One feature of the radio background is conspicuous by its absence. It is well known that in the space between the stars of our galaxy there is a substantial amount of neutral (un-ionized) hydrogen radiating at its characteristic wavelength of 21 centimeters. The 21-centimeter emission has been sought in the spectrum of the cosmic background radiation and has not been found. Consequently there cannot be much neutral hydrogen in the space between the galaxies. This result is of particular interest because according to the canonical hot-big-bang theory, to which I shall return below, the universe must have been full of neutral hydrogen when the initial fireball of the big bang had cooled off. Presumably much of the hydrogen has been used up in the building of stars and galaxies, and the rest may have been reionized.

The next region of the spectrum in which the cosmic background radiation has been detected is the microwave region. The microwave background predominates at all frequencies between 500 MHz and 500 GHz (gigahertz, or 10^9 cycles per second), corresponding to wavelengths between 60 centimeters and .6 millimeter. The microwave background was discovered in 1965 by Arno A. Penzias and Robert W. Wilson of Bell Laboratories [see "The Primeval Fireball," by P. J. E. Peebles and David T. Wilkinson; SCIENTIFIC AMERICAN, June, 1967]. The early measurements of the intensity of the radiation at various wavelengths produced a curve resembling that of a "black body" (an ideal radiator) at a temperature close to 3 degrees Kelvin (degrees Celsius above absolute zero). The radiation seemed to be constant in strength across the sky, and its existence apparently fitted perfectly into the framework of the big-bang theory.

Since that time many more measurements of the microwave background have been made. All have confirmed its black-body curve between 408 MHz and 115 GHz, corresponding to wavelengths between 74 centimeters and 2.6 millimeters. The best and most recent value for the characteristic temperature of the radiation is 2.76 degrees K.; the measurements are so accurate that it is unlikely that this figure differs from the true one by more than about 3 percent. Instruments carried aloft by balloons and rockets should soon yield accurate measurements in the highest range of microwave frequencies, between 115 GHz and 500 GHz, corresponding to wavelengths between 2.6 millimeters and .6 millimeter. These measurements must be made from above most of the earth's atmosphere because the atmosphere strongly absorbs radiation of millimeter wavelengths. They are very important measurements because they will provide the final check on whether or not the microwave curve is truly a black-body one.

The canonical hot-big-bang theory is an outline that has recently been developed to account for the overall history of the universe. It has been deduced by starting at the present condition of the universe and working backward in time, using all the known laws of physics to calculate what the main processes were at each stage. The details of the calculations are fascinating; it is quite surpris-



NEUTRAL (UN-IONIZED) HYDROGEN GAS does not fill the space between the galaxies, at least insofar as it has not been detected by radio telescopes. If the universe were filled with hydrogen, presumably the gas that is farther from the earth would be receding faster than the gas that is closer (*a*), just as the galaxies are observed to recede. Therefore the emission line at the radio wavelength of 21 centimeters (corresponding to a frequency of 1,420 megahertz) of the gas farther from the earth (*b*) would be Doppler-shifted more toward longer wavelengths and lower frequencies than the emission line of the gas closer to the earth would be. The result would be that all the shifted emission lines from the gas at the various distances would add up (*c*) to produce a "step" (*light color*) in the radio spectrum below 1,420 MHz. No such step, however, has ever been found (*dots in color*) in the radio spectrum (*d*). The clear signal at exactly 1,420 MHz is from gas in our own galaxy.

ing how much can be reliably deduced about what went on so long ago. Here, however, there is room only for a brief summary.

The illustration on page 33 charts the history of the universe from the time when its overall temperature was 10^{12} degrees K. Before that time the universe was full of short-lived exotic particles and antiparticles at tremendous density, temperature and pressure. These particles were in equilibrium with the field of radiation, that is, the particles could interact to produce photons and the photons could interact to produce particles. The higher the energy of the photons was, the more massive and peculiar the particles were that each photon could create. By the time the temperature had dropped to 10^{12} degrees K., however, the universe was so cool that the only particles whose existence depended on an equilibrium with photons were pairs of positrons and electrons and pairs of neutrinos and antineutrinos. At that stage some protons and neutrons were left, but all the other heavy particles and antiparticles had been annihilated.

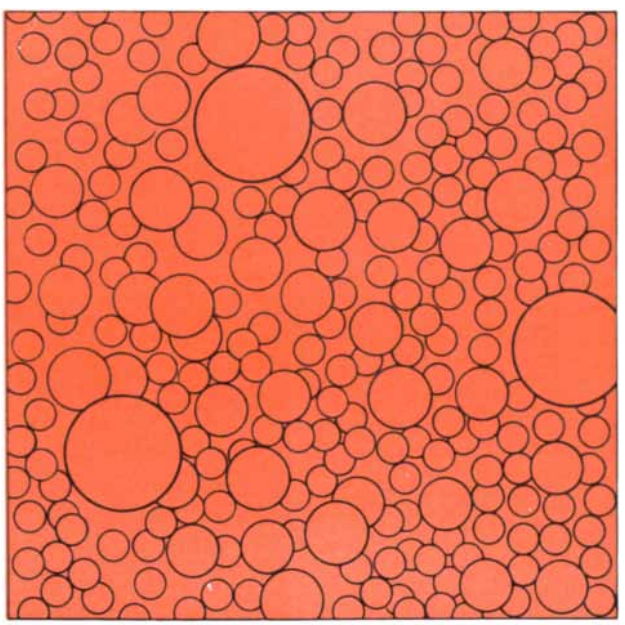
Before the temperature had fallen to 10^{11} degrees K. the density of matter, although still great by present standards, was low enough for the neutrinos and antineutrinos to cease interacting with the other particles. From that time on these neutrinos and antineutrinos went their separate ways. They are presumably still around, but at present there does not seem to be any means of detecting them.

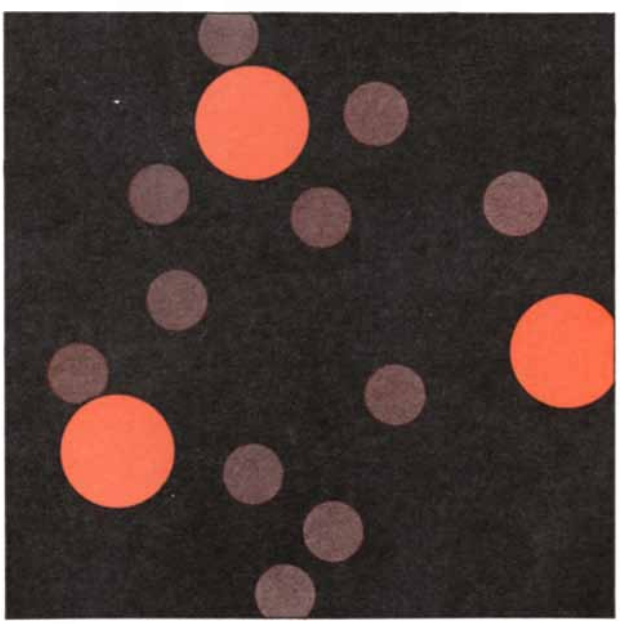
When the temperature had dropped to 10^9 degrees K., the photons did not have enough energy to supply the rest-mass energy equivalent to the mass of the positron-electron pairs (according to the formula $E = mc^2$). Thus the equilibrium between the photons and the pairs of particles was disrupted: positrons and electrons that recombined to produce photons were no longer replaced by the reverse reaction. The positrons were steadily annihilated, leaving a small excess of electrons.

At about the same temperature the protons and neutrons underwent a series of nuclear reactions that resulted in the formation of helium nuclei (composed of either two protons and one neutron or two protons and two neutrons). Most of the helium in the universe today was formed at that time; the number of helium atoms observed in the present universe is an important check on conditions at that stage of the evolution of the universe. No free neutrons survived this stage. The universe at that time was composed of protons and helium nuclei that, together with the electrons, made up an ionized gas in thermal equilibrium with the photons. The enigmatic neutrinos were also still around. Photons in existence at this stage soon interacted with the ionized gas and do not survive to the present day.

When the temperature had dropped below about 5,000 degrees K., the nuclei and the electrons of the ionized gas recombined to give rise to an un-ionized gas. This gas did not interact further with the photons, so that those photons were undisturbed from that time on. They are what we detect when we observe the microwave background today. Since the time when they were created the Doppler shift caused by the expansion of the universe has weakened the radiation; although it started off at the time of recombination as black-body radiation with a temperature of some 5,000 degrees K. (corresponding to the radiation field at the surface of the sun), it is now black-body radiation at a temperature of only 2.76 degrees K.

The canonical hot-big-bang theory is the framework within which many astrophysicists are currently attempting to understand all the events in the evolution of the universe. In spite of the great leap in understanding brought about by the discovery of the microwave background, many questions remain to be answered, and the answers will need to be fitted into place. Why and how did galaxies form? Why are they the size they are and not larger or smaller? Why do they rotate? Where do their magnetic fields come from? Why and how did quasars form? Why are there fewer quasars now than there were in the past? These questions and many others are all being attacked by trying to find explanatory processes in the universe described by the canonical hot-big-bang model.





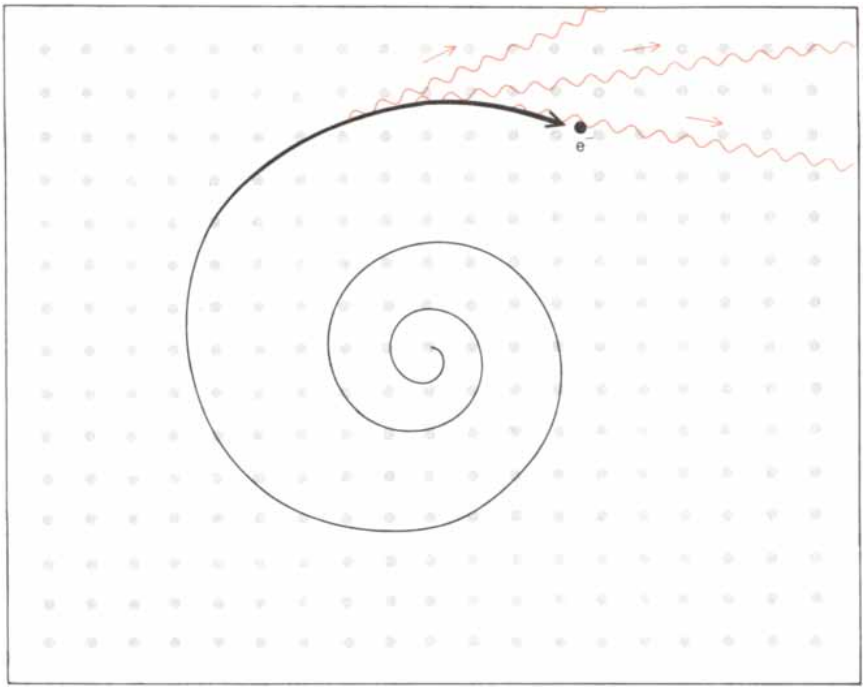
OLBERS' PARADOX states that if the universe were infinite in extent and all the stars were stationary with respect to one another, then the surfaces of the stars could be seen in all directions and the night sky would be very bright (*left*). Since such a phenomenon is not observed, something is wrong with that model of the universe. In fact, it is the expansion of the universe that both reddens and weakens the light of distant stars (*right*) so that the night sky is mostly black. Paradox also applies to other regions of spectrum.

There are some interesting problems at a more fundamental level that seem not so much to invite an answer from within the framework of the model as to demand an explanation in order that the model itself seem less arbitrary. Choosing to work backward from the present state of the universe to gain some knowledge of the initial conditions is not at all arbitrary, but it does not suffice to *explain* the initial conditions. Probably the most we can expect from this approach is that we shall be able at least to *describe* those conditions.

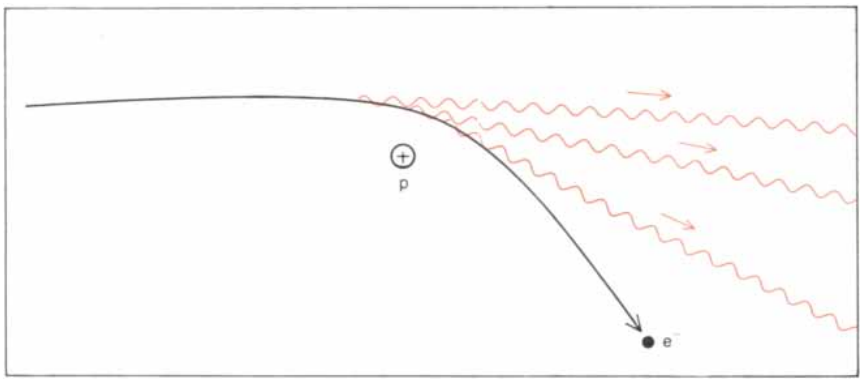
One unanswered question in this category is: Why is the universe expanding at all? We know it is expanding now, and as we work backward we calculate that it was expanding in all the earlier stages as well. But what started the expansion in the first place? There are other such questions, perhaps less obvious but no less important. For example, after the vast numbers of particles and antiparticles had annihilated themselves, why was there a small residuum of real particles (the protons, electrons and neutrons) that constitute the matter in the universe at the present time? Presumably there could just as easily have been a larger or smaller residuum of real particles, or a large or small residuum of antiparticles, or an exact cancellation of the two with no particles or antiparticles left at all. There is nothing in physics that would lead us to prefer any one of these possibilities. Why, then, is there precisely the observed density of real particles? This question goes right back to the initial conditions, because the most likely possibility is that the excess was always there and that it has been a characteristic feature of the universe at all times. It is not yet clear where the answers to the deeper questions are to be found, but these problems are certainly among the most challenging and stimulating in modern astronomy.

Let me return now to the observational situation. With the microwave background, as with the radio background, many attempts have been made to find differences in brightness between different directions in the sky, but no such differences are clearly apparent. The present state of the measurements is that variations in brightness in any angular area of the sky from 180 degrees across to about .1 degree across must be no greater than .1 percent. In other words, the microwave background is very uniform indeed.

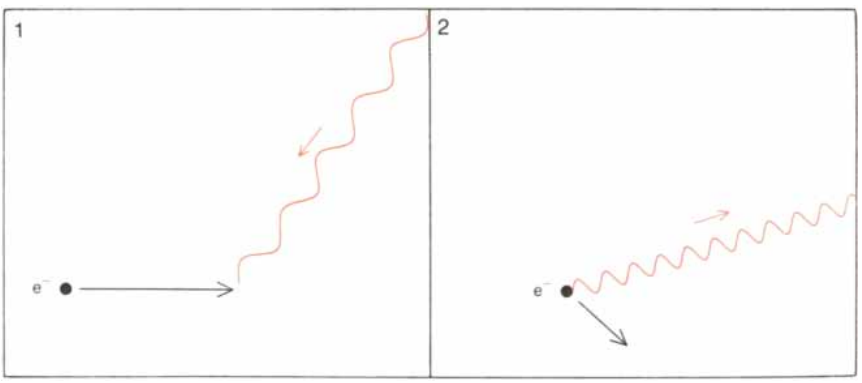
It is possible to infer many interesting consequences from this fact. First, the solar system must be moving no faster



SYNCHROTRON RADIATION (*waves in color*) emitted by a charged particle (in this case an electron) spiraling in a magnetic field probably accounts for background radiation in radio region. Here the lines of magnetic force are perpendicular to the page (*gray dots*). Electron is spiraling up from the page and is emitting radiation tangent to its path.



BREMSSTRAHLUNG RADIATION is generated when an electron passes so close to a nucleus (*plus sign in circle*) that its trajectory is bent. The slowing of the electron results in the emission of photons. This mechanism probably gives rise to the cosmic background radiation in the microwave region. (*Bremsstrahlung* is the German for braking radiation.)



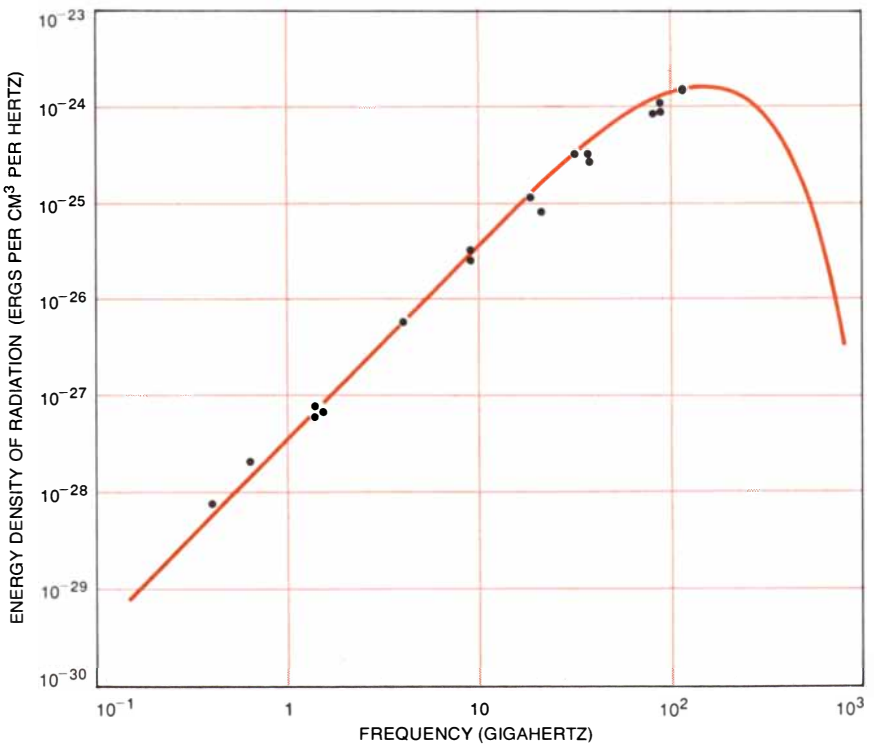
INVERSE COMPTON SCATTERING probably accounts for the background radiation in the X-ray and gamma-ray region. Here a low-energy photon impinges on a high-energy electron (*1*). Electron imparts some of its energy to photon and is itself slowed down (*2*).

than some 300 kilometers per second with respect to the frame of reference defined by the microwave background. If it were, the Doppler effect would cause the radiation from the direction in which the solar system is heading to be brighter than that from the rest of the sky by about .1 percent. It is likely that a small improvement in these observations will reveal the velocity of 200 kilometers per second of the solar system's rotation around the center of our galaxy.

A second consequence is that the universe must be expanding at the same rate in all directions. Otherwise the differences among the Doppler shifts of the radiation from the various regions of the recombining ionized gas that is responsible for the microwave background would cause brightness variations across the sky. A third consequence is that the universe cannot be rotating with any appreciable angular velocity or again the relativistic Doppler effect would give rise to observable brightness variations. The upper limit set for any possible rotation by these measurements is the phenomenally low value of a billionth of a second of arc per year.

The measurements of the uniformity of the background radiation on the smallest angular scales are designed to detect fluctuations in the density of the recombining ionized gas that condensed into the clusters and superclusters of galaxies in the present-day universe. Most calculations predict that the expected nonuniformities in brightness will be very small. Thus it is not too surprising that they have not yet been found.

An intriguing phenomenon within our own galaxy has been discovered through the microwave background. In the interior of certain small, dense clouds of gas and dust along the Milky Way there is a substantial concentration of formaldehyde molecules (H_2CO). Radio observations of these clouds have revealed an absorption line in their spectra at a wavelength of six centimeters, a wavelength characteristic of the formaldehyde molecule. At that wavelength the only continuous-spectrum radiation strong enough to be absorbed by the formaldehyde is the microwave background. The fact that the formaldehyde is absorbing energy rather than radiating it indicates that its temperature must be lower than the 2.76 degrees K. of the microwave background. In fact, the temperature of the formaldehyde is about one degree K. This raises the question of how the formaldehyde ever got so cold and how it stays that way. After all, if the formaldehyde were left to itself, it would be warmed to 2.76 degrees by the microwave background radiation. Some kind of previously unsuspected cosmic refrigerator must be working inside the clouds to keep the formaldehyde chilled.



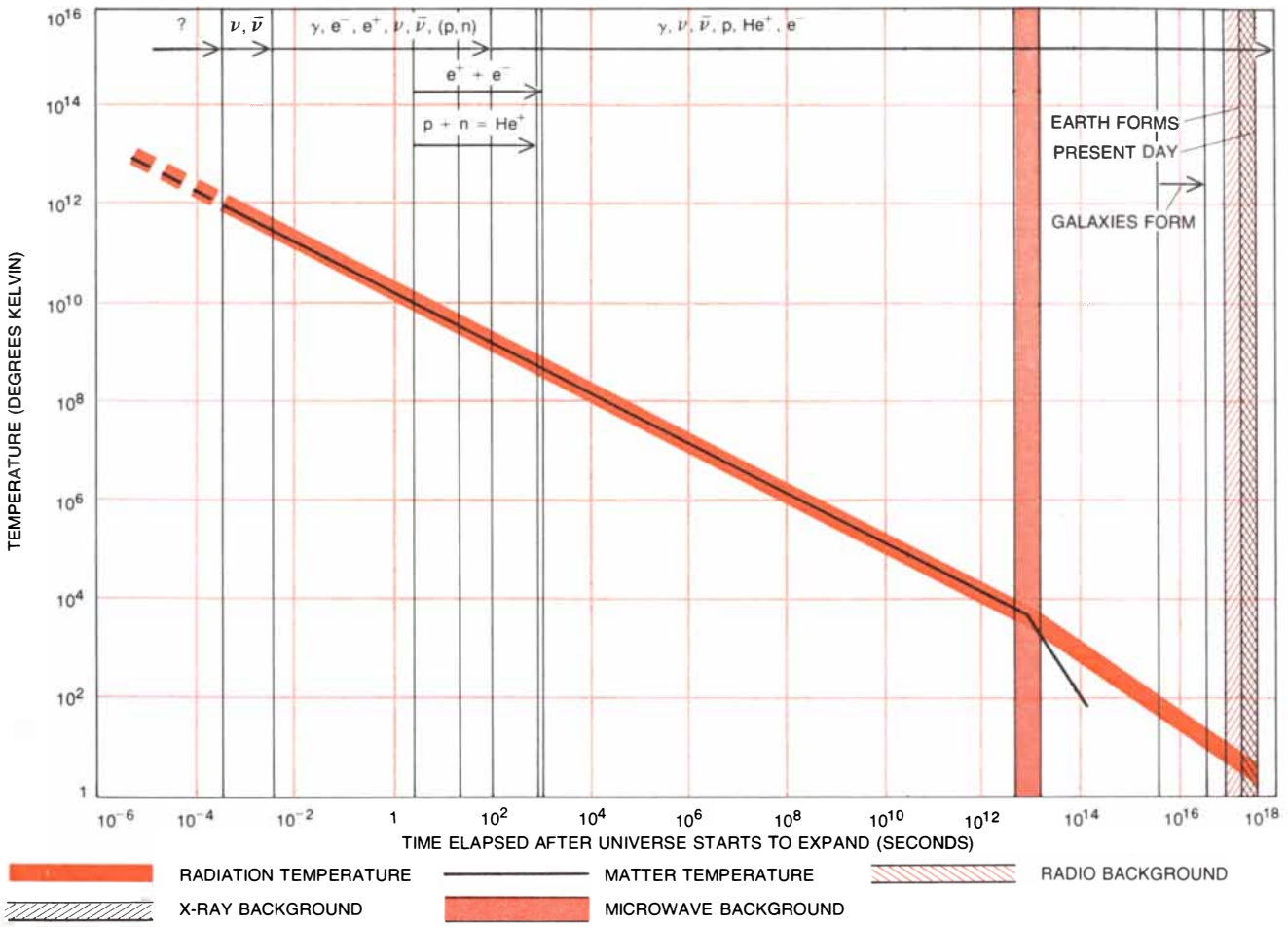
SPECTRUM OF MICROWAVE BACKGROUND shows how well the measurements (*dots*) fit the theoretical curve of a black body (an ideal radiator) at a temperature of 2.76 degrees Kelvin. Further measurements are needed in range of frequencies between 10^2 and 10^3 gigahertz (10^9 cycles per second) to confirm that the spectrum is indeed a black-body one.

In the X-ray region the cosmic background is represented by radiation at frequencies higher than 2.5×10^{17} Hz, corresponding to a wavelength of 1.3 nanometers. This radiation has a nonthermal spectrum that extends well into the gamma-ray region; the highest-energy photons detected so far have an energy of a little more than 100 million electron volts. The origin of the X-ray and gamma-ray background is not yet settled, but it certainly comes from outside our galaxy. The intensity of the radiation is much the same in all directions away from the plane of the Milky Way, where the sources would presumably be concentrated if they were within the galaxy.

The X-ray background is probably the sum of the radiation from a number of discrete sources, just as the radio background is the sum of the radiation from the radio galaxies and quasars. Attempts have been made to detect a graininess in the X-ray background that would reveal whether or not it is coming from a number of discrete sources, but the sensitivity of X-ray telescopes is not yet high enough to reveal the expected fluctuations. Moreover, too few extragalactic X-ray sources have been detected for the contribution of such sources to the X-ray background to be reliably calculated. Nonetheless, it is quite likely that the total emission from all X-ray sources can account for the entire background.

In the gamma-ray region the situation is not so clear. Gamma-ray telescopes are not yet sensitive enough to find any individual sources. The smooth continuity of the spectrum of the background radiation at the X-ray wavelengths and the gamma-ray wavelengths suggests that the gamma rays have the same origin as the X rays, but this need not be true.

The study of the background radiation in the X-ray and gamma-ray regions of the spectrum is still in its infancy. There is surely much interesting information to be gained from such investigations. The full value of even the present observations cannot be realized, however, until the basic question of the radiation's origin is settled. There is no shortage of possible mechanisms for generating the photons; the inverse Compton effect and the *Bremsstrahlung* mechanism are both likely candidates [*see illustrations on page 31*]. Nor is there any lack of hypotheses on the radiation's place of origin. The definitive observa-



OUTLINE OF EVENTS IN THE UNIVERSE since the "big bang" shows when and how the cosmic background radiation originated in the various regions of the spectrum. Events in the universe within the first one-thousandth (10^{-3}) of a second after the big bang are not well understood, principally because they are dominated by interactions of nuclear particles that are not well understood. Up until a hundredth (10^{-2}) of a second after the big-bang neutrinos (ν) and antineutrinos ($\bar{\nu}$) are plentiful; they easily interact with photons (γ) and other particles. Thereafter the neutrinos and antineutrinos do not interact further, and so they play little part in subsequent physical processes. From 10^{-2} second until 100 seconds after the big bang the universe consists mostly of photons, electrons (e^-), positrons (e^+), neutrinos, antineutrinos and a trace of protons (p) and neutrons (n). During this time and continuing somewhat thereafter all the positrons combine with electrons ($e^+ + e^-$); in addition neutrons combine with protons to make helium nuclei (He^+). Most of the helium in the present universe was synthesized at this time. From 100 seconds after the big bang right up to the present the universe consists mostly of photons, neutrinos, antineutrinos, protons, helium nuclei and just enough electrons to keep everything electrically neutral. The particles of the ionized gas of hydrogen and helium interact frequently with the photons of radiation, so that the matter and the radiation stay at the same temperature. That temperature, however, is steadily decreasing as the universe expands. Somewhere in the interval between about 100 and 10^{14} seconds after the big bang the energy density of the electromagnetic radiation drops below the rest-mass energy of the matter, so that the photons and the particles no longer interact so freely. The large-scale dynamics of the universe change as a result, and the temperature drops off a little faster than before. At about 10^{13} seconds after the big bang electrons recombine with the ionized gas, emitting visible radiation that was subsequently Doppler-shifted by the expansion of the universe to the microwave region of the spectrum; the microwave background is this radiation from the recombination. The gas (matter) and the radiation now cool separately, each at its own pace; the final temperature of the radiation at the present time is 2.76 degrees K. Both the X-ray background and the radio background originate later, when X-ray sources and radio sources came into being. Too little is known about origin of gamma-ray background to include it in illustration.

tions have simply not yet been made.

In the infrared, visible and ultraviolet regions of the spectrum the cosmic background radiation has not yet been detected. There are technical difficulties in the way of some observations in these regions. For example, infrared and ultraviolet observations cannot be made from the ground because the earth's atmosphere strongly absorbs such wavelengths, and a balloon or a rocket is an exceedingly tricky observing platform. There are natural obstacles in the way of other observations. The faint glow of the earth's atmosphere at night, the zodiacal light and the faint stars in our galaxy are together at least 100 times brighter than the background radiation would be at the visible wavelengths. Direct observations of the background radiation may never be made in the far-ultraviolet region: neutral hydrogen atoms in the interstellar space of our galaxy absorb these photons so strongly that the extragalactic background radiation probably cannot reach the solar system at all.

As I have indicated, however, the extension of observations of the cosmic background radiation in other regions of the spectrum is far from hopeless. Indeed, it seems certain that we can look forward to observations that will lead to new and exciting inferences about the nature and history of the universe in the large.

The Neurobiology of Cricket Song

The song pattern of each cricket species is stored in its genes. The songs are thus clues to the links among genetic information, development, the organization of the nervous system and behavior

by David Bentley and Ronald R. Hoy

Nowadays few people live where they can hear crickets singing on summer evenings, but makers of motion pictures know that nothing evokes a bucolic mood more effectively than the sound of crickets chirping in the background. Cricket song, which may seem like a random sequence of chirps and trills, is actually a communication system of considerable complexity. As Richard D. Alexander of the University of Michigan and others have shown, each species of cricket has a distinctive repertory of several songs that have evolved to transmit messages of behavioral importance.

From the work of many laboratories, including our own at the University of California at Berkeley and at Cornell University, it is known that the nerve networks needed for generating the songs of crickets are closely allied to those involved in flight. Both systems develop in stages as the cricket passes through its growth cycle from the larva to the adult. Through breeding experiments it has also been shown that the distinctive song patterns of various species are not learned behavior but are encoded in the insect's genes. Thus we have found that hybrids produced by mating different species exhibit song patterns that are intermediate between those of the parents. Progress is also being made in discovering the genes that control the song patterns and finding where they are located among the cricket's chromosomes. Ultimately it should be possible to piece together all the links in the chain from a sequence of chemical units in the DNA of the cricket's genes to the specification of a nerve network that leads to the production of a distinctive song. Cricket song is only one example of animal behavior that has a large genetically determined component.

The commonest cricket song is the calling song, which is sung by the males to guide sexually receptive females to the singer's burrow. The calling songs of different species that mature in the same area at the same time of year are always distinct. Confusion would result if all the males sang the same song. Once the male and the female have found each other, a new song, the courtship song, facilitates copulation. Following the transfer of the spermatophore, or sperm sac, the male may sing a postcopulatory song (known to French investigators as the "triumphal song"), which may help to maintain proximity between the partners. When a male cricket invades the territory of another male, a vigorous fight frequently results. (Cricket fights are even a traditional sport in the Far East.) Fighting is accompanied by the aggressive, or rivalry, song, which is sung by both combatants in an intense encounter and is nearly always sung by the winner. Thus the communication system consists of transmitters, which are always males, and receivers, which are both males and females, together with a variety of signals that convey information.

How is information encoded in the song? Each song is a sequence of sound pulses. The cricket generates a pulse by scissoring its fore wings once, drawing a scraper on one wing across a toothed file on the other [*see illustration on opposite page*]. This produces a remarkably pure tone. Features of the song theoretically capable of carrying information include the pitch, the relative amplitude of the pulses and their pattern in time. The temporal pattern has been shown to be the critical factor. Among different species the pattern varies from simple trills to complex sequences of chirps and trills with different intervals.

Fascinating as cricket communication may be to students of animal behavior, why should it interest the authors, who are neurobiologists? The answer is that one hopes the analysis of simple nerve networks associated with simple behavior will provide a foundation for the future understanding of more complex networks and more complex behavior, up to and including the behavior of our own species. Just as investigation of the bacterium *Escherichia coli* and the fruit fly *Drosophila* has been fundamental to current knowledge of molecular biology and genetics, we hope that through the study of cricket singing and similar simple behavioral systems some doors in neurobiology that have so far been closed will now be opened.

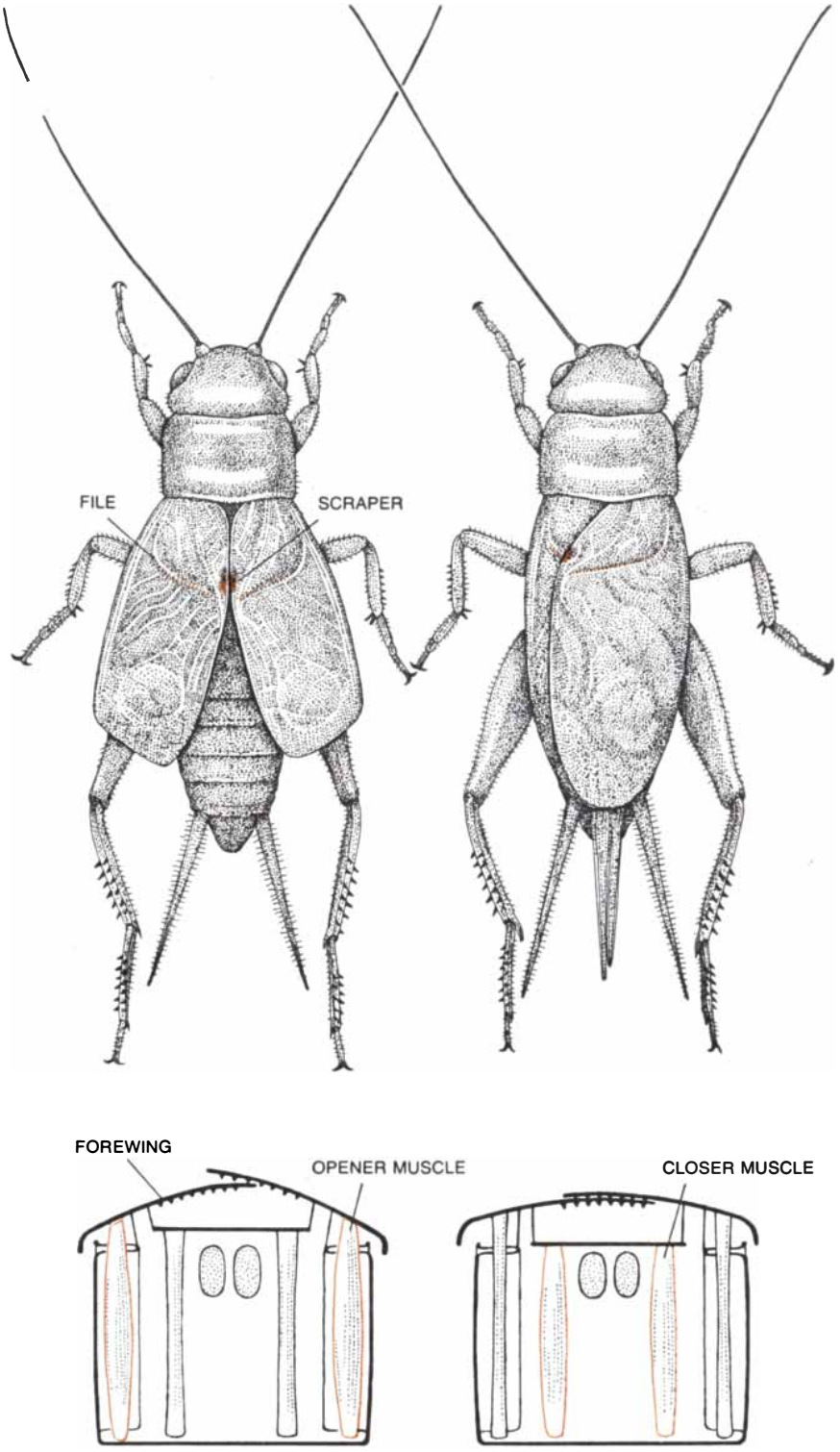
Throughout the animal kingdom neurons, or nerve cells, are basically similar in operation. Furthermore, both in vertebrates and in higher invertebrates some assemblies of neurons are organized in characteristic ways to facilitate the execution of sensory or motor tasks. The nervous systems of invertebrates are more amenable to analysis, however, because they generate simpler and more stereotyped behavior, because the neurons are fewer and larger and because many neurons are uniquely identifiable. The last feature means that individual neurons can be repeatedly "queried" by the investigator, whereas their vertebrate counterparts are nameless faces that can be polled once but then become lost in the crowd. Repeatability is so important to progress that investigation of invertebrate networks has proved a very powerful technique in analyzing nervous systems [see "Small Systems of Nerve Cells," by Donald Kennedy; SCIENTIFIC AMERICAN, May, 1967]. The special appeal of crickets lies in the access they

provide to a broad range of problems.

The cricket nervous system is a chain of 10 ganglia, or knots of neurons: two in the head, three in the thorax and five in the abdomen. Each ganglion consists of a cortex, or outer layer, of nerve-cell bodies that surrounds a dense feltwork of nerve fibers called the neuropile. The interactions between neurons that control behavior take place within the neuropile. These interactions produce trains of impulses that are conducted along axons either through connectives to other ganglia or through nerves that run to muscles and other peripheral structures. Information from sensory neurons lying in the peripheral parts of the cricket's body is conducted along axons through nerve trunks into the ganglia.

Where in this simple nervous system are the song patterns generated? Franz Huber, the founding father of cricket neurobiology, who is now at the Max Planck Institute for Behavioral Physiology at Seewiesen in Germany, demonstrated with the aid of his students Wolfram Kutsch, Ditmar Otto and Dieter Möss that only the two thoracic ganglia nearest the cricket's head ganglia are necessary for singing. This left open the question of what elements of the pattern are generated within the central nervous system and what elements rely on sensory feedback from the periphery. The experiments of the late Donald M. Wilson of Stanford University on locust flight suggested that virtually the entire pattern might be produced by neural circuits within the ganglia [see "The Flight-Control System of the Locust," by Donald M. Wilson; SCIENTIFIC AMERICAN, May, 1968]. This view was strongly supported by Huber's group in studies in which they observed the effect on the cricket's song patterns when the peripheral sensory system was either heavily loaded or acutely deprived. Neither condition had any significant effect on the song pattern.

One of us (Bentley) then began studying the song-production mechanism with the aid of microelectrodes implanted in various cells of the cricket's nervous system. This work was begun in Huber's laboratory and continued at Berkeley. In an early group of experiments the cricket's thoracic ganglia were completely isolated from sensory timing cues by the cutting of the peripheral nerves. Recordings from identified motor neurons showed that the cricket's nervous system could still produce a motor pattern practically indistinguishable from the normal calling-song pattern. This implied that the two anterior thoracic ganglia must



CRICKET SONG IS PRODUCED by specialized structures that are activated when the cricket closes its wings. The upper pair of diagrams show the wings moving from an open position (*left*) to a closed position (*right*). The lower pair of diagrams are simplified cross sections of the same positions as viewed from the front. When the wings are closing, a reinforced segment of cuticle (the scraper) on the edge of one wing bumps across a series of teeth, or ridges (the file), on the underside of the other wing. Both wings are similarly equipped, so that it does not matter which wing is on top and which on the bottom. The movement of the scraper across the file causes the wing to vibrate at about 5,000 cycles per second, producing a remarkably pure tone. Each closure of the wings produces a single sound pulse that lasts roughly 25 milliseconds, or about 125 cycles. The actual linkage between muscle contraction and wing movement involves a complex set of sclerites (small pieces of cuticle hinged to other pieces) that connect the wings to the thorax and muscles.

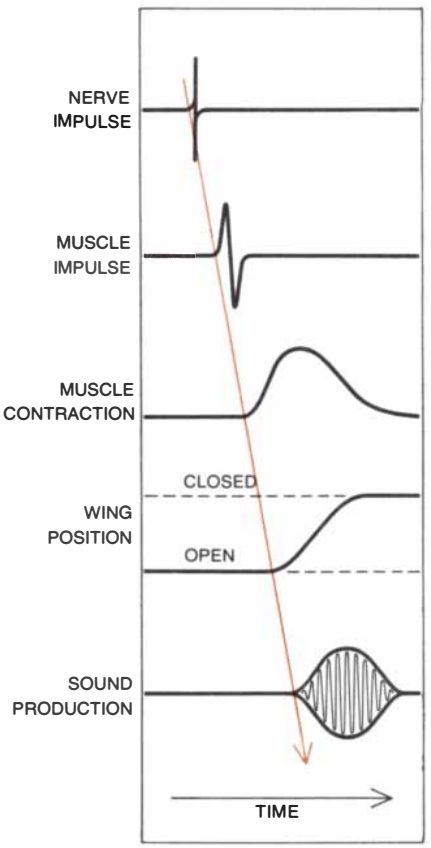
contain a network of nerve cells that are responsible for generating the calling-song pattern and that they are remarkably independent of sensory input.

The next task was to try to identify among the 1,000 or more nerve cells in each ganglion the neurons concerned with singing. During singing the wings of the cricket are operated by a small set of powerful "twitch" muscles. Each muscle is driven either by a single "fast" motor neuron or by up to five such neurons. The arrival of a nerve impulse at the bundle of muscle fibers that are innervated by a particular motor neuron results in a large action potential, or electrical impulse, in the muscle. Thus action potentials in a muscle unit are a direct one-to-one monitor of impulses in the corresponding motor neuron [*see illustration at left below*].

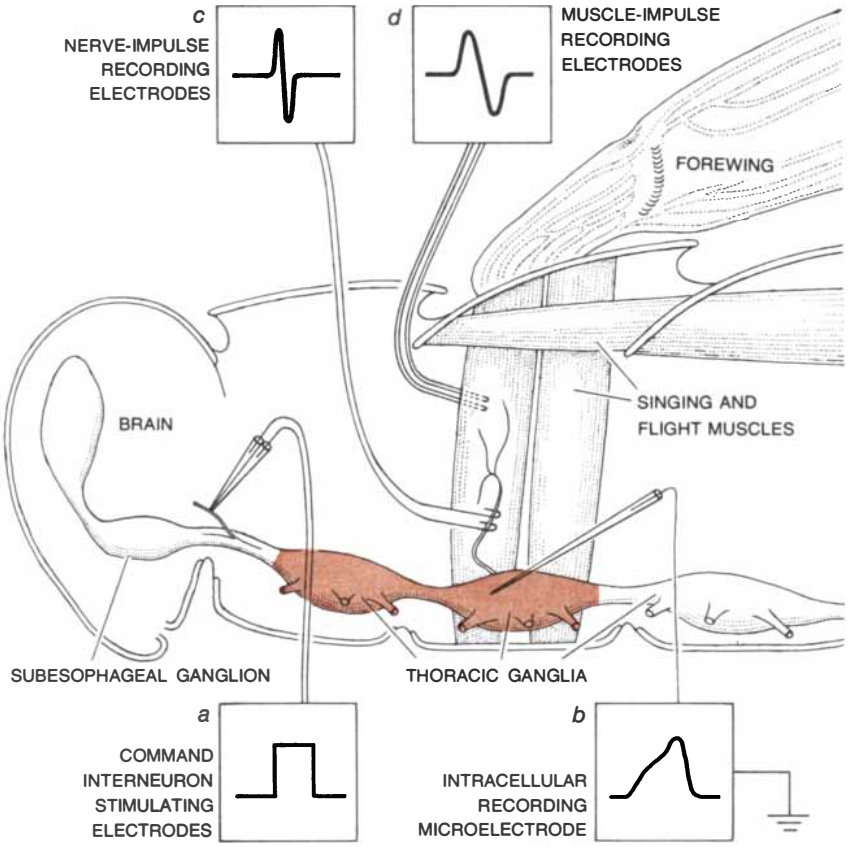
Fine insulated wire electrodes, which will record these muscle action potentials, can be inserted through tiny holes drilled in the cricket's exoskeleton and implanted in each unit of any selected muscle. Many such electrodes can be implanted in an animal without interfering with its normal behavior. Therefore by successively implanting each muscle any behavior can be characterized in terms of which motor neurons are active, of the sequential impulse pattern in each neuron and of the relative timing of discharge in the different neurons. With this technique the motor neurons involved in the cricket's calling song were discovered and labeled according to the muscle units the neurons innervate.

Within the ganglion the same neurons can be found and identified with the aid of intracellular microelectrodes, ultrafine glass pipettes through which dye can be injected. The tip of the electrode is driven into the neuron's cell body or one of its fibers. Once embedded the electrode can be used in either of two ways, passively or actively. When it is used passively, the electrode records the electrical activity of the cell and the synaptic inputs to the cell, either excitatory or inhibitory. When it is used actively, the electrode conveys current into the cell, making it possible to analyze the electrical activity within the cell and to stimulate the cell, revealing its effects on other cells [*see illustration at right below*]. When dye is injected into a cell through a micropipette, the dye permeates the cell body and all its fibers, revealing a structure that can be examined by either optical or electron microscopy.

With these techniques it has been possible to identify the activity patterns of the neurons involved in cricket singing, to learn their characteristic morphology



NEURAL EVENTS leading to a single pulse of the cricket song begin with the firing of a motor neuron (*top trace*) in one of the cricket's thoracic ganglia (*location "b" in illustration at right*). The arrival of the nerve impulse triggers a muscle impulse, or action potential (*location "d" at right*), that contracts one of the wing-closing muscles. The closing of the wing causes the scraper on one wing to rub across the file underneath the other wing, producing a sound pulse.



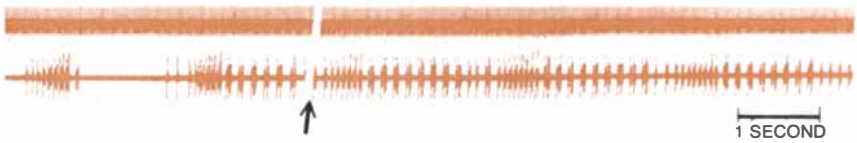
NEUROPHYSIOLOGY OF CRICKET SONG is studied with the aid of implanted microelectrodes that enable investigators to either trace or actively elicit the flow of nerve impulses that result in a sequence of chirps and trills. The cricket's central nervous system consists of a chain of 10 ganglia, of which only five, including the "brain" ganglion, are shown here. The two ganglia in color are sufficient for generating normal song. The song pattern can be elicited by stimulating specific "command" interneurons that lie in the nerve bundle connecting the two head ganglia to the thoracic ganglion (*a*). The command interneurons turn on the thoracic interneurons and motor neurons that generate song. Impulses from motor neurons are conducted along peripheral nerves to the song muscles. Vertical muscle fibers shown close the wings to produce a sound pulse and also to elevate the wings in flight. Horizontal muscle fibers open the wings in singing and depress the wings in flight.

and to discover how they are connected to other cells, particularly how motor neurons are connected to muscle units. In this way every fast motor neuron involved in singing was located, filled with dye and mapped within the ganglion.

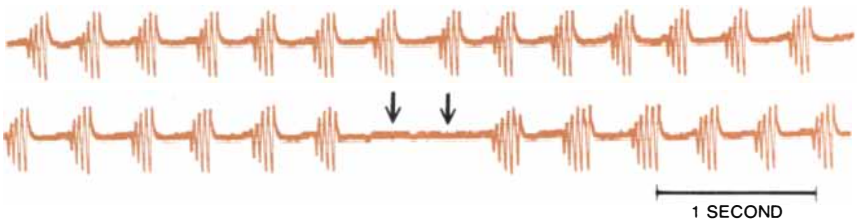
What, then, are the characteristics and interconnections of the motor neurons that underlie the generation of cricket-song patterns? Are interneurons, or intermediate neurons, involved, and if so, what is their role? Like any motor pattern, the activity underlying the calling song requires a sequential timing of impulses in individual nerve cells and a coordinated timing of discharges in particular cell populations. The population of motor neurons involved in singing falls into two groups of synchronously firing cells that alternate with each other to open and close the wings. Intracellular recordings indicate that some synchronously firing motor neurons are coupled in such a way that an impulse in one greatly increases the probability of an impulse in its neighbor. The alternate firing of antagonistic motor neurons is established by the powerful inhibition of one group, the wing-closing motor neurons, during discharge of the other group, the wing-opening motor neurons. The wing-closing cells fire immediately after this inhibition, with the result that there is a characteristic spacing of impulses in the two groups [*see lower two illustrations at right*].

It has now been shown that interneurons help to establish the sequential timing of the song patterns. Even when crickets chirp normally, gaps appear in the song from time to time. The gaps do not, however, upset the established rhythm: the timing of the chirps continues as if there had been no gap [*see second illustration from top at right*]. This suggests that some internal oscillator, or "clock," within the ganglion has continued to run undisturbed in spite of the missing chirp. It has now been established that the motor neurons themselves are not part of the neuronal oscillator. During gaps not only do the motor neurons fail to fire but also the input signal that drives them is missing. Moreover, anomalous extra chirps that occur from time to time have no effect on the basic rhythm. One must conclude that the timing of the chirps is established by elements higher up in the cricket's nervous system, evidently interneurons whose output signal does not go directly to the motor neurons.

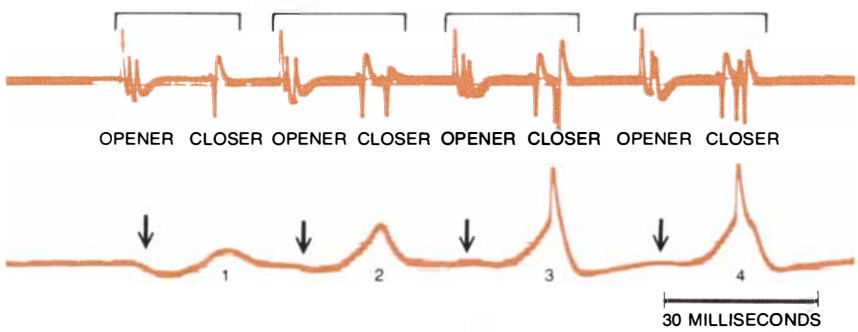
Although the interneuronal song oscillator is quite insensitive to influences



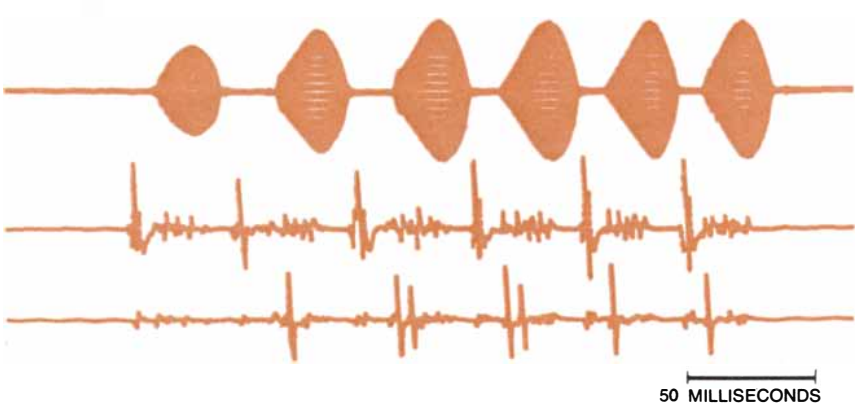
STIMULATION OF COMMAND INTERNEURONS (*top trace*) **causes motor neurons to discharge** (*bottom trace*) **in a typical calling-song pattern. Stimulus site is labeled** *a* **and recording site** *c* **in illustration at right on the opposite page. Motor neurons fire as long as command interneurons are stimulated; arrow indicates several minutes of continuous firing.**



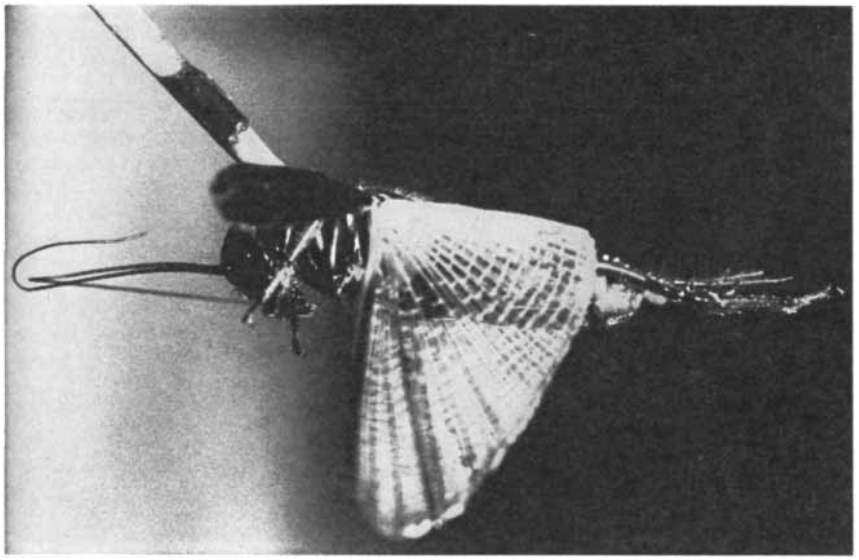
CHIRP REGULARITY is shown in this sequence of 26 consecutive chirps, recorded inside a motor neuron in the second thoracic ganglion (*site "b" in illustration at right on opposite page*)**. Each chirp consists of four or five sound pulses, marked by oscillations of intracellular potential. Continuous record is here divided into two rows and aligned to show how rhythm persists in spite of two skipped chirps** (*arrows*)**. Song resumes after the gap at exactly the right time, indicating existence of a "rhythm keeper" higher in the nervous system.**



CHIRP CONSISTING OF FOUR RAPID SOUNDS is produced by alternate firing of wing-opening motor neurons and wing-closing motor neurons. The top trace shows nerve impulses arriving at their respective muscles (*site "c" in illustration at right on opposite page*)**. The bottom trace shows a recording from the larger of two closing motor neurons involved in producing the top trace. Immediately after the discharge of wing-opening motor neurons the closing motor neuron is inhibited from firing** (*arrows*)**. Following inhibition the closing motor neuron is excited but first two excitations** (*1, 2*) **are below threshold.**



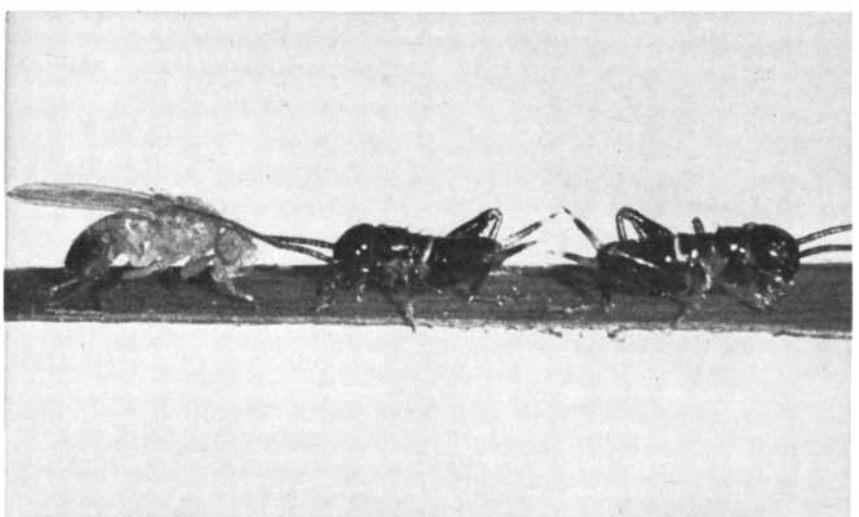
RELATION OF CHIRP SOUNDS TO MUSCLE IMPULSES is shown in simultaneous recordings. The top trace depicts the amplitude of the emitted sounds. The other two traces represent the impulses of a wing-opening muscle (*middle trace*) **and of a wing-closing muscle** (*bottom trace*)**. Muscle impulses were recorded at site** *d* **in illustration at right on opposite page. Simultaneous contraction of several wing-closing muscles produces sound pulse.**



FLIGHT-MUSCLE SYSTEM can be studied by tethering crickets in a low-speed wind tunnel. Flight employs many of the same muscles and motor neurons used in singing. The neuronal system involved in song generation appears to be actively suppressed until the nymph, or young cricket, undergoes a final molt and reaches adulthood. This is not the case with flight behavior, which can be elicited and studied in the wind tunnel when nymphs are still four molts away from adulthood. Fine wire electrodes can be implanted in tethered insects.

from outside the cricket's central nervous system, it can be manipulated internally. Huber and his colleagues have shown that singing behavior can be elicited either by electrical stimulation of the cricket's brain or by making small lesions in the brain. This indicates that interneurons running from the brain to the thoracic ganglia are capable of activating the song network. Cells of similar capability have been found in other simple nervous systems and are termed command interneurons.

At Berkeley one of us (Bentley) has been able to locate the axon of a command interneuron in the bundle of about 10,000 nerve fibers that runs between the cricket's brain and the first thoracic ganglion. The command interneurons are always found in the same location. They are bilaterally symmetrical, and when they are electrically stimulated at an appropriate frequency, they cause the song network to generate a perfectly normal calling-song pattern [*see top illustration on preceding page*]. One can show that a single command interneuron suffices to elicit the song pattern. There appear to be no conceptual or technical barriers to learning much more about how this hierarchically organized neural subsystem operates.



FRUIT FLY AND NEWLY HATCHED CRICKET are about the same size. A common fruit fly, *Drosophila melanogaster*, is at left; a "wild type" (genetically typical) nymph of the species *Teleogryllus oceanicus* is in the middle. Mass screening of cricket nymphs for interesting mutations can be done immediately after hatching, before the first molt, when they are termed first instars. Nymphs molt 10 times on their way to adulthood. The first-instar nymph on the right is a mutant that lacks certain sensory hairs on rear-end antennae.

Many important questions are presented by the appearance in the adult cricket of a neuronal network that will generate a behavior pattern as precise as cricket song with such reliability. When are the neurons built? When do the cells become physiologically mature and what kind of electrical activity do they exhibit before reaching maturity? When are the functional connections that coordinate activity of the cells established? Is the network assembled before or after the cricket becomes an adult? If it is after, does perfection of the pattern depend on acoustical feedback, that is, on the cricket's hearing its first attempts at singing and then making corrections? Some answers to these questions have been found for singing and also for the closely related behavior of flight.

The development of the cricket proceeds without any dramatic metamorphosis. The female deposits her eggs singly in the soil. Following embryonic development the eggs hatch into miniature nymphs about the size of a fruit fly, which conspicuously lack wings, reproductive structures and associated behavior. During postembryonic development, which is several times as long as embryonic development, the nymphs pass through 10 instars, or developmental stages, separated by molts. With each successive molt the nymphs increase in size and resemblance to adults except for certain structures such as the wings and the ovipositor: the tube through which the female lays her eggs. These structures are not fully developed until the final molt to adulthood.

The male cricket normally begins to call about a week after its final molt. Nymphal crickets never attempt to sing, even if they are placed in a situation that would stimulate singing in the adult. For example, nymphs are strongly aggressive in competition for food, but they do not move their small wing pads in the pattern of aggressive song. Either the neural circuits that mediate singing are not yet laid down or, if they are, they must

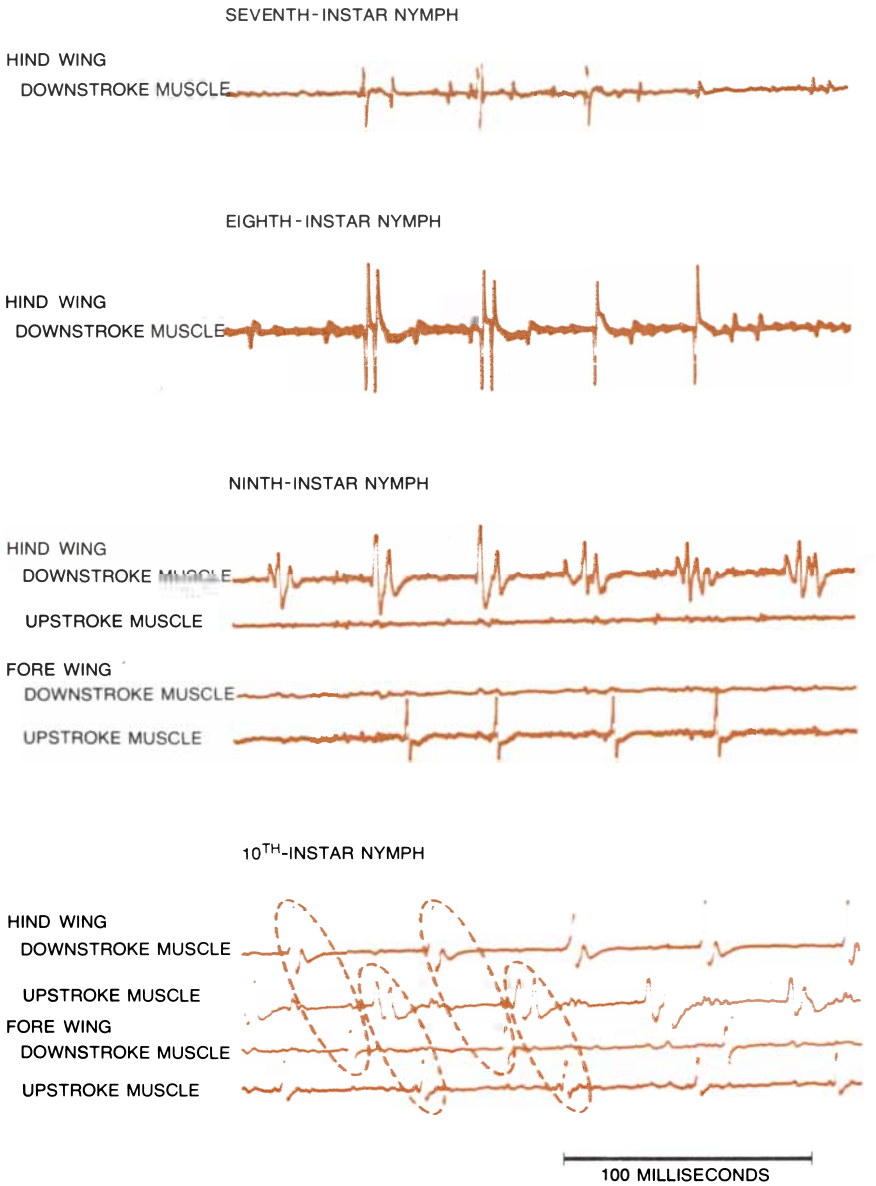
be actively suppressed. When we made lesions in the brain of last-instar nymphs in an area that would evoke singing in the adult, the wing pads finally moved in a pattern resembling song. To determine whether or not the motor pattern was the same as the one that gives rise to the calling song, we recorded muscle action potentials from identified motor units and compared the impulse pattern with the pattern the same unit would be expected to generate during the calling song of an adult [*see bottom illustration at right*].

Since the strength of the argument depends on the predictability of the adult motor pattern, this kind of analysis is possible only in animals, such as the cricket, that show highly stereotyped forms of behavior. Several conclusions can be drawn from this study: (1) the neuronal network for the calling song is completed in the nymph, (2) the assembly of the network does not depend on acoustical feedback and (3) song patterns are not prematurely activated in nymphs because of active inhibition originating in the brain.

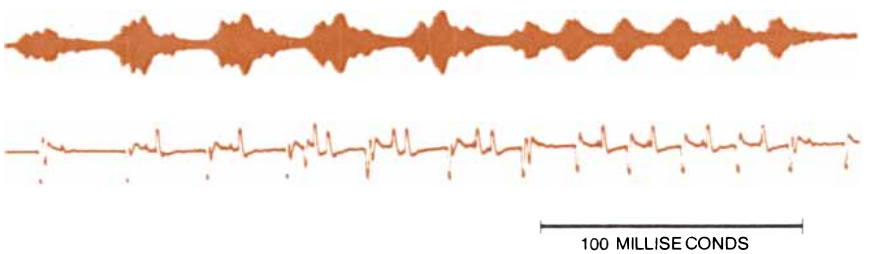
We have not followed the maturation of the song networks in detail because the brains of the younger nymphs are so small that it is difficult to make the lesions required to elicit singing behavior. This is not the case, however, with the closely related behavior of flight. The highly invariant, rhythmic motor pattern of flight is similar to singing in that it involves the same set of muscles and the same motor neurons to operate the fore wings and also their homologues that operate the hind wings. The motor pattern consists in the alternate firing of elevator (upstroke) motor units and depressor (downstroke) motor units, with the hind-wing segments leading their fore-wing counterparts by about a third of a wing-stroke cycle.

In nymphs there does not seem to be any suppression of the neuronal network for flight. As a result one can induce nymphs of very early instars to attempt flying by suspending them in a small wind tunnel. Electrophysiological recordings are made from identified motor units, and their performance is evaluated by comparing their pattern with the pattern the same unit would make in the adult.

We find the first definite signs of the motor pattern of flight in nymphs of the seventh instar. Removing the nymph from contact with the ground and suspending it in a wind tunnel is sufficient to induce some flight motor neurons to discharge a few impulses at frequencies



ASSEMBLY OF NERVE NETWORK FOR FLIGHT is completed during the last third of the cricket's larval life. The records show muscle-impulse patterns produced by tethered nymphs trying to fly in a wind tunnel. In seventh-instar nymphs the pattern is only fragmentary. In later instars new muscles come into play and the pattern becomes stronger. In the last stage before adulthood muscles are properly coordinated: upstroke and downstroke units alternate and the hind wing leads the fore wing (*indicated by broken lines*).

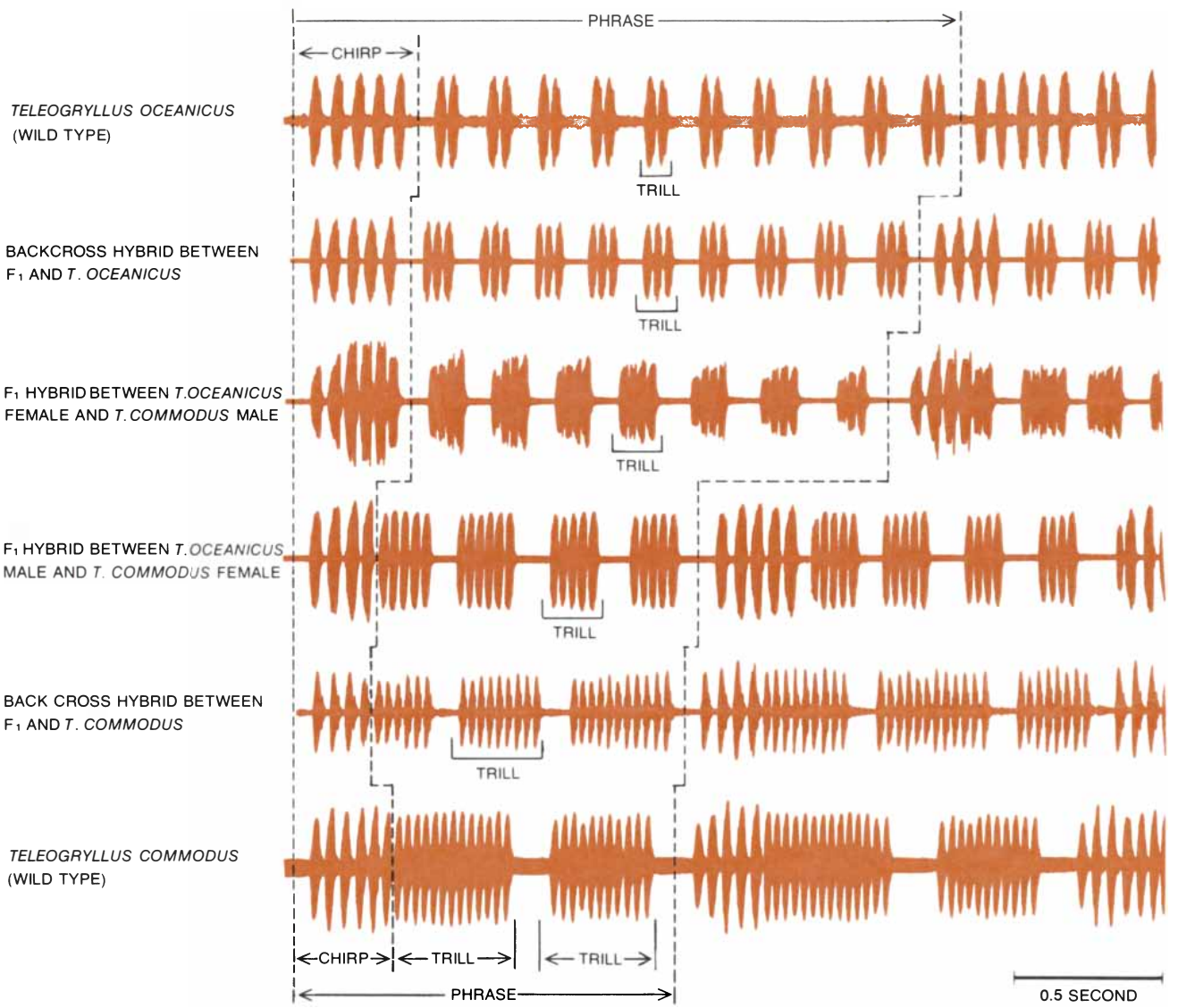


ASSEMBLY OF NERVE NETWORK FOR SINGING can be demonstrated by making lesions in the brain of 10th-instar cricket nymphs. Before the final molt to adulthood cricket nymphs do not attempt to sing. Certain lesions, however, that elicit singing in adult crickets also elicit the calling-song motor pattern in nymphs. The top trace is the calling-song sound-pulse pattern of an adult of the species *T. commodus*. The bottom trace shows the closely parallel activity of wing-opening muscles (*downgoing impulses*) and wing-closing muscles (*upgoing impulses*) elicited by brain lesions in a 10th-instar nymph of the same species.

approaching the normal rate of the wing stroke [*see top illustration on preceding page*]. During subsequent development the performance improves in several respects: first, there are more impulses per burst, corresponding to wing strokes of greater amplitude; second, there are more bursts per response, corresponding to more wing strokes and longer flights, and third, additional motor neurons are recruited into the pattern. As with singing, the neuronal network involved in flight seems to be fully assembled by the last instar, although the overall frequency of its oscillatory behavior does not reach normal speed until after the molt to adulthood.

How does the neuronal network develop structurally before its physiological activation begins? The information we have suggests that it develops as follows. Cell bodies and peripheral axons (long fibers, one from each cell body) arise while the cricket is still in the embryo stage. The richer growth of dendrites (short fibers) within the ganglia may come during the first third of postembryonic development. By filling identical neurons with dye one can show that by the sixth instar, halfway through postembryonic development, the major branching network has been completed. In the next instar the first signs of physiological activity in adult patterns can be detected. During the last third of postembryonic development the sequential firing pattern steadily improves and precise coordination with other neurons is achieved. This last step may reflect the actual establishment of synapses, or connections, between neurons. By the last instar the neuronal network is fully assembled and potentially operative, although it may be suppressed by inhibition from the brain. Thus immediately after the molt to adulthood the nervous system of the cricket is ready to generate both flight and the calling song.

It is well established that in order to attract females of the same species



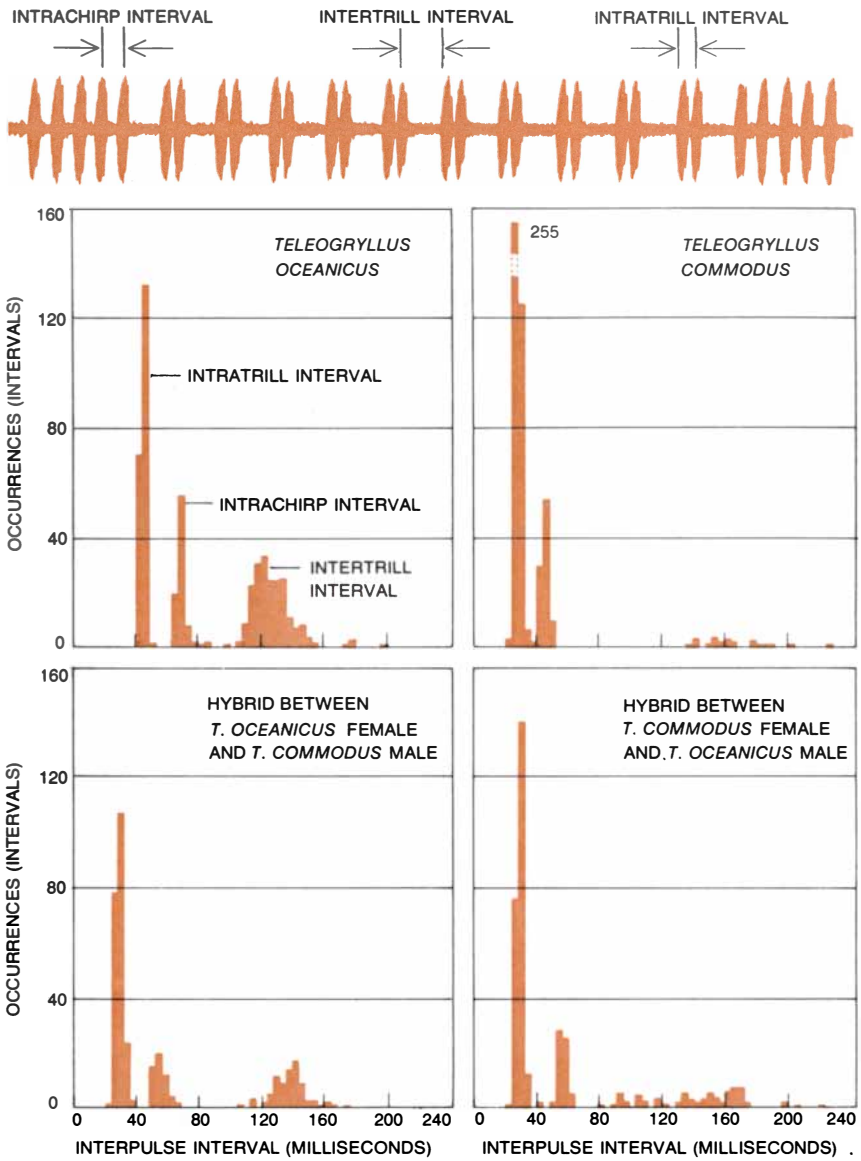
SONG PATTERNS OF HYBRID CRICKETS shift systematically in proportion to the ratios of the different wild-type genes inherited by the individual. These records show the song patterns of two cricket species and their hybrids. The records are aligned so that a complete phrase of the song starts at the left; each phrase consists of a chirp followed by two or more trills. The phrase of *T. oceanicus* (*top*) is not only much longer than the phrase of *T. commodus* (*bottom*) but also distinctively different. In each of the last three patterns the first trill is fused to the chirp. The F_1, or first-generation, hybrids of these two species produced the third and fourth traces. Again they are quite different depending on which species served as the male parent and which as the female parent. The second and fifth traces were produced by backcrosses between the two different F_1 hybrids and members of the parental species.

successfully the male cricket must broadcast a very precise message. What is the source of the information underlying this precision? We have seen that neither motor practice of the songs nor acoustical feedback is required. The correct pattern arises from the neural properties and neural connections established during development. How do they become properly established? One hypothesis invokes the environmental information available to cricket nymphs during their development. For example, some songbirds have been shown to remember song patterns heard during their adolescence and to defer the use of the information until the following year in the songs they sing as adults. The main alternative hypothesis is that all the necessary information for cricket singing is stored genetically and is read out in the form of neuronal structures during the course of development.

These hypotheses can be tested by changing either the environmental input or the genetic one during development and observing the effects. We raised crickets under a variety of environmental conditions, including different regimes of population density, diet, temperature, cycles of light and darkness, and of course acoustical experience. Some crickets heard no songs, some heard only songs of their own species and some heard only songs of another species. In every case male crickets that had reached maturity produced the calling song characteristic of their own species. This indicates that environmental information is not utilized in the determination of the song pattern.

What would happen, however, if a wild-type (genetically "normal") male of one species were mated with a female of another? What song would the hybrid male offspring of such a union sing? Since these particular hybrids are fertile, we were able to backcross them with individuals of the parental species. From such genetic manipulations we learned that each genotype (that is, each hybrid, backcross or other mixture) gives rise to a unique calling song and that all individuals of each genotype sing the same song. Even more remarkable, the song patterns shift systematically according to the proportion of the wild-type genes carried by the male cricket [*see illustration on opposite page*]. One can only conclude that the information specifying song patterns is encoded in the genes.

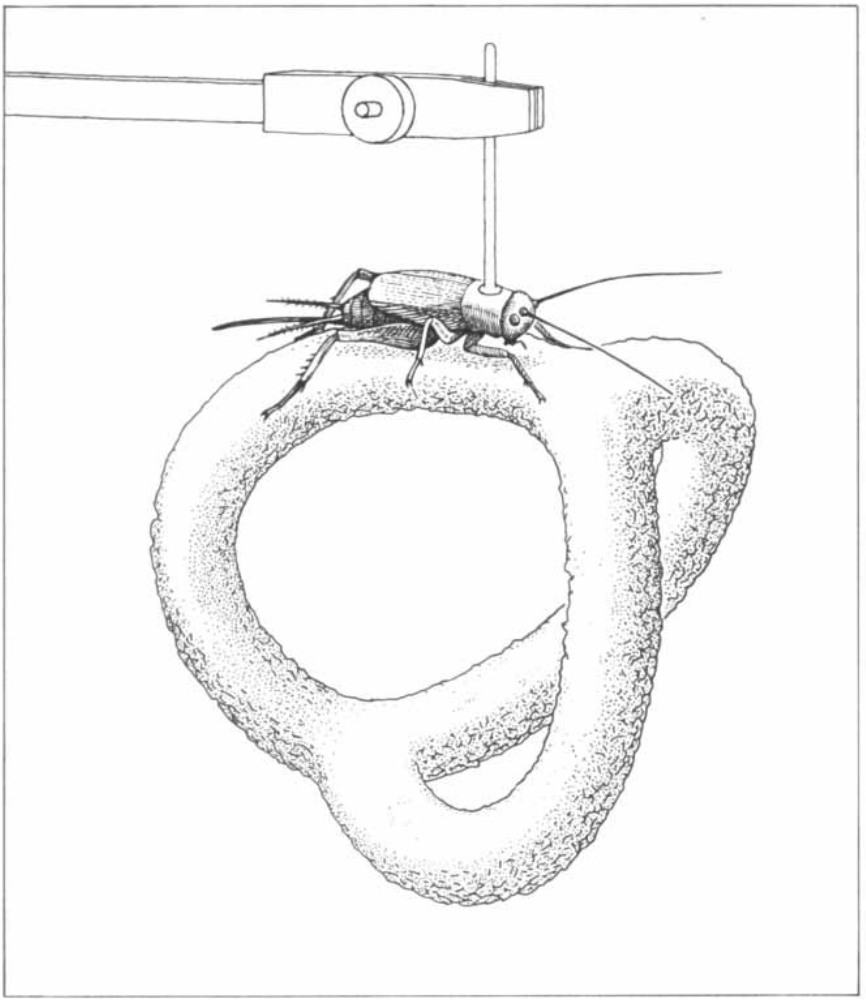
In order to give rise to the song-generating neuronal network the information coded in the genes must be read out during development by a series of complex and subtle interactions between the cricket's environment and the genes of the cells involved. It seems, however, that the range of possible products of this interaction is stringently limited. If development is successful, the calling song of the adult is a very accurate reflection of the genotype.



PRECISION OF SONG PATTERN becomes evident when the intervals between sound pulses in the calling song are measured for several hundred pulses. The two top histograms show the intervals in the calling songs of wild-type *T. oceanicus* (*left*) and *T. commodus* (*right*), which also appear in the illustration on the opposite page. When hybrids are made between these two species (*bottom*), their intertrill intervals resemble those of the species that served as the maternal parent: *T. oceanicus* on the left, *T. commodus* on the right. This shows that the genes influencing the intertrill interval are on the *X*, or sex, chromosome.

How many genes are involved and where are they located on the cricket's 15 chromosomes? A start toward answering these questions can be made by examining the pattern of inheritance of features of the calling song. If a particular feature (such as the number of chirps or the interval between chirps) were determined by a single gene that was dominant over the corresponding gene in another species, the feature should be transmitted unchanged to the first-generation (F_1) hybrids between the species.

When we examined 18 features in the calling songs of two cricket species (genus *Teleogryllus*) and their F_1 hybrids, we found no evidence that the features involved the dominance of single genes. If a character were controlled by a



TETHERED FEMALE CRICKET WALKING ON Y MAZE reveals her degree of preference for calling songs of males of different species by the choice she makes when she comes to a fork in the *Y*. The cricket actually holds the featherweight Styrofoam maze as she travels along it. One loudspeaker is located on the left side of the cricket and another on the right side. In each test the cricket hears only one male calling song, played 40 times through one speaker or the other in random order. The frequency with which the cricket turns toward the song is taken as an index of its attractiveness (*see illustration on opposite page*).

single nondominant gene, the crossing of an F_1 individual with a wild-type individual of the parental species should give rise to two distinct classes of backcross offspring, one like the parent and one like the F_1 individual. The more genes there are that influence a character, the broader and smoother is the distribution of types produced by backcrossing. Our analysis of many backcrosses has failed to reveal any examples of a simple bimodal distribution, which would indicate single-gene control of some characteristic of cricket song. Therefore we conclude that many genes are required to specify the neuronal network responsible for song production.

Genes that influence a particular characteristic or behavior, such as cricket song, can be localized on a specific chromosome, provided that they are on the *X* chromosome. Female crickets, like the females of many other species, have two *X* chromosomes (*XX*), whereas male crickets have only one *X* chromosome (and lack the *Y* chromosome found in many other animals). As a result two types of cross can be made between two species, one using males from species *A* and females from species *B* and the other using males from species *B* and females from species *A*. Male offspring from these crosses will be genetically alike except that they will have *X* chromosomes from different maternal parents. Thus differences in the songs of the two types of male can be attributed to genes located on the *X* chromosome. Analysis of hybrid calling songs reveals that certain elements of the song pattern (for example the interval between trills) do appear to be controlled by genes on the *X* chromosome and that other elements are not [*see illustration on preceding page*]. The genetic system that specifies the neuronal network accounting for cricket song is therefore a complex one, involving multiple chromosomes as well as multiple genes.

So far we have written exclusively about the transmitter in the cricket-song communication system. What about the receiver? A good deal has been learned about the way the female responds to the male's song. For example, Thomas J. Walker of the University of Florida and others have studied the selective responsiveness of females to song patterns. The female's orientation to a sound source and attraction to it have been investigated recently at Berkeley by Rodney K. Murphey and Malcolm Zaretsky. Zaretsky and John Stout in Huber's laboratory have begun to identify and characterize the sensory interneurons involved in responding to the song and "recognizing" it.

A fundamental problem common to the analysis of all animal communication systems is how the timing and the synchronous evolution of the transmitter and receiver are maintained. Found everywhere on the globe, crickets are classified into about 3,000 species whose song patterns have diverged widely in the course of evolution. How has it happened that in each case the receiver has changed along with the transmitter, so that the female still responds selectively to the call of a male of the same species?

One of us (Hoy), in collaboration with Robert Paul, has been studying this problem, first at the State University of New York at Stony Brook and recently at Cornell. Experiments were designed to quantify the ability of female crickets to detect and select calling songs of their own species, to determine the role of the genotype in that selectivity and to explore the relation between the genetic systems that control song transmission and song reception.

In these experiments a female cricket is suspended by her thorax and allowed to hold a hollow sphere of Styrofoam cut in the form of a continuous *Y*-shaped maze [*see illustration on this page*]. As she "walks" on the maze, which she is actually holding, she periodically comes to junctions that call for a decision to turn right or left. On each side of her there is a small loudspeaker through which different song patterns can be played. In each experiment the walking female is required to make 40 choices, 20 while the song is played through one speaker and 20 while it is played through

the other. The number of decisions made to turn toward the source of the sound divided by the total number of choices is taken as an index of the "attractiveness" of the song. Each female is tested only once and is presented with only one song. The tests clearly establish that female crickets prefer the calling song of the males of their own species.

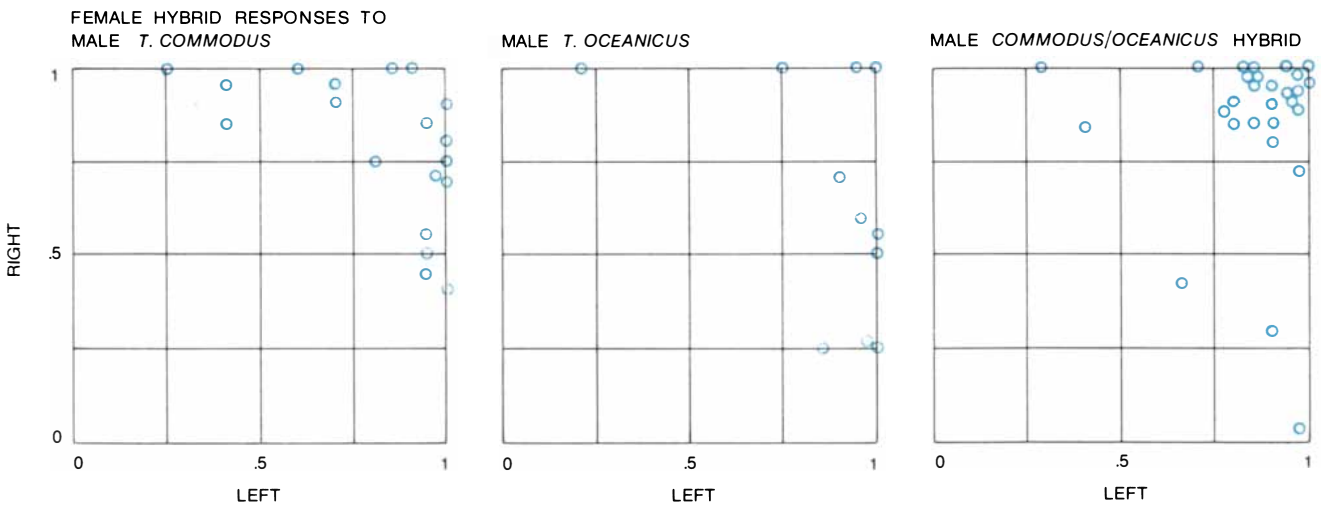
The role of the genes in establishing this preference can be investigated by manipulating the genotype. In a typical study crickets of two different species are mated and the hybrid F_1 females are tested with songs of three types: the calling songs of the males of each parental species and the calling song produced by the females' F_1 hybrid brothers. Surprisingly, the hybrid females prove to be attracted to the songs of their brothers much more than to the songs of either parental species [*see illustration below*]. This result demonstrates that genetically shared information specifies the pattern of song recognition as well as the pattern or song production. Moreover, it suggests that similar genetic systems could be involved in encoding information for constructing either a neuronal network that will respond to a specific song pattern or a network that will produce a specific song pattern. Indeed, there is the fascinating possibility that some of the same genes are involved in both systems. Such an assemblage of genes would be a failsafe means of ensuring the synchronous evolution of the transmitter and the receiver.

The experiments described above firmly establish the link between genetically stored information and the cricket's nervous system, but how does the first control the design of the second? What kind of information about the structure, the physiology and the connectivity of neurons is stored, and how is it read out? Two quite different strategies for approaching the problem immediately suggest themselves and are currently being pursued by one of us (Bentley) at Berkeley. The first is to focus attention on single neurons and ask what features of the nervous system are actually under genetic control. The second is to concentrate on single genes and ask what a particular gene contributes to the design of the nervous system.

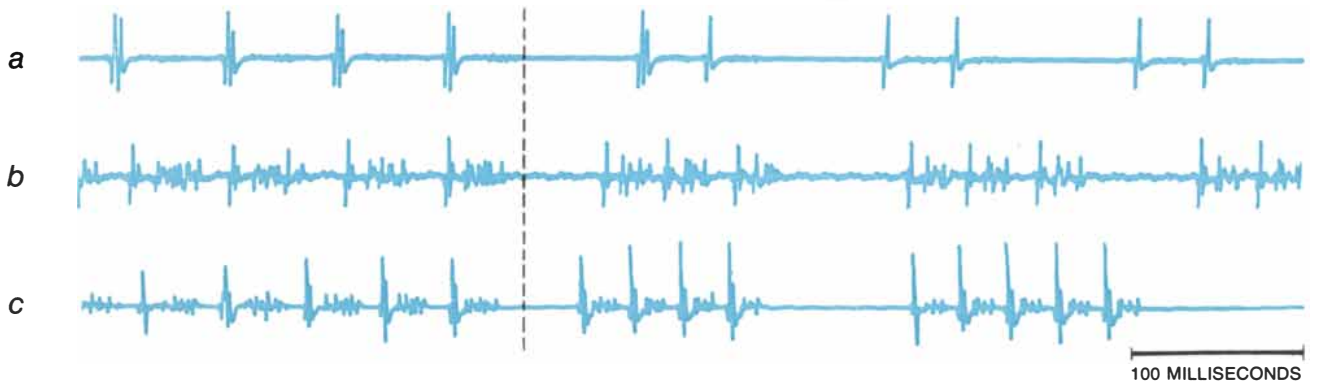
The first question can be tackled straightforwardly by crossing different species and hybrid individuals, thereby constructing cricket nervous systems according to different genetic blueprints. Then by examining identifiable homologous neurons in the different systems one can determine what is different about these neurons. The firing pattern during the calling song of two particular neurons in five different genotypes has now been examined: two wild types, the F_1 cross and two backcrosses. Not surprisingly, one finds that the song precisely reflects the firing pattern of the motor neurons, that neurons of each genotype fire in a distinctive pattern and finally that very small differences in pattern can be genetically specified. For example, motor neurons usually fire only once for each pulse of the trill sound. One wild-type cricket, *Teleogryllus oceanicus,* has trills consisting of two short pulses, whereas the backcross between the F_1 hybrid and *T. oceanicus* has three-pulse trills [*see top illustration on next page*]. This means that the actual difference in firing patterns of the responsible motor neurons in the two genotypes is only a single impulse. It is a remarkable example of fine genetic control.

Experiments are now in progress to discover why the neurons of the backcross fire three times rather than twice. One possibility is that there is a difference in how the neurons are excited by command interneurons. If one artificially stimulates the appropriate interneurons in the connective bundle between the cricket's brain and its thorax, one finds that only a slight increase in the rate of stimulation is needed to change the firing rate of the motor neurons involved in the calling song from a two-pulse pattern to a three-pulse one [*see bottom illustration on next page*]. This result suggests that the effect of the genetic change could be a similar increase in the firing rate of the command interneurons or perhaps an increased efficiency in the transmission of impulses at the synapses. There are many other possibilities, but these experiments at the very least show that it is possible to get at the heart of the pattern-generating mechanism and directly test the effect of genetic manipulation.

The alternative strategy of examining the role of single genes is also being investigated at Berkeley. One begins this process by accumulating a "stable" of organisms with mutations in a single gene. The mutations can be induced by exposing the organisms to X rays or to



FEMALES' PREFERENCE FOR MALE SONGS is plotted in scattergrams. Each female is required to make 40 choices while walking on a *Y* maze, 20 while the sound is played through one speaker and 20 while the sound is played through the other. Each open circle represents a 40-choice test. If the female always turned toward the song of a particular male whether played on her left or her right, the song would score 1 on both axes and an open circle would be placed in the extreme upper right corner. The females whose preferences are plotted here were all hybrid offspring of a *T. oceanicus* female and a *T. commodus* male. The three scattergrams show the females' relative preference for the song of a *T. commodus* male (*left*), the song of a *T. oceanicus* male (*middle*) and the song of a hybrid male whose genes closely resemble those of the females being tested (*right*). Females clearly prefer their "brother's" song.



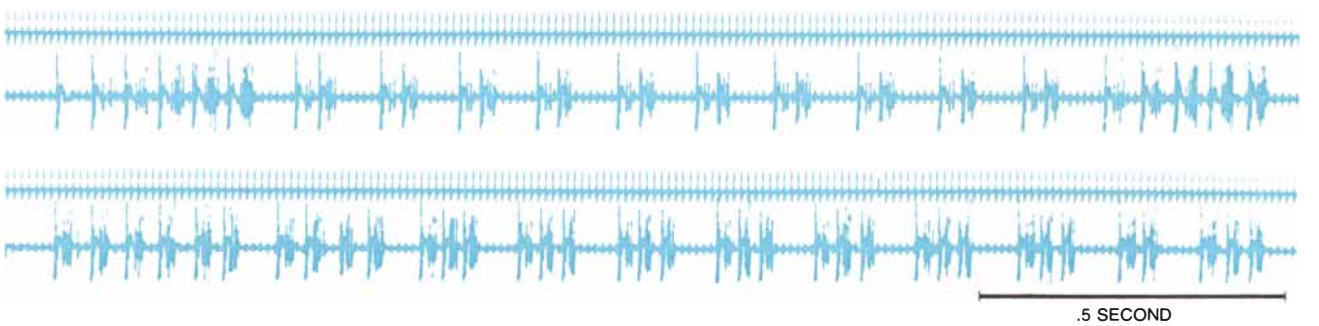
NEURAL ACTIVITY UNDERLYING CALLING SONG is patterned according to different genetic specifications, as illustrated by these three records of the firing of a particular identified motor neuron in three different crickets during the calling song. The crickets that produced the traces are of the same genetic type as those that produced the first three sound traces shown in the illustration on page 40: a wild-type *T. oceanicus* (*a*), the F_1 hybrid between a *T. oceanicus* female and a *T. commodus* male (*c*) and the backcross between the F_1 hybrid and *T. oceanicus* (*b*). The vertical broken line marks the end of a chirp and the start of a trill. It is evident that genetically stored information exerts extraordinary control over the output of the nervous system. Thus the backcross (*b*) has a three-pulse trill whereas its wild-type parent has a two-pulse trill and its F_1 hybrid parent has a trill of four or five pulses.

mutagenic chemical compounds. When crickets are raised at elevated temperatures (about 35 degrees Celsius, or 95 degrees Fahrenheit), they have a generation time of about six weeks. One female can produce as many as 2,000 eggs, and the resulting nymphs exhibit a wide diversity of behavioral characteristics. The mass screening of mutants for interesting behavior patterns can be done with first-instar nymphs that are no larger than fruit flies and are just as plentiful [*see bottom illustration on page 38*]. When an interesting mutant is found, it can be grown to an adult 1,000 times larger than a fruit fly in which single nerve cells are readily accessible for study.

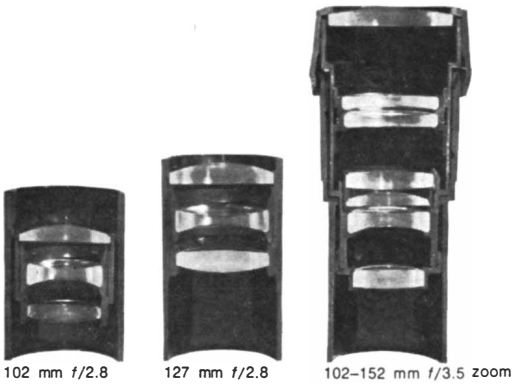
The first behavior selected for screening is the evasive leap elicited by the stimulation of the cricket's cerci, which may be called rear-end antennae. The neuronal circuits involved in this response had previously been analyzed by John M. Palka and John Edwards of the University of Washington and by Murphey, working at the University of Iowa. In the screening program at Berkeley two mutants with an abnormal leap response have been isolated and established in breeding lines. In one case the mutant gene is a recessive gene on the *X* chromosome; in the other the gene is a dominant gene on one of the autosomal chromosomes (chromosomes other than the *X* sex chromosomes).

The mutants exhibit a selective loss of a single class of receptor hairs on the cerci. Each hair activates a single sensory neuron that has a direct synaptic connection with certain large, identified interneurons. The mutants are being studied to see whether or not the sensory neurons are also affected by the mutation and whether or not the structure of the interneurons has been changed by the lack of normal input from the sensory neurons. The ease with which such mutants can be isolated encourages hope that the single-gene strategy will ultimately be successful in the analysis of cricket song.

The promise of the approach we have taken in our study of cricket behavior lies in combining several levels of analysis in a single animal. This allows for a powerful infusion of techniques between levels, for example asking developmental questions by means of single-gene mutations or genetic questions by means of single-neuron recordings. An important feature of this approach is that it offers some relief from an affliction of neurobiology that has been called the chimera problem: the accumulation of volumes of data on different aspects of very different creatures. The cricket work links the several levels of analysis in a unitary system and provides a high degree of confidence on how biological integration is achieved. We view the cricket as a kind of decathlon performer in neurobiology: it may not excel at any one thing, but it can be counted on for a sound performance in every event.



CHANGE FROM TWO-PULSE TO THREE-PULSE TRILL can be artificially evoked in the calling-song pattern of a wild-type *T. oceanicus* cricket by changing the firing rate of command interneurons. In each pair of records the top trace shows the stimulus applied to the command interneuron and the bottom trace shows the impulse pattern of song motor neurons. In the bottom pair of traces the firing rate of the command interneuron has been increased about 10 percent, causing a shift in the motor pattern from the wild-type two-pulse trill to the three-pulse trill characteristic of the backcross whose trill appears in trace *b* in the illustration at the top of the page. Thus the command interneuron may be the neural element responsible for the difference in song patterns of the two genotypes.



102 mm f/2.8 127 mm f/2.8 102–152 mm f/3.5 zoom

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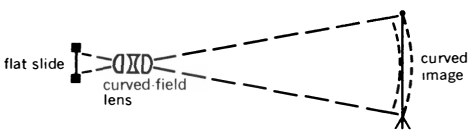
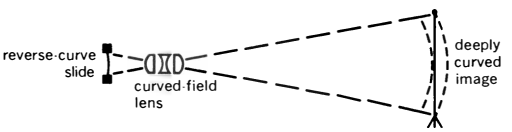
Let $\sum \frac{n'-n}{nn'r} > 0$ on purpose

KODAK CAROUSEL Projectors for 135 slides now come from the factory with KODAK Projection EKTANAR C Lenses. "C" indicates "curved field." Most Carousel projectors are used for screening family slides in the cardboard or plastic open mounts from the processing laboratory—mostly camera originals, some duplicate slides. "Kodak is putting a better lens on them," shoppers will be told. Details would be of scant interest.

KODAK EKTAGRAPHIC Slide Projectors are for audiovisual use. "Audiovisual" means "not for mere enjoyment." They are sold by audiovisual dealers, have a grey finish, and a few additional features. There is a choice of the new curved-field lenses or a flat-field lens. For certain audiovisual applications, "curved-field" may give worse results instead of better, e.g., slides mounted in glass, glass slides, "super slides" (38 mm square), ordinary open-mounted slides reversed to read right for rear projection, certain teaching slide sets on the market that have been produced by contact printing so that when you hold them up they read right with the dull side toward you. "Worse results" means that unceasing efforts to get everything readably sharp at the same time unfocus the mind from the subject of the slide. Admirably simple educational technology stumbles over itself.



This you don't want



. . . and certainly not this.

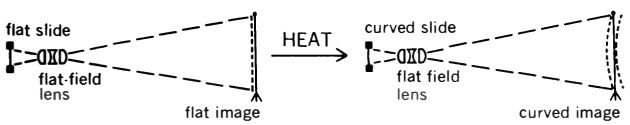
Details:

Take two identical open-mounted 135 slides that carry sharp, fine detail over much of the image area. Screen side by side, focusing very carefully. One is very definitely the sharper all the way from center to edge. Interchange the slides. The same projector is again just as definitely the sharper. It has a better lens than the other. It might fetch a little something extra in price if claimed to have been ground by the skilled hands of a follower of Spinoza's craft, apprenticed at 14.

Baloney. Lens performance is a matter of correcting the aberrations: longitudinal and lateral chromatism, spherical, coma, astigmatism, distortion, field curvature. These are mathematically inherent in any axially symmetrical surfaces that separate media of differing refractive index. For the lens speed required, the angular field to be covered, the number of elements economically permissible, the kinds of glass available, an applied mathematician must balance off effects at the various surfaces to minimize the overall aberrations. The outcome is a sheet of paper bearing the radii, thicknesses, spacings, and glass selections. Then the skilled hands can make themselves useful.

Still a slight aroma of baloney lingers. The high-speed digital computer has been invented. An optimization program shrinks years of design time to weeks or days. The program runs; there is little computational artistry to admire.

So the designer faces up to realities that had once been considered the concerns of other departments. Even the magical hands of the long-gone old craftsman could not have compensated for the fact that what's being projected is no flat surface but a small sheet of plasticized cellulose ester coated with layers of dyed gelatin and now being cooked with a high-intensity lamp.

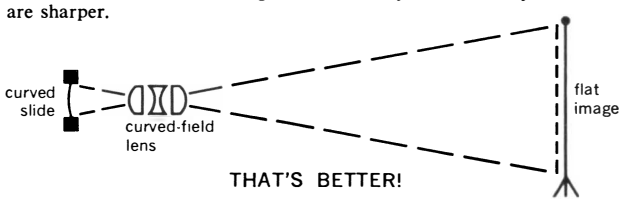


The first step in designing the Ektanar C lenses was not the turning on of the computer. It was an exhaustive statistical study of the shape assumed by open-mounted 135 slides from many different processors in all Carousel and Ektagraphic slide projectors, and how optical density affects the curl. A usefully consistent value of curvature emerged.

Early last century a man named Petzval proved on paper that when astigmatism is corrected so that sagittal and tangential foci coincide, they lie on a surface whose radius of curvature, R, at the axis is given by

$$\frac{1}{R} = \sum \frac{n'-n}{nn'r}$$

A zero Petzval sum being no cinch in a working lens, one leaves in some astigmatism so that the best compromise between sagittal and tangential focus lies on a flat plane. But since we now want a curved field we don't need the astigmatism. Now you know why the slides are sharper.



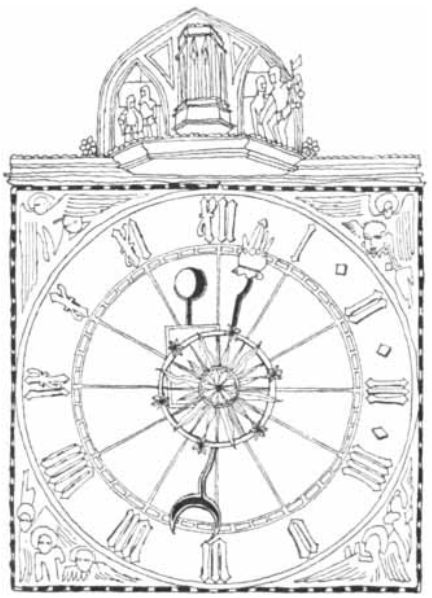
THAT'S BETTER!

Shopmanship still counts, though, but not on a surface-by-surface, brass-ring-by-brass-ring basis that would restrict superior lenses to families that can also afford "his and her" airplanes. Today top-grade craftsmanship is amplified many thousandfold by working on tooling instead of production.

Design of machines that grind, polish, and center the glass lens elements occupies whole Kodak careers. Design of other machines that squirt one plastic here and another kind of plastic there to hold the elements in place occupy other Kodak engineering careers. The properties of the plastics and the statistics of spacing and centering tolerances enter into the optical computations themselves. The outcome demanded is a bright, sharp image to look at, not a formula on a sheet of paper.

Kodak

SCIENCE AND THE CITIZEN



The Lepton and the Hadron

The community of physicists is in one of its periodic states of agreeable mystification: two groups of experiments have produced results that no one can understand. Several months ago workers at the Stanford Linear Accelerator Center (SLAC) found that when high-energy electrons collide with high-energy positrons, they give rise to unaccountably large numbers of hadrons: particles such as pions that are associated with the "strong," or nuclear, force. More recently three groups at the Fermi National Accelerator Laboratory, the site of the world's most powerful accelerator, have found that when protons collide with neutrons or other protons, they give rise to a surprising number of electrons and muons. Electrons and muons are classified as leptons, which should arise only rarely from a collision between two hadrons. Leptons are associated with the electromagnetic force and the weak force; they are not supposed to "feel" the strong force. These three forces, together with gravitation, are thought to be sufficient to account for all physical interactions.

In the SLAC experiments a storage ring is used to hold electrons circulating in one direction and positrons circulating in the opposite direction. On a signal the two beams of particles are made to collide, with an energy equivalent to five billion electron volts (GeV). When an electron and a positron meet, they annihilate each other, releasing all their energy of motion and of rest mass in the form of a photon, the quantum of electromagnetic energy. The photon can then decay into hadrons or leptons, provided that equal numbers of particles and antiparticles are created. The hadrons produced are chiefly pions; the leptons are electrons and muons.

The ratio of hadrons to muons created in electron-positron annihilations violates the ratio predicted by the "quark" model, which has enjoyed a decade of remarkable success in predicting the outcome of many other particle experiments. According to the simple quark theory, hadrons such as pions or kaons (known collectively as mesons) are composed of two quarks, whereas hadrons such as protons and neutrons (known as baryons) are composed of three quarks. One remarkable feature of quarks is that they carry less than a full unit of electric charge: their charge is either $\pm 1/3$ or $\pm 2/3$.

On general grounds it was believed the ratio of hadrons to muons produced in the electron-positron reaction would be related to the charge on the three quarks needed to produce a hadron. More specifically the ratio should be 2/3, which is the sum of the squares of the individual quark charges, regardless of the energy of collision. Initial experiments conducted at energies below 3 GeV at the Italian national physical laboratory in Frascati gave a hadron-muon ratio of more than twice the predicted value. At 5 GeV the ratio of hadrons to muons rises to more than six to one.

Various attempts have been made to save the quark model. One simple suggestion is that the experimental energies are not high enough for the quark effects to become dominant. More elaborate proposals invoke more quarks per hadron than the three specified in the simple quark model. (There are now hypothetical sets of red, white and blue quarks, and an extra "charm" quark.) By adding quarks it is possible to get hadron-muon ratios as high as six to one.

Other suggestions are more audacious. It has been pointed out that the well-verified theory of quantum electrodynamics has not been tested at distances of less than 5×10^{-15} centimeter. Conceivably the electron may have a tiny core, with a diameter of, say, 10^{-16} centimeter, that has the properties of a hadron. If that were the case, electron-positron collisions at high energies would increasingly assume the character of hadron-hadron collisions, which would readily give rise to more hadrons.

The second group of experiments that have physicists perplexed are the converse of the electron-positron experiments: they involve the unexpected appearance of leptons in collisions between hadrons. Hints of direct lepton production had been observed earlier in accelerator experiments conducted at Serpukhov in the U.S.S.R. and at the Brookhaven National Laboratory. At the Fermi Laboratory the leptons appeared when protons of 300 GeV were directed against metal targets. Such collisions normally produce pions. At 300 GeV, however, one lepton (either a muon or an electron) was observed for every 10,000 pions. This rate of lepton production is 10 to 100 times higher than is predicted by the quark model or by any other model of proton-proton interactions.

American Ways of Death

There are indications that improved medical care—or something else—is finally reducing the toll of heart diseases in the U.S. On the other hand, more Americans have been dying recently of cancer, emphysema or cirrhosis of the liver, or have been killing themselves or being murdered. These are some of the findings of a study by the National Center for Health Statistics of mortality trends from 1950 to 1969 for the 15 leading causes of death (groups of causes, in most cases), which in 1969 accounted for 89 percent of the country's deaths.

These were the leading 15 in 1969, ranked according to their mortality rate per 100,000 of the total U.S. population: diseases of the heart, malignant neoplasms (cancers), cerebrovascular diseases, accidents, influenza and pneumonia, certain causes of mortality in early infancy, diabetes, arteriosclerosis, bronchitis (and emphysema and asthma), cirrhosis of the liver, suicide, congenital anomalies, homicide, nephritis and nephrosis and peptic ulcer.

Trends in mortality rates by cause of death are obscured by a number of factors, including changes in the age structure of a population, improved diagnosis and changes in the rather arbitrary categorization of diseases into internationally accepted groups of "causes." After age

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adjustment, however, certain trends are apparent. The death rate increased between 1950 and 1969 for six of the causes. The largest increase, more than 100 percent from 1954 to 1969, was for bronchitis, emphysema and asthma; the largest rise by far was for emphysema, which is often attributed to the effects of smoking or air pollution. There was a 75.5 percent rise in the death rate by homicide and a 67 percent increase for cirrhosis. The death rate for cancers was up just 3.4 percent, but death from cancer of the respiratory system more than doubled. Major decreases were recorded for nephritis and nephrosis, arteriosclerosis and cerebrovascular diseases. The 15 percent decrease for diseases of the heart is significant because this category accounted in 1969 for more than a third of all deaths in the U.S. The drop in the death rate may reflect improved treatment of chronic high blood pressure and of coronary emergencies.

Age-adjusted rates were calculated separately for males and females and for "whites" and "all others"—primarily blacks. The mortality rates were higher for others than whites in all categories except four: suicide, arteriosclerosis, congenital anomalies and bronchitis-emphysema-asthma. The rates were higher for men than for women in all categories but one: diabetes. In two other categories, however, there was a sharp reduction in the mortality sex ratio. Whereas male deaths from peptic ulcer decreased during the 20 years, the rate for females went up. And the rate of women's deaths by suicide also increased in relation to the rate for men.

For a Few Cents per Ton

For the next few decades at least the U.S. will be relying increasingly on its large supplies of coal as a source of energy. About 57 percent of the nation's coal reserve lies in the region west of the 100th meridian, which passes through the middle of North Dakota and Texas and forms much of the western boundary of Oklahoma. A significant part of the Western coal (some 27 billion tons, or 25 percent of the reserve) can be obtained by the methods of surface mining or strip-mining that have been employed in recent years on approximately 1.3 million acres of Eastern coal fields. The question thus arises of what can be done to rehabilitate the land that will be disturbed, which could be as much as 1.5 million acres. A committee of the National Academy of Sciences–National Academy of Engineering has looked into this question and concluded that much of the land could and should be rehabilitated and that the cost of doing so should be borne in the first instance by the mining industry.

The committee's report, *Rehabilitation Potential of Western Coal Lands,* was made to the Ford Foundation, which commissioned the study through its Energy Policy Project. "We believe," the committee said, "that those areas receiving ten inches (250 mm) or more of annual rainfall can usually be rehabilitated, provided that evapotranspiration is not excessive, landscapes are properly shaped, and techniques demonstrated to be successful in rehabilitating disturbed rangeland are applied.... The drier areas ... pose a more difficult problem. Revegetation of these areas can probably be accomplished only with major, sustained inputs of water, fertilizer and management." It will also be necessary, the committee said, to make certain that the plant community consists of "a mixture of species capable of sustaining the former native animals."

The committee also found that, although the technology exists for rehabilitating most of the land that has been surface-mined in the U.S., little of it has been applied properly. Moreover, "most state laws governing surface mining and rehabilitation in the West do not provide for adequate planning, monitoring, enforcement and financing of rehabilitation." For these reasons the committee recommended that surface mining "should not be permitted on either public or private lands without the prior development of rehabilitation plans designed to minimize environmental impacts, to meet on- and off-site air and water pollution regulations, and to define a timetable for rehabilitation concurrent with the mining operation." Minimum regulations should be established promptly by Federal statute, the committee said.

Although the cost per acre of rehabilitation may be high, according to the committee, it will be manageable if it is amortized over the period of time required for rehabilitation to succeed. That period is likely to be many years. "In any case a cost of several thousand dollars per acre may represent only a few cents per ton on the coal removed."

Lesser Nobility

The supposed "nobility" of the elements that make up Group Zero in the periodic table was first compromised in 1962, when Neil Bartlett, then at the University of British Columbia, synthesized xenon hexafluoroplatinate ($XePtF_6$). Soon after Bartlett's announcement several other noble-gas compounds were made, chief among them the xenon fluorides (XeF_2, XeF_4 and XeF_6) and xenon trioxide (XeO_3). A number of others have been synthesized since, but the variety of the noble-gas compounds has nevertheless remained extremely limited. Except for a few substances stable only at low temperature, all the compounds have been formed by bonds between a noble gas (almost always xenon) and either fluorine or oxygen.

The synthesis of a compound in which xenon is bonded to nitrogen has now been reported. The compound is fluoroxenonimidobis(sulfuryl fluoride), which can be written $FXeN(SO_2F)_2$. It was prepared by Darryl D. DesMarteau and Robert D. LeBlond of Kansas State University, who are presenting their results in *Chemical Communications.*

The principal difficulty encountered in preparing noble-gas compounds is the high ionization potential of the Group Zero elements: the amount of energy required to remove an electron from an atom. This barrier is overcome by the high electronegativity, or affinity for electrons, of fluorine and certain fluorine-containing radicals; oxides and other compounds of xenon are made by substitution from the fluorides. DesMarteau and LeBlond produced a xenon-nitrogen bond by substituting for a fluoride a nitrogen-containing radical that is highly electronegative.

The radical is imidobis(sulfuryl fluoride), which is employed in the synthesis in the form of an acid, $HN(SO_2F)_2$. It reacts with xenon difluoride (XeF_2) to yield the desired product and hydrogen fluoride. In addition to its electronegativity the imidobis(sulfuryl fluoride) group has another property that was essential in this preparation: it is resistant to degradation by xenon difluoride and hydrogen fluoride, which in combination form a powerful oxidizing agent.

At room temperature fluoroxenonimidobis(sulfuryl fluoride) is a relatively stable, white, crystalline solid. Evidence of the presence of a xenon-nitrogen bond was obtained by nuclear-magnetic-resonance studies of the material.

Tools before Man

One common tool of the Stone Age is a heavy chopper that was shaped into a rough triangle by striking flakes from both sides of a flint core. The French, who first found these tools in large numbers, named them *coups de poigne,* or "hand axes." It has long been taken for granted that the implements,

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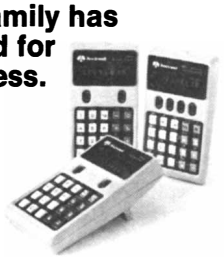


typically associated with what is called the Acheulean culture, were made by men, that is to say members of the genus *Homo*. That assumption has now been questioned.

Writing in *Nature*, Glynn Isaac and Garniss Curtis of the University of California at Berkeley report that recent refinements in dating techniques show that the hand axes and other Acheulean tools found at a site in East Africa near Olduvai Gorge are at least a million years old and perhaps 1.5 million years old. The tools were discovered by Richard Leakey not long ago in the Peninj formation in Tanzania, west of Lake Natron. Outside Africa the earliest-known Acheulean tools are scarcely more than half a million years old.

No human remains were associated with the Peninj tools, but a fossil jaw, found at a lower level in the formation and thus even older than the tools, evidently represents the African hominid *Australopithecus*. This precursor of the genus *Homo* has already been credited with making very crude pebble tools—pumice flakes and choppers—that are 2.5 million years old. The pumice tools were unearthed by Leakey a few years ago in the Koobi Fora area of northern Kenya, east of Lake Rudolf.

Credit for making the Koobi Fora artifacts goes to *Australopithecus* more or less by default. The oldest-known fossils of the other possible manufacturer, *Homo erectus*, are less than two million years old and are also from Java, on the other side of the Indian Ocean. Until now, however, no one has suggested that *Australopithecus* made such sophisticated tools as Acheulean hand axes.

Isaac and Curtis note that, regardless of who made the Peninj hand axes, the gap of as much as a million years between the Acheulean of Africa and the Acheulean of Europe will require a modification of the current view of human evolution. "It will be necessary," they conclude, "to consider the possibility that hominids were essentially restricted to tropical and warm temperate zones for a much larger fraction of their evolutionary history than has hitherto been envisaged."

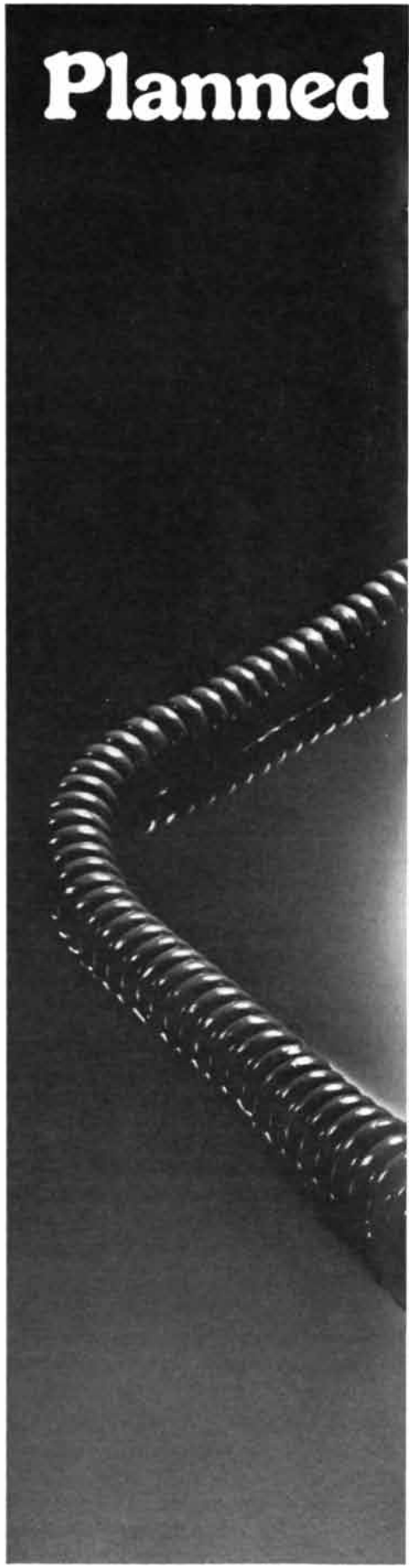
Streaker

It has been emerging recently that two years ago the earth had an extraordinary encounter with another celestial body. In broad daylight on August 10, 1972, a meteor whose brightness was estimated to be between that of the full moon and the sun streaked across the sky above three Western states and the Canadian province of Alberta. The object never fell to the ground. It continued right on through the upper atmosphere and back out into space.

Such a grazing encounter between a meteorite and the earth is unique, writes one of the witnesses, Luigi G. Jacchia of the Smithsonian Astrophysical Observatory, in *Sky and Telescope*. The meteor was photographed by a number of people along its path, and the height of its vapor trail was measured with a theodolite by a surveyor near Billings, Mont. Heat from the friction of the meteorite's passage through the atmosphere was detected by an infrared radiometer aboard an Air Force satellite. The reason the meteor did not attract wider notice at the time was that, in this age of artificial satellites and long-range rocket tests, it was assumed that it had been caused by a man-made object. Then, when the orbit of the object was calculated on the basis of data from the infrared radiometer and the surveyor's sighting, it became clear that it had been a meteorite.

At the time of the encounter the earth was moving in its orbit at a velocity of 29.4 kilometers per second. The meteorite was crossing the plane of the earth's orbit from south to north at an angle of 15 degrees, and it overtook the earth from behind at a velocity of 34.8 kilometers per second. Its initial velocity with respect to the earth was 10.1 kilometers per second, which was increased to 15 kilometers per second by the earth's gravity. The meteorite entered the atmosphere above Beaver, Utah; it came closest to the ground at a height of 58 kilometers above southern Montana. It left the atmosphere above Alberta midway between Calgary and Edmonton. The total length of the path was 1,500 kilometers, which the object traversed in 101 seconds. As a result of its close encounter with the earth it now has a new heliocentric orbit whose closest approach to the sun is the earth's orbit and whose greatest distance from the sun is in the middle of the asteroid belt between the orbits of Mars and Jupiter.

Estimates of the meteorite's size vary widely because of uncertainties in observations of its brightness and in measurements of how much it was decelerated by the friction of the earth's atmosphere. Jacchia's own calculation from the brightness is that the object had a diameter of 13 meters (43 feet) and a mass of 4,000 metric tons—about 8 percent of the size of the object that produced the well-known Barringer meteor crater in Arizona. Jacchia concludes: "No matter how you look at it, it was an extraordinary fireball!"



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THE ORIGINS OF ALIENATION

It seems clear that the degree of estrangement between young people and adults in the U.S. is currently higher than it has been in other times. The causes lie in evolutionary changes in the American family

by Urie Bronfenbrenner

Profound changes are taking place in the lives of America's children and young people. The institution that is at the center of these changes and that itself shows the most rapid and radical transformation is the American family, the major context in which a person grows up. The primary causes and consequences of change, however, lie outside the home. The causes are to be found in such unlikely quarters as business, urban planning and transportation systems; the ultimate effects of change are seen most frequently in American schools and–not as often but more disturbingly–in the courts, clinics and mental and penal institutions. The direction of change is one of disorganization rather than constructive development.

The disorganization is experienced at two levels. In the first instance it affects the structure and function of society and its primary institutions; then it is rapidly reflected in the structure and function of individual human beings, particularly those who are still in the process of development: children and young people. The crux of the problem lies in the failure of the young person to be integrated into his society. He feels uninterested, disconnected and perhaps even hostile to the people and activities in his environment. He wants "to do his own thing" but often is not sure what it is or with whom to do it. Even when he thinks he has found it–and them–the experience often proves unsuccessful and interest wanes.

This feeling, and fact, of disconnectedness from people and activities has a name that has become familiar: alienation. My purpose here is to explore the origins of alienation, to identify the circumstances that give rise to it and to consider how these circumstances might be altered in order to reverse the process. As I have suggested, although alienation ultimately affects the individual, it has its roots in the institutions of the society, and among these institutions the family plays a particularly critical role. I can therefore begin my inquiry by examining the changes that have taken place in the American family over recent decades.

Family Structure

The family of 1974 is significantly different from the family of only 25 years ago. Today almost 45 percent of the nation's mothers work outside the home. The greatest increase has occurred for mothers of preschool children: one in every three mothers with children under six is working today. As more mothers go to work, the number of other adults in the family who could care for the child has shown a marked decrease. For example, 50 years ago half of the households in Massachusetts included at least one adult besides the parents; today the figure is only 4 percent.

The divorce rate among families with children has risen substantially during the past 20 years. The percent of children from divorced families is almost twice what it was a decade ago. If present trends continue, one child in six will lose a parent through divorce by the time he is 18.

In 1970, 10 percent of all children under six–2.2 million of them–were living in single-parent families with no father in the home, almost double the rate for a decade ago. The average income for a single-parent family with children under six was $3,100 in 1970–well below the "poverty" line ($4,000 per year for a family of four). Even when the mother worked, her average income of $4,200 barely exceeded the poverty level. Among families in poverty 45 percent of all children under six were living in single-parent households; in nonpoverty families the corresponding figure was only 3.5 percent.

Of the 5.6 million preschool children whose mothers are in the labor force, one million live in families below the poverty line. Another million children of working mothers live in near-poverty (income between $4,000 and $7,000 for a family of four). All these children would have to be on welfare if the mother did not work. Finally, there are about 2.5 million children under six whose mothers do not work but whose family income is below the poverty level. Without counting the many thousands of children in families above the poverty line who are in need of child-care services, this makes a total of about 4.5 million children under six whose families need some help if normal family life is to be sustained.

The situation is particularly critical for the families of black Americans. Of all black children 53 percent live in families below the poverty line; the corresponding figure for whites is 11 percent. Of all black children 44 percent have mothers who are in the labor force; the corresponding figure for whites is 26 percent. Of all black children more than 30 percent live in single-parent families; the corresponding figure for whites is 7 percent. The census does not provide comparable information for other groups living under duress, such as American Indians, Mexican Americans and whites living in Appalachia. If and when such data become available, they are likely to show similar trends.

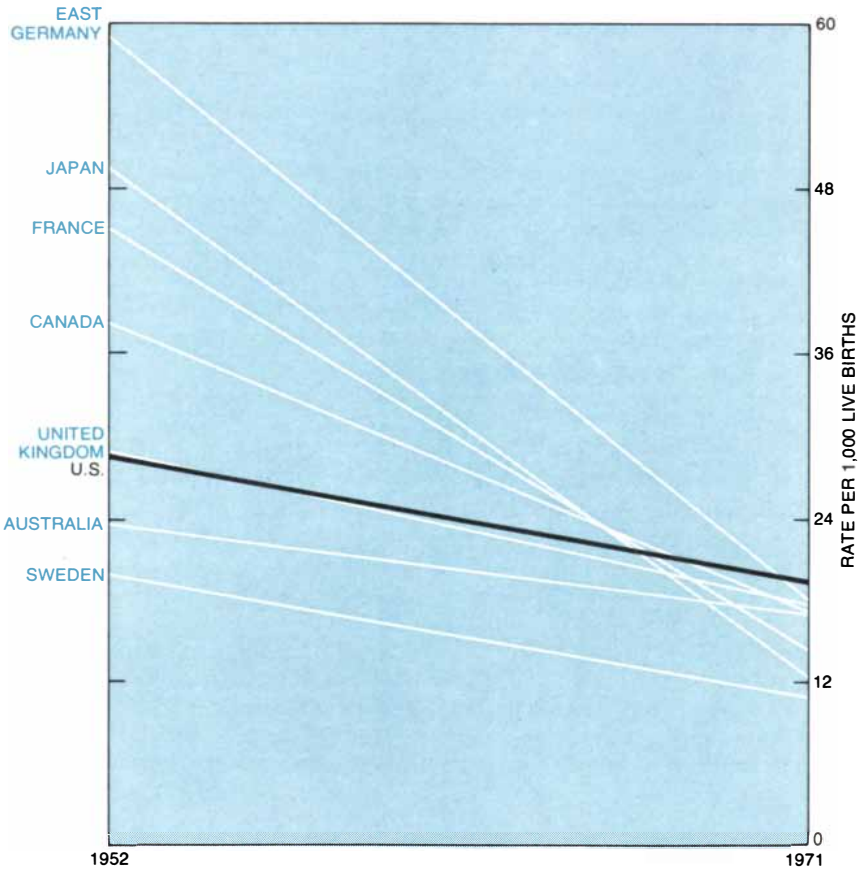
During the past decade many of us have become familiar with the plight of poor families in general terms, but we may not yet have recognized the impact of poverty at the concrete level and our own direct responsibility for its destructive effects. A case in point is the scandal of infant mortality. At the latest count, in 1972, the U.S. ranked 14th in the

world in combating mortality during the first year of life—behind East Germany—and our ranking had been dropping steadily. The overall figures for the U.S., dismaying as they are, mask even greater inequities. Infant mortality is almost twice as high for nonwhites as for whites; within New York City it is three times as high in central Harlem as it is in Forest Hills. Several different studies have related infant mortality to inadequate prenatal care. What happens if that care is delivered to poor people? The answer to that question is available in data from the maternal- and infant-care projects the Department of Health, Education, and Welfare financed in the mid-1960's in slum sections of 14 cities. In the target areas of such programs there was a dramatic drop in infant mortality: from 34.2 per 1,000 live births in 1964 to 21.5 in 1969 in Denver, from 33.4 to 13.4 in Omaha, from 25.4 in 1965 to 14.3 in 1969 in Birmingham. Among the populations served by these programs there were also significant reductions in premature births, in repeated teen-age pregnancy, in conceptions by women over 35 and in the number of families with more than four children. It is a reflection of our distorted priorities that these programs are currently in jeopardy even though their proposed replacement through revenue-sharing is not yet on the horizon. The phasing out of these programs will result in a return of mortality to the earlier levels: more infants will die.

The record in infant and maternal care is only one example of this country's failure to support its children and families living in poverty. It is not only disadvantaged families, however, that experience frustration and failure; for families that can get along the rats may be gone but the rat race remains. The demands of a job that claims mealtimes, evenings and weekends as well as days; the trips and moves necessary to get ahead or simply to hold one's own; the increasing time spent commuting, entertaining, going out, meeting social and community obligations—all of these produce a situation in which a child often spends more time with a passive babysitter than with a participating parent.

The forces undermining the parental role are particularly strong in the case of fathers. Compare, for example, the results of a study of middle-class fathers who told interviewers they were spending an average of 15 to 20 minutes a day playing with their one-year-old infants with another study in which the father's voice was actually recorded by means of a microphone attached to the infant's shirt. "The data indicate that fathers spend relatively little time interacting with their infants. The mean number of interactions per day was 2.7, and the average number of seconds per day was 37.7."

Another factor reducing interaction between parents and children is the changing physical environment in the home, in which proliferating television-viewing areas and playrooms and "family rooms" and master bedrooms increasingly separate the generations. Perhaps the ultimate in isolation is reached in a "cognition crib" described in a brochure I received recently in the mail. It is equipped with a tape recorder that can be actuated by the sound of the infant's voice. Frames built into the sides of the crib make possible the insertion of "programmed play modules for sensory and physical practice." The modules come in sets of six, which the parent is "encouraged to change" every three months in order to keep pace with the child's development. Since "faces are what an infant sees first, six soft plastic faces... adhere to the window." Other modules include mobiles, a crib aquarium, a piggy bank and "ego-building mirrors." Parents are hardly mentioned except as potential purchasers.

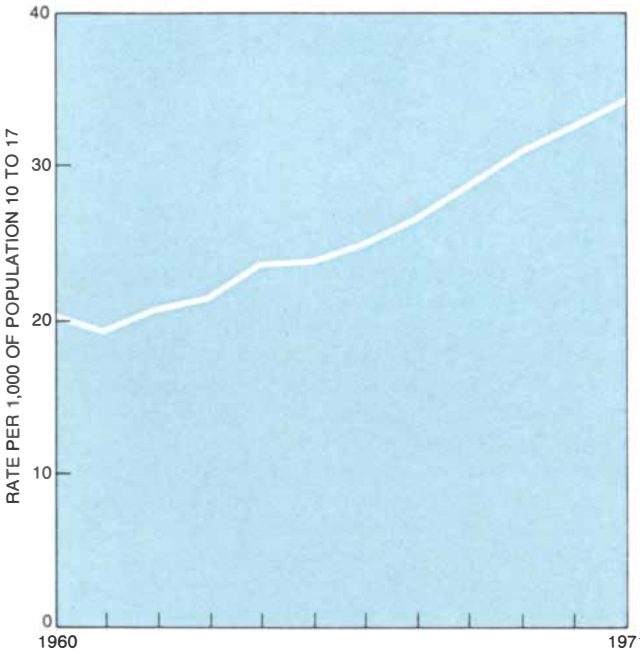


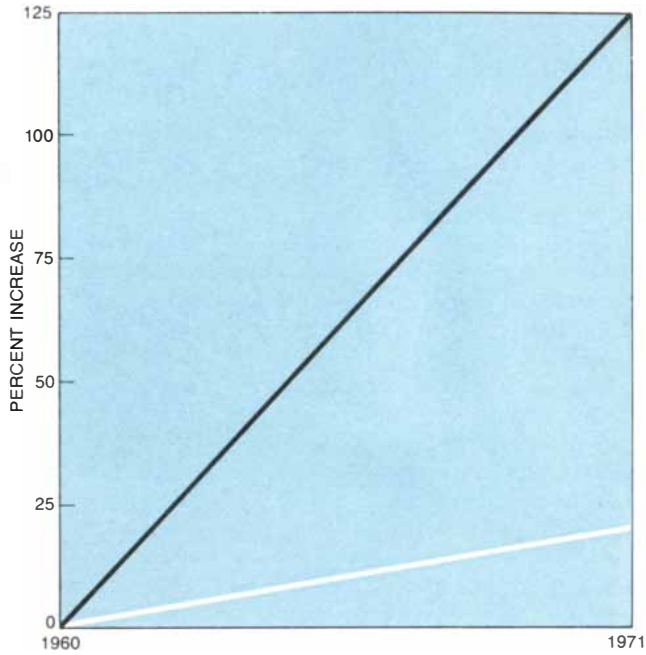
INFANT MORTALITY (deaths before one year of age) is one of the indexes of maternal and child care by which the U.S. no longer ranks well among advanced industrial nations. Recent studies have correlated infant mortality specifically with poor prenatal health care.

Isolation

It is not only parents of whom children are deprived but also people in general. Developments of recent decades—many in themselves beneficent—conspire to isolate children from the rest of society. The fragmentation of the extended family, the separation of residential and business areas, the breakdown of neighborhoods, zoning ordinances, occupational mobility, child-labor laws, the abolition of the apprentice system, consolidated schools, supermarkets, television, separate patterns of social life for different age groups, the working mother, the delegation of child care to specialists—all these manifestations of progress operate to decrease opportunity and incentive for meaningful contact between children and people older or younger than themselves.

This erosion of the social fabric isolates not only the child but also his family. In particular, with the breakdown of the community, the neighborhood and the extended family and the rise in the





INCREASE IN JUVENILE CRIME is reflected by the rate of U.S. juvenile delinquency cases other than traffic offenses (*left*) and by the large increase in arrests of people under 18 (*black*) compared with the smaller increase (*white*) for those 18 and over (*right*).

number of homes from which the father is absent, increasingly great responsibility has fallen on young mothers. For some of them the resulting pressures appear to be mounting beyond the point of endurance. The growing number of divorces is now accompanied by a new phenomenon: the unwillingness of either parent to take custody of the child. In more and more families the woman is fleeing without waiting for a formal separation. Increasing numbers of married women are being reported to police departments as missing, and news reports indicate a quantum leap in the number of runaway wives whom private detectives, hired by fathers who are left with the children, are trying to find.

There is a more gruesome trend: The killing of infants under one year of age has been increasing sporadically since 1957. The infanticide rate rose from 3.1 per 100,000 of the infant population in that year to 4.7 in 1970. A similar pattern appears for less violent forms of child abuse that involve bodily injury. A 1970 survey of more than 1,300 families projected a nationwide total of from two to four million battered-child cases a year, with the highest rates occurring among adolescents. Significantly, more than 90 percent of the incidents took place in the child's home. The most severe injuries occurred in single-parent homes and were inflicted by the mother herself, a fact that reflects the desperation of the situation faced by some young mothers today.

The centrifugal forces generated within the family by its increasing isolation propel its members in different directions. As parents spend more time in work and community activities, children are placed in or gravitate toward organized or informal group settings. Between 1965 and 1970 the number of children enrolled in day-care centers doubled, and the demand today far exceeds the supply. More and more children come home from school to an empty house or apartment. When he is not in preschool or school, the child spends increasing amounts of time in the company of only his age-mates; the vacuum created by the withdrawal of parents and other adults has been filled by the informal peer group. A recent study has found that at every age and grade level children today show greater dependence on their peers than they did a decade ago. A parallel investigation indicates that such susceptibility to group influence is higher among children from homes in which at least one parent is frequently absent. Moreover, peer-oriented youngsters describe their parents as being less affectionate and less firm in discipline. Attachment to age-mates appears to be influenced more by a lack of attention and concern at home than by any positive attraction of the peer group itself; in fact, these children have a rather negative view of their friends and of themselves as well. They are pessimistic about the future, they rate lower in responsibility and leadership and they are more likely to engage in such antisocial behavior as lying, teasing other children, playing hooky or "doing something illegal."

These, of course, are among the milder consequences of alienation. The more serious manifestations are reflected in the rising rates of youthful runaways, school dropouts, drug abuse, suicide, delinquency, vandalism and violence documented for the White House Conference on Children in 1970 and in more recent government publications. The proportion of youngsters between the ages of 10 and 18 arrested for drug abuse doubled between 1964 and 1968. Since 1963 juvenile delinquency has been increasing at a higher rate than the juvenile population; more than half of the crimes involve vandalism, theft or breaking and entry; if the present trends continue, one in every nine youngsters will appear in juvenile court before the age of 18. These figures index only offenses that are detected and prosecuted. One wonders how high the numbers must climb before we acknowledge that they reflect deep and pervasive problems in the treatment of children and youth in our society.

The Neglected Family

What is the ultimate source of these problems? Where do the roots of alienation lie? Studies of human behavior have yielded few generalizations that are firmly grounded in research and broadly accepted by specialists, but there are two answers to the foregoing questions that do meet these exacting criteria.

1. Over the past three decades liter-

ally thousands of investigations have been conducted to identify the developmental antecedents of behavior disorders and social pathology. The results point to an almost omnipresent overriding factor: family disorganization.

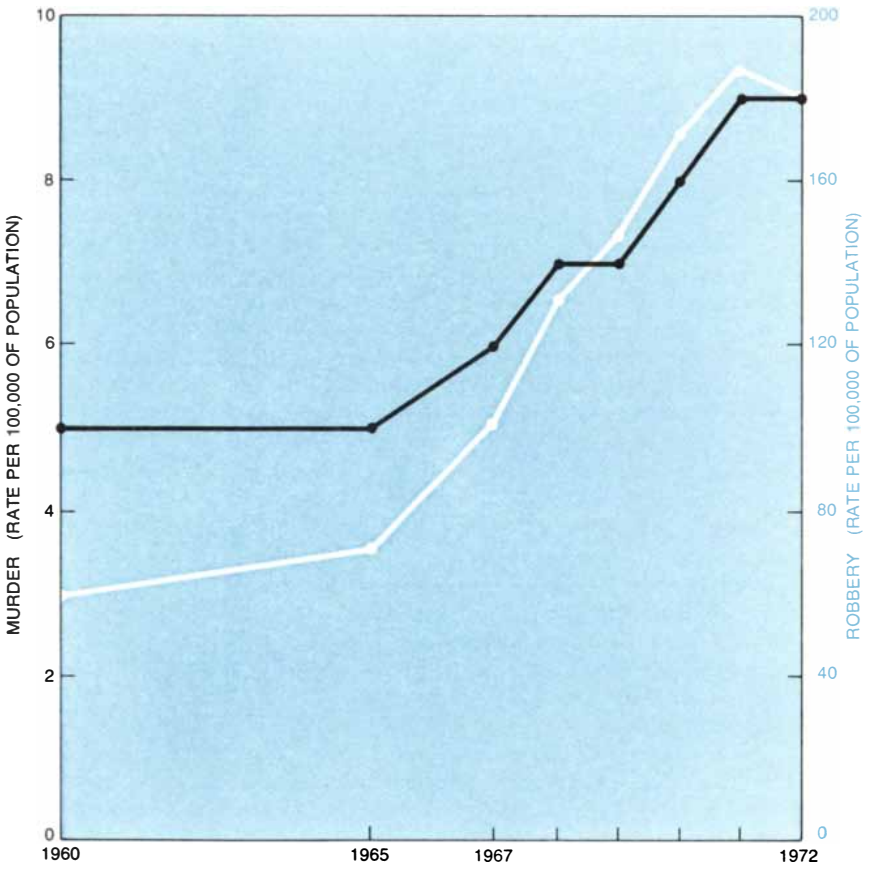
2. Much of the same research also shows that the forces of disorganization arise primarily not from within the family but from the circumstances in which the family finds itself and from the way of life that is imposed on it by those circumstances.

Specifically, when those circumstances and the way of life they generate undermine relationships of trust and emotional security between family members, when they make it difficult for parents to care for, educate and enjoy their children, when there is no support or recognition from the outside world for one's role as a parent and when time spent with one's family means frustration of career, personal fulfillment and peace of mind, then the development of the child is adversely affected. The first symptoms are emotional and motivational: disaffection, indifference, irresponsibility and inability to follow through in activities requiring application and persistence. In less favorable family circumstances the reaction takes the form of antisocial acts injurious to the child and to society. Finally, for children who come from environments in which the capacity of the family to function has been most severely traumatized by such destructive forces as poverty, ill health and discrimination, the consequences for the child are seen not only in the spheres of emotional and social maladjustment but also in the impairment of the most distinctive of human capacities: the ability to think, to deal with concepts and numbers at even the most elementary level.

The extent of this impairment in contemporary American society, and its roots in social disorganization, are reflected in recent studies. A New York State commission on education studied more than 300 schools and reported that 58 percent of the variation in student achievement could be predicted by three socioeconomic factors: broken homes, overcrowded housing and the educational level of the head of the household; when racial and ethnic variables were introduced into the analysis, they accounted for less than an additional 2 percent of the variation. And there is a secular trend: each year "more and more children throughout the state are falling below minimum competence."

How are we to reverse this trend? The evidence indicates that the most promising solutions do not lie within the child's immediate setting, the classroom and the school. An impressive series of investigations, notably the studies published by James Coleman in 1966 and by Christopher Jencks in 1972, demonstrate that the characteristics of schools, of classrooms and even of teachers predict very little of the variation in school achievement. What does predict it is family background, particularly the characteristics that define the family in relation to its social context: the world of work, neighborhood and community.

The critical question thus becomes: Can our social institutions be changed—old ones modified and new ones introduced—so as to rebuild and revitalize the social context that families and children require for their effective function and growth? Let me consider some institutions on the contemporary American scene that are likely to have the greatest impact, for better or for worse, on the welfare of America's children and young people.



INCREASE IN VIOLENT CRIME is reflected in Federal Bureau of Investigation statistics covering murders and nonnegligent manslaughters (*black curve and scale at left*) and robberies (*white curve and scale at right*) known to and reported by police departments.

Day Care

Day care is coming to America. The question is what kind. Shall we, in response to external pressures to "put people to work" or for considerations of personal convenience, allow a pattern to develop in which the care of young children is delegated to specialists, further separating the child from his family and reducing the family's and the community's feeling of responsibility for their children? Or will day care be designed, as it can be, to reinvolve and strengthen the family as the primary and proper agent for making human beings human?

As Project Head Start demonstrated, preschool programs can have no lasting constructive impact on the child's development unless they affect not only the child himself but also the people who constitute his enduring day-to-day environment. This means that parents and other people from the child's immediate environment must play a prominent part in the planning and administration of day-care programs and also participate actively as volunteers and aides. It means that the program cannot be confined to the center but must reach out into the home and the community so that the entire neighborhood is caught up in activities in behalf of its children. We

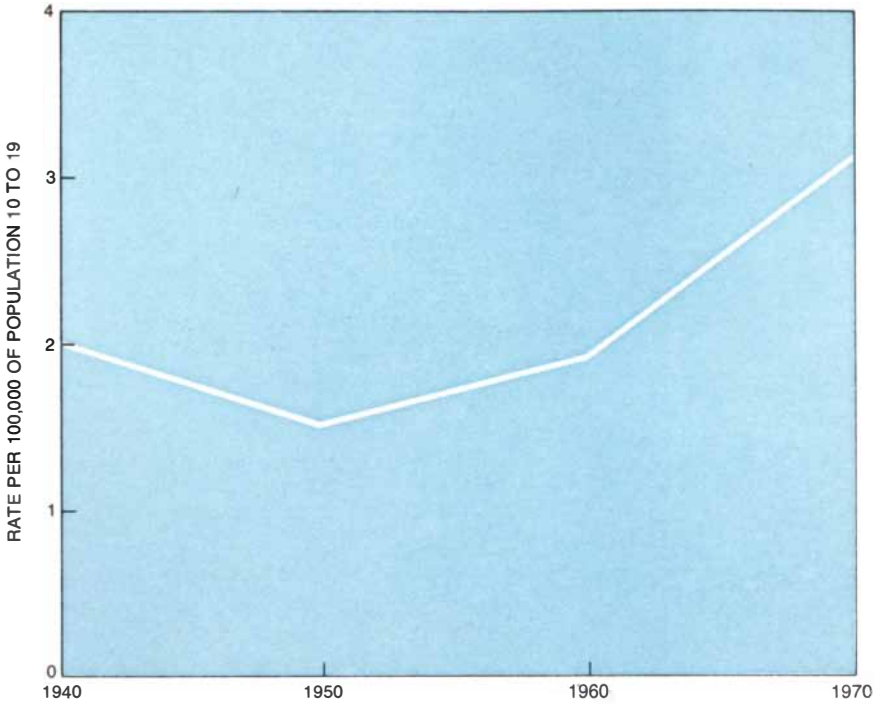
need to experiment with putting day-care centers within reach of the significant people in the child's life. For some families this will mean neighborhood centers, for others centers at the place of work. A great deal of variation and innovation will be required to find the appropriate solutions for different groups in different settings.

Such solutions confront a critical obstacle in contemporary American society. The keystone of an effective day-care program is parent participation, but how can parents participate if they work full time—which is one of the main reasons the family needs day care in the first place? I see only one possible solution: increased opportunities and rewards for part-time employment. It was in the light of this consideration that the report of the White House Conference urged business and industry, and governments as employers, to increase the number and the status of part-time positions. In addition the report recommended that state legislatures enact a "Fair Part-Time Employment Practices Act" to prohibit discrimination in job opportunity, rate of pay, fringe benefits and status for parents who sought or engaged in part-time employment.

I should like to report the instructive experience of one state legislator who attempted to put through such a bill, Assemblywoman Constance Cook of New York. Mrs. Cook sent me a copy of her bill as it had been introduced in committee. It began, "No employer shall set as a condition of employment, salary, promotion, fringe benefits, seniority" and so on that an employee who is the parent or guardian of a child under 18 years of age shall be required to work more than 40 hours a week. Forty hours a week, of course, is full time; Mrs. Cook informed me that there was no hope of getting a bill through with a lower limit. It turned out that even 40 hours was too low. The bill was not passed even in committee. The pressure from business and industry was too great, and they insisted on the right to require their employees to work overtime.

(There is a ray of hope, however. In the settlement of the United Automobile Workers' 1973 strike against the Chrysler Corporation a limit was placed for the first time on the company policy of mandatory overtime.)

These concerns bring me to what I regard as the most important single factor affecting the welfare of the nation's children. I refer to the place and status of women in American society. Whatever the future trend may be, the fact remains that in our society today the care of children depends overwhelmingly on women, and specifically on mothers. Moreover, with the withdrawal of the social supports for the family to which I alluded above, the position of women and mothers has become more and more isolated. With the breakdown of the community, the neighborhood and the extended family an increasing responsibility for the care and upbringing of children has fallen on the young mother. Under these circumstances it is not surprising that many young women in America are in revolt. I understand and share their sense of rage, but I fear the consequences of some of the solutions they advocate, which will have the effect of isolating children still further from the kind of care and attention they need. There is, of course, a constructive implication to this line of thought, in that a major route to the rehabilitation of children and youth in American society lies in the enhancement of the status and power of women in all walks of life—in the home as well as on the job.



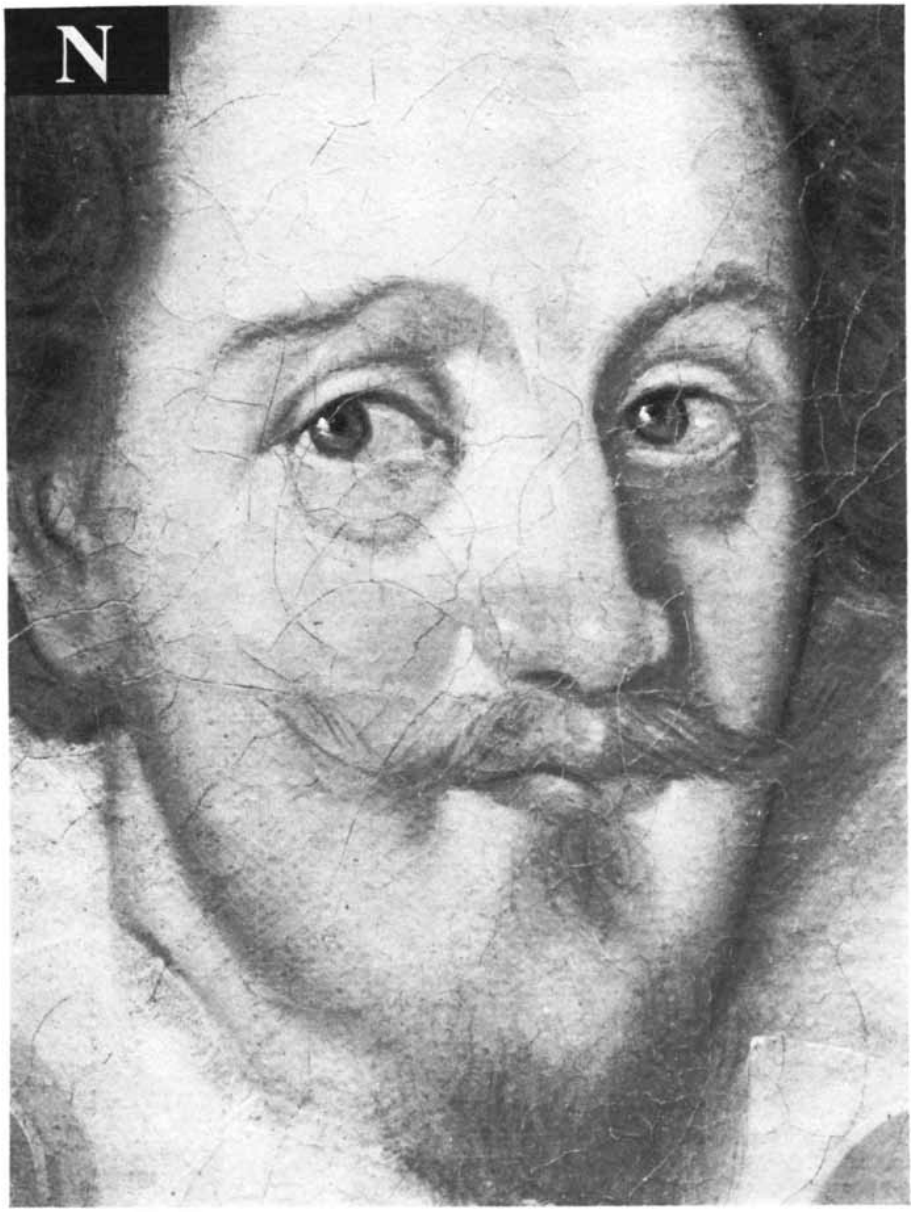
JUVENILE SUICIDE RATE (for adolescents from 10 to 19 years old) has risen recently. The rate for the population as a whole, in contrast, has stayed around 11 since World War II.

Work and Responsibility

One of the most significant effects of age segregation in our society has been the isolation of children from the world of work. Once children not only saw what their parents did for a living but also shared substantially in the task; now many children have only a vague notion of the parent's job and have had little or no opportunity to observe the parent (or for that matter any other adult) fully engaged in his or her work. Although there is no systematic research evidence on this subject, it appears likely that the absence of such exposure contributes significantly to the growing alienation among children and young people. Experience in other modern urban societies indicates that the isolation of children from adults in the world of work is not inevitable; it can be countered by creative social innovations. Perhaps the most imaginative and pervasive of these is the common practice in the U.S.S.R., in which a department in a factory, an office, an institute or a business enterprise adopts a group of children as its "wards." The children's group is typically a school classroom, but it may also include a nursery, a hospital ward or any other setting in which children are dealt with collectively. The workers visit the children's group wherever it may be and also invite the youngsters to their place of work in order to familiarize the children with the nature of their activities and with themselves as people. The aim is not vocational education but rather acquaintance with adults as participants in the world of work.

There seems to be nothing in such an approach that would be incompatible with the values and aims of our own society, and this writer has urged its adaptation to the American scene. Acting on this suggestion, David A. Goslin of the

This 300-year-old portrait looks well restored.



Portrait of Colonel Nels Assersen, painted in 1623 by Georg Günther Kräil de Bemeberg. Both photographs are enlarged from Polaroid Type 55 negatives.

These two prints from Polaroid instant negatives reveal a problem which must be solved in our lifetime. The price of failure will be the loss of many of our noblest paintings from the past.

That is the opinion of Dr. Björn Hallström, director of the Institute of Technology of Artistic Materials and head of the Art Conservation School of the Royal Swedish Academy of Fine Arts in Stockholm.

Dr. Hallström is specifically concerned about the long-term effects of certain early relining techniques on paintings. In these commonly employed restoration procedures, a painting threatened by flaking pigment or decomposing canvas has a new fabric pasted to its back. The painting may then appear quite revitalized. But beneath the "restored" surface, deterioration may actually accelerate.

Our Polaroid prints, for example, show a detail from a portrait painted in 1623. The painting was relined around 1930 and photographed some 40 years later. Under normal light (left) it looks fine. But the ultraviolet reflectogram (right) shows dark areas of decomposition in the relining paste. In time, such deterioration irreversibly alters a painting's color and characteristic craquelure.

Dr. Hallström suggests that the Polaroid instant photographs which reveal this problem can also help to solve it. Essentially, he proposes a standardized system of photoanalysis for all public collections. Each painting would be photographed using different kinds of radiation.

White light, flatly illuminating the canvas, gives a normal picture. *Raked white light* reveals surface damage, undulations in the canvas, etc. *Ultraviolet light with UV absorbing filters* on the camera shows fluorescence in the painting and indicates previous retouching. *Ultraviolet light plus a lens filter which*

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absorbs visible fluorescent light gives a UV reflectogram which can reveal decomposition invisible to the naked eye.

Polaroid Type 105 (3¼ x 4¼ pack format) and Type 55 (4 x 5 sheet format) positive/negative films are basic to Dr. Hallström's system for several reasons:

First, of course, they are *instant* films. This is particularly helpful in terms of UV reflectograms because some filters separate fluorescent areas better than others. If the Polaroid print shows poor separation, the filter can be changed, and the picture retaken on the spot.

Second, Type 105 and Type 55 provide an instant high resolution negative with the positive print. So enlargements can be made for closer scrutiny.

Finally, the superb tonal qualities of these films are especially useful in recording the low-brightness range of UV reflectograms.

Because of these advantages, and because Hallström's Polaroid technique is quick, economical and effective, it could be used to analyze all of our great paintings. And deterioration could often be detected and stopped before it went too far. Furthermore, periodic examination of newly relined paintings would indicate the restoration techniques most likely to truly conserve the art which we hold in trust for future generations.

The conservation of art treasures: A new use for Polaroid Instant Positive/Negative Films.

Russell Sage Foundation persuaded the Detroit *Free Press* to participate in an unusual experiment as a prelude to the White House Conference on Children. By the time it was over two groups of 12-year-old children, one from a slum area and the other predominantly middle class, had spent six to seven hours a day for three days in virtually every department of the newspaper, not just observing but participating actively in the department's work. There were boys and girls in the pressroom, the city room, the composing room, the advertising department and the delivery department. The employees of the *Free Press* entered into the experiment with serious misgivings, but, as a documentary film that was made of the project makes clear, the children were not bored, nor were the adults—and the paper did get out every day.

If a child is to become a responsible person, he not only must be exposed to adults engaged in demanding tasks but also must himself participate in such tasks. In the perspective of cross-cultural research one of the most salient characteristics of the U.S. is what Nicholas Hobbs, a former president of the American Psychological Association, has called "the inutility of childhood." Our children are not entrusted with any real responsibilities. Little that they do really matters. They are given duties rather than responsibilities; the ends and means have been determined by someone else and their job is to fulfill an assignment involving little judgment, decision making or risk. This practice is intended to protect children from burdens beyond their years, but there is reason to believe it has been carried too far in contemporary American society and has contributed to the alienation of young people and their alleged incapacity to deal constructively with personal and social problems. The evidence indicates that children acquire the capacity to cope with difficult situations when they have an opportunity to take on consequential responsibilities in relation to others and are held accountable for them.

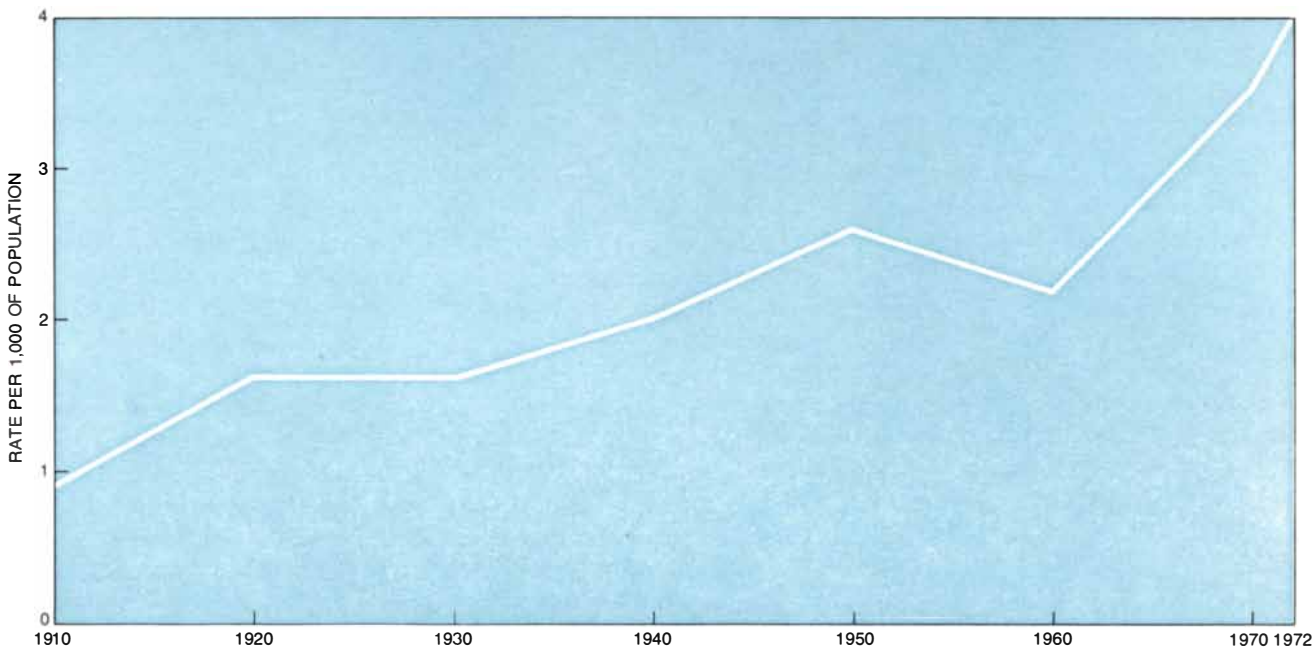
School

Although training for responsibility by giving responsibility clearly begins in the family, the institution that has probably done the most to keep children insulated from challenging social tasks is the American school system. For historical reasons rooted in the separation of church and state this system has been isolated from responsible social concern in both content and actual location. In terms of content, education in America, when viewed from a cross-cultural perspective, seems peculiarly one-sided, emphasizing subject matter to the exclusion of another fundamental aspect of the child's development for which there is no generally accepted term in our educational vocabulary: what the Germans call *Erziehung*, the Russians *vospitanie* and the French *éducation*. Perhaps the best equivalents are "upbringing" or "character education," expressions that sound outmoded and irrelevant to us. In many countries of western and eastern Europe, however, the corresponding terms are the names of what constitutes the core of the educational process: the development of the child's qualities as a person—his values, motives and patterns of social response.

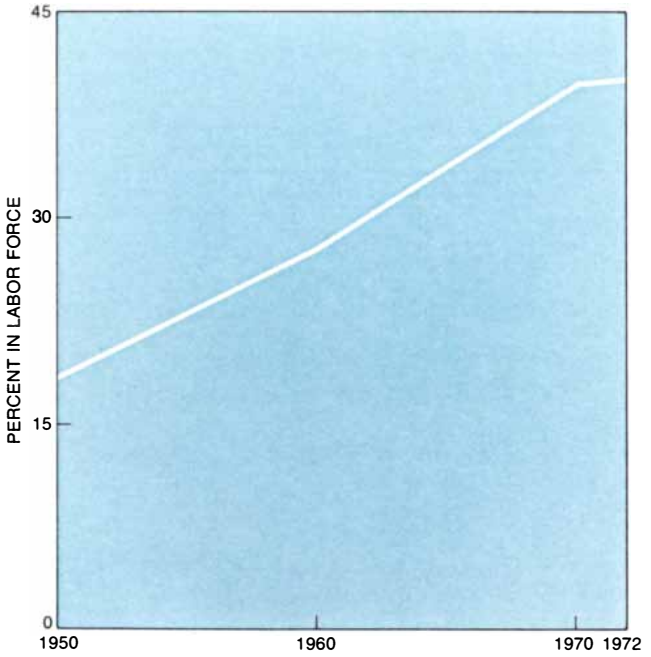
Our schools, and consequently our children, are also physically insulated from the life of the community, neighborhood and families the schools purport to serve and from the life for which they are supposedly preparing the children. And the insularity is repeated within the school system itself, where children are segregated into classrooms that have little social connection with one another or with the school as a common community for which members can take active responsibility.

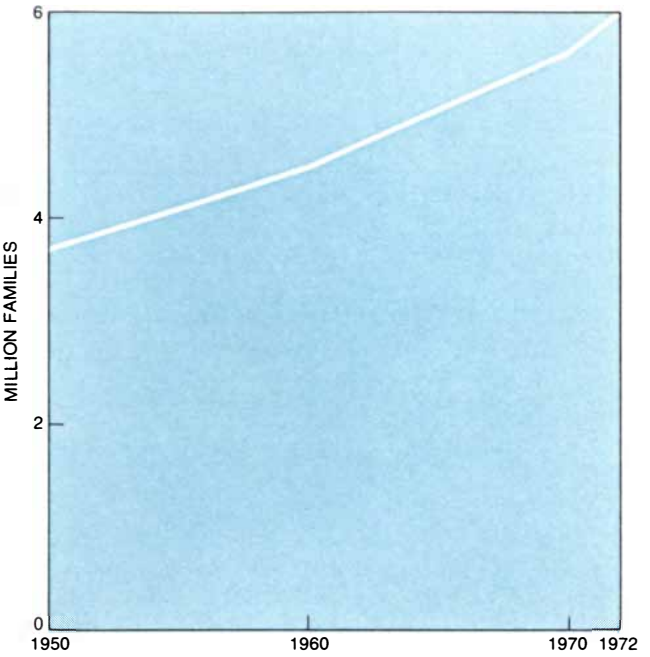
During the past decade the trend toward segregation of the school from the rest of the society has been accelerated by the forces of social disorganization to which I have referred. As a result the schools have become one of the most potent breeding grounds of alienation in American society. For this reason it is of crucial importance for the welfare and development of school-age children that schools be reintegrated into the life of the community.

It is commonplace among educators to affirm that the task of the school is to prepare the child "for life." There is one role



DIVORCE RATE, a mirror of some of the pressures on the U.S. family, has doubled in each of the past two 30-year periods. Divorce now comes somewhat later in marriage, so that the number of children involved in each divorce has risen disproportionately.





STRESS ON MOTHERS is suggested by data for working mothers (*left*) and for families headed by women (*right*). The curve at left shows specifically the labor-force participation rate for married women whose husbands are present and who have children up to 17 years old at home. The female heads of families include women who are single, divorced or widowed or whose husbands are absent.

in life the overwhelming majority of all children will ultimately play but for which they are given virtually no concrete preparation. It is parenthood. In cross-cultural observations I have been struck by the American child's relative lack of ease in relating to infants and young children, engaging their interest and enjoying their company. With the important exception of certain minority groups, including blacks, many young people never have experience in extended care of a baby or a young child until they have their own.

A solution to this problem, which speaks as well to the need to give young people in our society genuine and consequential responsibility, is to introduce truly functional courses in human development into the regular school curriculum. These would be distinguished in a number of important ways from units on "family life" as they are now usually taught in junior high school (chiefly to girls who do not plan to go on to college). Now the material is typically presented in vicarious form, that is, through reading or discussion or possibly through role-playing rather than actual role-taking. In contrast, the approach being proposed here would have as its core a responsible and active concern for the lives of young children and their families. Such an experience could be facilitated by locating day-care centers and preschool programs in or near schools so that they could be made an integral part of the curriculum. The older children would work with the younger ones on a regular basis, both at school and in the young children's homes, where they would have an opportunity to become acquainted with the youngsters' families and their circumstances.

Neighborhood

Much of what happens to children and families is determined by the ecology of the neighborhood in which the family lives. The implication of this principle for our own times is illustrated in a research report on the effect of some "new towns" on the lives of children. The study compared the reactions of children living in 18 new model communities in West Germany with those of youngsters living in older German cities. The research was conducted by the Urban and Planning Institute in Nuremberg. According to a report in *The New York Times,* in the new towns, "amid soaring rectangular shapes of apartment houses with shaded walks, big lawns and fenced-in play areas, the children for whom much of this has been designed apparently feel isolated, regimented and bored." The study found that the children gauged their freedom not by the extent of open areas around them but by the liberty they had to be among people and things that excited them and fired their imagination.

The implications of such research are self-evident. In the planning and design of new communities, housing projects and urban renewal, both public and private planners need to give explicit consideration to the kind of world being created for the children who will grow up in these settings. Particular attention should be given to the opportunities the environment presents (or precludes) for the involvement of children with people who are both older and younger than themselves.

Among the specific factors to be considered are the location of shops and businesses where children can have contact with adults at work, recreational and day-care facilities readily accessible to parents as well as children, provision for a family neighborhood center and family-oriented facilities and services, the availability of public transportation and —perhaps most important of all—places to walk, sit and talk in common company.

It may be fitting to end this discussion with a proposal for nothing more radical than providing a setting in which young and old can simply sit and talk. The fact that such settings are disappearing and have to be recreated deliberately points both to the roots of the problem and to its remedy. The evil and the cure lie not in the victims of alienation but in the social institutions that produce alienation, and in their failure to be responsive to the most human needs and values of a democratic society.

SUPERHARD MATERIALS

The hardness of a substance depends on the strength and orientation of the bonds between its atoms. The strongest symmetrical bonds are found in diamond and in the synthetic material cubic boron nitride

by Francis P. Bundy

It is widely known that diamond is harder than any other material, but it is not generally appreciated how much harder it is. Corundum, the mineral ranked next below diamond on the hardness scale devised by Friedrich Mohs, is only a fifth as hard as diamond. Cubic boron nitride, a synthetic material that is at least twice as hard as corundum and is the second-hardest of all materials, is still only about half as hard as diamond.

If these relations are to be understood, it is necessary that one know exactly what property is denoted by the concept of hardness. For many years the term was defined empirically: a substance was considered harder than another if it could scratch, abrade or deform the other and yet itself remain unscathed. By testing many materials in this way one can establish a hierarchy of hardness; such a "scratching order" is the basis of the Mohs scale. This definition remains valid, and indeed it is of considerable practical importance. The durability of gemstones, for example, derives from their resistance to abrasion by dust and grit. A diamond can be abraded effectively only by other diamonds; since diamond particles are rare in the environment, a diamond is indeed "forever," as the advertisements state. Perhaps more important, it is the wearing and cutting properties of the hardest materials that are essential to their employment in industry.

A more fundamental definition of hardness explains it in terms of the chemistry and geometry of crystal structure. The resistance of a hard substance to deformation depends on the tenacity with which its atoms resist movement with respect to one another; this tenacity is in turn related to the strength and distribution in space of the forces that hold the atoms in position in the crystal structure. The study of such interatomic forces can reveal why one substance is harder than another, and in particular it can help to explain the distinctive properties of the "superhard" materials, such as diamond and cubic boron nitride.

Until relatively recently all the hardest materials were natural products and had to be obtained by mining. Today we can manufacture many of them, including diamond. Cubic boron nitride of course is available only as a man-made product.

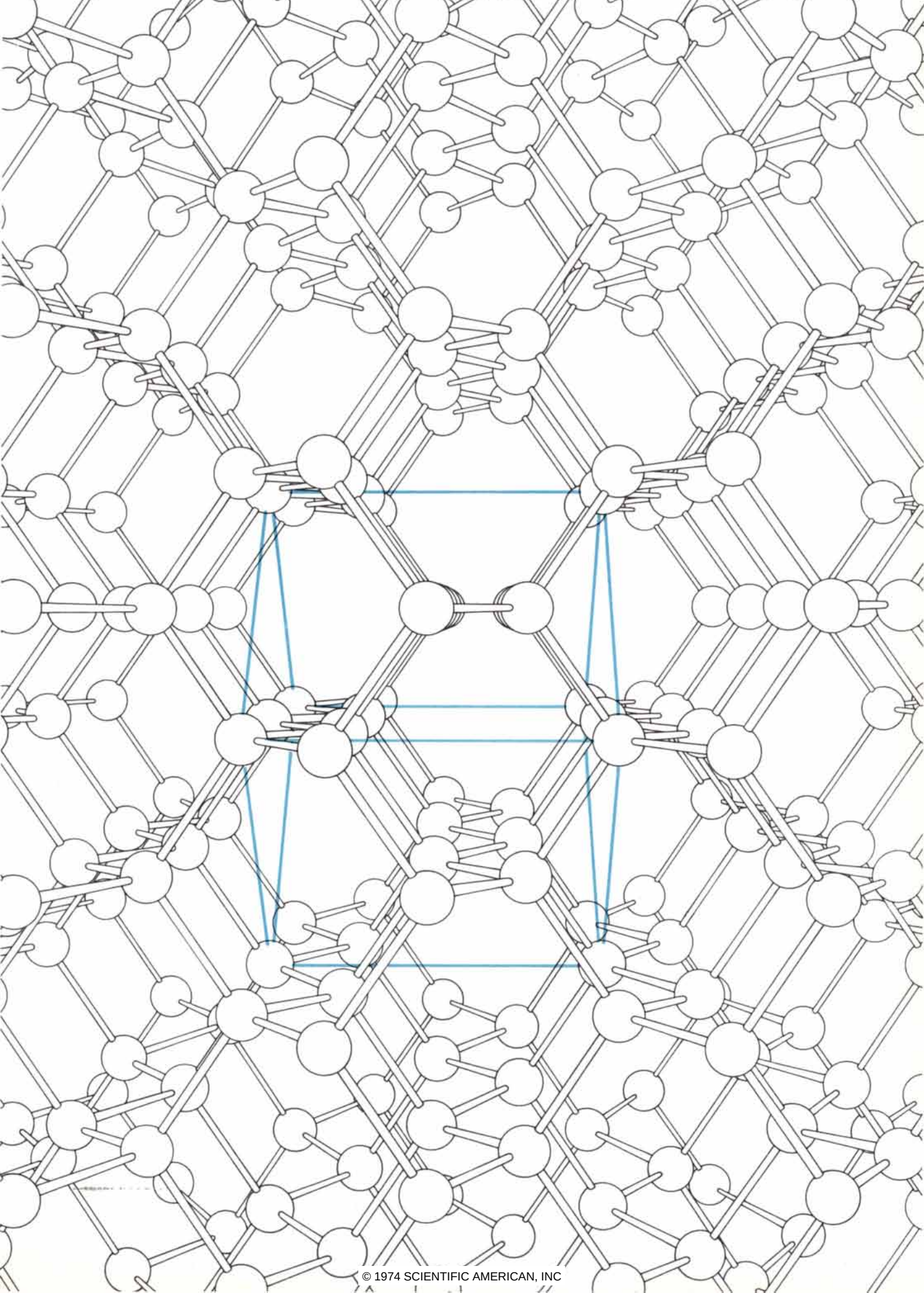
The first reported reproducible synthesis of diamond in the laboratory was achieved in 1954 by H. Tracy Hall, Herbert M. Strong, Robert H. Wentorf, Jr., and me at the General Electric Research and Development Center [see "Synthetic Diamonds," by P. W. Bridgman; SCIENTIFIC AMERICAN, November, 1955]. The process by which diamond is manufactured consists in converting carbon from one crystalline form to another. The raw material is graphite, which is subjected to very high pressure (more than 50,000 atmospheres) and high temperature (about 1,300 degrees Celsius). To form diamond it is also necessary that one of a group of related metals, such as iron, nickel or cobalt, be present in the molten state; the exact mode of action of these metals is not clear, but they apparently serve as catalysts and solvents.

From our laboratory synthesis a commercial process has been developed, and today factories in South Africa, Ireland, Sweden, Japan and the U.S.S.R. as well as in the U.S. manufacture diamond grit and small crystals employed industrially in cutting and grinding tools. In the U.S. it is likely that more than half of the diamond grit used in industry is man-made.

The synthesis of cubic boron nitride is very similar to that of diamond. The starting material is a form of boron nitride whose structure is analogous to that of graphite, and the conditions of pressure and temperature required are essentially the same. A different group of catalyst-solvents is required for this conversion, however; they include, among many others, the alkali metals and their nitrides. Cubic boron nitride was first made by Wentorf in 1956; it too has important industrial applications.

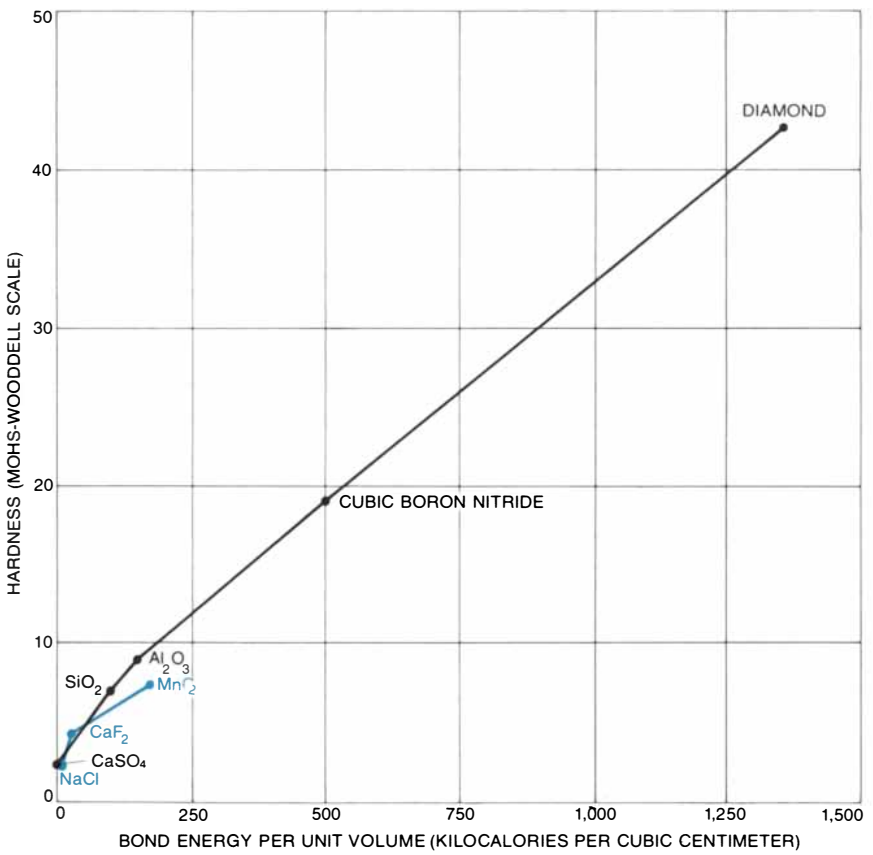
In order to investigate the properties and behavior of diamonds (whether natural or synthetic) and cubic boron nitride, one must have a quantitative measure of hardness; the Mohs scale is inadequate for making such measurements. Mohs was a German mineralogist who introduced his scale about 1820. It employs 10 minerals as standards, ranked in order of hardness. Other materials can be tested against the 10 standards and thereby assigned intermediate positions in the table, but the scale does not indicate how hard any particular

CRYSTAL LATTICE of diamond consists of carbon atoms distributed in an infinitely repeating array. Each atom lies at the center of a regular tetrahedron whose vertexes are defined by the four nearest neighboring atoms. Connecting the atoms are covalent bonds; it is the strength and the symmetrical arrangement of these bonds that are responsible for the hardness of diamond. The cube inside the lattice (*color*) is a unit cell of the crystal. The view into the lattice is nearly parallel to one of the planes called the dodecahedral planes.



MATERIAL	FORMULA	MOHS	KNOOP	MOHS-WOODDELL
TALC	$Mg_3Si_4O_{10}(OH)_2$	1	—	1
ROCK SALT	NaCl	2	32	2
CALCITE	$CaCo_3$	3	135	3
FLUORITE	CaF_2	4	163	4
APATITE	$Ca_5F(PO_4)_3$	5	430	5
FELDSPAR	$KAlSi_3O_8$	6	560	6
QUARTZ	SiO_2	7	820	7
TOPAZ	Al_2SiO_4	8	1,340	8
CORUNDUM	Al_2O_3	9	2,100	9
CUBIC BORON NITRIDE	BN	9+	4,500-4,800	19
DIAMOND	C	10	7,000	42.5

HARDNESS SCALES employ three different techniques of measurement. The Mohs scale assigns a hardness value to a substance according to where it falls in a "scratching order" of 10 standard minerals. The Knoop scale measures the stress required to indent the substance; the values given are in kilograms per square millimeter. The Mohs-Wooddell scale measures resistance to abrasion; in the upper portions of the scale it is more precise than the Mohs scale. For cubic boron nitride some investigators dispute the range of values given.



CHEMICAL THEORY OF HARDNESS interprets the property as a function of the energy per unit volume of the bonds between the atoms of a crystal. When the relation is plotted graphically, materials are separated into two groups. The Group *B* minerals (*colored line*), none of which are very hard, are characterized by ionic bonding between atoms. The Group *A* substances (*black line*), which include all the hardest materials, are bonded covalently. Within Group *A* the relation between bond energy density and hardness is nearly linear.

substance is; all measurements made with it are relative [*see top illustration at left*]. Newer methods have shown that each material in the Mohs scale, up to Mohs 9 (corundum), is about 1.2 times as hard as the preceding material. Thus the scale is almost logarithmic from Mohs 1 through Mohs 9, a range that includes all but a few substances. The interval between 9 and 10, however, spans a hardness ratio of approximately 5, that is, diamond is about five times as hard as corundum.

Hardness scales developed more recently make possible quantitative measurements and give a more accurate indication of the range of hardness at the upper end of the Mohs scale. The Knoop scale, adopted by the Bureau of Standards in 1939, measures the hardness of a material by making an indentation in its surface. Pyramid-shaped diamond "indentors" are pressed against the surface with increasing force; hardness is calculated in terms of the stress, in kilograms per square millimeter, required to produce a permanent deformation. On this scale the hardness of corundum, for example, is 2,100 kg/mm^2.

A relative hardness scale that eliminates some of the nonlinearity of the Mohs scale was devised in 1935 by Charles E. Wooddell of the Carborundum Company. In Wooddell's method a small specimen of the material to be tested is embedded in resin with samples of a number of other materials of known hardness. The samples are ground to a common level, then abraded by a lapping wheel for about two minutes under specified standard conditions. The loss of material from each sample is then measured and the ratio of the losses determined. Wooddell indexed his scale by assigning quartz and corundum their Mohs values of 7 and 9, and the scale is therefore called the Mohs-Wooddell scale. It extends linearly above Mohs 9 to place diamond and the other very hard materials in their proper positions with respect to the rest of the scale. South American brown bort, a kind of diamond, has a Mohs-Wooddell hardness of 42.5.

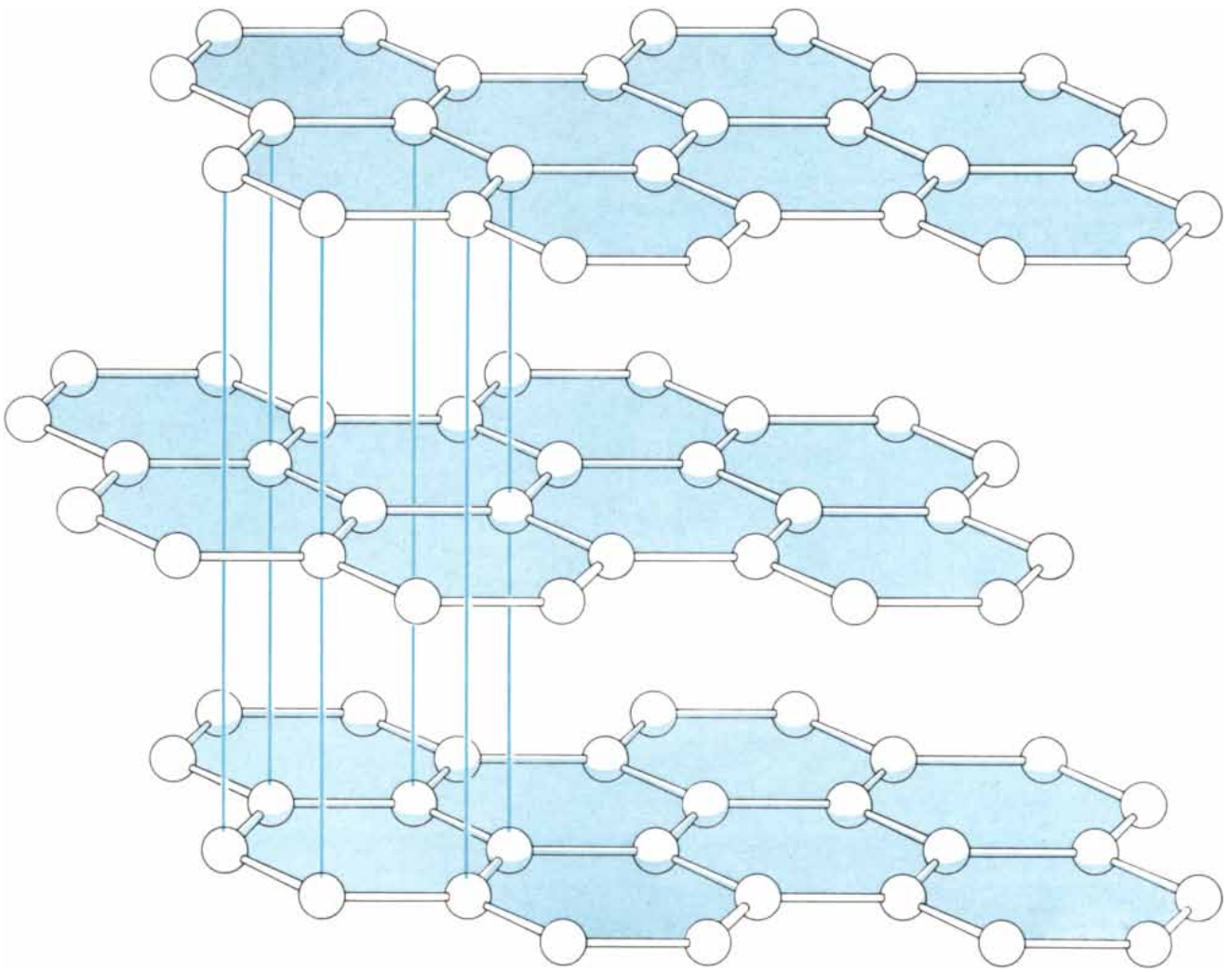
The Knoop scale expresses hardness in force per unit area; in the early 1960's J. N. Plendl and Peter J. M. Gielisse, then of the Air Force Cambridge Research Laboratories, interpreted hardness in terms of bonding energy per unit volume. From infrared absorption spectra Plendl determined the energy of the interatomic bonds and the type of bonding in a variety of materials. Plendl and Gielisse then studied the relation be-

tween binding energy per unit volume and hardness as measured on the Mohs-Wooddell scale. The substances they tested fell into two groups. Group *A*, which includes all the very hard materials, consists of crystals whose atoms are bound to one another covalently. Group *B* substances are bound ionically; an example is sodium chloride, a relatively soft crystal (Mohs value 2). When binding energy per unit volume is plotted against Mohs-Wooddell hardness, the substances in the two groups form lines indicating a clear relation between the two properties. In Group *A* hardness is approximately proportional to binding energy per unit volume [*see bottom illustration on opposite page*].

Binding energy is not the only determinant of hardness; for a material to be extremely hard the bonds between its atoms not only must be strong but also must be oriented symmetrically. The effect of asymmetry is dramatically illustrated in the two crystalline forms of carbon: graphite and diamond. In graphite the carbon atoms are arranged in hexagons that form extended planes. Within a plane the atoms are packed tightly together, with an interatomic distance of 1.42 angstroms, but the planes are relatively far apart from one another, being separated by 3.354 angstroms. (One angstrom is 10^{-8} centimeter.) Each atom is surrounded by and tightly bonded to three neighboring atoms in the plane but is only loosely bonded to the relatively distant atoms of the adjacent planes [*see illustration below*].

In diamond, on the other hand, each atom is surrounded by four others that form the vertexes of a regular tetrahedron; the atoms are arrayed symmetrically and are all equidistant, with a bond length of 1.544 angstroms. In diamond the interatomic distance is actually slightly greater, and the binding energy slightly less, than it is within the planes of graphite, and within these planes graphite is therefore the hardest of all materials. Because the planes can be easily separated and slid over one another, however, graphite in gross form is weak. Its laminate structure makes it slippery, and it is widely utilized as a dry lubricant. Graphitic boron nitride, which also consists of planes loosely bonded together, has similar properties.

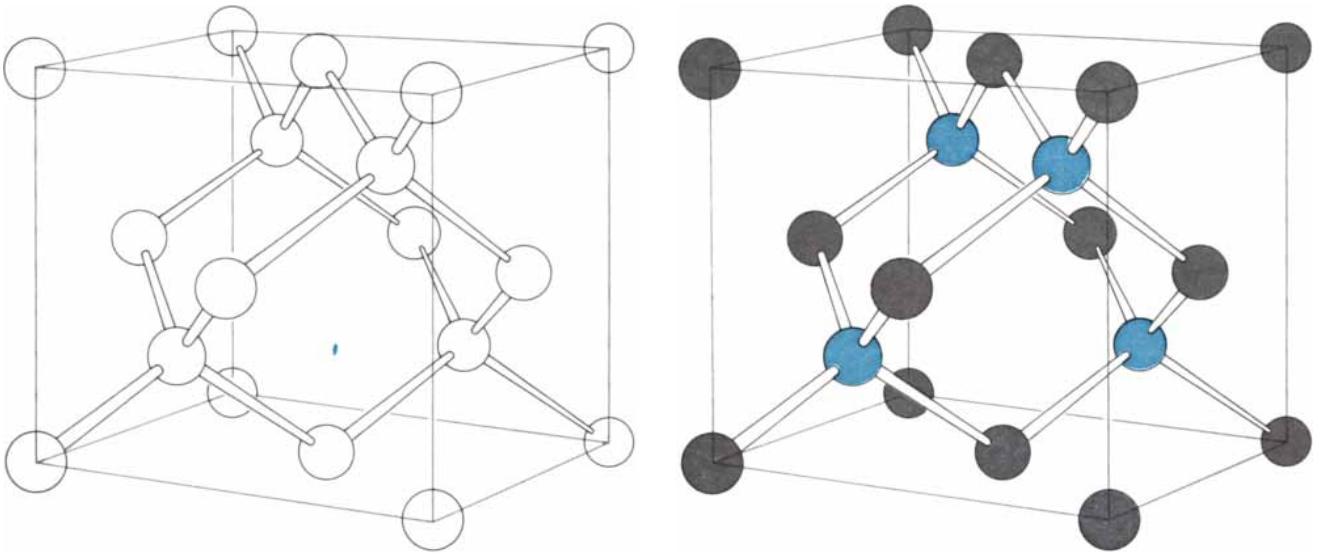
The crystal structure of diamond is called diamond cubic; the unit cell of the crystal is a cube with an atom at all the corners and at the center of each face, and at four additional positions in the interior. The structure of a cubic boron nitride crystal is exactly the same, except that boron and nitrogen atoms al-



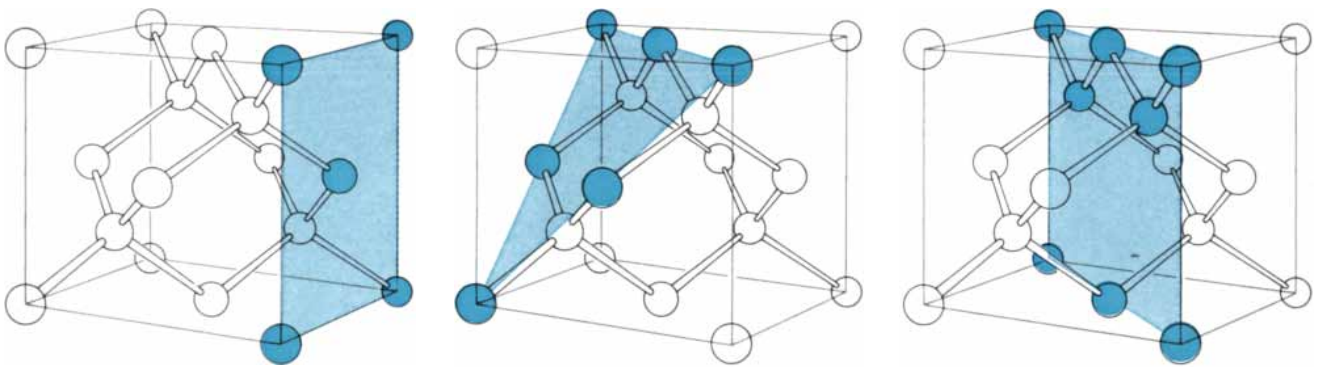
GRAPHITE, which is identical in composition with diamond (both materials consist entirely of carbon), has a different crystal structure. In graphite the atoms are bonded strongly to one another in hexagons arrayed in planes; within these planes, in fact, graphite is harder than diamond. The planes are only loosely held together, however, so that the material in gross form is weak. Graphite is the raw material for the manufacture of diamonds, and an analogous form of boron nitride is employed in making cubic boron nitride.

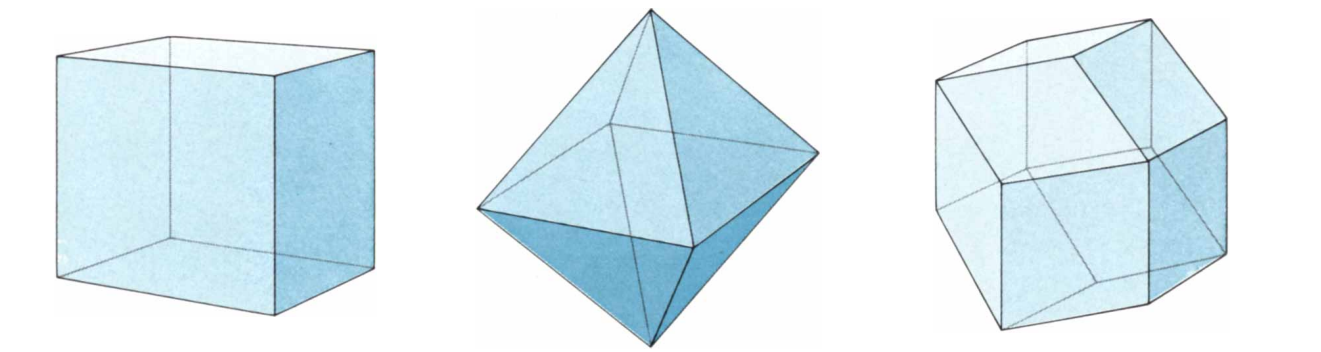
ternate in the lattice [*see upper illustration below*]. The electron structure of the bonds in the two crystals is very similar also, since boron (valence 3) and nitrogen (valence 5) form pairs of atoms sharing eight valence electrons, just as pairs of carbon atoms (valence 4) do.

During the growth of a diamond or a cubic boron nitride crystal the faces that are most likely to develop are the cube faces, those parallel to the sides of the unit cell; the octahedral faces, those parallel to the planes drawn from the diagonal of one face to an opposite corner of the unit cell, and the dodecahedral faces, those parallel to the diagonals of the faces of the unit cell [*see lower illustration below*]. As is implied in the names of the faces, the crystal shapes that result from growth exclusively in one of these regimes are respectively a cube, an octahedron and a dodecahedron. Diamonds in nature often have all three kinds of face.



UNIT CELLS of diamond (*left*) and cubic boron nitride (*right*) have the same structure. Each cell is a cube made up of 18 atoms: one at each of the corners and at the center of each face and four in the interior. In diamond all the atoms are carbon; in cubic boron nitride they are boron (*gray spheres*) and nitrogen (*colored spheres*). Structure of the entire crystal is implicit in the unit cell.





MOST COMMON FACES OF A DIAMOND CRYSTAL are parallel to one of three kinds of plane in the unit cell. The cubic planes (*left*), of which there are six, are the faces of the unit cell itself. The octahedral planes (*center*) extend from the diagonal of a face to an opposite corner; eight such planes can be produced by reflection and rotation. The dodecahedral planes (*right*) are diagonals of the unit cube; there are 12, two for each possible orientation of the cube. Below the crystal planes is the form generated when the crystal grows exclusively on each kind of plane; real diamonds often have facets representing growth in each of the regimes.

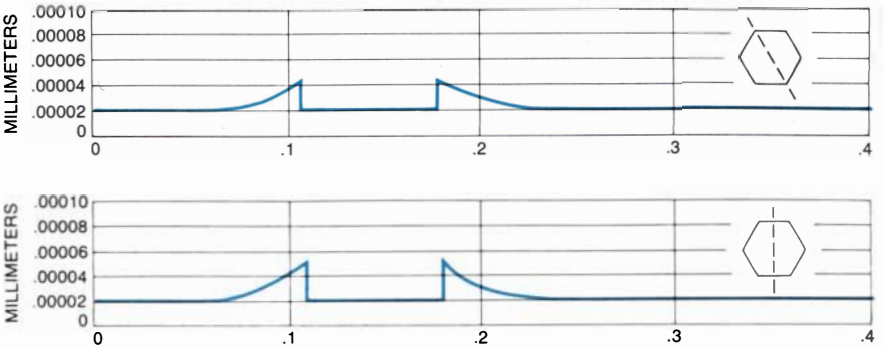
A diamond cleaves most readily along the octahedral planes. When a diamond cutter wishes to divide a large crystal in two, he first determines the directions of the crystal planes, then places the cleaving wedge parallel to an octahedral plane. The wedge does not "cut" the stone in the way a knife cuts bread; when it is struck sharply, it cleaves the crystal along its weakest plane.

The diamond cutter's wedge, made of steel that in comparison with diamond is quite soft, is able to fracture a diamond because the hardest materials are invariably brittle. They resist distortion strongly, but when they do yield, they do so by breaking rather than by flowing plastically. In recent years a number of experimenters have attempted to study the events surrounding the failure of diamond crystals, and to determine whether or not they deform plastically under any circumstances.

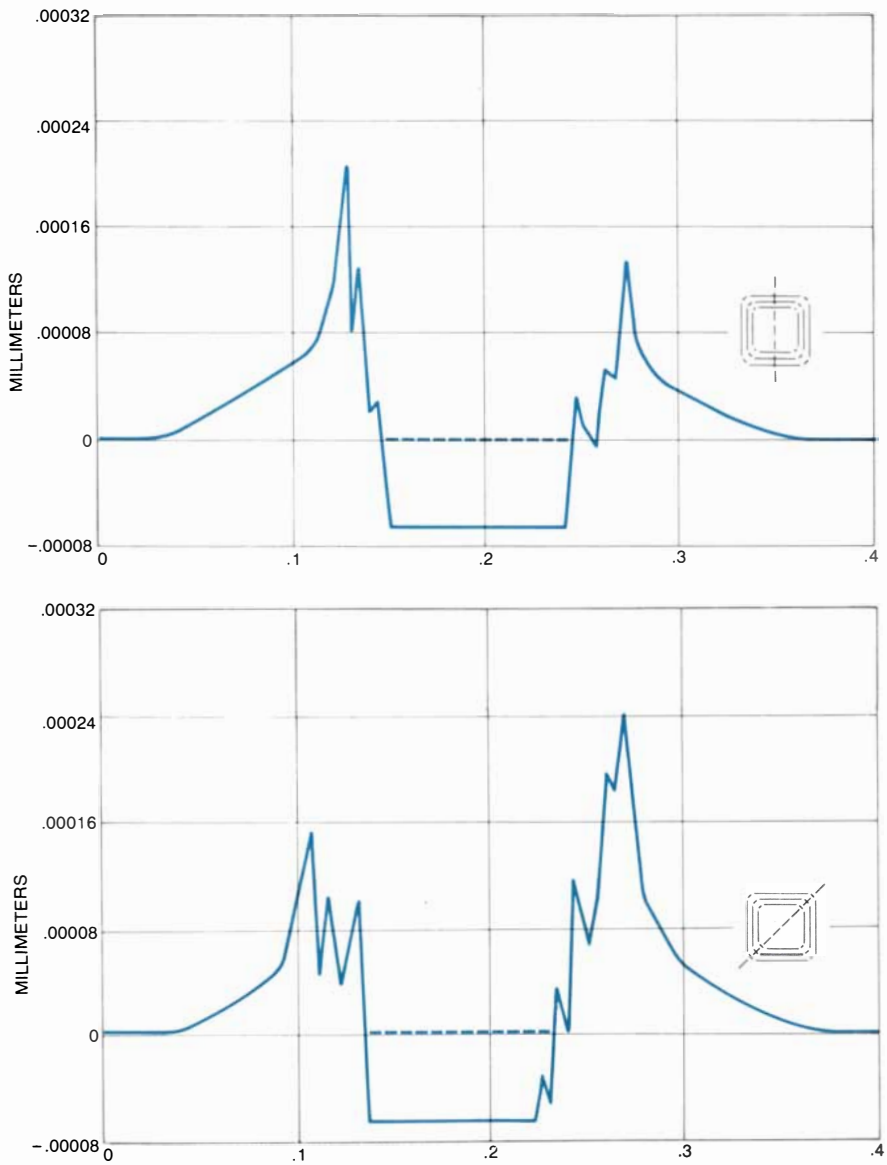
When a conical diamond indentor is pressed against a diamond surface, compressive forces are highest at the point of contact, but shear and tensile stresses are highest in the surrounding area. When the surface is stressed beyond its elastic limit, it usually fails by local fracturing or cleaving along octahedral planes at the periphery of the contact area. The pattern of the damage depends on which face of the crystal is being tested, but in all cases the area of damage is very small and could be described as a microscopic bruise [*see illustrations at right*].

V. R. Howes and the late Samuel Tolansky of the Royal Holloway College of the University of London reported on an extensive series of tests of this kind in 1955. When an octahedral face is bruised, the resulting crack rings are hexagonal. If the indentor is pushed only hard enough to produce a single crack ring, the area inside the ring returns elastically to its original level, and the only permanent damage is the surrounding asperity. To produce this degree of damage requires a pressure of about 140,000 atmospheres. With higher loads additional crack rings develop surrounding the first one and the contact area remains below its original level.

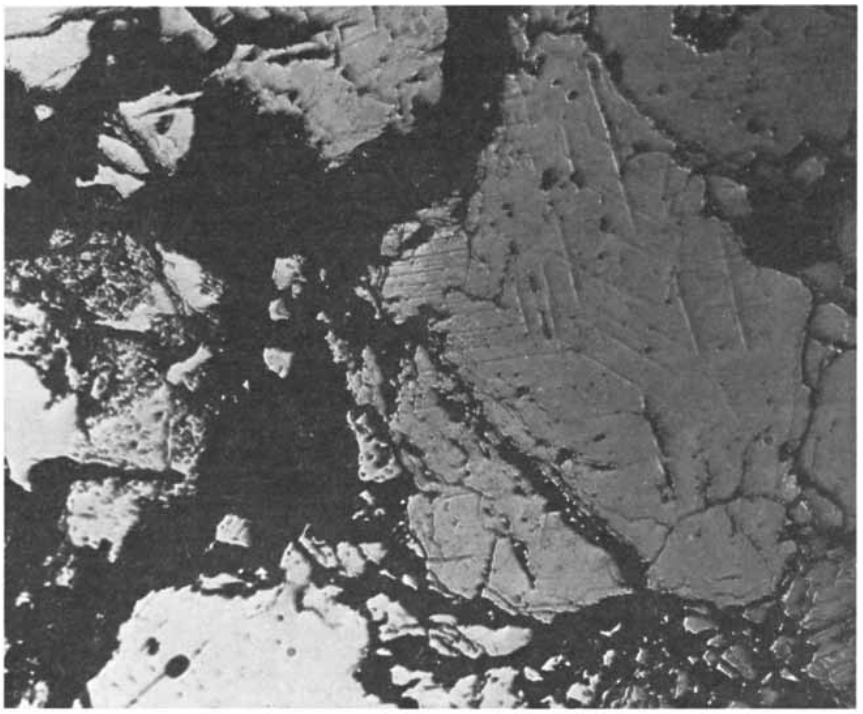
When a cube face is deformed, the crack pattern is approximately square and the magnitude of the surface defects is considerably greater. Much higher pressure, however (about 330,000 atmospheres), is required to generate the first crack. It therefore appears that a cube face resists injury better than an octahedral face but is more severely damaged once it succumbs. Because of the greater



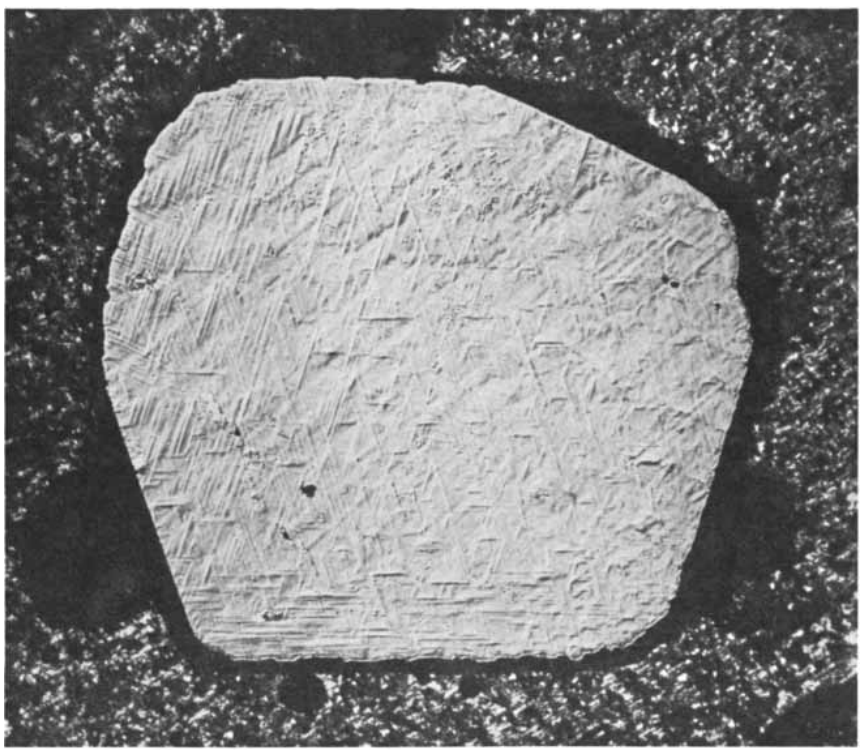
MICROSCOPIC BRUISE on the surface of a diamond was produced by indenting the crystal with a conical diamond stylus at a pressure of about 140,000 atmospheres. The injury was made on an octahedral face, and it consists of a single hexagonal crack ring. The orientation of the section drawings to the ring is shown by the inset figures. Because the area inside the ring has returned to its original level, it is believed damage is confined to the periphery of the stressed region, where tensile and shear forces are greatest. In both illustrations the vertical scale is magnified 1,000 times with respect to the horizontal scale.



BRUISE ON A CUBIC FACE consists of approximately square crack rings. The pressure required to damage this face, about 330,000 atmospheres, was much greater than that required on the octahedral face, and the extent of the damage produced once the surface yielded was also greater. Multiple crack rings developed, and the level of the surface inside the rings was permanently depressed. The vertical scale is again magnified 1,000 times.



SLIP LINES, which are evidence of plastic deformation, are visible in a polished specimen of framesite, a kind of natural diamond. The slip lines are the straight, bright markings distributed throughout the right half of the diamond in this photomicrograph. They are formed when one part of the crystal flows past another without cracking. There is evidence that plastic flow can be produced only by extreme mechanical stress at high temperature; if so, the diamond must have been subjected to such conditions sometime in its history.



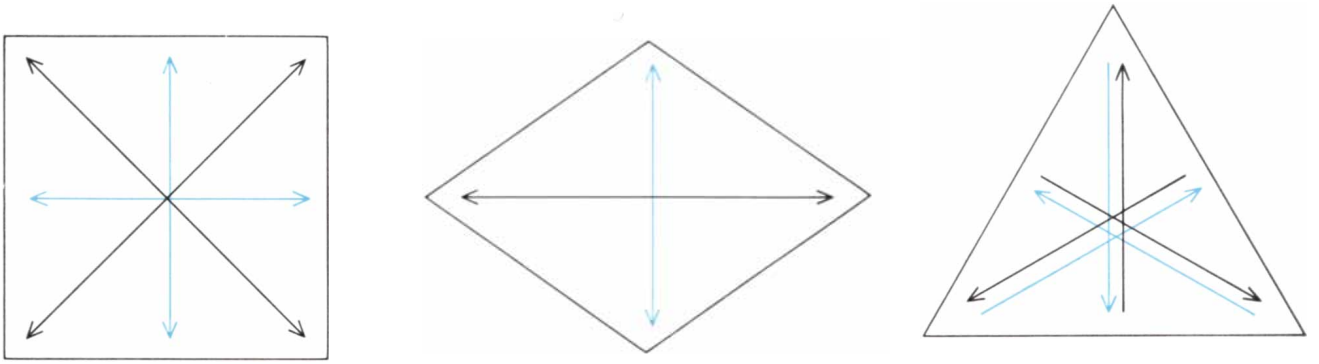
PLASTIC FLOW induced in the laboratory caused the numerous slip lines revealed in this photomicrograph of a small diamond. The crystal was one of a cluster compacted at high pressure and at a temperature above 950 degrees C. Because the aggregate of diamonds transmitted the pressure unevenly, stress developed in the crystal; under these conditions of pressure and temperature the stress was relieved by plastic flow rather than by cracking.

strength in the direction perpendicular to the cube face, crystals used as diamond indentors and anvils are oriented in this way.

In 1965 Trevor Evans and R. K. Wild of the J. J. Thomson Physical Laboratory at the University of Reading reported that they had induced plastic flow in small diamond plates, but only at high temperature. The plates were half a millimeter thick and were made so that the large surfaces were cube faces. The plates were supported at the edges by two tungsten wedges and deflected at mid-span by a third tungsten wedge. This assembly was placed in a furnace and surrounded with a nonoxidizing atmosphere, since at high temperature diamonds will burn in the presence of oxygen. Most of the specimens broke by brittle fracture, particularly at low temperature. At 1,800 degrees C., however, a few specimens were bent permanently; the plastic flow was along octahedral planes.

The shear stress required to produce plastic flow was dependent on the quantity of impurities present in the crystal and on how the impurities were distributed. Diamonds contaminated by a relatively large amount of nitrogen are classified as Type I; the nitrogen is distributed in "nitrogen platelets" parallel to the cube faces. Very pure diamonds, with few structural imperfections, are classified as Type II. Evans and Wild found that Type II crystals would deform plastically (under the proper conditions) at a stress of about 50 kg/mm^2, whereas Type I diamonds required stresses of from 80 to 120 kg/mm^2. It appears likely that the nitrogen platelets in Type I diamonds present barriers to the slipping of crystal layers along the octahedral planes.

Another attempt to produce plastic deformation in diamond, this time at room temperature, was made in 1969 by N. Gane and J. M. Cox of the Cavendish Laboratory at the University of Cambridge. Two sharp wedges of diamond, with their edges perpendicular to each other, were pressed together inside a scanning electron microscope so that the zone of contact could be observed under high magnification. In the opposed wedges shear stress could easily reach the theoretical shear strength of diamond, estimated to be about 12,000 kg/mm^2. When the wedges were pressed together, a threshold was observed below which no damage could be detected; when the threshold was exceeded, failure was abrupt, with the formation of



ABRASION RESISTANCE of diamond depends on which facet of the crystal is being abraded and on the direction in which the facet is rubbed. In the argot of diamond cutters each of the faces has "easy" directions (*colored arrows*) and "hard" ones (*black arrows*).

jagged surfaces. The shear stresses induced at this threshold were calculated to be of about the same magnitude as the theoretical shear strength.

The experiments of Evans and Wild and Gane and Cox strongly suggest that plastic flow in diamond is not possible at room temperature. It should be noted, however, that some investigators report having produced permanent depressions without cracks in diamond surfaces by applying pressure with a square pyramidal diamond indentor. Such minute indentations, if they are formed without cracking the surface, may be an indication of plastic flow at room temperature.

Some natural diamonds contain evidence that sometime in their history they may have undergone plastic deformation without fracture. The evidence consists of slip lines, or surface irregularities where two parts of the crystal have shifted with respect to each other. Slip lines are also generated when a cluster of small diamond crystals is compressed at high temperature; the uneven pressures of adjacent crystals pushing against one another evidently produce stress that, at sufficiently high temperature, is relieved by plastic flow [*see illustrations on opposite page*]. Robert C. DeVries of the General Electric Research and Development Center has shown that under these circumstances the minimum temperature for the process is about 950 degrees C.

Just as the effects of indentation are different for each of the faces of a diamond crystal, the effects of abrasion depend on which facet is being attacked and on the direction in which it is rubbed. Diamond cutters have long known that there are "easy" and "hard" directions; material is removed more efficiently in the easy directions. E. M. Wilks and John Wilks of the University of Oxford in 1972 conducted a quantitative investigation of the abrasion resistance of diamond in various orientations. They found that on the cube face the hard directions are parallel to the diagonals and the easy directions are parallel to the edges. On the dodecahedral face the hard direction is parallel to the long axis of the face and the easy direction is parallel to the short axis. On the octahedral face the hard direction is parallel to a line extending from the midpoint of an edge to the opposite apex and the easy direction is parallel to the same line but in the opposite direction. On every octahedral face there are thus three hard and three easy directions. The Wilkses also investigated the abrasion of facets inclined to a principal crystal face; in these cases abrasion resistance is a complex variable dependent on the angle of inclination and on whether one rubs "uphill" or "downhill" with respect to the reference face.

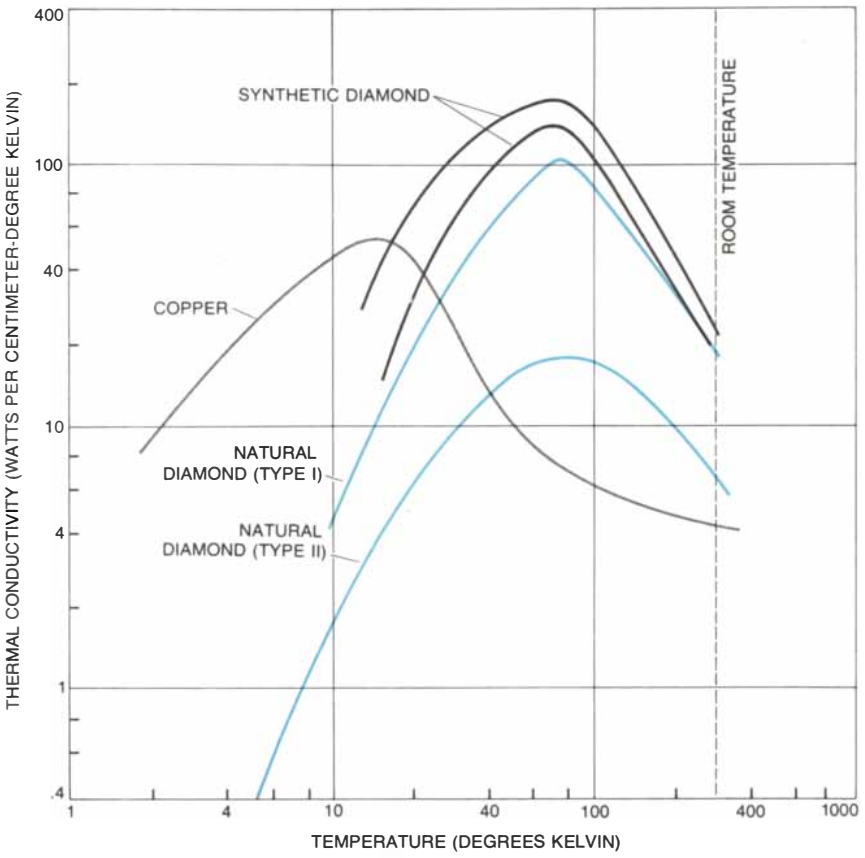
Hardness is not the only superlative quality of the diamond; of all known materials diamond is also the best conductor of heat. At room temperature a perfect single crystal of diamond conducts heat more than five times as well as silver or copper, the best metallic conductors.

The mechanism by which diamond conducts heat is different from that in metals. In a metal heat is conducted through the agency of free electrons that drift through the crystal lattice. In diamond and other very hard materials free electrons are not available and heat is conducted in the same way that sound waves are propagated: by the transfer of vibratory motion from one particle to the next. This process is extremely efficient in diamond because the particles—carbon atoms—are of low mass and because the forces binding the atoms together are strong and hence can readily transfer motion. Diamond is said to conduct heat by serving as a medium for phonons, the quanta of vibrational energy.

In order to conduct heat efficiently by this mechanism the diamond must be a single crystal, free of imperfections, dislocations and grain boundaries; polycrystalline aggregates of diamonds have much lower thermal conductivity. Among natural diamonds the pure but relatively rare Type II crystals are the best conductors; Type I diamonds are only about half as good because the submicroscopic nitrogen platelets they contain scatter phonons. The ideal is a completely regular and uniform structure. If just 1 percent of the carbon atoms in the crystal lattice are the isotope of mass 13 (among the majority of mass 12), the conductivity is reduced to about half of the theoretical maximum. For the same reason crystals made up of more than one kind of atom, as boron nitride is, have much lower thermal conductivity.

Most good heat conductors, such as the metals, are also good conductors of electricity; diamond is distinguished from these materials, and from other forms of carbon, in that it is an electrical insulator. This combination of properties makes it a suitable substrate for the mounting of semiconductor devices. By acting as a heat sink diamond would enable small transistors and other miniature electronic components to operate at higher power without overheating.

An extension of this idea is to fabricate the semiconductor itself from diamond. In its natural state diamond is an insulator because all its valence electrons are tightly bound; by "doping" a diamond crystal with atoms having more or fewer valence electrons than the atoms they replace in the crystal lattice it



THERMAL CONDUCTIVITY of diamond is the highest of all known materials through a wide range of temperatures. Unlike metallic conductors such as copper, diamond conducts by transmitting vibratory motion through the fixed elements of its crystal structure; it is a conductor of phonons, the quanta of vibratory energy. Type II and synthetic diamonds are better conductors of heat than Type I diamonds because Type I crystals contain impurities that scatter phonons. Diamond also differs from metals in that it is an electrical insulator.

should be possible to make diamonds that would be semiconducting. Adding a small amount of nitrogen, with five valence electrons, for example, should cause *n*-type semiconduction, in which the carriers of charge are excess electrons. Boron, on the other hand, with three valence electrons, should lead to *p*-type semiconduction, in which charge is carried by "holes" representing the absence of electrons. Boron-doped diamonds are in fact *p*-type semiconductors, but nitrogen-doped diamonds remain insulators at room temperature. It appears that the extra electrons conveyed to diamond by nitrogen doping may remain too tightly bound at ordinary temperatures to support conduction.

Cubic boron nitride may be converted to either a *p*-type or an *n*-type semiconductor by growing the crystal with a slight excess respectively of boron or nitrogen, or by doping it at high pressure and temperature with the desired element. Transistors or other electronic devices fabricated from this material would be expected to operate at much higher temperature than those made of germanium or silicon. They cannot be made now because the perfect crystals required cannot be grown.

For the time being the potential application of superhard materials to semiconductor technology is overshadowed by their employment in industry for grinding, cutting, shaping and polishing. In some cases the hardest of substances are the only ones capable of performing these functions, as in the shaping and sharpening of tools of cemented tungsten carbide, itself an extremely hard material. In other cases diamond and diamond-like crystals are merely more efficient and offer economic advantages. Diamond is often chosen, for example, to cut or drill stone, concrete, ceramic or glass; similarly hard tool steels can often be most effectively worked with grinding wheels containing an abrasive grit of cubic boron nitride.

For operations other than grinding the utility of these materials has been enhanced by the recent development of cemented or sintered compacts of very fine diamond or cubic boron nitride powders. Such compacts offer the hardness and resistance to dulling of diamond but are much tougher than single crystals of diamond, that is, they are not as susceptible to fracture. Applications include cutting tools for machining, cores for wire-drawing dies and the abrasion buttons of hard-rock drills and saws.

In machining, tools made of the superhard materials often work most effectively at high cutting speed, generating high temperature and pressure where the tool deforms the workpiece material. The tool cuts by producing a temperature that is high enough to soften the workpiece but that has no effect on the tool itself. For this purpose cubic boron nitride is often superior to diamond, since at high temperature diamond reacts with air and also with the iron in ferrous metals. Cubic boron nitride remains hard and inert far above the 800 to 900 degrees C. required in machining.

Compacts of diamond might also prove valuable in laboratory apparatus designed to produce very high pressures. For many years single crystals of diamond have been employed as anvils in small devices that generate pressures of up to 300,000 atmospheres. The working surface is the cube face of the crystal; the anvils have excellent resistance to indentation, but they tend to fail by gross cleavage. A compact of many small, randomly oriented diamond particles bonded together would have no favored planes of cleavage and therefore could be expected to withstand a higher average stress. At present compacts of the required quality can be made only in small sizes and only in certain shapes, so that apparatus employing them would have to be quite small. Even with these limitations, however, the compacts should make possible experiments employing pressures that would otherwise be unattainable.

As a final consideration, one might ask if there is any possibility of discovering or manufacturing a substance harder than diamond. In principle it is certainly not impossible; one need only find a substance in which the atoms are bound together in a symmetrical array with greater binding energy per unit volume than the carbon atoms in diamond. No such form of matter can be predicted from present knowledge, however, and since the elements of the periodic table are rather well known, the chances of making such a discovery appear to be very small.

Conversation Pieces

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Oh Say Can You See Discussions about whether or not we should continue to "go into space" often overlook a fundamental point—namely, that we are in space already. Each of us is an astronaut on a spacecraft called earth traveling around the sun at 67,000 miles per hour. The biological community that lives on the spacecraft has a fragile life support system—the thin film of soil, air and water in which we dwell. During the past century, the number of passengers aboard the spacecraft has increased tremendously; so also has their ability to consume its finite supplies. We see some of the results in the pollution of our environment and the decay of our resources.

As astronauts we need to monitor our spacecraft to see that we are not doing irreparable damage to its life support system. NASA has undertaken several programs which involve the development of advanced sensors. From a satellite or aircraft, these sensors can monitor air quality, determine the condition of crops, or help locate mineral resources. Currently, TRW is developing such a sensor for NASA. It is called MOCS, an acronym for Multichannel Ocean Color Sensor.

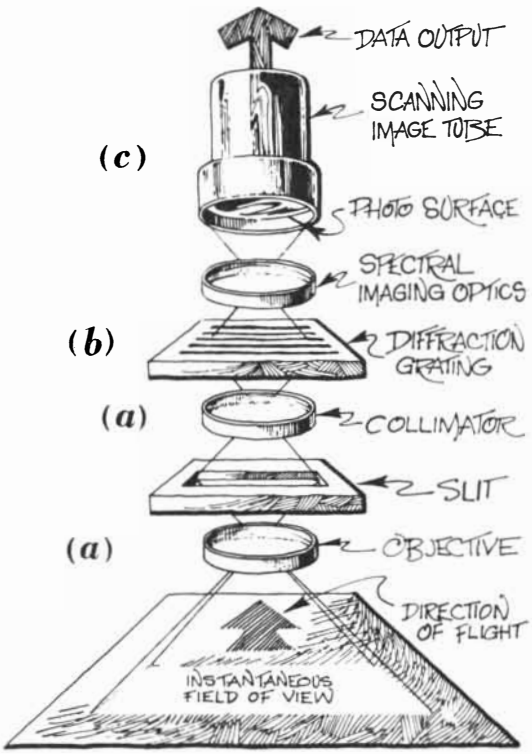
MOCS is based on the principle that sea water, plankton, and such pollutants as oil spills, sewage, and river sediments, all reflect light at different wavelengths and in varying proportions. MOCS measures these subtle differences with great sensitivity and better spectral resolution than any other available scanner. Its value lies in its ability to map the spread of pollutants as well as their effect on the chlorophyll content and other signs of health or sickness in the world's plankton beds. Only with a historical record based on hard facts, can all the arguments be settled as to whether ocean pollution has reached dangerous levels or not.

MOCS weighs less than 20 lbs., has no moving parts, and uses only 7½ watts of power. Yet it has produced some fascinating information about the spacecraft on which we live. Recently, for example, we tested MOCS by flying it in an aircraft at 37,000 feet over Clear Lake in California. MOCS showed that the lake teemed with sediments, algae growth, and foreign matter. In fact, the only thing clear about the lake was its ironic name.

We're happy to be associated with the excellent work NASA is doing in remote sensing. We hope that MOCS and other NASA sensors will help make spacecraft earth a habitable home for us all.

The Multichannel Ocean Color Sensor

Lenses (a) focus light through a slit onto a diffraction grating (b) which separates the light into its spectral components. These are focused on a dissector tube (c) which shows spatial variations of light across the field of view in one direction and spectral variations in the other. The raster scan then gives an electronic signal proportional to the spectral radiance of each spectral band in each element across the field of view.



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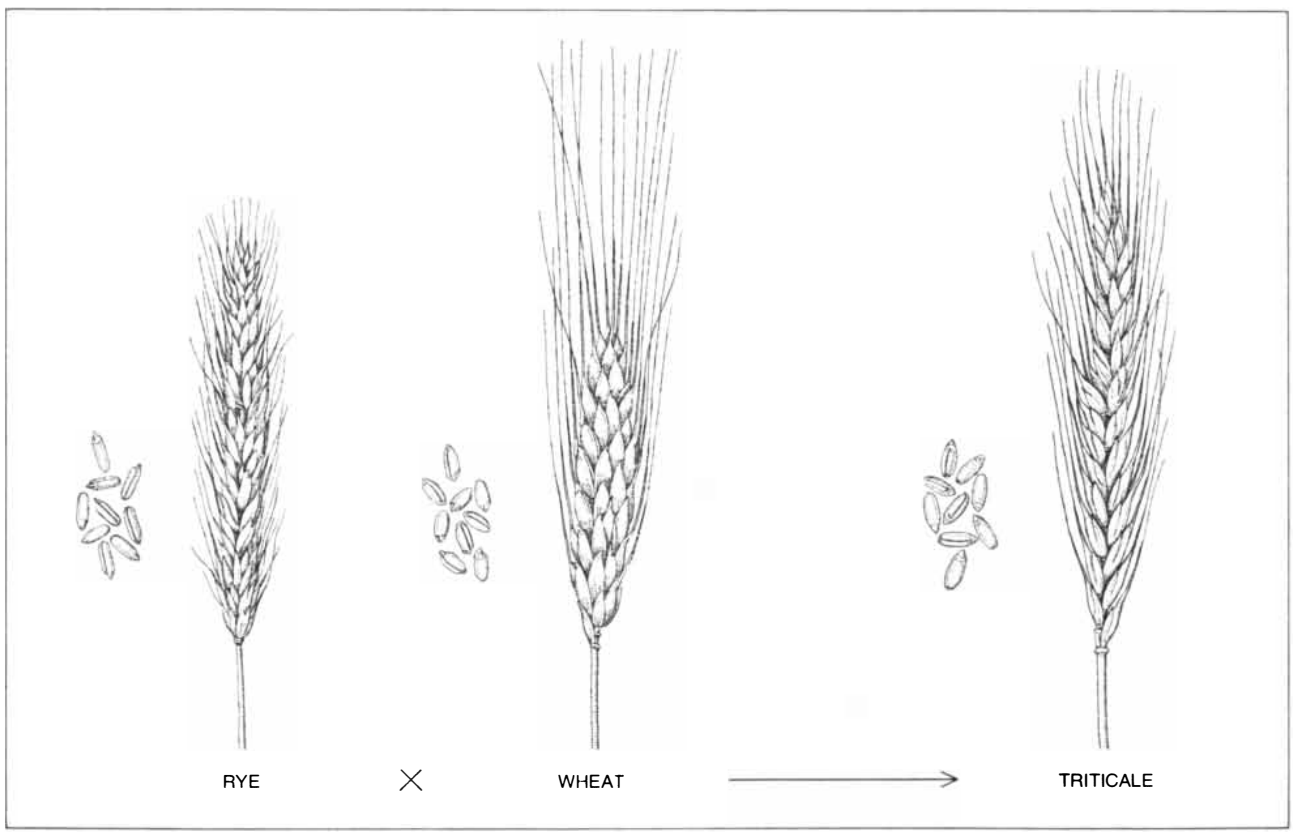
TRITICALE

This hybrid combines the high yield of one of its parents (wheat) with the ruggedness of the other (rye). It now seems certain that it will compete successfully with the traditional cereal grains

by Joseph H. Hulse and David Spurgeon

When wheat (genus *Triticum*) and rye (genus *Secale*) are artificially crossed, the product is an intergeneric hybrid that has characteristics of both parents. The hybrid is a new genus called triticale. What makes triticale interesting is that it combines the high protein content of wheat with the high lysine content of rye. With the proper genetic manipulations it can also combine the high yield of wheat with the ruggedness of rye. It is adaptable to unfavorable environmental conditions, such as cold weather and soils that are light, sandy or acid. Some advanced varieties of triticale appear to be more resistant to rust than wheat is. This characteristic of triticale, inherited from its rye parents, could prove to be one of its most important advantages because rust limits wheat production in many parts of the world, including the subtropical and tropical highlands. After years of research it now seems certain that triticale will become the first man-made cereal grain to compete successfully with the traditional cereals.

Triticale is being grown on more than 400,000 hectares (a million acres) in 52 countries under a wide variety of en-



HYBRID IS CREATED by crossbreeding wheat (genus *Triticum*) and rye (genus *Secale*). Triticale is a new genus, and many varieties of it with widely different characteristics can be produced. The crossing is accomplished by transferring pollen from a rye flower (the male parent) to the stigmata of a wheat flower (the female parent). The pollen-carrying parts of the wheat flower are first removed in order to prevent self-fertilization. Grains of triticale generally are larger than wheat grains and plumper than rye grains.

vironmental conditions, ranging from those found on the prairies of Canada to those in the foothills of the Himalayas. In some locations—in Ethiopia and India, for example—triticale has outyielded the best bread wheats. In Mexico the best triticale varieties are outyielding the highest-yield wheat varieties in both summer and winter plantings. In the same trial the highest triticale yield of 8,350 kilograms per hectare topped the highest wheat yield of 7,245 kilograms per hectare. Earlier problems such as excessive sensitivity to photoperiod (length of the day), low grain fertility, late maturity, low yield, lodging (collapse as a result of weak straw and a heavy head) and susceptibility to certain diseases have now been overcome to a considerable degree. These results seem to ensure that over the next few years triticale will become an important world food crop.

Members of the grass family (Gramineae) such as wheat, rye, barley and oats have played a key role in man's economic and social development. These cereal grains were evolved from wild grasses, probably in the Near East and Asia Minor. At the 6,700-year-old site of Jarmo in eastern Iraq, for example, carbonized kernels of primitive emmer wheat and einkorn wheat have been uncovered by archaeologists. Between 6000 and 3000 B.C. the cultivation of these wheats and of barley spread north and west through central Europe.

Wheat species are classified into three groups according to the number of chromosomes in their cells. The wheat genome (a complete inherited set of wheat genes) is carried by seven chromosomes. Since each wheat plant receives at least one complete set of genes from each of its parents, its cells contain at least two sets of chromosomes. Indeed, many wheat species have more than two sets. *Triticum aegilopoides* (wild einkorn) and *T. monococcum* (einkorn) are diploid: they have 14 chromosomes and thus two genomes. *T. dicoccum* (emmer) and *T. durum* (hard or macaroni wheat) are tetraploid: they have 28 chromosomes and thus four genomes. The common bread wheats such as *T. aestivum*, *T. sphaerococcum* and *T. compactum*, which account for most of the wheat grown commercially today, are hexaploid: they have 42 chromosomes and thus six genomes.

The rye genome can also be carried by seven chromosomes. The earliest-known cultivation of rye was in the Balkan peninsula and eastern Europe. Although many wild and weedy relatives exist, only one cultivated species, *Secale cereale*, is recognized. It has 14 chromosomes (two genomes) and is therefore diploid.

Triticale can be produced in two forms. If a tetraploid wheat (*T. durum*) is crossed with the diploid rye, the result is a hexaploid triticale. If a hexaploid wheat (*T. aestivum*) is crossed with rye, the result is an octoploid triticale. So far the hexaploid triticales have proved to be more stable than the octoploids.

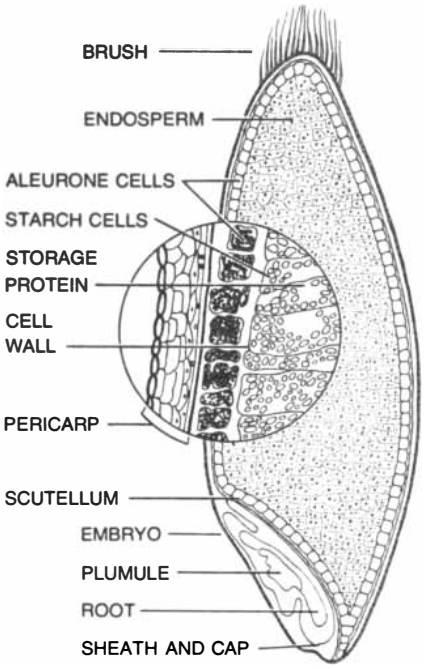
Since the wheat and rye genomes belong to different genera, some measure of genetic incompatibility is inevitable. The first cross between wheat and rye was reported in 1876 by A. Stephen Wilson in *Transactions of the Edinburgh Botanical Society*. He carried out his crossing experiments by dusting pollen from the rye plant onto the stigma of the wheat with a camel-hair brush. In most instances he first emasculated the wheat plant by removing the anthers: the saclike parts of the stamen that contain the pollen. Only a few seeds from the genetic crossing germinated, and they proved to be sterile. As Wilson reported, somewhat sadly, the hybrid plants were absolutely barren, "not a single kernel having been produced." The physical characteristics of the plants, however, led him to believe he had produced a hybrid with properties intermediate between wheat and rye.

In 1889 W. Rimpau of Germany described a spontaneously occurring, partly fertile wheat-rye hybrid. For the next several decades wheat-rye hybrids, because of their low fertility and the difficulty of obtaining viable seed, were little more than an academic curiosity. Then in 1937 Pierre Givaudon of France found that the treatment of seedlings with colchicine (an alkaloid derived from the autumn crocus) causes their chromosomes to double. This discovery opened the door for the metamorphosis of triticale from a laboratory curiosity into a potential food crop.

The reason most first-generation triticale seedlings are infertile is that they have only a single set of wheat chromosomes and a single set of rye chromosomes. The two sets of chromosomes cannot pair for the purpose of sexual reproduction, and no offspring can result. When colchicine is applied to the triticale seedling, however, the set of chromosomes is often doubled, making it possible for wheat chromosomes to pair with wheat chromosomes and rye with rye. Such a plant is fertile.

Another important factor in the development of triticale is the technique of embryo culture. Because of the comparative genetic incompatibility of the parental species, the hybrid embryos do not always develop normally. Their chances of survival can be increased by removing the embryo from the seed between 10 and 21 days after pollination and transferring it to an agar gel containing inorganic salts, other nutrients and sometimes plant growth hormones. The cultured embryo is kept in the dark until roots begin to appear; then it is allowed to grow in the light under constant illumination. When shoots have developed, the plant is potted in soil. When the hybrid plant has produced several shoots, it is treated with colchicine [*see illustration on next page*].

It should be emphasized that triticale is not a single plant species. Triticale is a genus and, like wheat and rye, it has many cultivars of widely different characteristics. When one reads reports that triticale has certain properties or prob-



TRITICALE KERNEL is shown in cross section. In actual size the kernel ranges from nine to 12 millimeters in length and up to three millimeters in width. It is usually yellowish brown in color. The pericarp consists of several layers derived from maternal-plant tissue that originally surrounded the embryo sac. Most of the protein is located in the aleurone layer and in the endosperm. The scutellum serves as a storage, digestive and absorbing organ for the plant's embryo, which is made up of a rudimentary root and a plumule. In general morphology and structure the triticale grain closely resembles that of its parents.

lems, one should keep in mind that the report is probably dealing only with one specific type of triticale grown under one set of environmental conditions. In past years reports of triticale have sometimes oversold it as a "superfood." Its failure to live up to such promotion has caused some disappointment among grain growers. Those closely involved with the development of triticale feel that what is wrong has to do more with promotion than with performance.

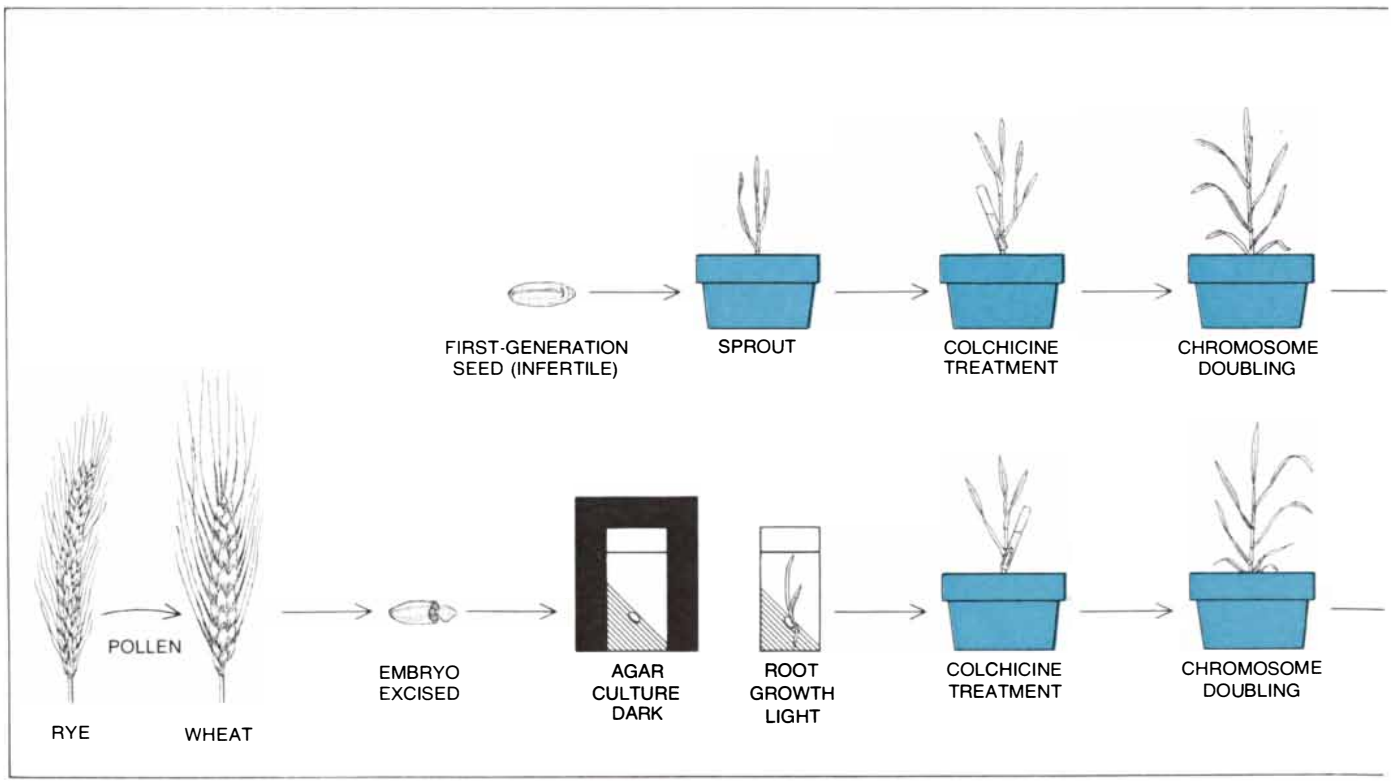
Today the most extensive and productive triticale research program is a cooperative undertaking of the University of Manitoba and the Centro Internacional de Mejoramiento de Maiz y Trigo in Mexico (CIMMYT, or the International Maize and Wheat Improvement Center). The Canadian program began in 1954 with the establishment of the Rosner research chair in agronomy at the University of Manitoba, which was endowed by the Samuel and Saidye Bronfman Family Foundation. Burton Charles Jenkins, the first Rosner professor, collected primary triticales from all over the world. They were grown in test plots, and the most promising were saved for improvement through hybridization [*see illustration on opposite page*]. At the same time the development of new primary triticales was undertaken.

Between 1959 and 1962 secondary triticales were produced by crossing the more fertile primary ones. In 1963, with the aim of getting two plant generations a year rather than one, the Manitoba program was extended to a winter nursery at Ciudad Obregón in Mexico. The triticales that had originated in Manitoba showed remarkable hybrid vigor in Mexico, but they were late in maturing and were too tall, and to a large extent the seed they produced was sterile. After harvest most of the seed was returned to Canada for summer planting, but some of it was taken south and sown in May at a CIMMYT research station in Toluca. This move proved to be highly rewarding in that it led to the joint triticale project of the University of Manitoba and CIMMYT, a large Mexican research institution that had successfully developed high-yielding dwarf wheat. The joint project was launched in 1964 with financial assistance from the Rockefeller Foundation.

By 1967 the University of Manitoba had developed varieties of triticale that in western Canada gave yields as high as standard varieties of bread wheat. Commercial production of triticale began in Manitoba on a modest scale, the better varieties being grown under contract for the fermentation and distilling industries. Interest was also shown in the new grain as a potential component in animal feeds. In 1970 the "Rosner" variety of triticale was licensed for sale to farmers in Canada.

In 1970 the government of Canada, through the Canadian International Development Agency and the International Development Research Centre, undertook to provide the Manitoba-Mexico triticale project with more than $3 million over a period of five years. The purpose of the project was to develop a high-protein cereal grain that would benefit malnourished people in the underdeveloped parts of the world. The first step was to develop triticale plants that would yield as much grain as the best cultivars of wheat, oats and barley.

Two major barriers had to be overcome. The fertility of triticale seeds was low, and abnormal development of the endosperm gave rise to shriveled seed.



FIRST-GENERATION TRITICALE SEEDS are usually sterile even though they may germinate. The sequence at top shows how the sterility is overcome by treating seedlings with the alkaloid colchicine. Application of this substance to the tip of a growing sprout interferes with mitotic division of cells in such a manner that the number of chromosomes is doubled. The doubled chromosome complement gives rise to fertile flowers that later grow on the stem. The seeds produced are also usually fertile. Some wheat-rye hybrids produce seeds that will not germinate, and embryo culture is required to produce first-generation seedlings. The technique, which is shown in the sequence at bottom, consists in excising the embryo from seeds that are immature (14 to

Because the Mexican research center has a large and diverse pool of wheat genes and an international network of collaborating plant scientists, it has concentrated on developing and testing a wide spectrum of new genetic combinations of triticale. The University of Manitoba has concentrated more on developing new techniques for increasing the number of viable crosses, looking for genotypes that are less sensitive to day length and for other characteristics such as cold tolerance and resistance to smut and rust diseases. Plant scientists at Manitoba also deal with the more fundamental problems related to infertility and shriveled seed.

In Mexico the project is under the direction of Norman E. Borlaug, who in 1970 received a Nobel peace prize for his outstanding research on high-yielding wheat varieties, and Frank J. Zillinsky, a Canadian plant breeder. The Manitoba program is guided by Leonard H. Shebeski and Edward N. Larter, who holds the Rosner chair. An advisory committee sponsored by the International Development Research Centre serves as an integrating body. The committee has links to the International Union of Food Science and Technology and to programs in a number of countries in Asia, Africa and Latin America.

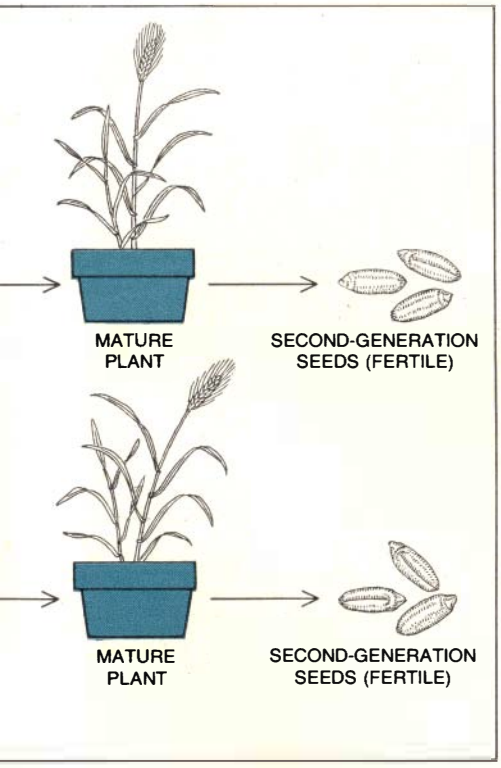
The Manitoba triticales were adapted to the long daylight hours of the prairie summer. When these triticales were grown in Mexico, with its much shorter days, they were late in maturing. In addition they grew tall and tended to lodge. Two approaches were made toward the reduction of lodging. The first was to introduce into some varieties genes that increase the thickness of the straw. The second approach was to incorporate genes from dwarf wheats or dwarf ryes.

The greatest progress in triticale breeding came not through a planned program but rather as the result of an accidental outcross. Here is how Borlaug describes it:

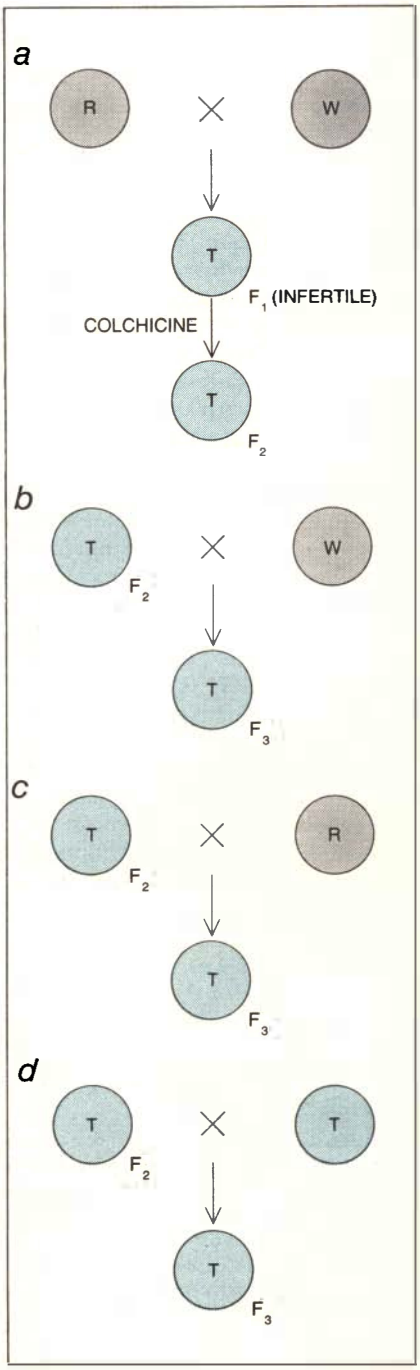
"I must tell you that the largest and most important step toward making the breakthrough in triticale improvement was executed by capricious mother nature herself, one early dawn March morning in 1967 in Ciudad Obregón, Sonora, while scientific man was still in bed. One promiscuous, venturesome stray wheat pollen grain with a potent and valuable 'genetic load' from the nearby wheat breeding plots floated across the road under cover of darkness and fertilized a sad but permissive tall, sterile degenerate triticale plant.

"A year later (two generations), scientific men identified several unusually promising plants in a segregating population. The genetic makeup of those plants clearly indicated the value of the illicit stray wheat pollen grain. Its triticale progeny indicated that in the act of fertilization it had dwarfed, introduced partial photoperiodic insensitivity and completely overcome the sterility barrier, which had inhibited progress in triticale improvement for decades. This seems to me to be nature's way of telling scientists not to become too arrogant."

The tall, sterile triticale plant was a hexaploid cross labeled X308. The wheat pollen that fertilized it most likely was from a Mexican dwarf bread wheat. The progeny of X308 and the unknown dwarf wheat are now called Armadillo. Advanced Armadillo strains have considerably higher fertility, better test weight, higher yield, better insensitivity to day length, earlier maturing characteristics, shorter straw length, higher resistance to lodging and better nutritional quality than older varieties of triticale. Selections from Armadillo have



20 days after fertilization) and culturing the embryo in an agar medium. The culture is kept in the dark until the embryo sprouts and then is kept in constant illumination. Later the sprout is transplanted to a peat pot and treated with colchicine.



BREEDING OF TRITICALE (*T*) begins (*a*) with a cross between wheat (*W*) and rye (*R*). The first-generation triticale plant (F_1) is made fertile with colchicine treatment, and the resulting seeds become the second generation (F_2). This generation and subsequent ones can be backcrossed to either parent or crossed with entirely different varieties of wheat or rye (*b*, *c*). Triticale-triticale crosses are also made (*d*). A primary triticale is one that is obtained from a wheat and rye cross or from crossing two triticales, each obtained from the same wheat and rye species. A secondary triticale is the result of crossing different varieties of triticale or of crossing a triticale with a wheat or a rye that was not a parental stock.

resulted in yield increases of from 50 to 60 percent above those of earlier strains of triticale. All these factors appear to be heritable and transmissible to the progeny of Armadillo.

Between 1967 and 1973 workers in Mexico and Manitoba succeeded in virtually redesigning the triticale plant genetically, so that most of its initial biological faults have been corrected. So successful has the triticale project been that CIMMYT is now collaborating with Lynn Bates of Kansas State University in research that is directed at producing other new cereal crop plants from crosses between different genera of the grass family.

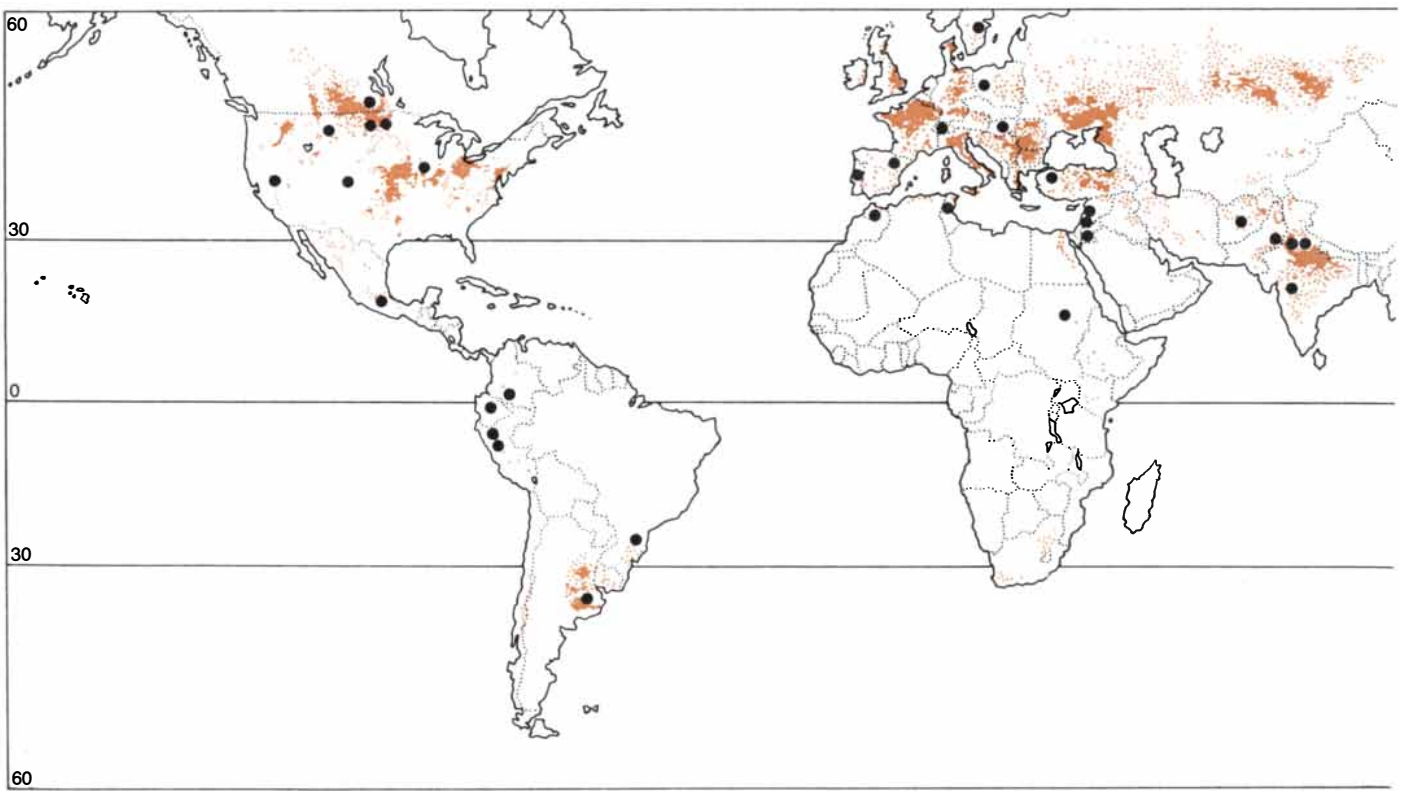
Another important aspect of the triticale program is the testing of new strains for disease resistance. Certain triticales show considerable resistance not only to rust but also to other common grain diseases such as bacterial stripe and leaf blight. An important disease to which triticale is not notably resistant is infection with the fungus ergot, which produces toxic substances. An intensive search for tetraploid and hexaploid wheats with high resistance to ergot is being conducted at the University of Manitoba. Some 15 varieties with high resistance to the disease have been identified and are being incorporated into the triticale breeding program.

Efforts are also being made to give triticale a wider genetic base. In 1973 a total of 1,200 wheat-rye crosses were made in the field by Manitoba workers, and 56 new hybrid plants from earlier crosses were produced by the colchicine technique. New methods of culturing embryos and of doubling chromosomes in young embryos are being sought. One method of doubling chromosomes that shows promise is the incorporation of colchicine into the culture medium.

Several basic studies have been undertaken at the University of Manitoba on the program to prevent the shriveling of triticale grain. There are two leads. One is that in shriveled grain an enzymatic process called alpha-amylase activity continues for a longer time than it does in unshriveled kernels. The alpha-amylase activity is often associated with premature germination; it may cause a breakdown of the starch in the endosperm and thus give rise to shriveling. The other lead is that genetic studies suggest that some of the rye chromosomes are associated with the shriveling.

So far there is little information about the performance of triticales under conditions of extreme drought, and more needs to be learned about their performance under a variety of agronomic conditions. CIMMYT has expanded its program to investigate the effects on triticales of seed spacing, row spacing, fertilizers and herbicides.

Cereal grains are the staple food of the majority of the people who live in underdeveloped countries. They provide between 70 and 80 percent of the total calories in the diet and more than two-thirds of the protein. The remainder of the protein is usually provided by legumes. Wheat is produced in larger quantities and grown over a larger area than any other single crop [*see illustration below*]. It grows best in temperate and subtropical climates and performs well in heavy loams and clay soils. Rye, which will grow in roughly the same regions as wheat, is much more tolerant of sandy and less fertile soils. Both the production of rye and the area planted to it have declined significantly in the past 20 years. It is hoped that triticale will demonstrate a greater environmental adaptability than either of its parents and that it will



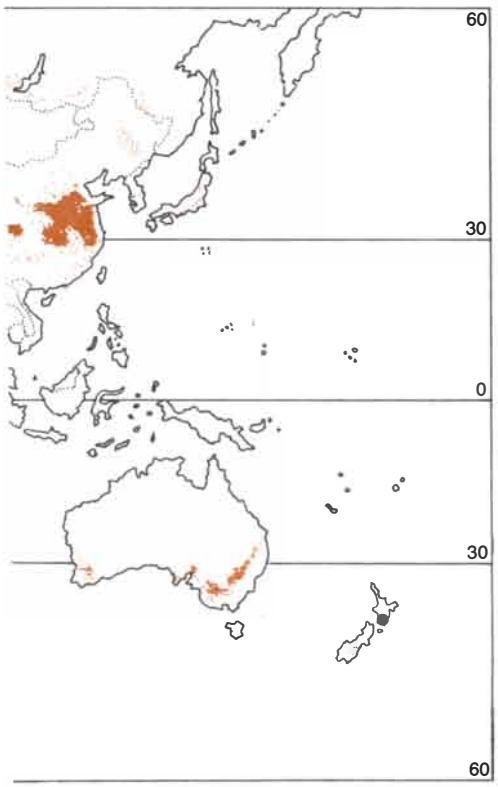
INTERNATIONAL TRITICALE PROGRAM is directed toward broadening the genetic base of triticale and developing varieties suited for cultivation in underdeveloped countries. Triticale can be grown in wheat-producing regions (*colored dots*) and also in marginal lands that do not support wheat crops. Nurseries throughout the world cooperating with the Centro Internacional de Mejoramiento de Maiz y Trigo in Mexico (the International Maize and Wheat Improvement Center) are indicated by solid black circles.

make it possible to grow a high-protein crop on what are now called marginal lands.

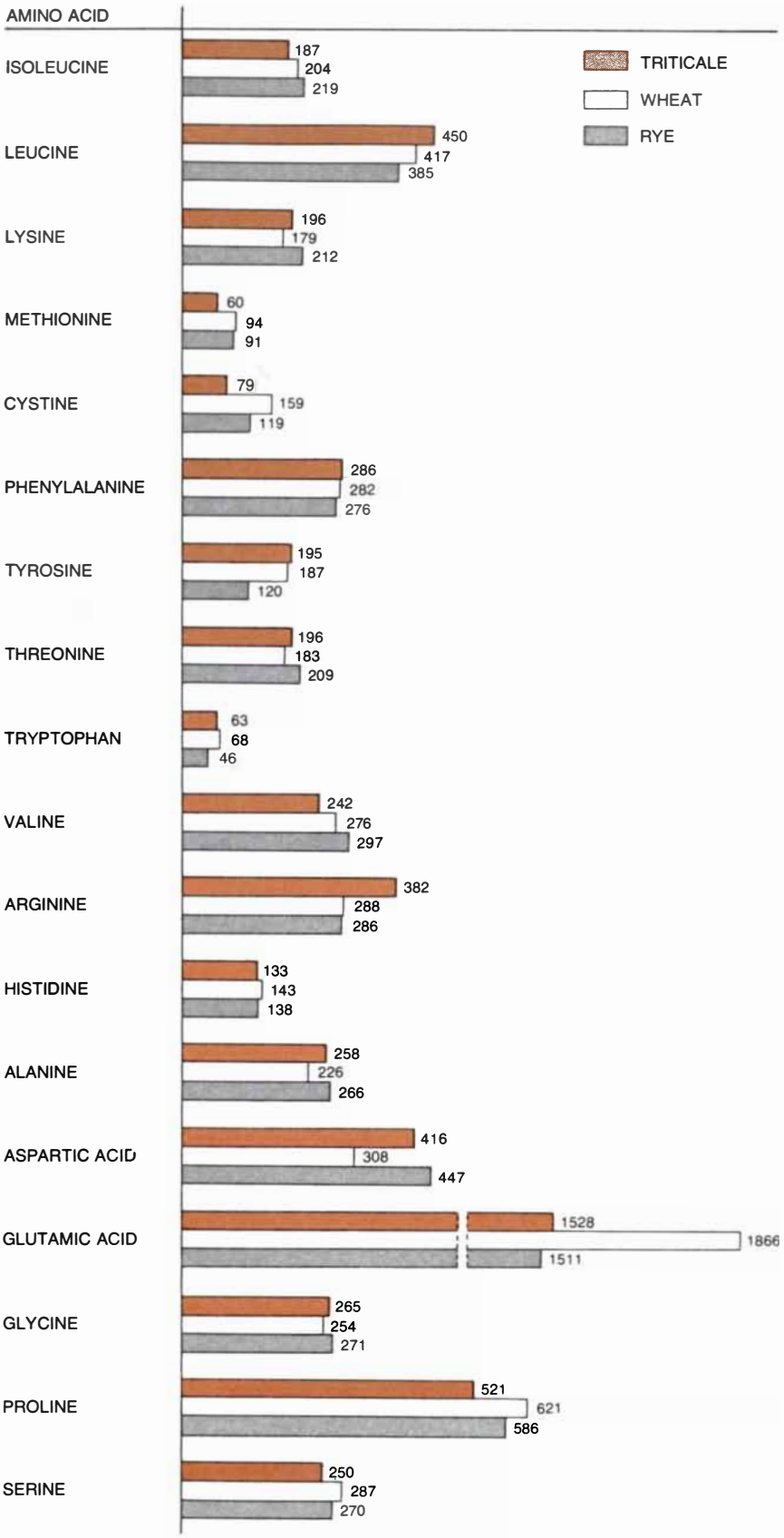
Wheat is the most popular cereal in the human diet because of its versatility and because a very white flour can be made from it. In addition the protein of wheat has unique physicochemical properties. When the protein is mixed with water, it forms the cohesive rubbery mass called gluten. The gluten made from bread-wheat flours of good quality will form a dough that is strong and elastic; it can be stretched and inflated without tearing or breaking. When the dough is baked, the gluten coagulates and the starch gelatinizes to yield the cellular, crust-covered material we know as bread.

Although the proteins of rye are generally similar to those of wheat, doughs made from rye flour tend to lack spring and to break when stretched. Bread made from rye flour tends to rise less than wheat bread, is much heavier, is darker in color and has a distinctive flavor. As a result it is now a common practice in making rye bread to mix wheat flour with rye flour.

Initially it was reported that the breadmaking quality of triticale flour



The international triticale nursery program has been financed by the Canadian International Development Agency and Canada's International Development Research Centre.



AVERAGE AMINO ACID CONTENT of triticale, wheat and rye is tabulated. The units are milligrams of amino acid per gram of total nitrogen. The data for wheat and rye are the average of a large number of analyses compiled by the Food and Agriculture Organization of the United Nations. The triticale data are the average of advanced triticale varieties grown throughout the world in 1972 and 1973. Some of the most promising varieties of triticale have a higher lysine content: an average of 250 milligrams per gram of nitrogen.

was quite poor and that it was possible to make a good bread only by blending the triticale flour with wheat flour. Recent studies of flour from advanced hexaploid triticales indicate that it is possible to make bread of acceptable quality with 100 percent triticale flour. A new technology is being developed that makes it possible to produce good bread from cereal flours that do not have the properties essential for conventional breadmaking. The new system, in which long periods of fermentation are replaced by mechanical development of the dough, allows acceptable bread to be made from physically weaker doughs such as those consisting of triticale flours and from mixtures of wheat flour and other cereals such as sorghum, millet and maize.

The protein content of any food must be considered not only on the basis of quantity but also in terms of nutritional quality, which is basically a function of the balance of essential amino acids. Of the 18 amino acids commonly found in natural edible protein, 10 are generally described as being essential for human adults and 11 as being essential for children. These essential amino acids cannot be synthesized by the body and must therefore be ingested. Rats are believed to require the same 10 amino acids that human beings do; other animals may have different requirements. Chickens and turkeys, for example, require 12 amino acids.

The biological value of a protein depends on its content of essential amino acids in relation to the requirements for these nutrients by the species in question. The essential amino acid in which a natural protein is most seriously deficient is called the first limiting amino acid for that protein source. In many cereals the first limiting amino acid is lysine. As a result plant breeders throughout the world have sought to develop high-lysine cereals. High-lysine corn hybrids have been successfully developed by introducing a gene known as opaque-2 into ordinary varieties of corn [see "High-Lysine Corn," by Dale D. Harpstead; SCIENTIFIC AMERICAN, August, 1971].

The protein content of common wheats varies from 6 to 23 percent, with a mean average of 12.9 percent on a dry-weight basis. The protein content of rye is lower, ranging from 6.5 to 15 percent, but its biological value is higher, primarily because of its higher lysine content. In some instances triticale combines the high total protein content of wheat and the high lysine content of rye.

EXPERIMENTAL TRITICALE grown in Mexico is part of the worldwide program for developing high-yielding varieties of the new cereal grain. One variety of triticale recently produced a higher yield than the best Mexican wheat growing in the same area.

In fact, CIMMYT reports that several advanced lines of triticale have a lysine content equal to that of high-lysine corn and a total protein content much higher than that of high-lysine corn. Preliminary reports from the 1972–1973 crops of triticale showed that some had a lysine content as high as 4.35 percent of the total protein. The average lysine content, however, is 3.14 percent of the total protein, and the average protein content is slightly higher than the mean protein content of the most commonly grown wheats [*see illustration on opposite page*].

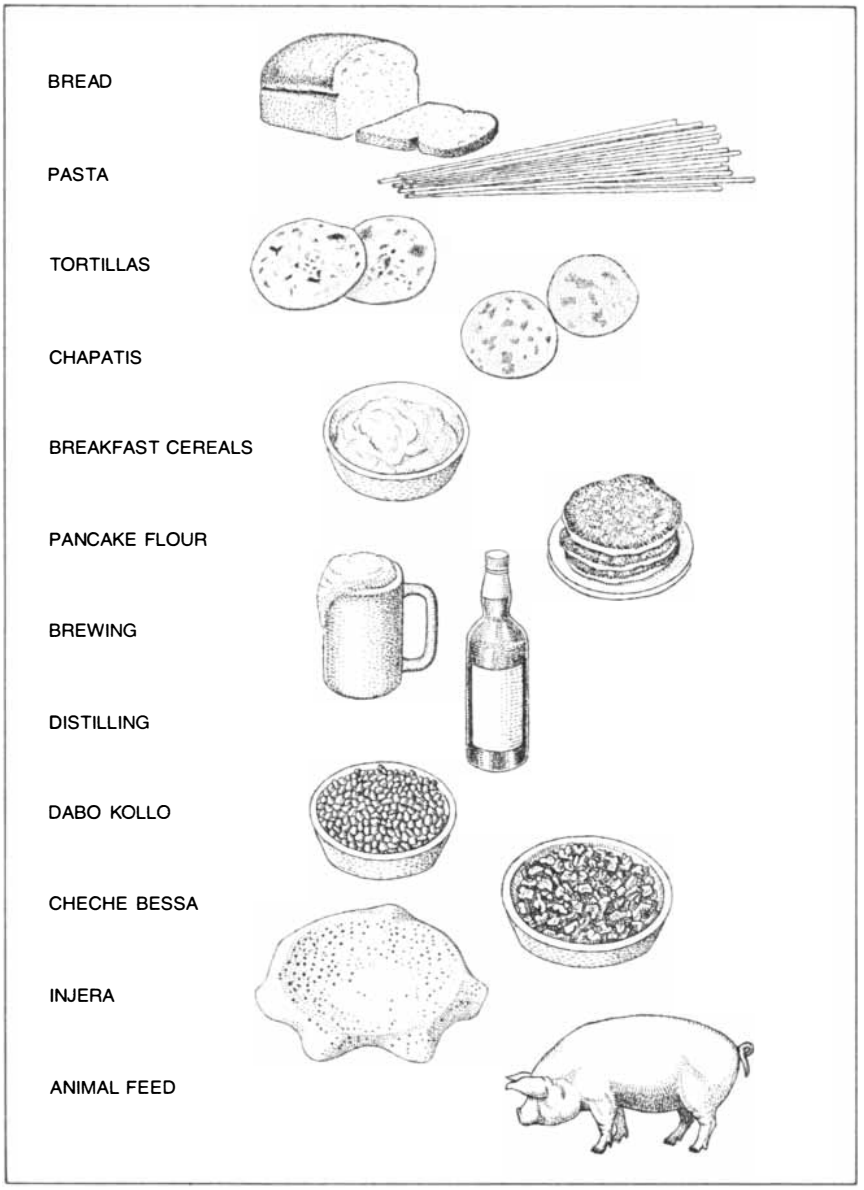
The protein content and the protein composition vary considerably among main components of the individual cereal grain: the endosperm, the seed coats and the embryo. The germ fraction, which includes the embryo, has the highest proportion of protein, but it is such a small part of the whole grain (2.5 percent) that its contribution to the total protein content is small. The endosperm and the surrounding aleurone layer provide approximately 88 percent of the total protein in a whole grain [*see illustration on page 73*].

Early varieties of triticale were reported to have a remarkably high protein content. In shriveled cereal grains the endosperm represents a much lower proportion of the whole grain than it does in plump seeds. As a result the proportion represented by the embryo and the aleurone layers is increased. The high proportion of shriveled grains in early lines of triticale probably accounts for the high protein analyses that were reported.

Tests on a variety of animals have shown that triticale is at least equal to, and is often superior to, wheat in biological value. Triticale grain has been fed to both beef and dairy cattle with success, and reports from U.S. workers indicate that triticale straw may also be a good forage crop for cattle. Hog-feeding trials suggest that triticale is equal to

barley in the diet of heavier animals but is inferior in the diet of lighter ones. Some workers have reported a loss of appetite in hogs fed large quantities of triticale. In some of these instances it is not clearly indicated whether or not the triticale used was clean or was infected with ergot. Where ergot infection is known to be present there is a marked reduction in the feed intake and weight gain of domesticated animals.

Studies of laying hens fed triticale indicated that important savings can be achieved by using high-protein triticales to reduce the amount of the more expensive protein concentrates, such as soybeans and fish meal, that are normally added to the feed. In feeding trials with chicks and broilers it appeared that the high-lysine varieties of triticale could be used to meet the birds' total protein requirement. The amount of protein supplement in diets for turkey poults can also be reduced by basing the feed on triticale. Much of the work published on triticale in animal diets was based on early varieties. Many of the trials need to be repeated with the advanced lines that are gradually becoming available in quantity.



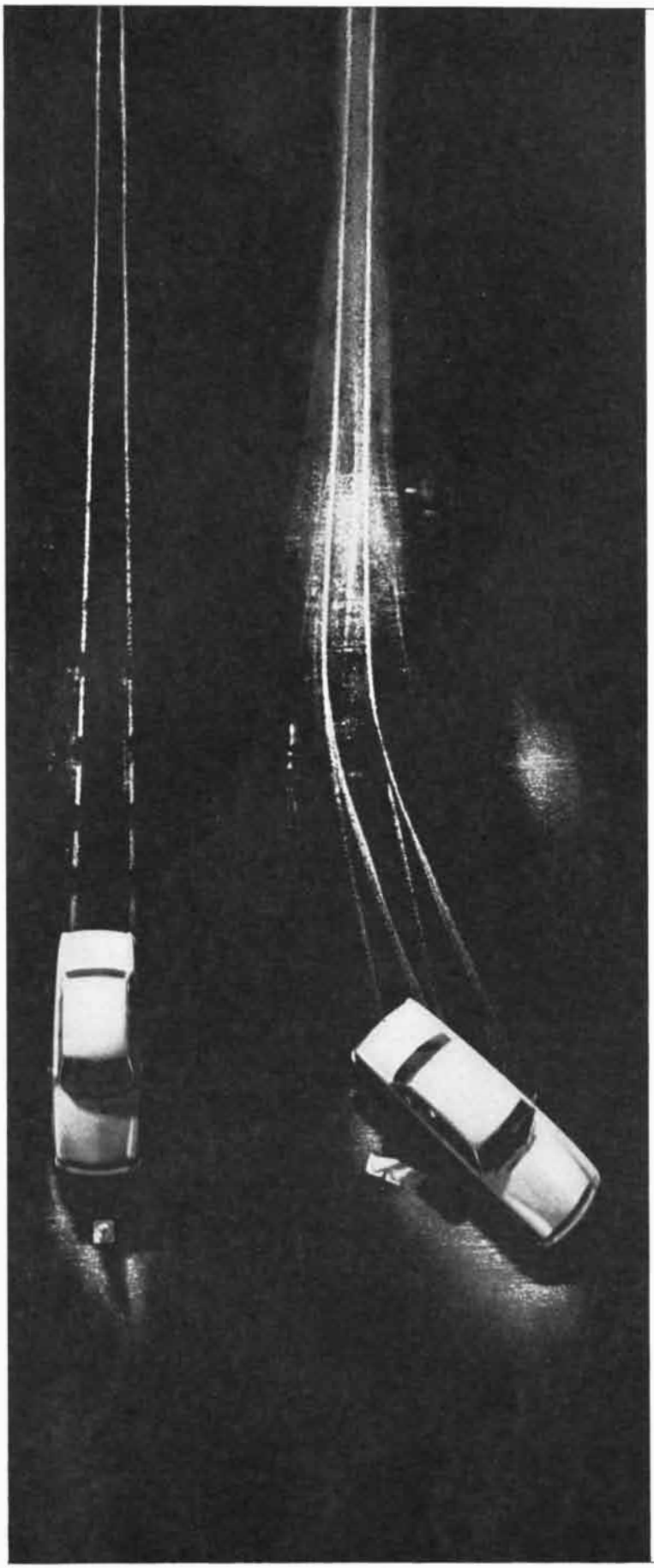
HIGH-PROTEIN TRITICALE can be substituted for other cereal grains in many traditional foods in order to improve their nutritional quality. Studies with foods such as tortillas in Mexico, chapatis in India and *dabo kollo, cheche bessa* and *injera* in Ethiopia indicate that the taste and texture of triticale-based foods are fully acceptable to the indigenous populations. Recent advances have opened the way to making acceptable breads with 100 percent triticale flour. Because of its high protein content triticale can also be substituted for more expensive protein concentrates such as soybeans that are added to animal feeds.

Although triticale will probably be used as animal feed and forage, the primary objective of the triticale project is to provide more food for the people who depend on cereal grains for their nourishment. In order to explore its potential use throughout the world the International Union of Food Science and Technology has formed a working group on triticale. This group, it is hoped, will explore the behavior of triticales when they are subjected to conventional processing and if necessary will devise processing techniques that are better suited to the new grain.

Triticale has potential for making not only bread but also foods such as pastas (macaroni, spaghetti and so on), breakfast cereals, pancakes, tortillas and chapatis. As we have mentioned, it can also be used in the brewing and distilling industries. In Ethiopia an experimental variety of triticale has produced yields 10 percent higher than the country's best bread wheat, and tests have shown that the triticale flour can be substituted for at least 50 percent of other cereal flours in the traditional Ethiopian bread *injera*. In Mexico triticale flours have been used for making tortillas, and the results have been quite satisfactory. The triticale tortillas have almost the same characteristics as wheat tortillas. These tests indicate that triticale can be used to make traditional food products that are fully acceptable to various indigenous populations and that triticale can be put to good use in countries where food shortages and nutritional shortcomings exist in the greatest measure.

Much, of course, remains to be done. The shriveling of triticale grains, although its incidence is significantly lower than it was, is not totally overcome. New strains with broader adaptability are being sought, as are genotypes with improved disease resistance.

The most recent advances in triticale development are largely the outcome of the cooperative project of the University of Manitoba and CIMMYT in Mexico. Research on triticale has spread throughout the world, and further improvements in the properties of this hybrid can be confidently expected. In one respect the triticale project sponsored by the International Development Research Centre has provided more than just the tangible benefits of triticale itself. It also serves as an excellent model of an integrated, international approach to creating new and improved sources of food, in which equal concern is given to biological quality, agronomic properties and the potential utility of the product.



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HOW ACTINOMYCIN BINDS TO DNA

The antibiotic acts to block the synthesis of protein by binding to the double helix of DNA. A three-dimensional picture of how it does so has been worked out with the aid of X-ray crystallography

by Henry M. Sobell

The actinomycins constitute a well-known class of antibiotic substances produced by various species of the soil bacterium *Streptomyces*. First isolated in the early 1940's by Selman A. Waksman and his colleagues at Rutgers University, they came into medical prominence soon afterward when it was found that actinomycin D can be extremely effective in the treatment of certain kinds of cancer. The extreme toxicity of actinomycin D, however, has limited its wider clinical use, and for this reason a great deal of time and effort has been spent in attempting to chemically modify the molecular structure of the substance in order to reduce its toxicity while maintaining its biological activity. These efforts have not yet proved successful.

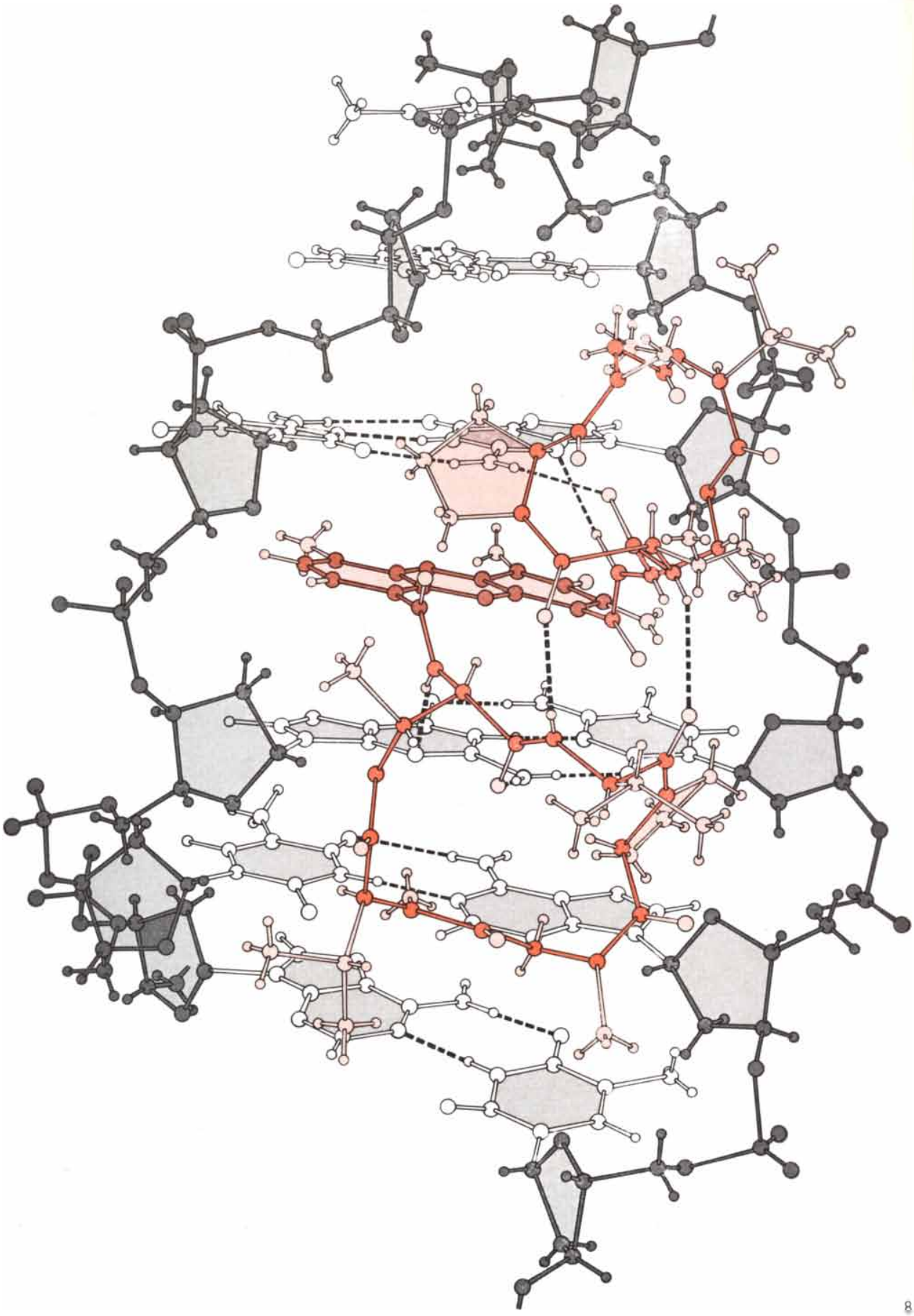
Actinomycin D has also attracted the intense interest of molecular biologists. It has been known for some time that this antibiotic somehow interferes with the process by which genetic information is "read out" of the DNA molecule. A gene consists of nothing more than a specific sequence of base pairs in DNA. The genetic message is transmitted by first copying the base-pair sequence onto a molecule of messenger RNA; this is the operation called transcription. Messenger RNA then directs the complex process by which amino acids are assembled into a particular protein molecule. The latter process, which is accomplished within the cell organelle known as the ribosome, involves many different protein factors and two other types of RNA: transfer RNA and ribosomal RNA. Actinomycin acts early in this series of events by inhibiting the formation of messenger RNA. It also stops the manufacture of transfer RNA and ribosomal RNA. It does so by binding tightly to DNA, thereby inhibiting the RNA polymerase enzyme from performing its function, which is to build RNA chains [*see top illustration on page 84*].

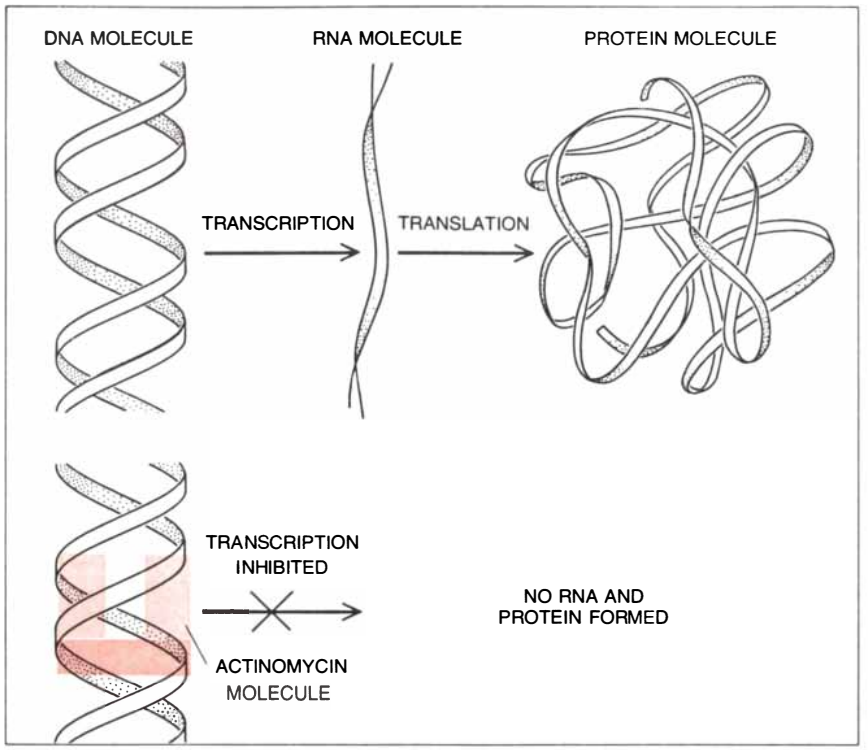
Just how actinomycin binds to DNA had been a matter of controversy for years. In the 1950's Hans Brockmann and his colleagues at the University of Göttingen succeeded in establishing the chemical structure of actinomycin D and proved the structure by synthesizing the antibiotic in their laboratory. Their experiments showed that actinomycin consists of a phenoxazone-ring system linked to two cyclic pentapeptide (five-peptide) chains [*see bottom illustration on page 84*]. The pioneering work of the Göttingen group led to the synthesis of a large number of different actinomycin derivatives whose structure could be correlated with their biological activity. Knowledge of the chemical structure of a molecule such as actinomycin does not, however, uniquely define the molecule's three-dimensional structure. This distinction subsequently proved to be a major stumbling block in attempting to understand how the antibiotic interacts with DNA.

The first clue to the nature of the actinomycin-DNA interaction came from the observation by Irving H. Goldberg at the Harvard Medical School and Edward Reich and his colleagues at Rockefeller University that actinomycin requires the presence of guanine to bind to DNA. Guanine is one of the four bases in DNA, the others being adenine, thymine and cytosine. The DNA molecule consists of two polynucleotide chains wound around each other and connected by hydrogen bonds through the mechanism of adenine-thymine and guanine-cytosine base-pairing. In many ways the molecule resembles a spiral staircase. The two chains correspond to the bannisters; the base pairs, to the steps. Topologically there are two distinct grooves in the DNA molecule: a wide groove and a narrow one. Each groove has its own distinctive set of chemical groups available for hydrogen-bonding to other molecules. The Harvard and Rockefeller investigators proceeded to ask if some specific chemical feature of the guanine molecule could be identified that might play a key role in the binding of actinomycin to DNA. If so, it should be possible to determine which groove in the DNA helix actinomycin binds and hence to understand the nature of the interaction of actinomycin with DNA. They approached the question in the following way.

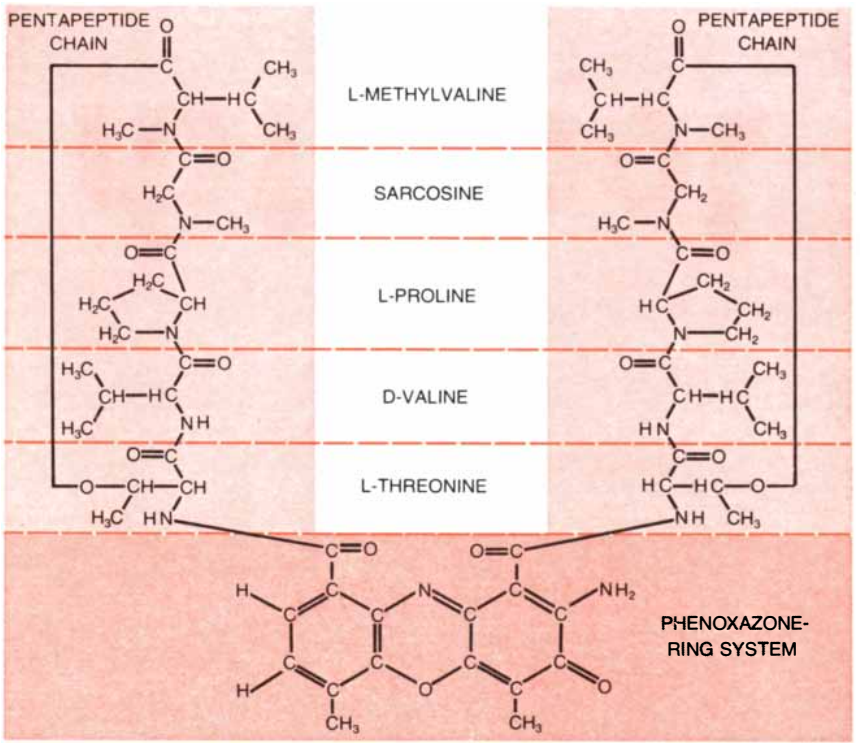
It is possible to construct DNA-like molecules with a perfectly alternating sequence of adenine and thymine. These molecules can then be used as templates for the DNA polymerase enzyme to manufacture a DNA-like polymer in which adenine is replaced by the closely

THREE-DIMENSIONAL VIEW of the binding of actinomycin to DNA is presented in the drawing on the opposite page. The actinomycin molecule is shown in tints of color; it consists of a phenoxazone-ring system (*dark color*) linked to two cyclic polypeptide chains (*medium color*), each of which is composed of five amino acids (*light color*). The DNA molecule consists of two helical polypeptide "backbones" (*dark gray*) cross-linked by paired nucleotide bases (*white*). The genetic information contained in a DNA molecule is encoded in the specific sequence of the base pairs. By binding to the DNA double helix actinomycin inhibits the "read out" of the genetic message and therefore blocks protein synthesis. Larger balls represent carbon, oxygen, nitrogen and phosphorus atoms. Smaller balls are hydrogen atoms. Broken lines are hydrogen bonds. Ring structures are shaded.





ACTION OF ACTINOMYCIN is summarized in these schematic diagrams. Normally a gene is expressed by first copying its particular base-pair sequence into single-strand messenger RNA, an intermediate molecule that then proceeds to direct the complex process of protein synthesis (*top*). Actinomycin interferes with the early transcription step by preventing the RNA polymerase enzyme from synthesizing the RNA chains (*bottom*).



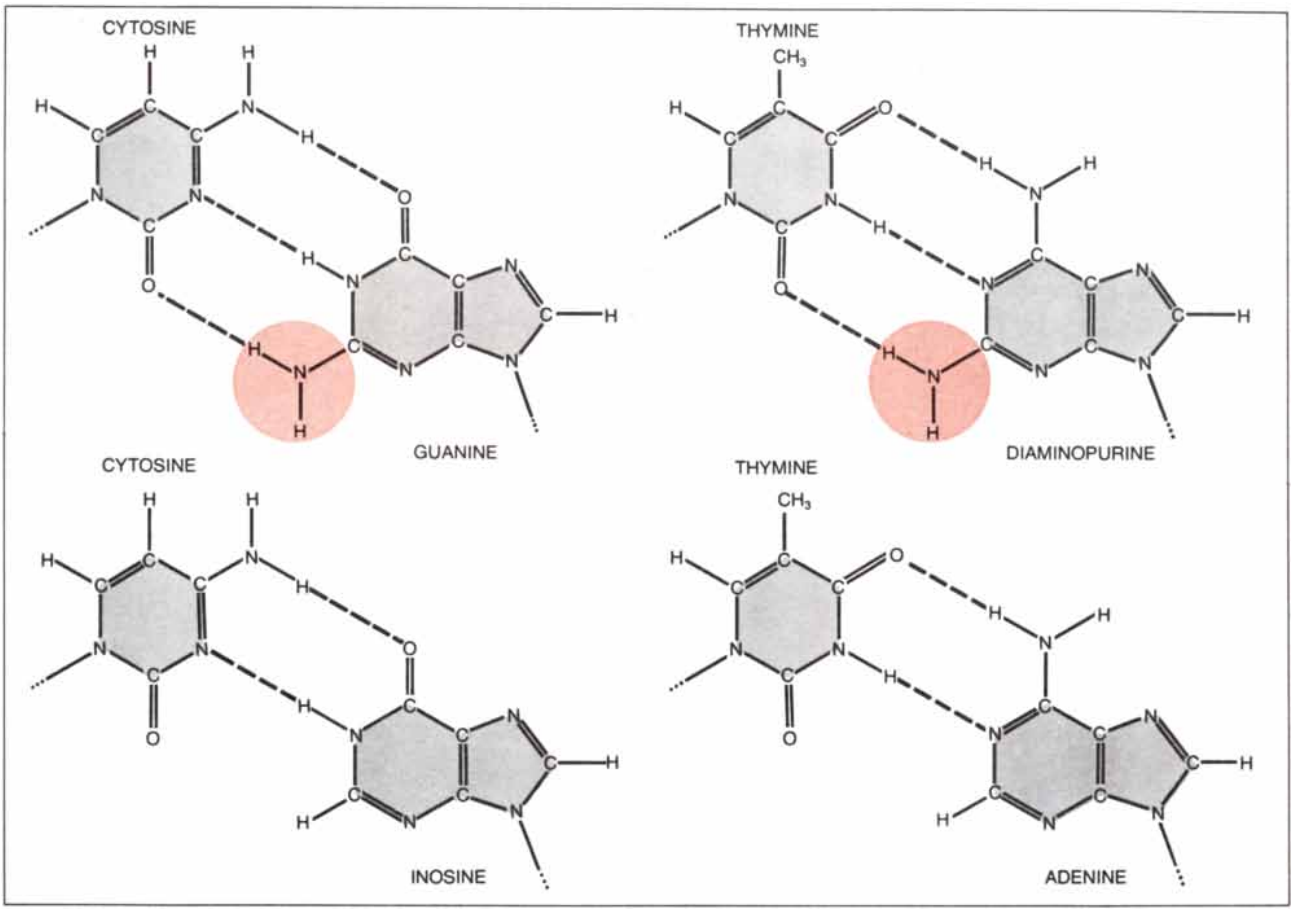
CHEMICAL STRUCTURE of actinomycin D was determined in the 1950's by Hans Brockmann and his colleagues at the University of Göttingen. The phenoxazone-ring system and the five amino acids in each cyclic pentapeptide chain are labeled. The knowledge of the chemical structure of such a molecule, however, does not uniquely define its three-dimensional structure; this made it difficult to understand how the antibiotic interacts with DNA.

related adenine derivative 2,6-diaminopurine. In a similar way one can make DNA-like molecules that consist solely of guanine and cytosine, either as homopolymers (with one strand consisting of guanine and the other of cytosine) or as alternating polymers (with perfectly alternating guanine-cytosine sequences on both strands). These molecules can then be used as templates to construct polymers in which guanine is replaced by inosine, a closely related purine base. The resulting polymers are double-helix structures in which the two polynucleotide chains are held together by a specific base-pairing arrangement [*see illustration on opposite page*].

The Rockefeller workers next proceeded to investigate the ability of these polymers to bind actinomycin. The answer was clear-cut. Those polymers containing an amino group at the No. 2 position of the purine bind actinomycin tightly, whereas polymers lacking this functional group do not bind actinomycin at all. The No. 2 amino group on the purine is therefore essential for the binding of actinomycin to these polymers. This clearly implicated the narrow DNA groove as the site for actinomycin-DNA binding and suggested a hydrogen-bonding specificity in the interaction.

In many ways the results of these polymer studies had been anticipated by W. Kersten at the University of Münster a few years earlier. He had discovered that actinomycin interacts with a variety of purine nucleosides in aqueous solution. He showed that the compound deoxyguanosine (guanine linked to a deoxyribose sugar) interacts most strongly with actinomycin. Other compounds (such as guanosine, adenosine and deoxyadenosine) also interact with actinomycin but not as strongly. Compounds such as inosine, cytidine and thymidine did not significantly interact with actinomycin in these studies. The Harvard and Rockefeller investigators subsequently extended the studies to include other purine nucleosides. Although the results of these studies had initially suggested a correlation with the polymer results, it was found that the specificity of the interaction was not an absolute one. No clear statement could be made regarding the relevance of these studies to an understanding of the nature of the actinomycin-DNA interaction.

In addition to the evidence that guanine is required for the actinomycin-DNA interaction, it was long suspected that actinomycin "intercalates" into DNA. The concept of intercalation was proposed as early as 1960 by Leonard S.



HYDROGEN-BONDING OF BASE PAIRS in synthetic DNA-like molecules was studied by groups of investigators at the Harvard Medical School and Rockefeller University in an early attempt to understand the interaction of actinomycin and DNA. Actinomycin was found to bind to those polymers that contained an amino ($-NH_2$) group at the No. 2 position of the purine (*colored circles in molecular diagrams at top*). Polymers lacking this functional group (*bottom*) did not bind actinomycin. These studies suggested a hydrogen-bonding specificity in the actinomycin-DNA interaction. They also implicated the narrow DNA groove as binding site.

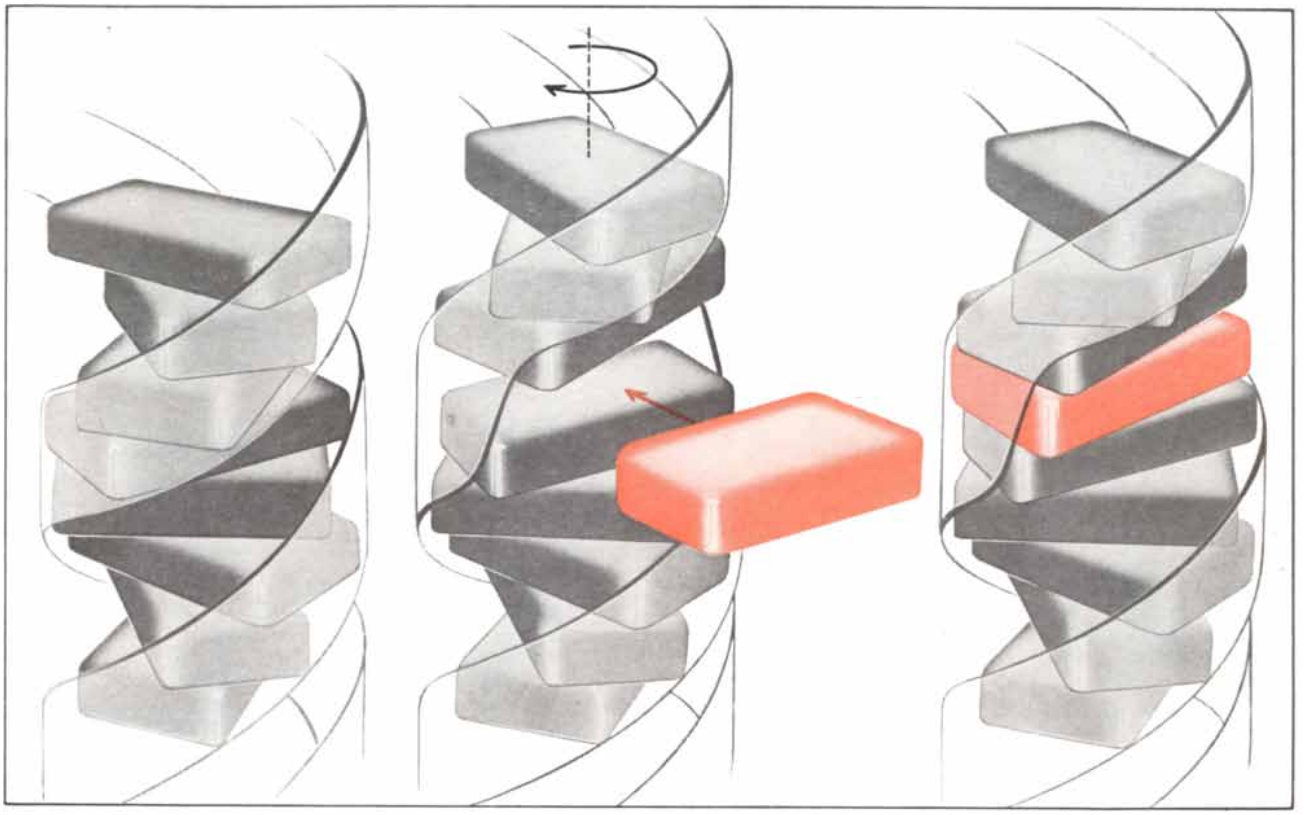
Lerman of Vanderbilt University as the most probable mode of interaction between DNA and the mutation-inducing compounds known as the aminoacridines. The term refers to the ability of these molecules to bind to DNA by sliding between adjacent base pairs in the DNA helix. In order for this to happen DNA must unwind slightly to allow adjacent base pairs to come apart a distance of 3.4 angstroms. That leaves enough space for the flat aminoacridine molecule to fit in and to bind to DNA [*see illustration on next page*].

Since the DNA molecule becomes longer and stiffer on binding an intercalating dye, one usually observes an increase in the viscosity of DNA solutions and a decrease in the rate at which DNA sediments in an ultracentrifuge. These two effects on the hydrodynamic behavior of DNA are indicative of an intercalative process. They have been observed for a large number of intercalating drugs and antibiotics that bind to DNA. It was therefore puzzling that actinomycin yielded precisely opposite results. Characteristically one observes a decrease in viscosity and an increase in the sedimentation rate when adding actinomycin to DNA solutions. How could this paradox be resolved if in fact actinomycin was intercalating into the DNA helix?

The paradox was resolved by Werner Müller of the University of Göttingen and Donald M. Crothers of Yale University. It was known that in aqueous solution actinomycin molecules tend to dimerize (that is, to aggregate in pairs). Although the precise manner in which this happens was not understood, it seemed reasonable to assume that the aggregation reflects an interaction between either the phenoxazone rings or the peptide groups of the actinomycin molecules. Müller and Crothers reasoned that if actinomycin does bind to DNA by intercalation, the puzzling hydrodynamic observations could be explained by peptide-peptide interactions between bound actinomycin molecules. That would tend to clump the DNA, reducing its viscosity and increasing its sedimentation rate. The idea was tested in the following way.

The DNA was first cut into pieces a few hundred base pairs long. DNA molecules of this size behave like rigid rods and cannot easily fold back on themselves as longer polymers can. Actinomycin was then added to these "sheared" DNA preparations. Sure enough, Müller and Crothers observed the hydrodynamic changes expected for an intercalating dye: an increase in viscosity and a decrease in sedimentation rate. They went on to perform a number of additional experiments, all of which supported the intercalation concept.

The notion that actinomycin binds to DNA through intercalation was further supported by the finding that actinomycin unwinds "supercoiled" DNA. This important additional piece of evidence was provided a few years ago by Michael Waring of the University of Cambridge. Closed circular DNA is an essential intermediate in the life cycle of many viruses, and it can readily be prepared in the laboratory. During the rep-



CONCEPT OF INTERCALATION was first proposed as the most probable mode of action between DNA and a class of mutation-causing compounds called the aminoacridines. Molecules of this class (*colored block*) are believed to bind to the DNA double helix (*ribbonlike structure*) by sliding between adjacent base pairs (*gray blocks*). The DNA molecule must unwind slightly (18 degrees) in the process, enabling the adjacent base pairs to separate just far enough (3.4 angstroms) to allow the aminoacridine molecule to fit in. Since the DNA molecule becomes longer and stiffer on binding an intercalating dye, one characteristically observes an increase in the viscosity of DNA solutions and a decrease in the sedimentation constant of DNA. The fact that these two effects are observed when actinomycin is added to solutions of cut-up DNA molecules suggests that actinomycin also binds to DNA through intercalation.

licative cycle of the virus its DNA exists as a double circular structure consisting of right-handed supercoils. DNA in this form has a more compact structure and therefore sediments more rapidly in the ultracentrifuge. If one adds an intercalative dye to the DNA preparation, one characteristically observes first a decrease in its sedimentation rate and then an increase [*see illustration on opposite page*]. This behavior can be explained as follows.

An intercalative dye unwinds the DNA helix at the immediate site of intercalation. The sense in which this unwinding occurs is such that progressive binding of the dye relieves the strain in a right-handed supercoiled DNA structure by reducing the number of its supercoils. As this happens the DNA becomes longer and stiffer and loses its original compact structure. It therefore sediments more slowly in the ultracentrifuge. When enough dye is bound to closed circular DNA, all superhelix structure is lost; further binding of the dye causes the appearance of left-handed supercoils and a reappearance of the compact superhelix form. This is detected by an increase in the rate at which DNA sediments in the ultracentrifuge. The hydrodynamic properties of closed circular DNA in the presence of an intercalating dye had been carefully studied by Waring and others. The technique is now a standard one for deciding whether or not a given drug or dye binds to DNA by intercalation. By these criteria, therefore, actinomycin was clearly intercalating into DNA.

It was against this background that our group at the University of Rochester became interested in the three-dimensional aspect of the binding of actinomycin to DNA. Our research had previously centered on trying to understand the phenomenon of cocrystallization between base-pair constituents in DNA. These studies had demonstrated that compounds such as guanine and cytosine possess a great deal of intrinsic hydrogen-bonding specificity in solution and crystallize together as complexes in the solid state. We reasoned that the actinomycin-deoxyguanosine complex discovered earlier by Kersten might have some bearing on our understanding of the actinomycin-DNA interaction, and therefore we proceeded to attempt the cocrystallization of these compounds from a mixture of ethanol and water. To our amazement we discovered large single crystals of an actinomycin-deoxyguanosine complex. One of the most interesting features of this complex was the fact that it contained precisely two deoxyguanosine molecules for every actinomycin molecule. Little did we realize that hidden in this simple ratio was the key to an understanding of the binding of actinomycin to DNA.

Once a complex of this type has been crystallized one can visualize its three-dimensional structure at the atomic level by means of X-ray crystallography. Without going into a detailed discussion of this technique, suffice it to say that the determination of the crystal structure of the actinomycin-deoxyguanosine complex, one of the largest organic structures of its type ever determined, required 14 months of continuous labor on the part of workers at Rochester and at the University of Michigan. Although small by protein standards, this structure has been a remarkable one not only in

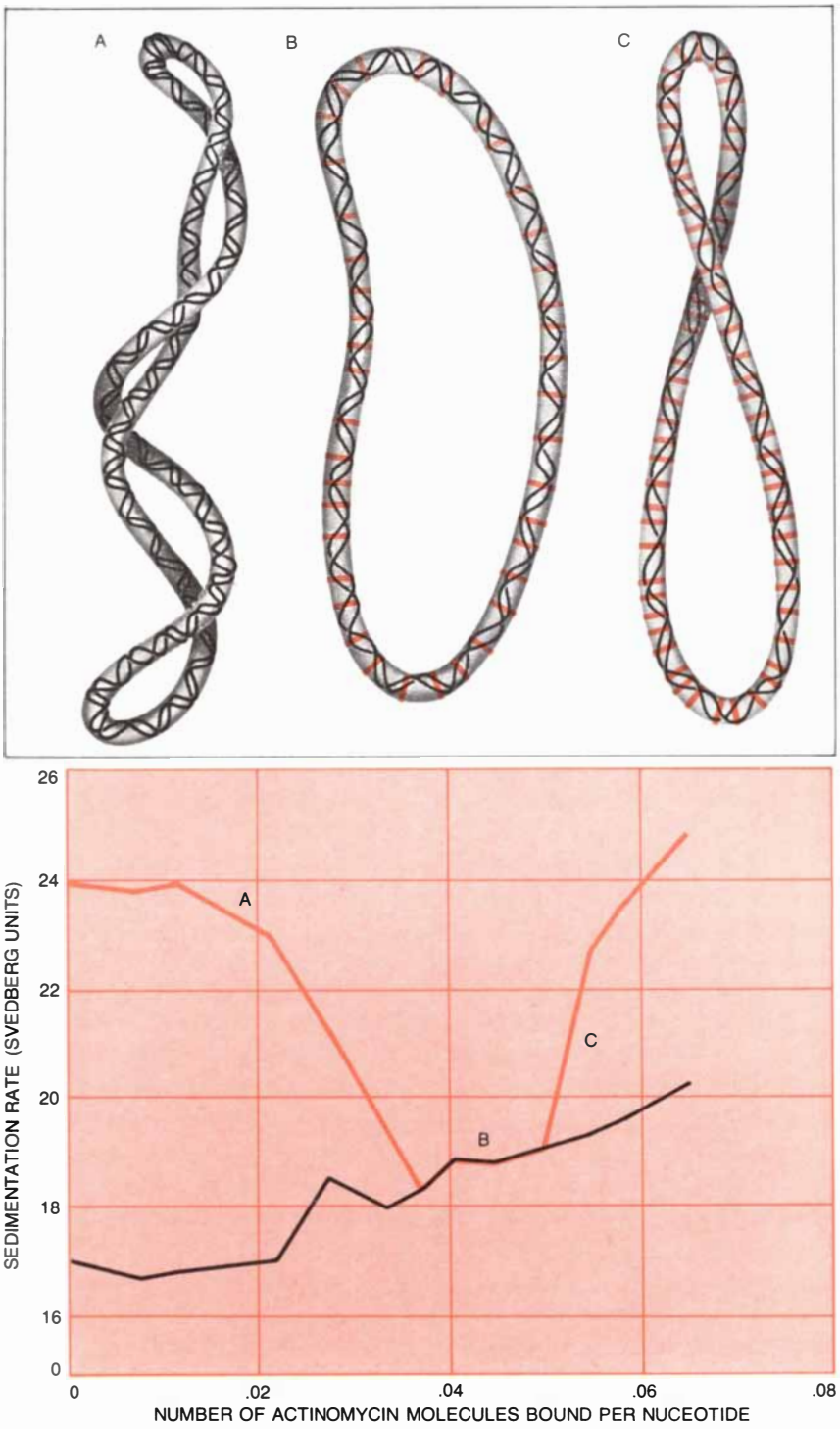
illuminating the nature of actinomycin-DNA binding but also in heralding the concept that symmetry is exploited in the interactions of proteins with nucleic acids.

The first discovery concerning the three-dimensional structure of actinomycin is that the two pentapeptide chains are related by twofold symmetry. In other words, they are twisted with respect to each other by 180 degrees of arc. The phenoxazone-ring system lies roughly perpendicular to the chains and projects well away from them. This can be seen in computer-assisted drawings of the actinomycin molecule as determined by X-ray crystallography [*see illustration on next page*]. The conformations of the peptide linkages are also surprising. Normally peptide linkages in proteins exist in the *trans* conformation (referring to a particular spatial arrangement of atoms around the peptide bond). In actinomycin two peptide linkages exist in the *cis* conformation. Because of the existence of these *cis* linkages it had not been possible to predict accurately the three-dimensional structure of actinomycin from model-building studies alone. Strong hydrogen bonds connect neighboring cyclic pentapeptide chains. The molecule has little flexibility, owing to the tight cyclic nature of both the pentapeptide chains and the hydrogen bonds connecting them.

In keeping with the twofold symmetry of the complex the two deoxyguanosine molecules interact with the two cyclic pentapeptide chains and stack on alternate sides of the phenoxazone-ring system [*see illustration on page 89*]. Strong hydrogen bonds connect the No. 2 amino groups of the guanine with the carbonyl oxygens of both threonines. Weaker hydrogen bonds connect a nitrogen atom in guanine with the nitrogen-hydrogen groups on these same threonines. These hydrogen bonds play a key role in the association and explain the specificity that actinomycin demonstrates for deoxyguanosine molecules in the model reaction and in the binding reaction with DNA.

The 2 : 1 deoxyguanosine-to-actinomycin ratio of the complex is a direct consequence of the twofold symmetry of actinomycin and reflects the two chemically equivalent binding sites available to deoxyguanosine in forming the complex.

Let us now consider how one constructs a picture of the binding of actinomycin to DNA, utilizing the three-dimensional information about the actinomycin-deoxyguanosine complex derived



SENSITIVE TEST FOR INTERCALATION is performed by following the hydrodynamic properties of "supercoiled" closed circular DNA in the presence of increasing concentrations of a drug or dye. An intercalative dye unwinds the DNA double helix at the immediate site of the intercalation. The sense in which this unwinding occurs is such that progressive binding of the dye relieves the strain in a right-handed supercoiled DNA structure (*A*) by reducing the number of its supercoils. As the unwinding proceeds the DNA becomes longer and stiffer, losing its original compact structure. It therefore sediments more slowly in an ultracentrifuge. When enough dye is bound to the closed circular DNA, all superhelical structure is lost (*B*); further binding of the dye causes the appearance of left-handed supercoils (*C*) and eventually the reappearance of the compact superhelical form. This is detected by an increase in the rate at which the DNA sediments in the ultracentrifuge. When the experiment is performed with actinomycin D, the results show that the drug unwinds supercoiled closed circular DNA in a way consistent with the intercalation concept (*colored curve*). In a control experiment "nicked" closed circular DNA shows little change in its sedimentation properties with the addition of actinomycin (*black curve*).

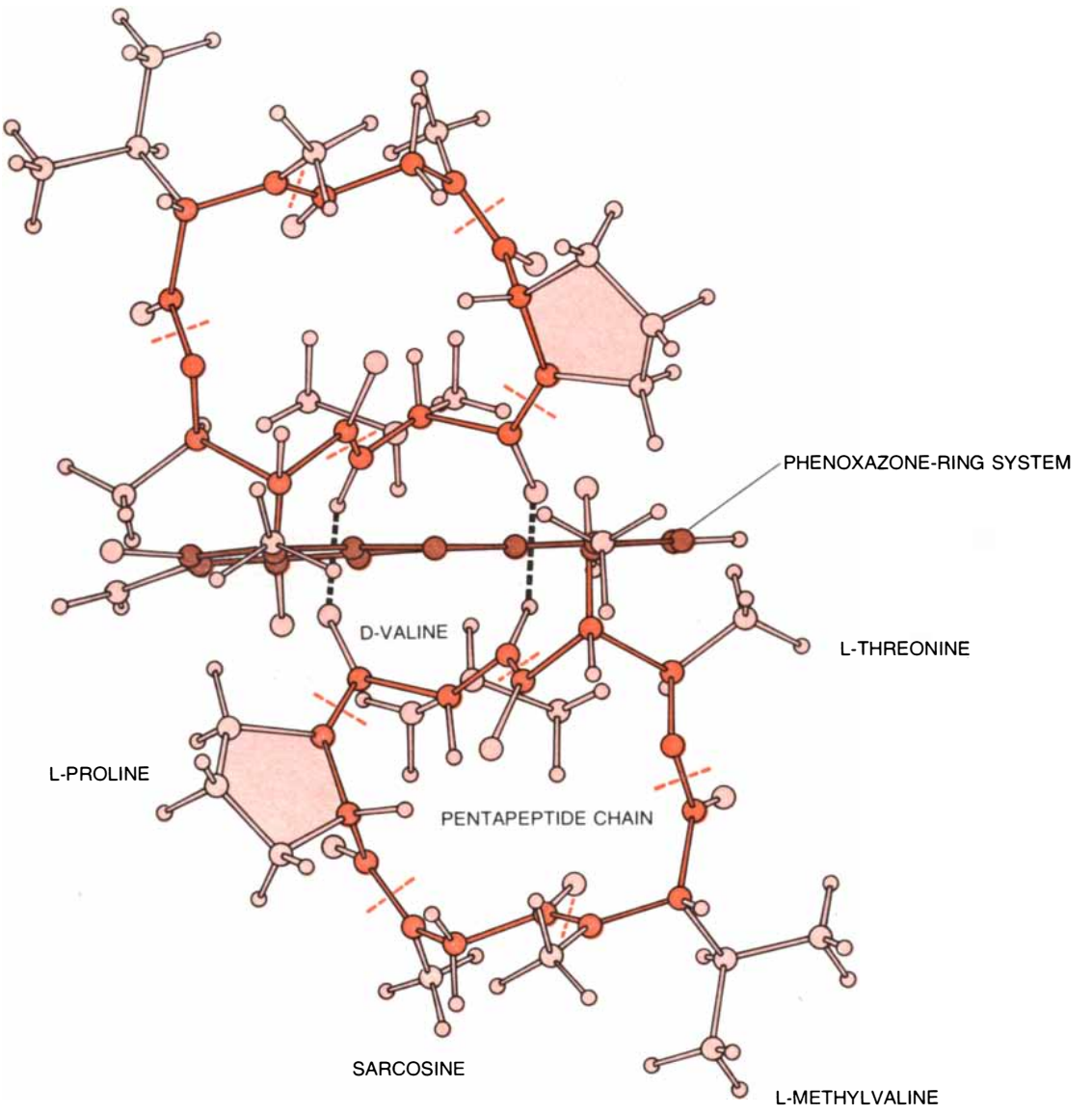
from X-ray crystallography. First deoxycytidine 5′-phosphate is placed opposite deoxyguanosine to form a hydrogen-bonded guanine-cytosine base pair. Adjacent deoxyguanosine and deoxycytidine residues immediately above and below the phenoxazone rings can then be connected by a phosphodiester bridge. This gives rise to an alternating guanine-cytosine sequence. Two base pairs are next added above and below the intercalated guanine-cytosine base-paired sequence. This completes the assembly of the actinomycin-DNA model complex.

Stereoscopic photographs of the assembly steps have been made with the aid of a computer-generated oscilloscope display of the model devised by Louis Katz of Columbia University [*see illustration on page 91*]. An artist's rendition of the complex further enhances visualization of the structure [*see illustration on page 83*].

In sum, the major features of actinomycin-DNA binding are (1) the intercalation of the phenoxazone-ring system on actinomycin between guanine-cytosine sequences in DNA; (2) the hydrogen-bonding between the peptide chain and the nucleic acid, the peptide portion of the actinomycin molecule lying in the narrow groove of the DNA helix and being hydrogen-bonded to deoxyguanosines on opposite DNA chains, and (3) the twofold axis of symmetry relating pentapeptide chains on the actinomycin molecule coinciding with the twofold axis of symmetry on DNA.

The most fundamental prediction of the three-dimensional actinomycin-DNA binding model is that actinomycin should preferentially bind alternating guanine-cytosine base sequences in DNA. The prediction has been confirmed in two different ways.

Robert D. Wells and John Larson of the University of Wisconsin have carried out detailed studies of how actinomycin binds to a large number of different DNA-like polymers incorporating small repetitive base sequences. Their results show that, as predicted, actinomycin binds the alternating guanine-cytosine polymer tightest and most efficiently compared with all the other synthetic DNA-like polymers tested. Other sequences containing guanine can bind to

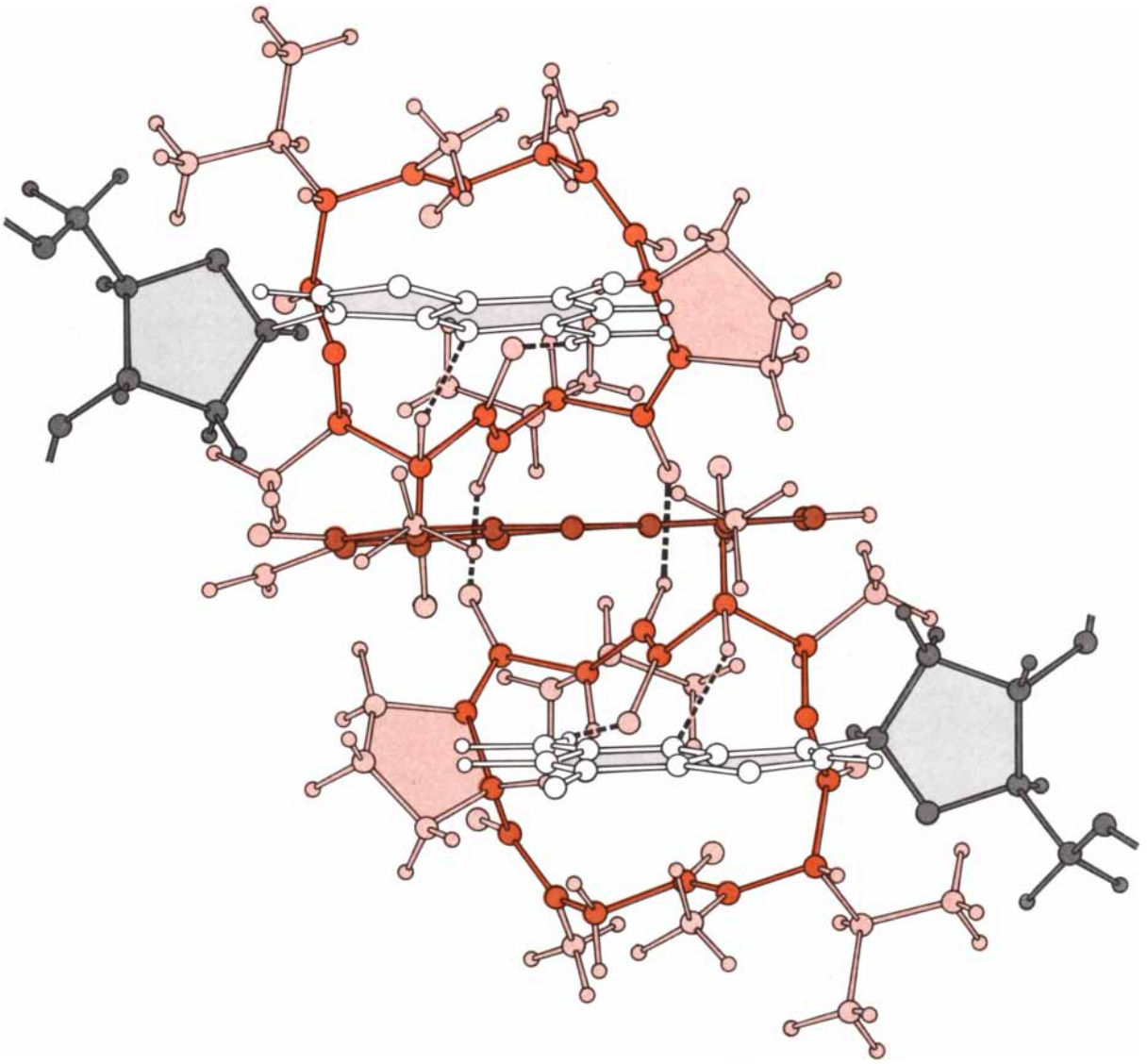


MOLECULE OF ACTINOMYCIN D, its three-dimensional structure revealed by X-ray crystallography, is depicted here with its phenoxazone-ring system viewed edge on, showing that the two pentapeptide chains are related by an approximate twofold axis of symmetry. The flat ring system lies roughly perpendicular to the chains and projects well away from them. The molecule is quite rigid, owing to the tight cyclic nature of the pentapeptide chains and to the hydrogen bonds connecting them (*broken black lines*).

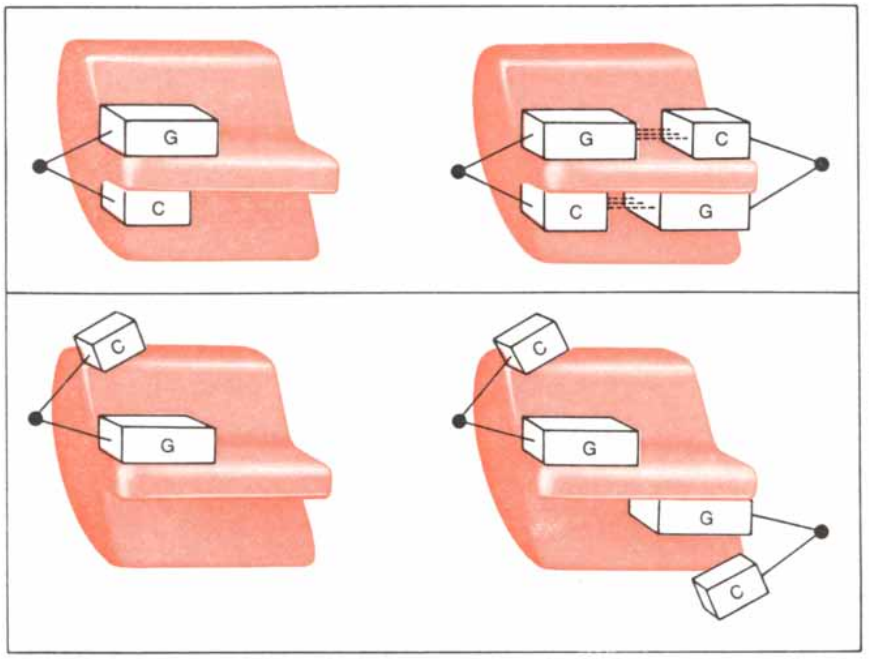
actinomycin, but not as tightly or efficiently.

The interaction of actinomycin with various dinucleotides has been studied spectroscopically by Thomas Krugh at Rochester. These studies indicate that the guanine-cytosine sequence binds "cooperatively" to actinomycin, whereas the interaction of other sequences with actinomycin is not cooperative. Cooperativity in this case means that the binding of one guanine-cytosine dinucleotide molecule to actinomycin facilitates the binding of the second molecule. This can be readily understood if one visualizes an intercalated complex held together by guanine-cytosine base-pairing [*see illustration on next page*]. On the other hand, the dinucleotide with the reverse (cytosine-guanine) sequence does not interact with actinomycin cooperatively. In this case the complex does not intercalate, and the dinucleotide molecules interact with each pentapeptide chain of the actinomycin molecule independently. These and other spectroscopic data support the actinomycin-DNA model derived from X-ray crystallography.

The three-dimensional actinomycin-DNA model reconciles the data that suggested intercalation with the evidence for hydrogen-bonded recognition and, in a sense, is a synthesis of the earlier models for actinomycin-DNA binding. The specificity actinomycin demonstrates in binding double-helical DNA, but not double-helical RNA (or an RNA-DNA hybrid helix), most probably reflects a spatial requirement imposed by the cyclic pentapeptides. The large number of spatial contacts made between the cyclic peptides and atoms in the narrow groove of the DNA helix undoubtedly provide added stabilization to the complex and act to exclude water during its formation. Amino acid substitutions that interfere with this favorable fit would reduce the biological potency of the antibiotic. When proline is replaced by hydroxyproline (or hydroxyproline acetate) in one cyclic pentapeptide, for example, the biological activity of the antibiotic is diminished some twentyfold. When proline is replaced by *L*-allo-hydroxyproline (a steric isomer of hydroxyproline) or *L*-allo-hydroxyproline acetate, however, there is only a small change in



ACTINOMYCIN-DEOXYGUANOSINE COMPLEX also exhibits twofold symmetry. The two deoxyguanosine molecules, each of which consists of guanine (*white*) linked to a deoxyribose sugar (*gray*), are hydrogen-bonded to the two cyclic pentapeptide chains and stack on opposite sides of the phenoxazone-ring system. The hydrogen bonds play a key role in the association and account for the specificity that actinomycin demonstrates for deoxyguanosine both in this model reaction and in the binding reaction with DNA.



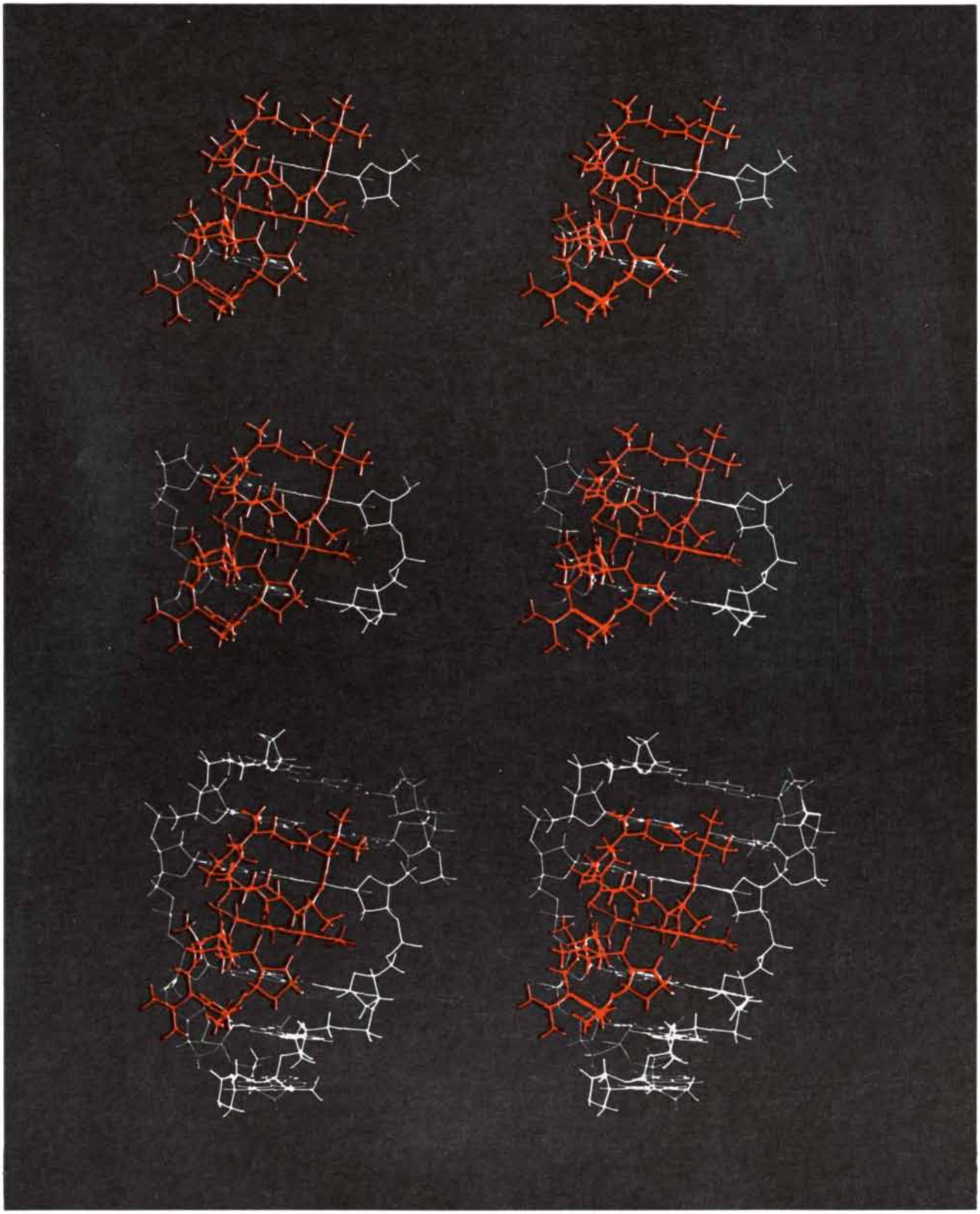
ACTINOMYCIN BINDS COOPERATIVELY to a DNA-like guanosine-cytosine nucleotide, an interpretation indicated by spectroscopic studies. This means that the binding of one guanine-cytosine molecule to actinomycin facilitates the binding of the second molecule (*top*). The dinucleotide with the reverse (cytosine-guanine) base sequence does not bind cooperatively (*bottom*). Spectroscopic findings such as these have tended to support the three-dimensional actinomycin-DNA binding model derived from X-ray crystallography.

biological activity. This position effect is readily interpretable from the three-dimensional model.

The binding of actinomycin to DNA demonstrates two important structural features utilized by DNA in binding other types of molecules. The first of these features, intercalation, is used in binding a large variety of drugs and antibiotics to the DNA helix; the actinomycin-DNA model has provided detailed structural information on this phenomenon. The second feature involves a general principle that several classes of proteins utilize in recognizing symmetrically arranged base sequences in DNA. One such class of proteins is the nuclease enzymes, which cleave DNA at regions containing symmetrically arranged nucleotide sequences. The first known enzyme of this class, a splenic acid deoxyribonuclease, was discovered many years ago by Giorgio Bernardi of the University of Paris. The enzyme is a dimer whose identical subunits are covalently linked. The enzyme cleaves both strands of DNA simultaneously (or very nearly so), and its action is strongly inhibited by actinomycin D. Although there are no sequence data concerning the site on DNA that the enzyme cleaves, Bernardi suggested that the guanine-cytosine sequence is the recognition site. That would allow symmetric recognition for the enzyme-substrate complex and explain the simultaneity in the kinetics of its cleavage. Direct sequence evidence for symmetric recognition, however, was first provided by Thomas J. Kelly, Jr., and Hamilton O. Smith at the Johns Hopkins University School of Medicine, who used highly purified preparations of a nuclease enzyme isolated from the bacterium *Hemophilus influenzae*. This enzyme, one in a class of enzymes known as restriction enzymes, "nicks" DNA (that is, breaks both strands of the DNA double helix) at specific sites, provided that these sites have not first been "modified." (Chemically, modification of DNA means methylation of adenine to 6-methylaminoadenine or cytosine to 5-methylcytosine. This is accomplished by a specific methylase enzyme.) A great deal is now known about the use of symmetric recognition by restriction endonucleases and modification methylases in bacterial systems. Herbert W. Boyer and his colleagues at the University of California School of Medicine in San Francisco demonstrated that a plasmid-induced restriction enzyme known as the R_I restriction enzyme cleaves a symmetric sequence of DNA to generate single-strand ends four nucleotides long. (A plasmid is a circular DNA fragment that is capable of replicating itself and being transmitted between bacteria as a vector for genetic transfer.) Boyer's group proceeded to show that the modification methylase produced by the same plasmid uniquely methylates this sequence, converting an adenine molecule into 6-methylaminoadenine. DNA that has been modified in this way is now immune to attack by the R_I restriction enzyme.

This work has been extended to include another restriction-modification system produced by a different plasmid in *Escherichia coli*, known as the R_{II} system. The R_{II} restriction endonuclease cleaves a symmetric DNA sequence to generate single-strand ends five nucleotides long. The R_{II} modification methylase specifically methylates this sequence. Both the R_I and the R_{II} restriction endonucleases and modification methylases are dimers with identical subunits. Their symmetric interactions with DNA utilize the two different twofold axes of symmetry present on the DNA helix. Restriction endonucleases that generate single-strand ends containing an odd number of nucleotides bind DNA along an axis of symmetry that lies at the level of a base pair. Restriction endonucleases that generate single-strand ends containing an even number of nucleotides bind DNA along an axis of symmetry that lies between two adjacent base pairs. Similar patterns of protein–nucleic acid recognition may be utilized by the modification methylases in their interaction with DNA.

Another class of proteins that utilize symmetry in their interaction with DNA includes the genetic regulatory molecules known as repressors. These proteins bind to specific regions of DNA (called "operator" regions) and inhibit the transcription step in protein synthesis. The nucleotide sequence of two operator regions has recently been independently determined by Walter Gilbert and Mark S. Ptashne of Harvard University. Both sequences incorporate blocks of symmetric sequences that can be utilized in protein–nucleic acid interaction. It is possible that the actinomycin-DNA model may have features in common with these larger repressor-operator complexes. If it should be possible to cocrystallize an operator DNA sequence with a repressor protein, X-ray crystallography may someday be able to provide exciting details of the molecular basis for biological regulation.



KEY STEPS in the assembly of the actinomycin-DNA binding model are portrayed in these four pairs of stereoscopic photographs, made with the aid of a computer-generated oscilloscope display of the model devised by Louis Katz of Columbia University. Actinomycin is shown in color; DNA parts are in white. In the first assembly step (*top*) deoxycytidine 5′-phosphate was placed opposite deoxyguanosine to form a hydrogen-bonded guanosine-cytosine base pair. In the next step (*middle*) adjacent deoxyguanosine and deoxycytidine residues immediately above and below the phenoxazone-ring system are connected by a phosphodiester bridge, giving rise to an alternating guanine-cytosine sequence. In the final step (*bottom*) two base pairs are added above and below the intercalated guanine-cytosine base-paired sequence, thus completing the complex. In this projection most of the base pairs are viewed edge on.

The Rise of Coal Technology

The Industrial Revolution in England was the culmination of two centuries of earlier technological development whose distinctive characteristic was the widespread and sophisticated use of coal

by John R. Harris

The genesis of the Industrial Revolution is conventionally set in England in the second half of the 18th century. The technological developments usually associated with it are a series of inventions, in particular James Watt's steam engine and a number of new machines in the textile industry, such as the power loom and the spinning jenny. The significance of the technical advances made in this period is undisputed; they proved to be powerful instruments, capable of transforming the social and economic order. The inventions of the late 18th century, however, were largely the culmination of an earlier period of technical development, whose history is less well known. The most distinctive characteristic of this earlier technology, which came to dominate British industry in the two centuries that preceded the Industrial Revolution, was the increasingly widespread and sophisticated utilization of coal in industry.

In those 200 years coal replaced wood and charcoal in many industrial processes, among them glassmaking and the smelting of nonferrous metals. The mining of coal itself became an industry of considerable size, and the need to transport coal from the mining regions to centers of population and industry by straining existing means of transport eventually led to the creation of an extensive network of turnpikes, navigable rivers and canals. By the middle of the 18th century this coal technology clearly distinguished the industrial development of England from that of other nations of comparable wealth and culture.

Before the Industrial Revolution began, coal had become almost the sole fuel of British industry, although not all industrial development was related to coal technology. The principal sources of industrial power at the time were not fuels at all but the horse and wind and water mills; steam did not emerge until after 1700. Moreover, until the late 18th century the connection between the coal-fueled industries and the new textile machinery was tenuous. Nevertheless, coal technology was the most significant and fertile innovation in this period of industrial development. As techniques were invented in order to introduce or extend the utilization of coal in a particular industry, the same techniques were taken up by an ever widening circle of other industries. As a conse-

BRITISH GLASSWORKS (*left*) used coal in a version of the reverberatory furnace with an updraft cone (*a*). The reverberatory furnace, which played a vital role in the growth of several other industries, was so named because it "reverberated," or reflected, the heat of

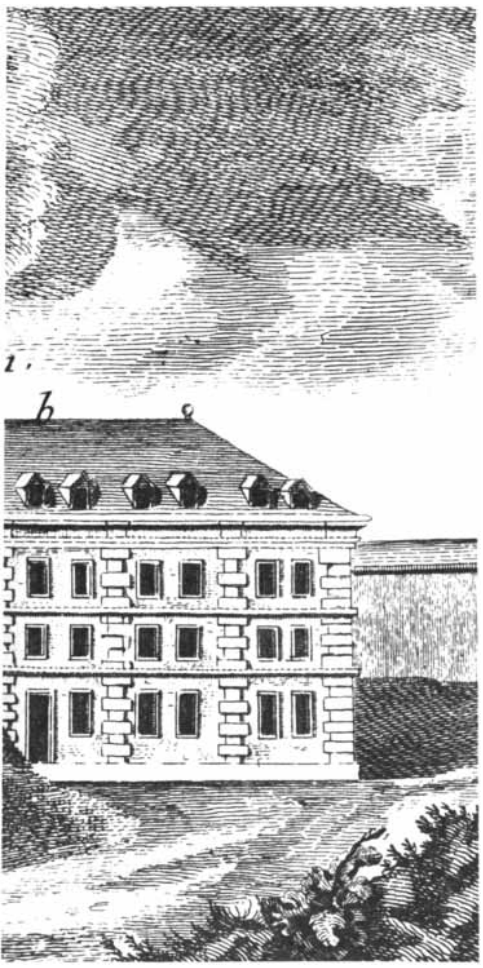
quence there emerged in England by the 18th century a large and diverse industrial community bound together by a technology held in common. This technology, based on coal, was the foundation for the accelerating industrial development that began in the late 18th century.

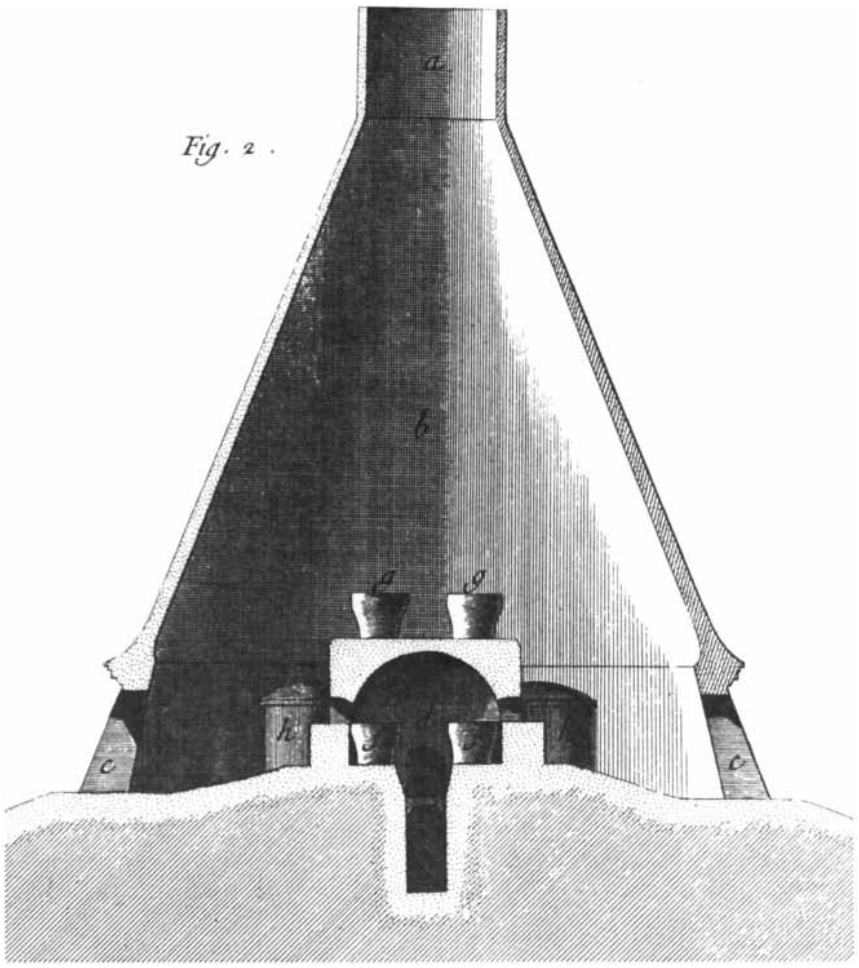
The early importance of coal to the British economy was established in the 1930's by John U. Nef of the University of Chicago. In *The Rise of the British Coal Industry* Nef demonstrated that coal had been adopted by much of British industry by the middle of the 17th century. He showed that almost every British coalfield was being exploited between 1540 and 1640, a period he regarded as seminal. He calculated that British coal production at the end of the 17th century was between two and three million tons per year; although the accuracy of this estimate has been questioned, Nef was certainly correct in saying that British production was of a different order of magnitude from that of any other nation and that British superiority in coal output was maintained throughout the 18th century.

A few of Nef's contentions, however, are less satisfactory. For example, it is probably an exaggeration of the importance of coal to say that it significantly influenced the size and capitalization of and number of people employed by British industrial units in the 17th century, or that such changes might constitute a prior industrial revolution. Another disputed point, and one that is important to an understanding of the antecedents of the Industrial Revolution, is Nef's contention that the century ending about 1640 was succeeded by a period of much less significance to technological development, until rapid progress was resumed in the late 18th century.

Nef did show that by 1640 many British industries had adopted coal. In the Middle Ages coal had been employed, where it was available, by blacksmiths, armorers and some other metalworkers; by the 16th century it had spread to coppersmiths, pewterers and gunsmiths, and it was subsequently adopted in wiredrawing. At the beginning of the Tudor period in the late 15th century coal was being burned on the coasts of England to extract salt from seawater, and not long after it was applied to lime-burning. In dyeing and some other textile-finishing operations there are early instances of experiments with coal fuel, and in these trades and in feltmaking the practice became widespread under the late Tudors, near the end of the 16th century. The manufacture of coke began in the 1620's, when the new fuel was adopted by the brewing industry for drying malt. By the early 17th century coal had entered brick, tile and earthenware manufacture; by the mid-17th century it was being employed in the infant chemical industry in the refining of saltpeter, alum and copperas, in the making of gunpowder and in the boiling of starch, soap and sugar.

The production of glass with coal,





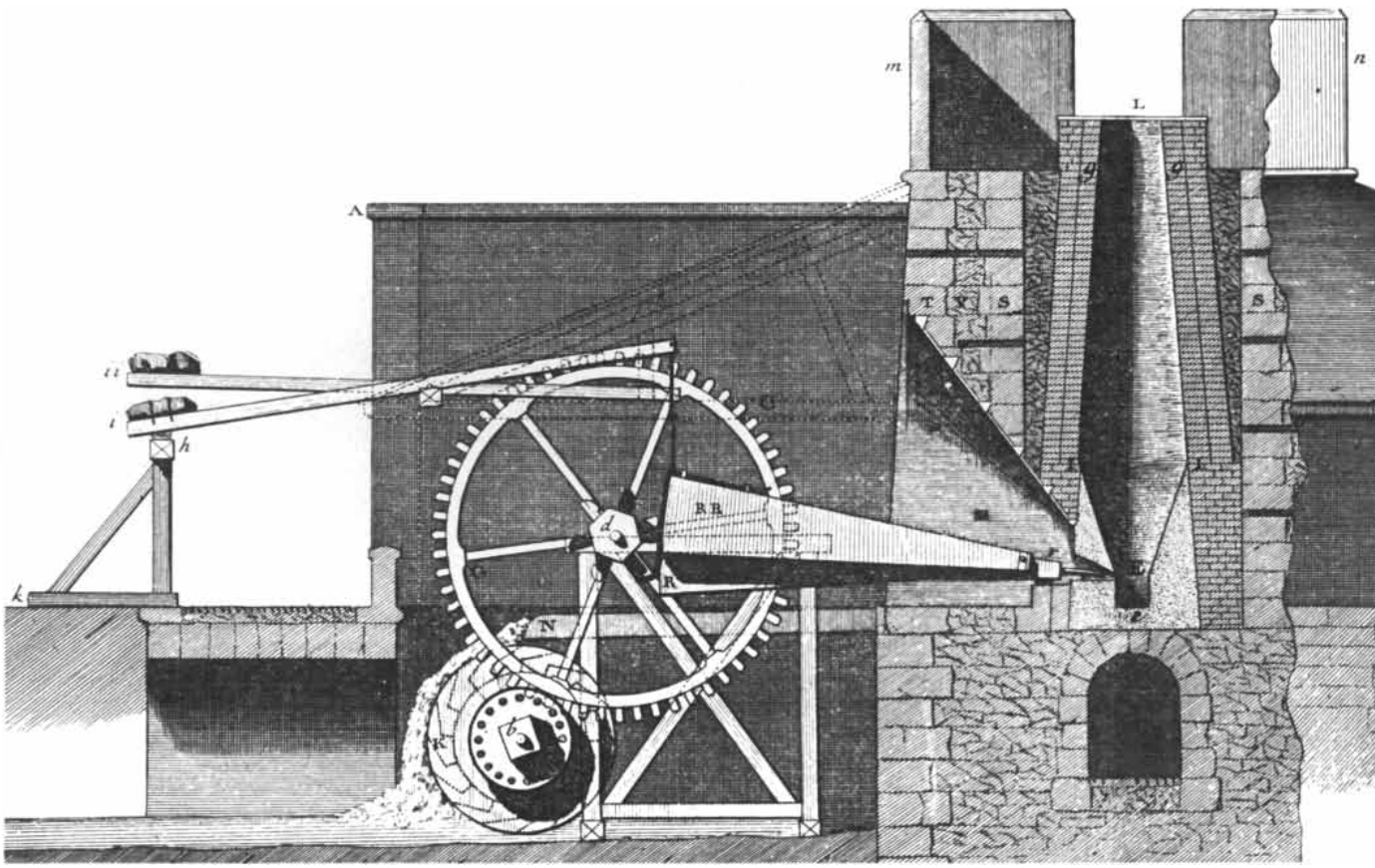
combustion onto the material being heated. In this particular furnace glass materials were heated in pots or crucibles with open tops (*section drawing*). In England many of the vessels were covered. The illustrations are from Denis Diderot's *L'Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers*. The style of the building to right of the furnace is distinctly French.

which began in 1612, was of particular significance. In glassmaking coal was burned in a variant form of the device called the reverberatory furnace, which later played an important role in the growth of several other major industries [*see illustrations on preceding two pages*]. Such furnaces were well described by a writer of the time as "Furnaces of division, wherein the material or metal to be melted or wrought is kept divided from the Fewell." They embodied an arched roof, which "reverberated," or reflected, the heat of combustion onto the material to be heated. This arrangement prevented contamination by impurities in the fuel; in the glass industry a further measure taken to achieve this end was the enclosure of the glass mixture in a covered crucible.

As Nef made clear, these advances in coal technology were of great importance to the future of British industrial development, but, contrary to Nef's contention, in the century that followed there was no period of technological stagnation or retardation. After the revolution of 1640 and the interregnum the use of coal continued to spread to new industries, and methods for employing the new fuel became increasingly sophisticated.

Some of the new developments were simply refinements or extensions of older ones. For example, methods of boiling salt with coal were improved and adopted at inland salt fields. Other new applications required true innovation in techniques or materials. The manufacture of glass in closed crucibles proved particularly influential, because the method required fireclay containers capable of withstanding temperatures higher than those evolved in wood-burning furnaces. Once such containers had been successfully fabricated for glassmaking they subsequently appeared in other industries, where they made new processes possible. By the end of the 17th century steel was being made in covered containers in a closed furnace; this English steel gained a high reputation in Continental Europe, although its basic raw material was usually Swedish iron. In the 1740's the crucible was involved in another contribution to British metallurgy when Benjamin Huntsman, a Sheffield clockmaker who was seeking a suitable metal for watch springs, developed a method for producing cast steel in crucibles. The glass industry itself made an important advance in the 1670's with the invention of flint glass, an expensive glass suitable for cutting or etching that derives its distinctive properties from its content of lead. Flint glass came to be known as English crystal and was not successfully copied by the French until the late 18th century.

An even more significant development, however, was the first smelting of nonferrous metals in a reverberatory furnace, which was achieved in the 1680's; it was important economically as well as

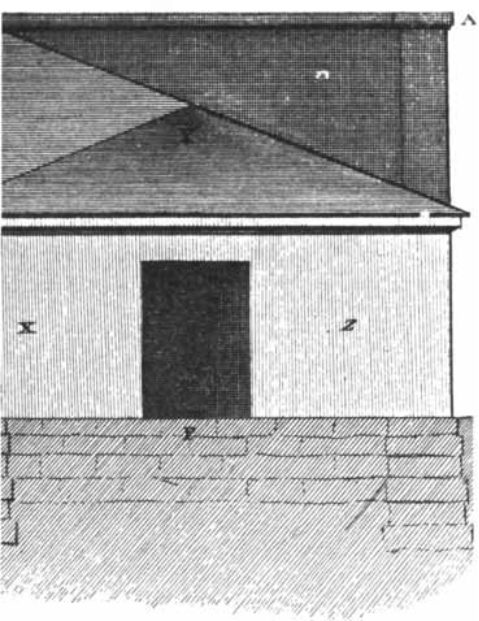


EIGHTEENTH-CENTURY BLAST FURNACE of the charcoal type is clearly shown in this illustration from Diderot's encyclopedia. The height of the shaft (*EL*) was about 25 feet. The blast was supplied by a pair of bellows (*RR*) powered by water and blowing alternately. The early coke furnaces were similar in principle and construction but the lines of the interior of the furnace may have differed slightly. A charge of iron ore (washed, dried and pulverized), charcoal and a limestone flux were fed into the throat of the furnace (*L*). The furnace was kept full as the charge descended through the shaft, sustained by the outward flare of the

technologically, because England, by contemporary standards, was rich in ores of copper, tin, lead and zinc. The reverberatory method of smelting was introduced in Bristol, and by 1702 good brass was being made there with coal fuel.

The reverberatory furnace thus became one of the distinguishing characteristics of British technology by the 18th century, and the advantages it offered led to British superiority in a number of trades. Before 1700 England had taken the lead in clock and watch manufacture, partly because of the quality of the tools available; these included early machine tools. The best files in Europe were also British-made, and England was coming to dominate the production of inexpensive earthenware, which was fired in coal-fueled kilns.

As might be expected, the expanding industrial employment of coal led to increased demand for the fuel and thereby to improvements and innovations in the coal-mining industry itself. The "coal-viewers," or mining engineers, of the North East of England became expert in the use of the boring rod to find new seams and turned the railed way into an industrial device of major significance. Perhaps the most remarkable development in mining, however, was the invention of a machine to pump ground water from the mine shaft: the Newcomen engine.



boshes, or sides, of the furnace (*EI*). The blast of air rushing up through the descending mass maintained combustion. The charge settled as charcoal was consumed and as iron and slag were drawn off hearth (*E*).

In the first decade of the 18th century there were two revolutionary advances in British technology, both of them associated with coal. One was the Newcomen engine, the other was the first smelting of iron with coke by Abraham Darby.

Darby first made iron with coal in 1709 in a blast furnace at Coalbrookdale in Shropshire, having moved there from Bristol. In Bristol, Darby had been involved in the brass industry at a time when coke was employed in the reverberatory furnaces that produced the necessary copper. In the blast furnace, unlike the reverberatory furnace, the fuel and ore are in contact. Air forced through the furnace burns the fuel at high temperature; the ore is reduced and the molten iron is tapped off at the bottom [*see illustration at left*]. The product is pig iron, which has a relatively high carbon content; it is brittle and cannot be worked by hammering like wrought iron, but it is easily cast.

Although Darby's invention enabled British foundrymen to establish a commanding lead in the production of large castings, the effects of the new technique on the economy and technology of the nation as a whole were of limited consequence for several decades. Unlike most of the pig iron made during the period, which was smelted with charcoal, the pig iron made by Darby's method could not be converted in a forge to wrought iron, the metal most in demand. Darby's discovery was nevertheless a breakthrough, an invention that was to be of immense importance in the future.

The steam engine devised by Thomas Newcomen about 1705 is one of the major monuments in the history of technology; it was the first practical source of motive power independent of animal strength and the elements, and it might be compared in importance to the invention of the wheel and axle or the discovery of iron. Newcomen's engine was preceded by one built by Thomas Savery, an English military engineer, in 1698, but Savery's engine was not of commercial significance. In the Newcomen engine steam was admitted to a large, open-topped cylinder at low pressure and the cylinder was then cooled by injecting water; as the steam condensed it created a partial vacuum and a piston was pushed into the cylinder by atmospheric pressure. The reciprocating motion thus produced was utilized through a rocking beam; the crank for converting reciprocating motion to rotary motion was not applied to the steam engine until the 1780's [*see illustration on next page*].

The Newcomen engines were fueled by coal, but the engine has a more crucial connection with the coal industry. Its first major application was the "unwatering" of mines, a task for which waterpower was rarely suitable. It was adopted remarkably quickly and proved decisive to the continued growth of coal mining and nonferrous-metal mining in England. J. S. Allen of the Newcomen Society has shown that at least 104 of the engines were built before 1733, and it has been estimated that by the end of the 18th century there were about 1,500, perhaps three times as many as there were engines of the Watt type.

The series of developments chronicled above were all applied to industrial purposes within 50 years of the Restoration; they strongly suggest that technological growth was no less rapid in this period than in the century from 1540 to 1640 singled out by Nef. Since there is little evidence that industrial inventiveness declined in the next century, and since the importance of the chief inventions of the later period was certainly greater, Nef's "revolutionary" century therefore loses much of its significance.

Nevertheless, it is important to point out, as Nef did, that during the 17th century British technology reversed its position with respect to the rest of Europe. In 1600 England was parasitic on Continental technology and was avid to import skilled practitioners; by 1700 it had come to possess techniques envied on the Continent.

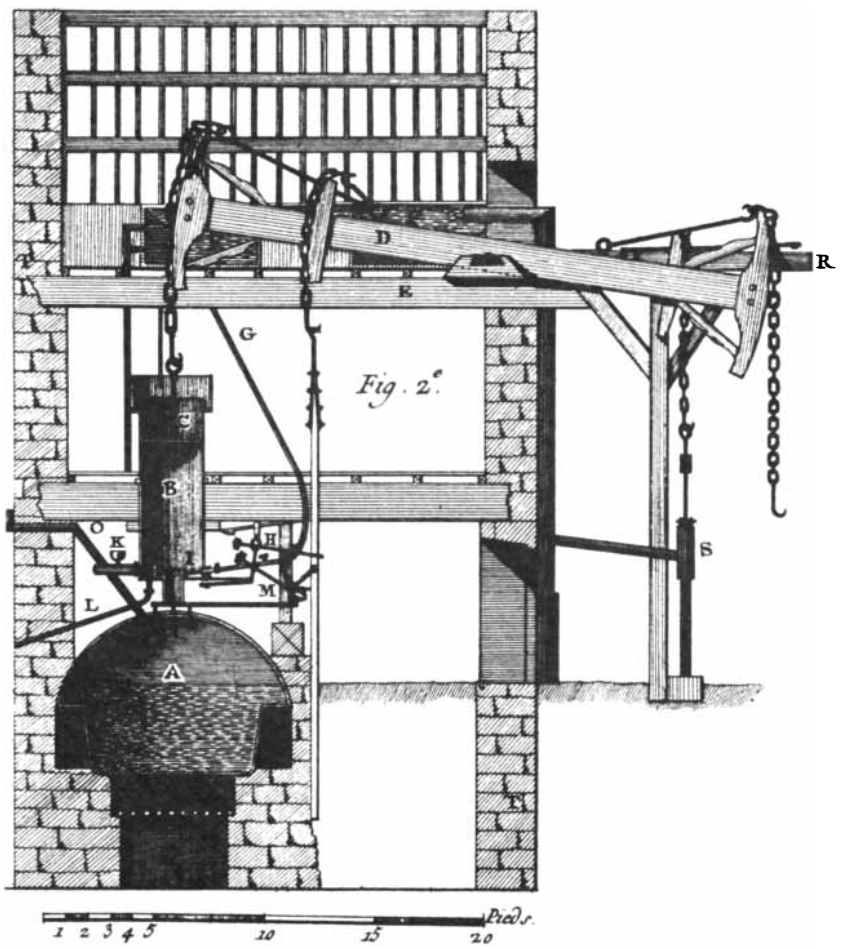
Although some of the innovations responsible for this change had little or nothing to do with coal, it nevertheless seems clear that the utilization of coal was the line of development with the greatest potential. Not only were the new industrial applications of coal numerous and individually important; many of these discoveries were related to one another and interlocked to form a cohesive technology founded on shared knowledge.

The introduction of coal in iron smelting provides an instructive example. Although the first success did not come until 1709 and the practice did not become general until the 1780's, the con-

version of the iron industry to coal had long been anticipated. In 1631 a Shropshire ironmaster wrote: "It may fall out hereafter that iron may be made with pit coal, then my coal will stand instead for my furnace, and coals may be brought to my furnace by waggons." The attempts of Dud Dudley to smelt iron with coal in the 1660's are often cited, and others pursued the same goal. William Rees of the University of Wales has compiled a list of 22 processes for which patents or licenses were issued between 1550 and 1695 for the making of iron by methods that do not employ charcoal; of these, 19 clearly involve coal.

Most of the early innovators were preoccupied with adapting the reverberatory furnace rather than the blast furnace to the production of iron; in fact, Rees has designated the era a "century of effort to apply the reverberatory principle to the making of iron." This fixed purpose is understandable considering the success of the coal-fueled reverberatory furnace in the refining of nonferrous metals and in many other processes. It should also be noted that the reverberatory method was eventually applied successfully to the conversion of pig iron to wrought iron. The conversion was achieved by a method called the puddling process, in which pig iron was remelted and manipulated in a coal-fired reverberatory furnace. The process was invented by Henry Cort in the 1780's.

The experiments in iron smelting attested to by patents and licenses surely represent only a small portion of those actually performed; indeed, there can be no doubt that the effort to produce inexpensive iron was carried out assiduously and almost continuously throughout the two centuries preceding the Industrial Revolution. Iron smelting, like other industries, was endeavoring to include itself within an emerging coal technology; this objective gave it a technological program, a focus of enterprise. Iron was merely the last major industry to make the essential transition.



NEWCOMEN ENGINE, the steam engine developed by Thomas Newcomen about 1705, was the first practical source of motive power independent of muscle, water or wind. Its first major application was the removal of ground water from mines, and it was vital for the growth of mining in England. Steam was admitted at low pressure to a large cylinder (*B*), which was then cooled. As the steam condensed, a piston (*C*) was pushed into the cylinder by atmospheric pressure, thus operating the pump rods attached to rocking beam (*D*).

As it became clear in many segments of the economy that coal contained the potential of more efficient production and lower costs, industries that had not yet adopted coal looked to those that had made the change most successfully and borrowed and adapted techniques and apparatus already available. Moreover, each industry that switched to coal found it necessary to innovate and to modify existing equipment and procedures in order to accommodate the new fuel. Higher temperatures attained by burning coal, for example, demanded modifications in the design of furnaces and made the need for improved refractory materials urgent.

In the search for better firebrick and more durable crucibles the British were to a great extent aided by ample and easily accessible natural resources. An excellent fireclay was mined at Stourbridge in Worcestershire, convenient to several industrial regions; in many cases fireclay was found in the coal seams themselves. The ideal combination was found in some mines in Staffordshire, where coal, an iron ore and fireclay were brought up the same shaft.

Problems of adapting to the new technology were solved by the exchange of knowledge within and between industries. Information on the varieties of coal suitable for different purposes, for example, was passed from industry to industry. Of particular value was information on which coals could be successfully converted to coke and on methods of making coke; the lack of this information was an impediment to those who first attempted to make coke-smelted iron on the Continent. As the wealth of experience with coal grew and as the battery of devices for its exploitation increased, the difficulties of conversion must surely have been lessened, but innovation and adaptation remained necessities. Rarely was it possible to substitute coal for wood without also replacing or at least modifying the grate, the furnace, the boiler and the tools used in firing and changing the mode of operation of the men who did the stoking. The need for continual innovation, the premium placed on ingenuity and the success achieved by it must have had a profound effect on the attitude of British industry toward technological change.

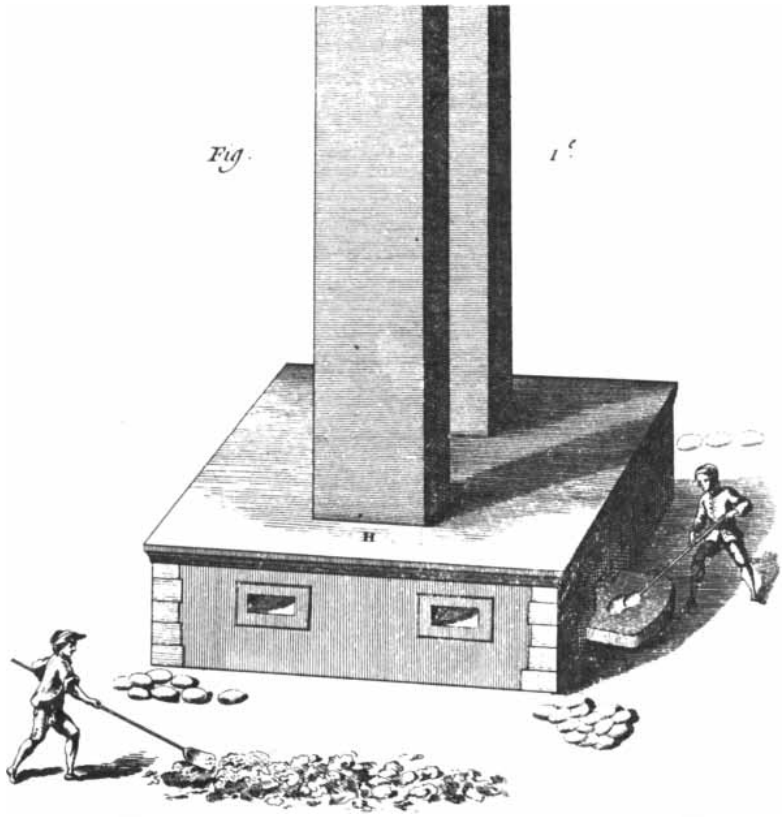
To a large extent coal technology during this period evolved on an empirical

basis, and changes of considerable magnitude could be introduced by the workman or artisan. One consequence of this mode of development is that historians have only a very uneven record of how changes came about and of the motives and methods of discovery of those who introduced them. Although a tradition of scientific and technical publishing was already established in England, the printed literature pertaining to coal technology is scanty. For example, England had the world's largest copper-smelting industry in the 18th century, yet we are dependent on Swedish, French and German works for descriptions of it. Similarly, the most detailed work on the coal industry and its operation (by J. F. C. Morand) is French.

Two possible explanations of this paucity of written records seem likely. One is that techniques for selecting and utilizing coal were already familiar at the end of the 17th century, when scientific literature first began to grow, and no purpose would have been served by publishing papers on methods and apparatus that were already known. The other possibility is that written exposition was not the best way to communicate the skills of the craftsman. Writers on technology tended to be concerned with underlying principles, but the essential knowledge to be communicated in transferring a technology consists of manual skills, or the knack of a process, and a knack is difficult to convey by word or diagram.

Again, the appearance of a literature dealing with industrial methods and materials may reflect not mastery of techniques but a desire to hasten industrial development by importing techniques from elsewhere. This hypothesis would explain the relative abundance of literature on furnace industries and coal mining in France, where the technology itself clearly lagged behind that of England. In spite of the extensive literature on the Continent, however, attempts to transplant British coal-based technology had little success until after the Industrial Revolution was well under way.

The reason for these failures is not difficult to determine: by the 18th century coal had created in England a broad spectrum of interdependent methods, processes, devices and tools, and these could not be exported piecemeal. In order to build the Newcomen engine one must be able to manufacture large cast-iron cylinders; to build the machine tools needed to make textile machinery one must have good tool steel; to make flint glass one needs adequate covered crucibles and the proper furnace. Taking bits of coal technology and trying to establish them abroad was difficult and usually futile; a collection of related technologies had to be acquired at once, together with workers who had the appropriate manual skills.



COPPER SMELTER of British pattern also utilized a coal-heated reverberatory furnace. The men ladle molten copper into shallow molds where the copper solidifies into laminated cakes. The furnace shown is said to have been built in France by British workers.

French attempts to adopt British iron-smelting methods, for example, were repeatedly frustrated. A French observer reported on the Darby coke-fired blast furnace as early as 1738 and witnessed the casting of cylinders for the Newcomen engine at Coalbrookdale. It was soon suggested that a factory employing the process be established in France; because of its potential importance to cannon production a succession of French technologists and industrialists visited works in England and then tried to reproduce the method at home. None of the attempts had a lasting effect. Some progress was finally made when William Wilkinson, brother of John Wilkinson, the great British ironmaster, built a cannon foundry at Indret and later an iron and munitions center at Le Creusot. The foothold established with Wilkinson's aid was precarious, however, and smelting with coke was discontinued. Apparently the French had no success at all importing British methods of converting pig to wrought iron, although the processes were known in France.

Much effort therefore produced little result, and the French iron industry, half a century behind the British in technique in 1789, dropped further behind by the end of the Revolutionary and Napoleonic wars. In 1812 a Frenchman who had been trying to refine iron with coal in a reverberatory furnace admitted that he had not known this was the system prevalent in England. Subsequently he obtained English books on the topic, but he reported that "through lack of sufficient explanation I have not been able to get any value from them." The most telling comment was made by a French ironmaster who wrote in 1814 that "the people who so readily propose the use of mineral coal in place of charcoal do not seem to stop and consider that this implies changing almost everything in the furnace, the refineries, the machinery, the workshops, that one has to be situated near mines producing the right kind of coal, to have the ore near the fuel and to train workers in the new kind of process." The problems of acquiring a deeply rooted and broadly diffused technology could not be better expressed.

MATHEMATICAL GAMES

On the fanciful history and the creative challenges of the puzzle game of tangrams

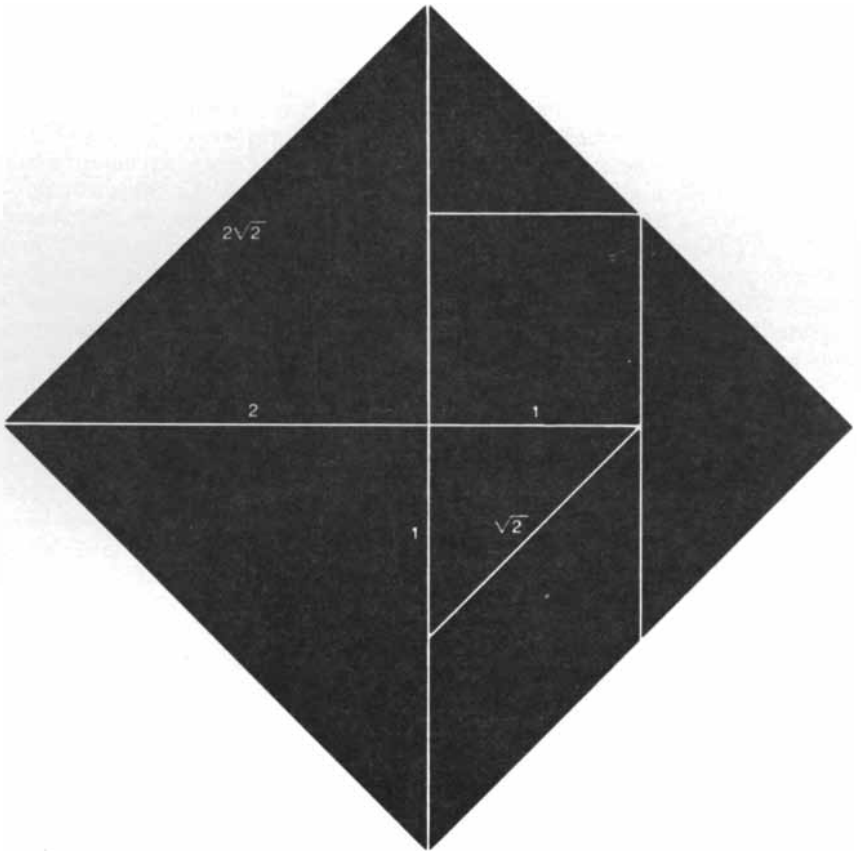
by Martin Gardner

"The seven Books of Tan... illustrate the creation of the world and the origin of species upon a plan which out-Darwins Darwin, the progress of the human race being traced through seven stages ...up to a mysterious spiritual state which is too lunatic for serious consideration."

—SAM LOYD, *The Eighth Book of Tan*

One of the oldest branches of recreational mathematics has to do with dissection puzzles. Plane or solid figures are cut into various pieces, and the problem is to fit the pieces together to make the original figure or some other figure. The outstanding recreation of this type since the Renaissance is the Chinese puzzle game known as tangrams.

Although tangrams and jigsaw puzzles have a superficial resemblance, they are poles apart in the kinds of challenge they offer. As Ronald C. Read points out in his book *Tangrams,* a typical jigsaw puzzle consists of hundreds of irregularly shaped pieces that fit together in just one way to make a large pattern. Little skill is required, just time and patience. Tangrams has only seven pieces, called tans. They are of the simplest possible shapes and are used to make an infinite variety of tangrams. In creating these figures a heavy demand is made on one's geometrical intuition and artistic ability.



The seven tans

The tans are obtained by slicing a square to produce two large triangles, a middle-size triangle, two small triangles, a square and a rhomboid [*see illustration on this page*]. Note that all the corners are multiples of 45 degrees. If a side of the square tan is taken as unity, a side of any tan has one of four lengths: 1, 2, $\sqrt{2}$ and $2\sqrt{2}$.

"At first we are amazed at the unfitness of the shapes... with which we are expected to accomplish so much," wrote Loyd, the American puzzle expert. "The number 7 is an obstinate prime which cannot be divided into symmetrical halves, and the geometrical forms... with harsh angles, preclude the possibility of variety, curves or graceful lines." After working for a while with the tans, however, one begins to appreciate the subtle elegance of the dissection and the richness of its combinatorial possibilities. All kinds of variant dissections, in imitation of tangrams, have been marketed from time to time, but not one has come even close to tangrams in popularity. As with origami, it is the very simplicity of the material and its apparent unfitness for artistic use that lie at the heart of its charm.

Tangram play falls roughly into three major categories:

1. Searching for one or more ways to form a given tangram, or for an elegant proof of the impossibility of forming a tangram.

2. Finding ways to depict, with maximum artistry or humor, or both, silhouettes of animals, human figures and other recognizable objects.

3. Solving a variety of problems in combinatorial geometry that are posed by the seven tans.

Many books, and even a few encyclopedias, declare that tangram play is about 4,000 years old. In this department for September, 1959, I called tangrams the oldest of dissection games and said that the Chinese had been amusing themselves with it for several thousand years. This is totally wrong. The man responsible for the myth is none other than Sam Loyd. In 1903, when Loyd was 61 and at the height of his fame, he published a little book (now extremely rare) called *The Eighth Book of Tan, Part 1.* No Western book on tangrams has been more original or influential. In addition to containing hundreds of excellent new figures, Loyd invented a preposterous legend about the pastime's origin. It was the greatest hoax in the history of puzzledom, and the number of

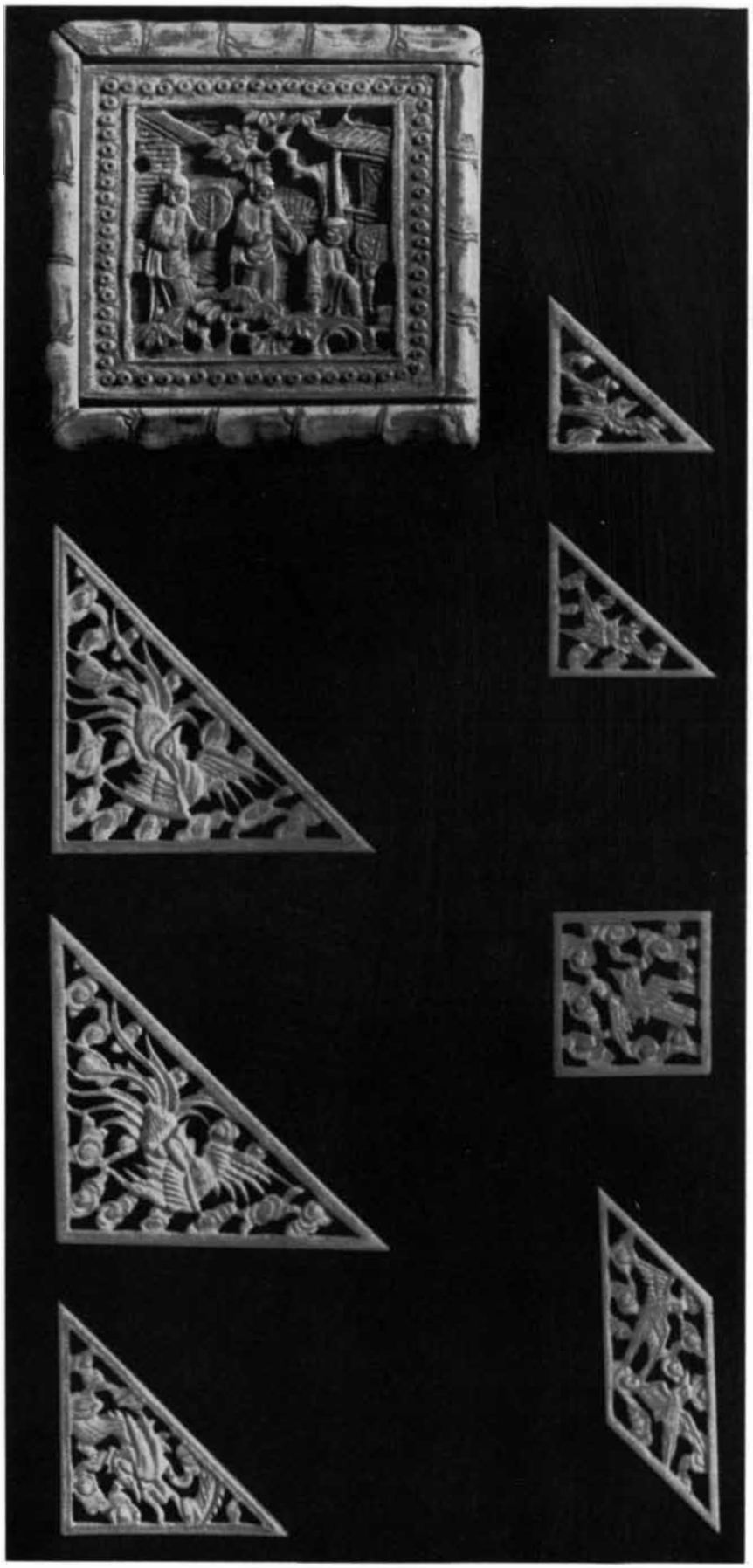
intelligent people taken in by it rivals the number of scholars who accepted H. L. Mencken's spurious history of the bathtub.

"According to the late Professor Challenor," Loyd wrote, "whose posthumous papers have come into the possession of the writer, seven books of Tangrams, containing one thousand designs each, are known to have been compiled in China over 4,000 years ago. These books are so rare that Professor Challenor says that during a forty years' residence in China he only succeeded in seeing perfect editions of the first and seventh volumes, with stray fragments of the second.

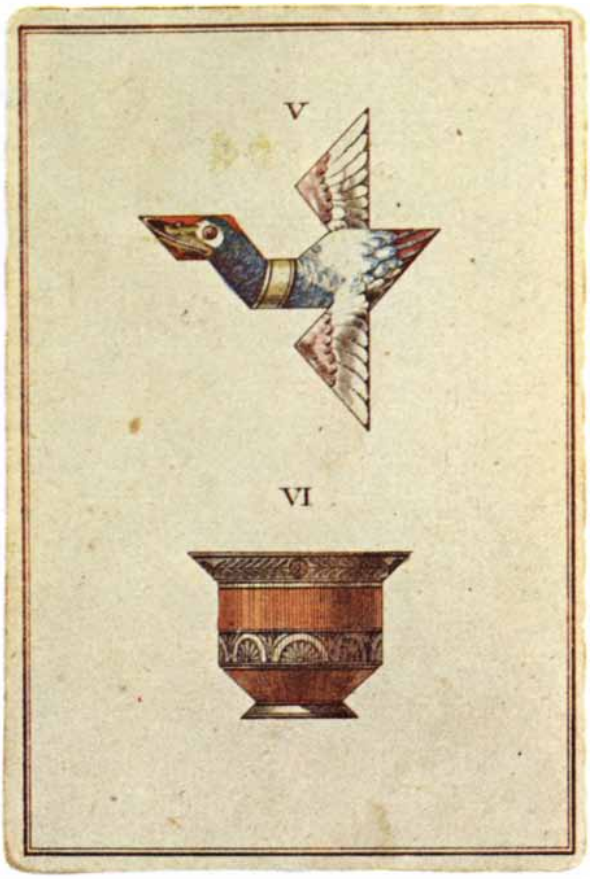
"In this connection it may be mentioned that portions of one of the books, printed in gold leaf upon parchment, were found in Pekin by an English soldier who sold it for £300 to a collector of Chinese antiquities, who kindly furnished some of the choicest designs presented in this work."

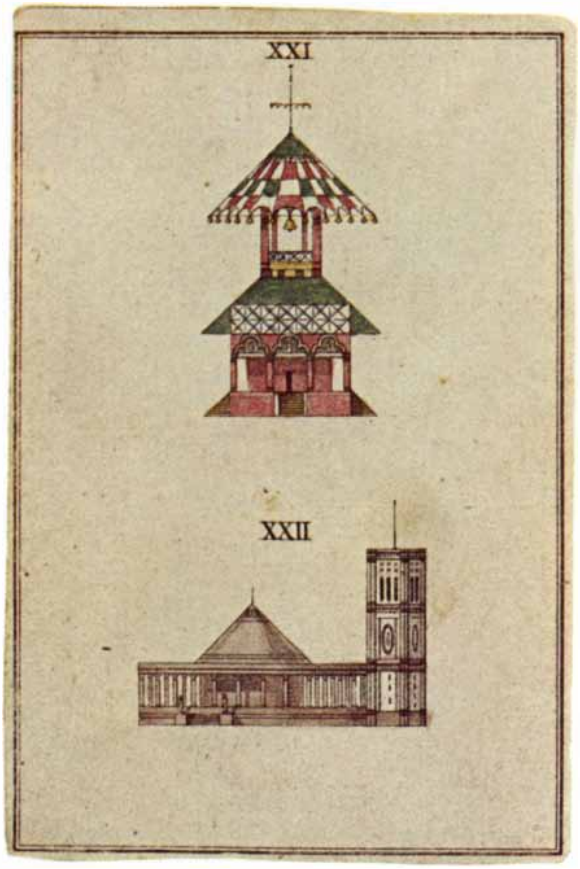
According to Loyd, Tan was a legendary Chinese writer who was worshiped as a deity. He arranged the patterns in his seven books to display seven stages in the evolution of the earth. His tangrams begin with symbolic representations of chaos and the yin-yang principle. These are followed by primitive forms of life, then the figures proceed up the evolutionary tree through fishes, birds and animals to the human race. Scattered along the way are tangrams of human artifacts such as tools, furniture, clothing and architecture. Loyd inserts remarks by Confucius, a philosopher called Choofootze, a commentator named Li Hung Chang and his mythical Professor Challenor. Chang is quoted as saying that he knew all the figures in the seven books of Tan before he could talk. And there are references to a "well known" Chinese saying about "the fool who would write the eighth book of Tan."

All of this, of course, was sheer fabrication. When Henry Ernest Dudeney, Loyd's British counterpart, wrote an article on tangrams for *The Strand Magazine* (November, 1908), he soberly repeated Loyd's legendary history. This aroused the curiosity of Sir James Murray, the distinguished lexicographer and an editor of the *Oxford English Dictionary,* who made inquiries through one of his sons, then teaching at a Chinese university. Oriental scholars had never heard of Tan or even the word tangrams. The game, Murray informed Dudeney, is known in China as *ch'i ch'iao t'u,* meaning "seven-ingenious plan" or, less literally, "clever puzzle of seven pieces."



Edgar Allan Poe's carved ivory tangram set





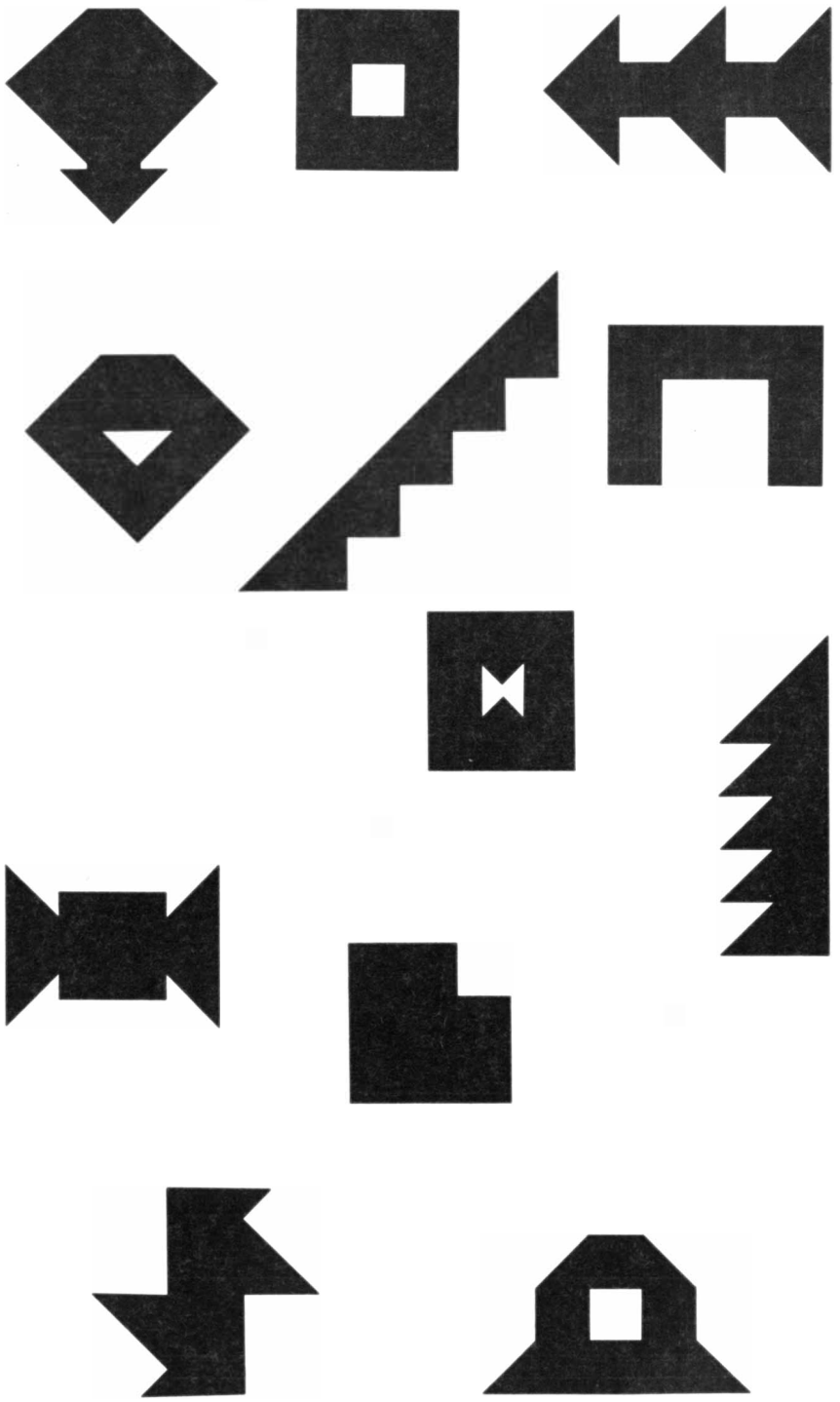
Early 19th-century tangram cards from a set owned by Tom Ransom of Toronto

Murray could find no record of the word tangram earlier than in an 1864 Webster dictionary. It had been coined about 1850, Murray guessed, by an American who probably combined *tang,* a Cantonese word for "Chinese," with the familiar suffix -gram, as in anagram or cryptogram. A different theory about the name has recently been advanced by Peter Van Note in his introduction to a Dover reprint of Loyd's fanciful book. Chinese families who live on riverboats are called *tanka,* and *tan* is a Chinese word for prostitute. American sailors, taught the puzzle by tanka girls, may have called it tangrams—the puzzle of the prostitutes.

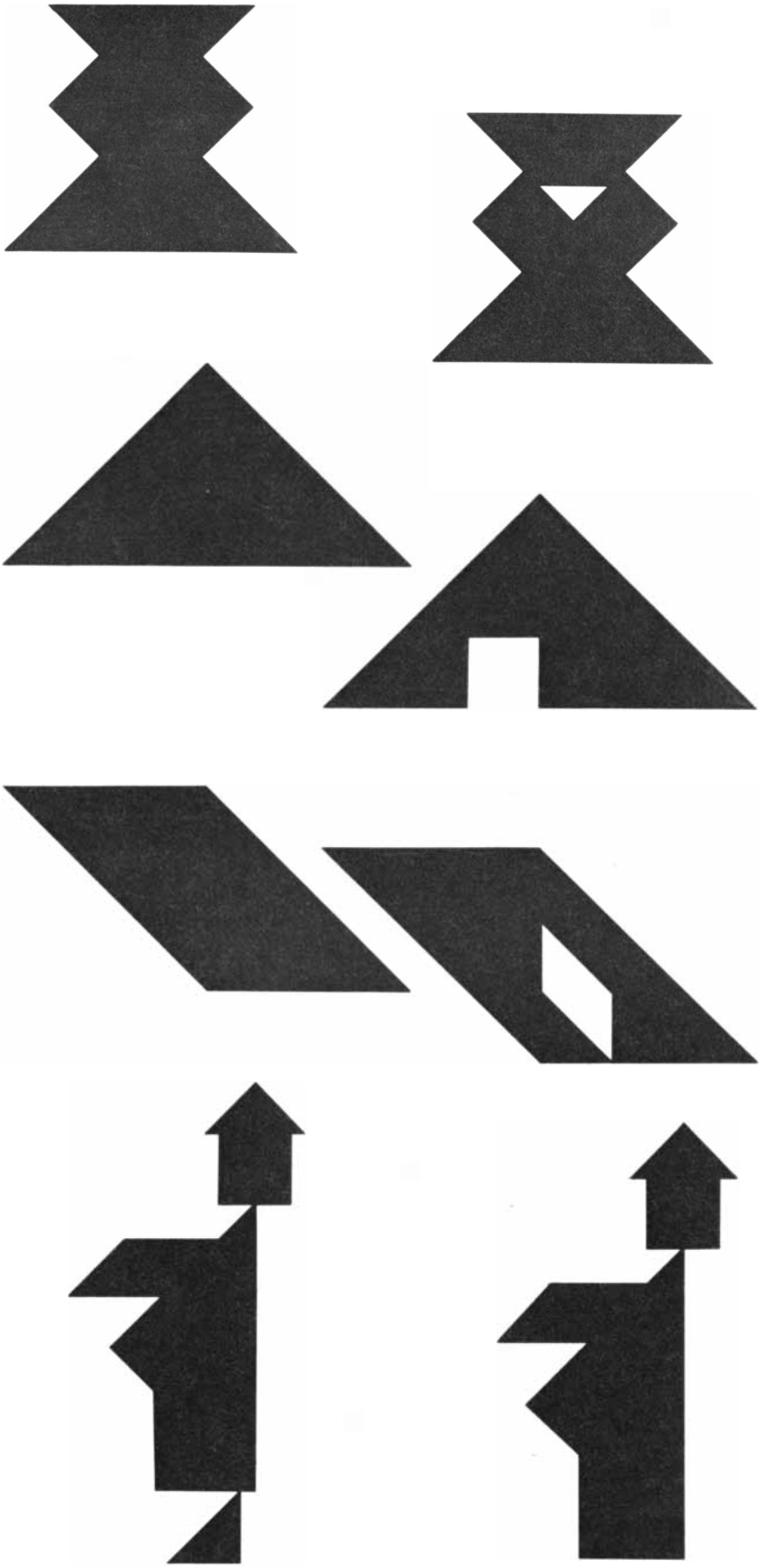
When Dudeney reported Murray's opinions, in *Amusements in Mathematics* (pages 43–46), he may have deliberately added a hoax of his own. An American correspondent, Dudeney writes, had told him that he owned a Chinese set of mother-of-pearl tans with an accompanying rice-paper booklet of more than 300 figures. The correspondent was puzzled by a mysterious inscription on the front page that he said he had tried to have translated, but no Chinese to whom he had shown it had been willing or able to read it. Dudeney reproduced the inscription and asked the reader for help. We do not know what the response was to this request, but Read, who owns a copy of the same booklet, had no difficulty clearing up the mystery. The inscription is nothing more than a caption under the tangrams of two men. The caption reads: "Two men facing each other and drinking. This shows the versatility of the seven-piece puzzle."

No one knows when tangrams originated. The earliest reference known is a book published in China in 1803. Its title, *The Collected Volume of Patterns of the Seven-Piece Puzzle,* suggests earlier books. Most scholars believe the game originated in China about 1800, became an Oriental craze and then spread rapidly to the West. The earliest Western books, says Read, were little more than copies of Chinese rice-paper booklets. The Western books even copied errors in the Chinese illustrations.

One of the earliest English books on tangrams, originally owned by Charles Lutwidge Dodgson (better known as Lewis Carroll), came into Dudeney's possession. It is called *The Fashionable Chinese Puzzle,* and it was first published in New York in 1817. Dudeney quotes from it a passage stating that the game was a favorite of "ex-Emperor Napoleon, who, being now in a debilitated state, and living very retired, passes many hours a day in thus exercising his patience and ingenuity." This too is an unsupported statement, undoubtedly false. The puzzle is said by Loyd to have been a favorite of John Quincy Adams' and Gustave Doré's, although I know of no basis for either assertion. We do know that Edgar Allan Poe enjoyed the game, because his imported set of carved ivory tans is owned by the New York Public Library. An anonymous French work, *Recueil des Plus Jolie Jeux de Société* (1818), may be a translation of Dodgson's English book, or vice versa. I have not seen a copy of either. An 1817 American book bears the title *Chinese Philosophical and Mathematical Trangram.* "Trangam" was an old English word for a trinket, toy or puzzle. Samuel Johnson misspelled it as "trangram" in 1712, and



Which tangram is impossible?



Tangram paradoxes

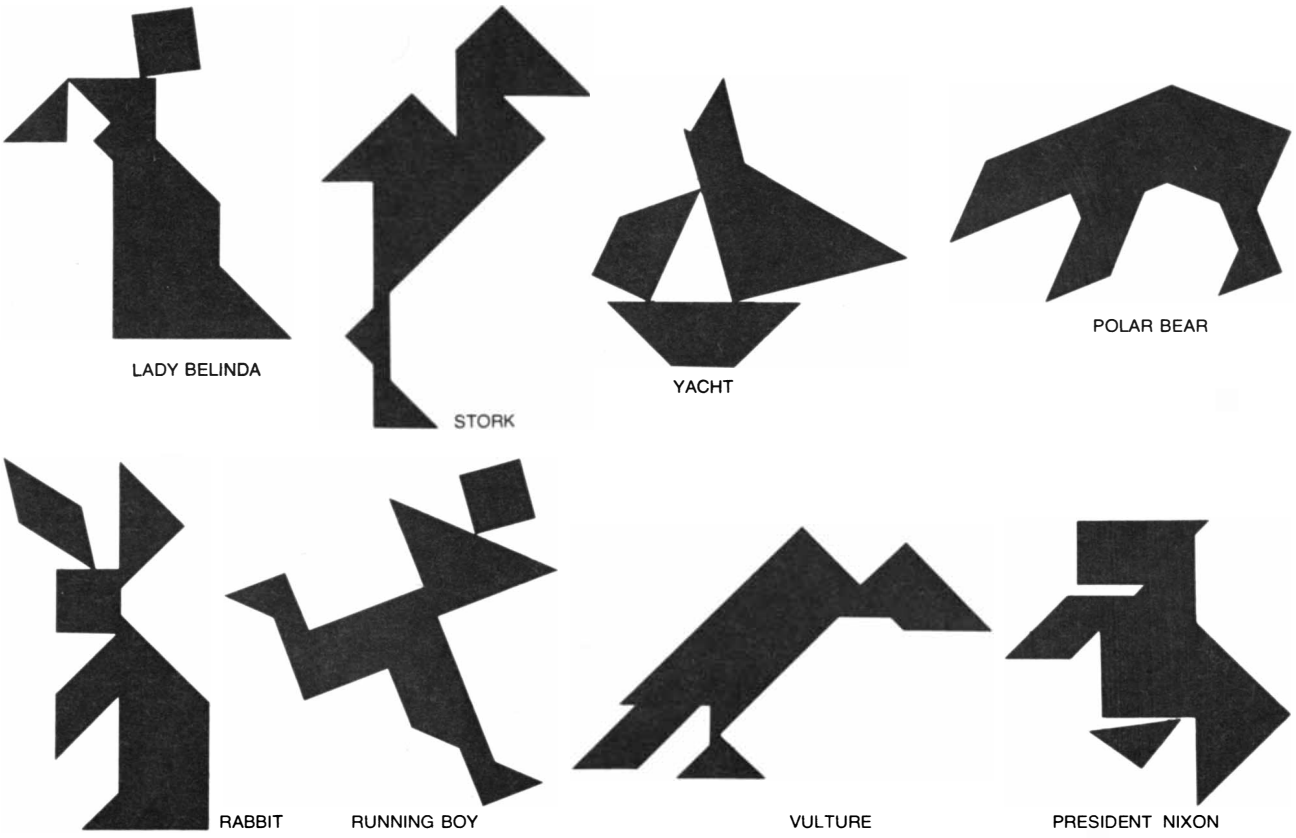
the spelling persisted in later dictionaries. Did the book's anonymous author revive an obsolete word that later evolved to "tangram," or did he misspell "tangram," a word already in use? One mystery novel, *The Chinese Nail Murders* (Harper & Row, 1961), by the Dutch diplomat and Orientalist Robert Van Gulik, is woven around a set of tangram patterns.

Poe's tans are shown in the illustration on page 99. The delicate filigree carving is characteristic of the old Chinese ivory tans. Note that the pieces pack into a square box in two layers. The two layers are squares of equal size, so that putting away the tans is a puzzle in itself. In 19th-century China, where tangrams were popular among adults (it is considered a child's pastime in the Far East today), the pieces were made in many sizes and from many different materials. Dishes, lacquer boxes and even small tables were given the shapes of the tans. In the U.S. one finds the puzzle currently on sale under such trade names as Pythagoras and Silhouettes. A sturdy set of nontoxic plastic pieces is obtainable postpaid for 53 cents (California residents must add three cents state tax) from Creative Publications, P.O. Box 10328, Palo Alto, Calif. 94303. The company also sells a children's book, *Tangramath,* by Dale Seymour, Read's book and sets of tangram stickers. Interested readers can ask for their free 1974 catalogue (the company sells mathematics curriculum materials with special emphasis on recreational mathematics) for details on prices and how to order.

So much for the historical background. Let us turn now to the first of the three categories of tangram play: solving given figures. The illustration on the preceding page shows a dozen interesting shapes on which the reader is invited to try his skill. Each requires all seven pieces. The rhomboid, the only asymmetrical tan, may be placed either side up. One figure in the illustration is not possible. Can the reader identify it and prove its impossibility?

The paired tangrams in the illustration at the left are samples of delightful paradoxes introduced by Loyd. (The first three pairs were devised by Loyd, the fourth pair was devised by Dudeney.) Although the figure at the right in each case seems to be exactly the same as its mate, except for a missing portion, each is made with all seven tans!

The tangrams in the illustration on the opposite page are not intended as patterns to be solved but as illustrations of the second category of play: creating



Tangram pictures

artistic and amusing pictures. "One remarkable thing about... Tangram pictures," wrote Dudeney, "is that they suggest to the imagination such a lot that is not really there. Who, for example, can look... at Lady Belinda... without soon feeling the haughty expression...? Then look again at the stork, and see how it is suggested to the mind that the leg is actually much more slender than any one of the pieces employed. It is really an optical illusion. Again, notice in the case of the yacht how, by leaving that little angular point at the top, a complete mast is suggested. If you place your tangrams together on white paper so that they do not quite touch one another, in some cases the effect is improved by the white lines; in other cases it is almost destroyed."

One can mix two or more sets of tans to produce more elaborate figures. Dudeney gives a number of these "double tangrams" in *536 Puzzles and Curious Problems* (Scribner's, 1967), pages 221–222, and others will be found in Read's book. I agree with Read, however, when he writes: "With fourteen pieces to play around with, one cannot help but feel that it should be possible to arrive at a reasonable likeness of just about anything. Consequently, the sense of achievement that one gets on producing a recognizable cow, sailing boat, human figure, or what have you, from a mere seven pieces, is quite lacking."

Combining two related tangrams, each made with seven tans, is a different matter. Four classic examples, all devised by Loyd, are a woman pushing a baby carriage, a runner being tagged out at home plate, two Indian braves and a man with a wheelbarrow [*see illustration on next page*]. Note that the man and the wheelbarrow are identical tangrams except for orientation.

The third category of tangram play, solving combinatorial problems, is the most interesting of all to mathematicians. There have been some remarkable new contributions made to this field by Read, a specialist in graph theory at the University of Waterloo, and by E. S. Deutsch, a computer scientist with P. S. Ross and Partners in Toronto. Some of their results will be presented in next month's column. Until then, to whet the reader's appetite, here are two problems that will be answered next month:

1. How many different convex polygons can be formed with the seven tans? There must not be any "windows" in the figures. Rotations and reflections are not, as is customary, considered to be different. Since all three- and four-sided polygons are convex, answering this question also gives the number of three- and four-sided polygons. It is easy to see that only one triangle is possible (since corners must be multiples of 45 degrees, the triangle must be a right isosceles one), but finding all the higher convex polygons is a bit tricky.

2. How many different five-sided polygons can be made? Now, of course, the figure can be nonconvex. This is not an easy question. Indeed, it has been answered for the first time by Read. The number is smaller than one might suppose (less than 20), although proving the number's correctness without a computer calls for considerable ingenuity.

Last month's problem was to prove that if a star number is multiplied by 3, and 2 is added, the result is a number that can be expressed as the sum of two consecutive squares and also as the sum of three consecutive squares. As explained last month, square stars are numbers of the form $6n(n-1)+1=m^2$, where n and m are positive integers. If the left side, which defines a star, is mul-

tiplied by 3, and 2 is added, the result is $18n(n-1)+3+2=18n^2-18n+5$. The expression is equal to the sum of two consecutive squares: $(3n-1)^2+(3n-2)^2$. If the right side of the equation, which defines a square, is multiplied by 3, and 2 is added, the result is $3m^2+2$. This equals the sum of three consecutive squares: $(m-1)^2+m^2+(m+1)^2$.

Here are some highlights from reader comments on the short problems in April:

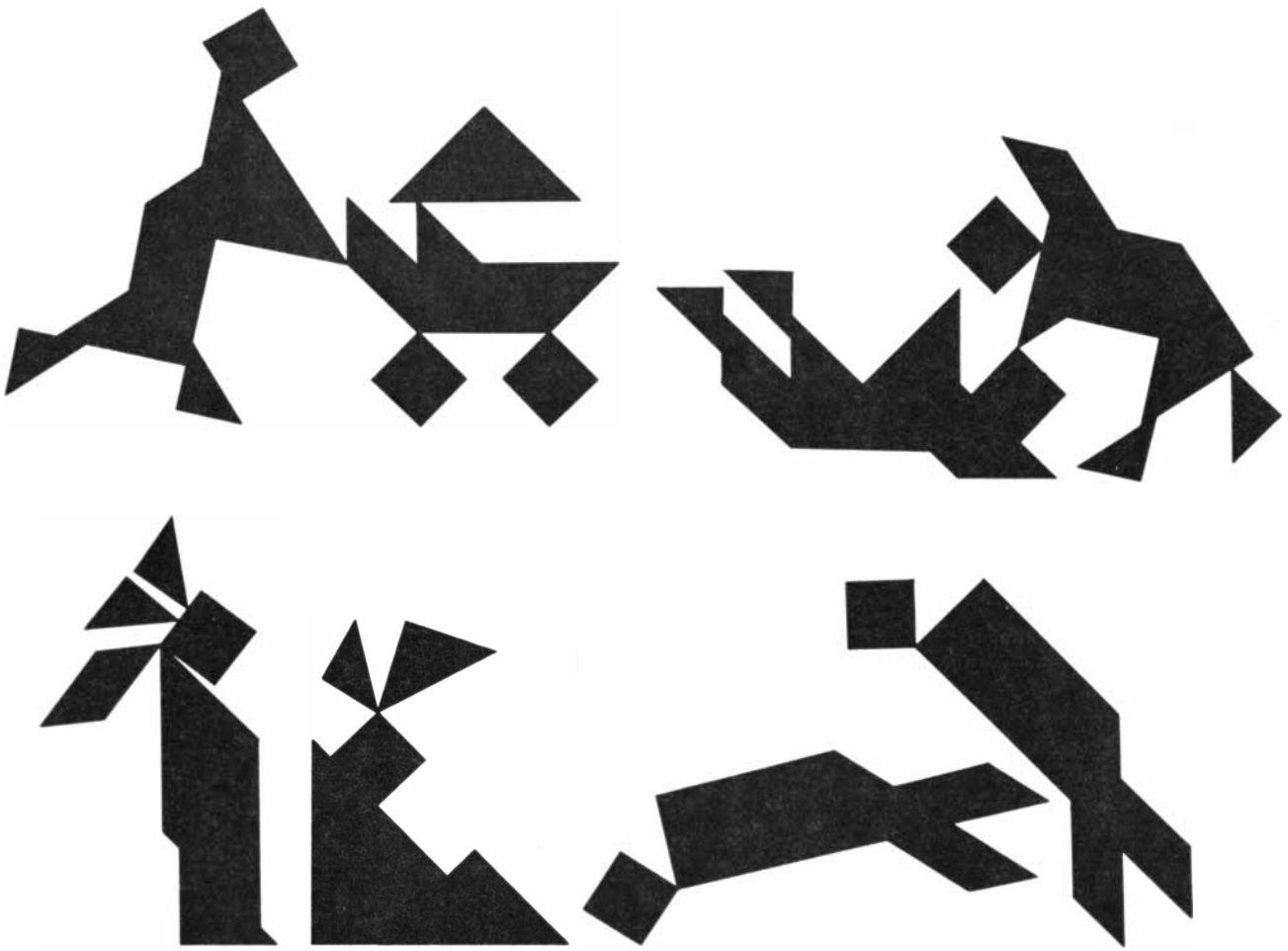
Kenneth M. Brown and Jon Petersen each proved that Murray Pearce's formulas for the gunport problem cannot be exceeded. It remains an open question whether there are rectangles for which Pearce's upper bounds cannot be achieved. Petersen and Douglas W. Oman independently found a procedure showing that all rectangles with areas smaller than 224 could meet the upper bounds. The general case is undecided, with the 14-by-16 rectangle being a likely candidate for the smallest counterexample. According to Pearce's conjecture, it should be possible to cover it with 75 dominoes that leave 74 holes.

Sharon Cammel and Jonathan Schonsheck, in a joint letter, pointed out that there are just two ways to move three toothpicks and make the fish swim the other way, one way sending it a trifle higher in the water, the other sending it lower. Tom Kellerman, age eight, found that by moving two toothpicks he could make the fish swim either up or down, although the fish became shorter and fatter.

The black and white sides of the chessboard were properly identified in Raymond Smullyan's monochromatic chess problem, but several readers asked themselves whether the problem could still be solved if the sides were reversed. Two readers independently sent the following "proof" that the uncolored pawn still must be black. Assume that the pawn is white. To reach the position shown in the problem it must move at least three times: a first move of two squares, then two captures. The other two white pawns must make at least four moves each to reach their positions. This includes six captures. Thus at least eight captures of black pieces, all on black squares, must be made by the three white pawns. At the start of the game Black has eight pieces on black squares. One of them, however, the king's knight, cannot move from its original cell. Black therefore has only seven white pieces on black cells that are available for capture. The initial assumption must be false. The uncolored pawn is black.

Unfortunately the proof is false also. William J. Butler, Jr., sent a legal game, conforming to the monochromatic proviso of the problem, in which the sides are reversed and the position shown in the problem is reached with the uncolored pawn being white. Can the reader spot the flaw in the above "proof" before it is revealed next month?

Using more liberal interpretations of the dialogue in the old burlesque routine proving that $7\times13=28$, Joseph H. Engel, Sumner Shapiro and Alan Wayne found other triplets of figures that could be added to the 22 that satisfy a strict interpretation of the dialogue. Wayne recalled having seen the routine per-



Double tangrams by Sam Loyd

formed several times on stage by the Abbott and Costello comedy team.

Alastair Anthony, Loyd E. Carlson, Robert S. Cushman, T. D. Dixon, Robert B. Ely III, John L. Miles, David L. Mott, Thomas Ross, George Rublein, Jeffrey Sherman and Joseph L. Ullman were the first of many readers to send alternate ways of proving the theorem about the three intersecting circles.

Several readers spotted a mistake in the illustration for the problem of knotting the ends of two hanging strings. The strings are too short to be tied. Paul Nelles considered the situation in which a side wall is so close to each string that if the magnet were tied to one end, it would collide with the wall when the string is swung. He suggested tying the table-tennis ball to the cord (or fastening it with the stamp), then swinging the string so that the ball bounces off the wall. Michael McMahon suggested using the stamp to attach the ball to the string and then, with a corner of the magnet, addressing the ball and mailing it to the other side of the room.

For the shelf-making problem E. N. Adams, Bill Kruger and Susan Southall each showed how the pliers could be opened and wired to the peg to make a tripod, and also how the angle irons could be wired flat to each end of the peg to make a stand. The second solution was also proposed by R. C. Dahlquist, P. C. Eastman and Ronald C. Read. Don L. Curtis threaded the wire through end holes of the angle irons and with the pliers tightened the wire around the board so that the angle irons were rigidly perpendicular to the board. He sent a photograph to prove that the stand supported a heavy vase of flowers. Robert Rosenwald and Allan Kiron each thought of using the pliers as a hammer for knocking corners of the angle irons into the board to make supports.

Wayne E. Russell noted that the bookcase problem did not rule out the possibility that the room was much higher than the cases. He showed that by raising one end of the large case high enough it could be reversed in three swings. Johannes Sack discovered the surprising fact that the minimum-move solution does not correspond to a solution with a minimum expenditure of energy. The given three-move reversal of the small bookcase carries the case at least 33 feet. If four moves are used (*D* counterclockwise 90 degrees, *C* counterclockwise 60 degrees, *D* counterclockwise 60 degrees, *C* clockwise 30 degrees), the case is carried only 18.8 feet, an energy saving of 43 percent.

THE AMATEUR SCIENTIST

An air flash lamp advances color schlieren photography

Conducted by C. L. Stong

J. Kim Vandiver of the Massachusetts Institute of Technology has opened a new dimension in color schlieren photography by adapting an air flash lamp to the schlieren interferometer. This lamp is one of many flash lamps devised by Harold E. Edgerton of M.I.T., with whom Vandiver works as a teaching assistant. An appreciation of Vandiver's technique requires a bit of background.

The schlieren interferometer provides a means of making regions of nonuniform density in a column of air visible. The instrument includes either a pair of lenses or a pair of concave mirrors. The lenses or mirrors are silvered on the front surface.

One lens or mirror of the pair bends the diverging rays from a narrow source of light into a cylindrical beam of parallel rays. The other lens or mirror intercepts the parallel rays and focuses them to a narrow bundle. Part of the bundle is intercepted by a transverse straightedge, such as a razor blade. The remaining rays proceed to a lens in the eye or in a camera [*see illustration below*].

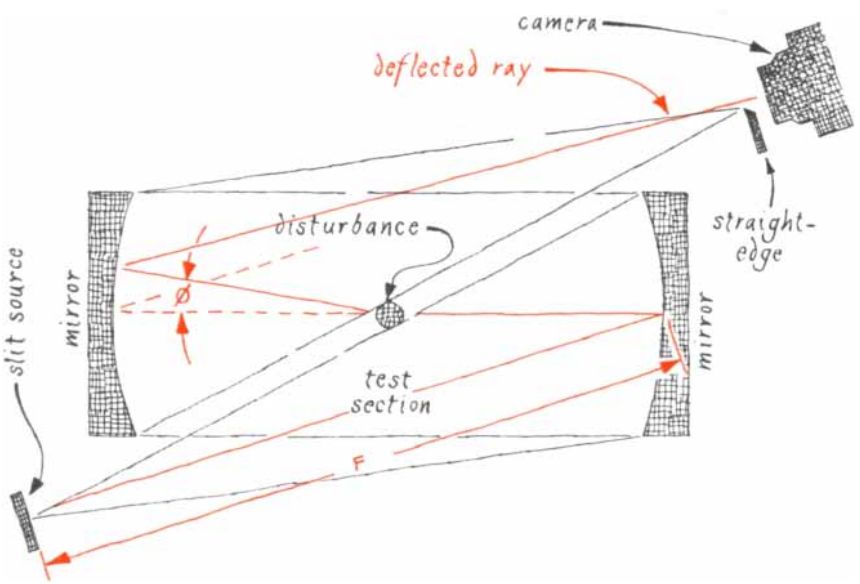
If the density of the air in the column of parallel rays is uniform, the resulting image appears uniformly illuminated. Variations in the density of the air between the lenses or mirrors deflect rays in the direction of increasing density. For example, a region of disturbed air can cause rays that would normally reach the eye or the camera to fall on the straightedge. The image would appear abnormally dark in the area formerly illuminated by those rays. Conversely, other regions of nonuniform density can deflect rays away from the obstructing straightedge. Areas of the image that receive this additional light would appear abnormally bright.

The combined effects result in a pattern of light and shade that depicts variations in the density of the air but does not identify regions of abnormally high or low density. This ambiguity can be resolved by adding to the basic schlieren interferometer an improvement that was described in these columns three years ago by Gary S. Settles, then an undergraduate at the University of Tennessee [see "The Amateur Scientist," SCIENTIFIC AMERICAN, May, 1971]. Settles provided the instrument with multiple sources of light in the form of four slits, each a distinctive color. They were arranged as a square array. A comparable set of four straightedges intercepted half of the light from each of the colored slits. The resulting patterns were multicolored. By taking account of the fact that light of known color is deflected toward regions of increasing density, Settles made the instrument into a powerful tool for analyzing various disturbances in air, including persistent supersonic flow.

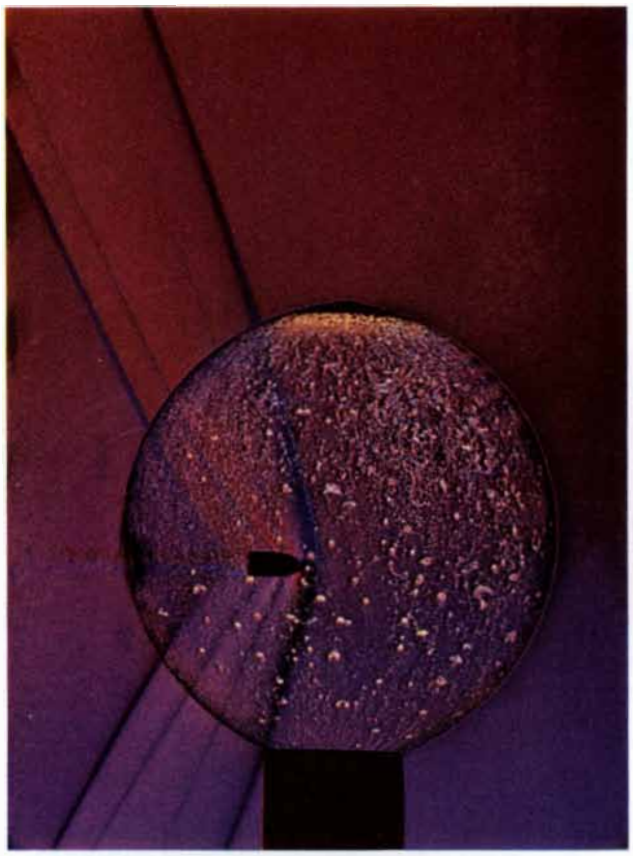
The instrument was not as effective for investigating transient disturbances because photosensitive color emulsions require relatively long exposure to the incandescent lamp Settles employed. This limitation has now been removed by Vandiver's substitution of the air flash lamp, which is based on the discharge of electricity through air at a rate of about 20,000 kilowatts for .3 microsecond. The lamp was described by Edgerton in 1961. Vandiver describes the apparatus and experiments that can be done with it.

"The potential subjects for color schlieren photography include most events that cause a change in the refractive index of a transparent medium. Such phenomena as the heat from a candle, the streamers in a soap bubble or the shock waves from a bullet, a firecracker or an electric spark can be photographed in strong, saturated color. The gradients of the refractive index can be deduced from the colors. The technique is sufficiently sensitive to reveal the heated air flowing upward from a hand.

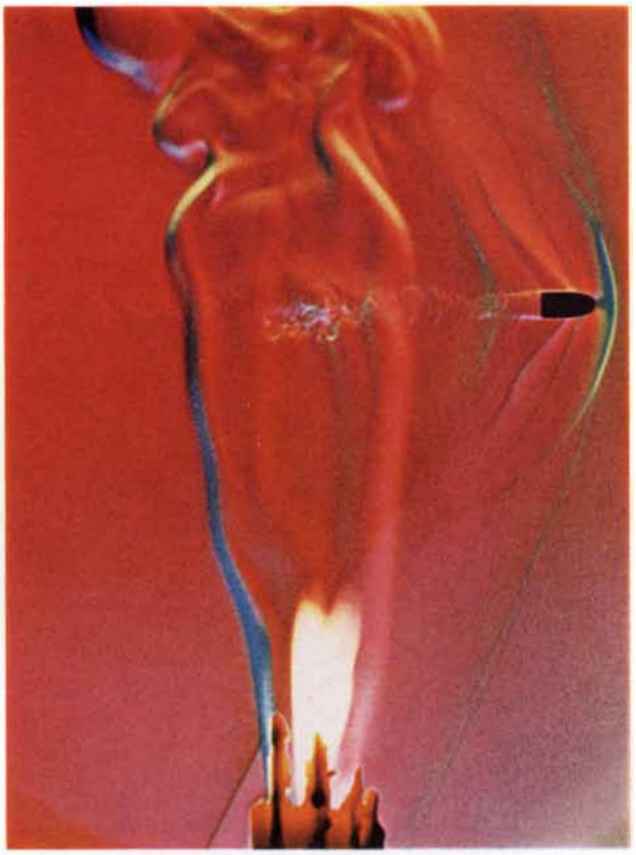
"Most photographs of this kind that have been published feature the flow of compressed air in supersonic wind tunnels. The steadiness of the conditions in a tunnel test allows long exposures. The shock waves from a bullet or an electric spark require exposures of less than a millionth of a second. The combination of the color schlieren interferometer and a high-intensity, submicrosecond flash



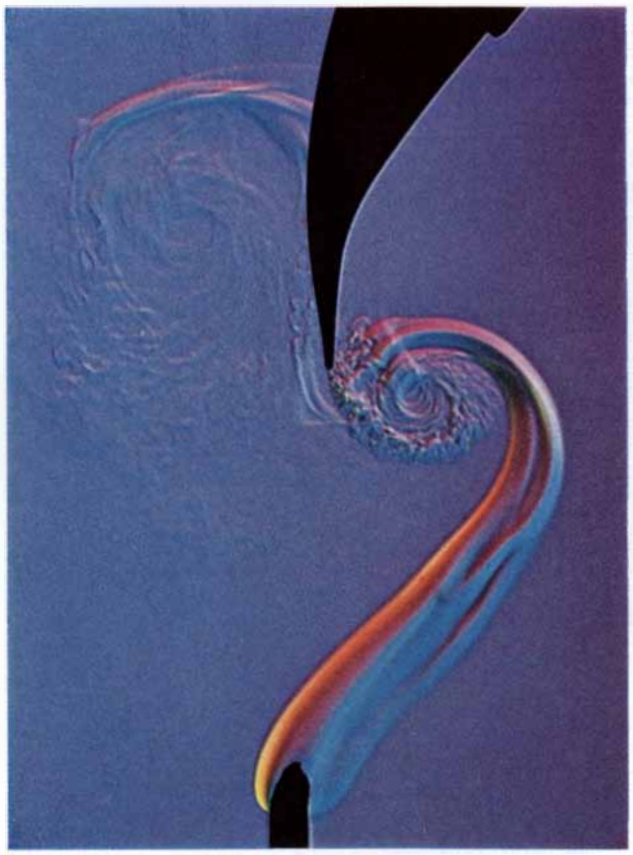
Components and optics of the schlieren apparatus



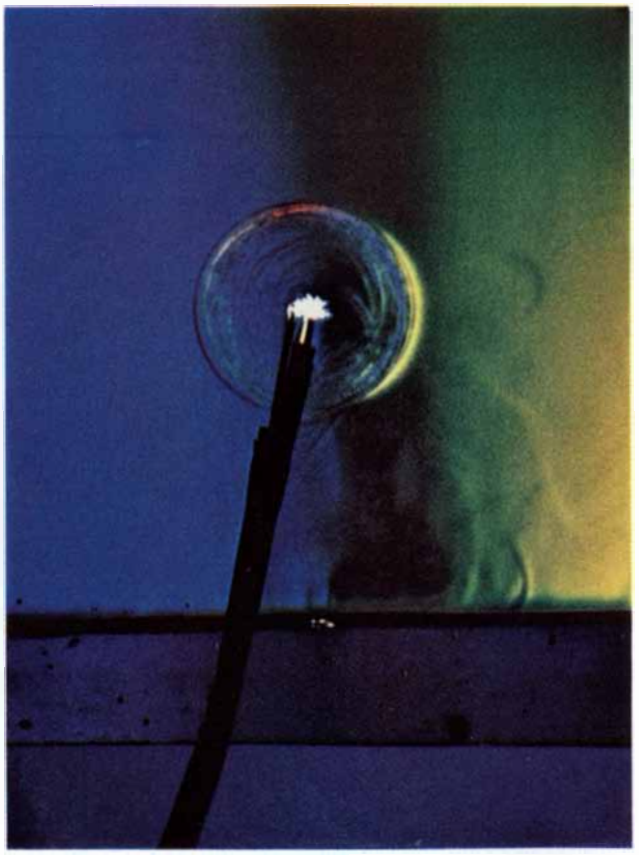
Bullet penetrating a soap bubble



Bullet passing through hot air above a candle



Vortex of a fan blade in the flame of an alcohol lamp



Vapor expanding from an underwater spark

lamp enables the experimenter to make striking photographs of many previously unseen phenomena, such as a bullet penetrating a soap bubble or a candle flame, a shock wave expanding at the rate of a mile per second from an underwater spark discharge and the vortex shed by the blade tips of an electric fan turning at 1,200 revolutions per minute.

"In the case of the underwater spark five joules of energy were discharged in about a millionth of a second. The vapor cavity reverberated, that is, it emitted a series of shock waves. Shock waves traveled through the water at a speed of one mile per second but moved up the wire even faster as disclosed by the relatively straight wave front tangent to the sphere.

"The bright spots on the surface of the soap bubble are normally unseen droplets of excess soap solution. Each one acts as a lens to refract the light. The vortex shed from the tip of the fan blade was made visible by heated air from an alcohol lamp below the blade.

"The apparatus will also serve for making photographs in black and white. An example is the fragmentation of liquid by high-velocity jets of gas. The accompanying photograph [*below*] was made in the course of investigating atomization as a technique for the production of powdered metal.

"The lenses or mirrors are the most critical parts of the schlieren apparatus. Every surface irregularity in a lens or a mirror generates a schlieren image. For this reason the quality of these components must approach perfection.

"Front-surface mirrors have numerous advantages over lenses in this application. Mirrors have no chromatic aberration, meaning that they contribute no spurious color to the image. Moreover, the glass for a mirror need not be of optical quality. Comparably corrected lenses of optical glass are prohibitively costly and all but impossible to make at home, whereas thousands of amateurs have made spherical mirrors of adequate quality as an intermediate step in generating the paraboloid required for a telescope objective.

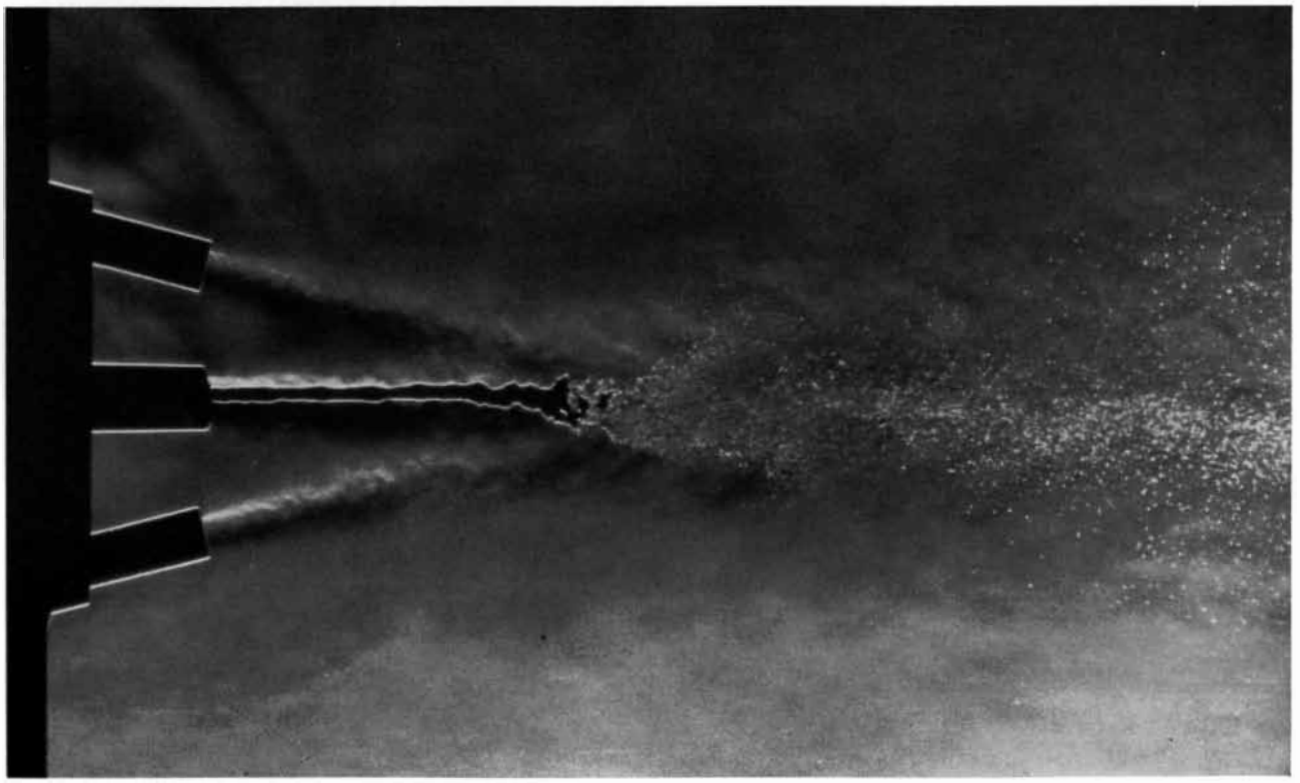
"The diameter and the focal length of the mirrors or lenses determine the sensitivity of the apparatus and the size of the image. These dimensions should be taken into account at an early stage in constructing an instrument. Consider a pair of mirrors or lenses of diameter D, area A ($\pi \times D^2/4$) and focal length F. Assume also a light source in the form of a slit of width w and length l. A color apparatus would have four slits of identical dimensions. Each slit would be a distinctive color. The following discussion will be confined to an instrument with a single horizontal slit, but the same reasoning applies to instruments with multiple slits and corresponding straightedges.

"The space between the lenses or mirrors of the instrument is known as the test section. It is illuminated by a homogeneous mixture of parallel rays that diverge from the slit or slits. A disturbance that alters the density of the air may cause the light in that area to deviate from its path by an angle ϕ. If the cross-sectional area of the disturbance is A_e, then the fraction of light so affected is $A_e/A = d$.

"A vertical deflection of ϕ radians may cause that portion of the light (d) to be displaced upward enough to miss the straightedge. The remaining fraction of the light ($l - d$) will remain focused on the straightedge. The amount by which the light is displaced at the straightedge is proportional to the product of the focal length and the deflection: $F \times \phi$.

"If the intensity of the light in the test section is expressed in lumens per square foot (I), the amount of light that passes over the straightedge and reaches the lens of the eye or camera is $I \times A_e \times F \times \phi/w$. The sensitivity of the system increases with the amount of light that passes over the straightedge. Hence sensitivity is directly proportional to the focal length of the lenses or mirrors and inversely proportional to the width of the slit source, as measured in a direction perpendicular to the straightedge.

"Light that grazes an opaque edge is diffracted or bent. For this reason source



Atomization of liquid in jets of nitrogen

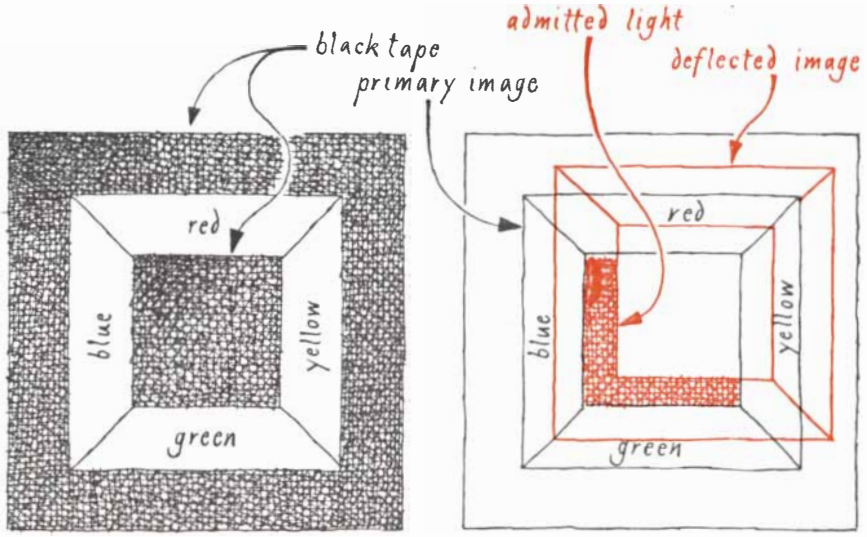
slits must be made at least .03 inch wide. Diffraction limits the sensitivity the designer can achieve by decreasing the width of the slit. Therefore instruments of the highest sensitivity must have lenses or mirrors of relatively long focal length.

"The intensity of the light (I) varies inversely with the square of the focal length: $I = BCP/F^2$, where BCP is the beam candlepower of the light emitted from the slit. For this reason long focal lengths that result in high sensitivity decrease the intensity of the light and increase the required exposure time. In practice the source is a rectangular slit illuminated from the rear by a lamp or a flash unit.

"The beam candlepower can be increased without lowering the sensitivity of the system by increasing the length of the slit, leaving the width unchanged. The length to which the slit can be increased is limited, however, by the diameter of the lens of the camera directly behind the straightedge. The depth of the field that can be photographed varies inversely with the diameter of the lens. As in the design of many instruments, a change in any of the dimensions requires a corresponding change in all the others for performance to be kept at an optimum level. Good instruments stand as monuments to compromise.

"The design must start with the assumption of some dimension. A reasonable starting dimension is the size of the camera, since the experimenter is likely to own a camera and in any case the instrument represents a substantial investment. The selection of the camera lens requires knowledge of the expected size of the image.

"If the distance to the object in the test section is made equal to half the focal length of the lenses or mirrors, the diameter of the circular image of the test section (d_c) can be found by dividing the diameter of the mirrors or lenses by the quotient of the focal length of the mirrors or lenses divided by the focal length of the camera lens minus 1/2: $d_c = d/(F/F_c) - 1/2$, in which F_c is the focal length of the camera. For example, if the diameter of the mirrors (d) is .254 meter, the focal length of the mirrors (F) is 2 46 meters and the focal length of the camera (F_c) is .4 meter, the size of the image would be $.254/(2.46/.4) - 1/2 = .254/5.65 = .045$ meter, or 45 millimeters, which can be photographed adequately with a 35-millimeter camera. Disks of glass for making spherical mirrors .254 meter (10 inches) in diameter are available in the U.S. from a number of distributors of optical supplies, including the Edmund Scientific Co. (300 Edscorp Building, Barrington, N.J. 08007). Images of larger size require sources of light so intense that they are too expensive for most amateurs.

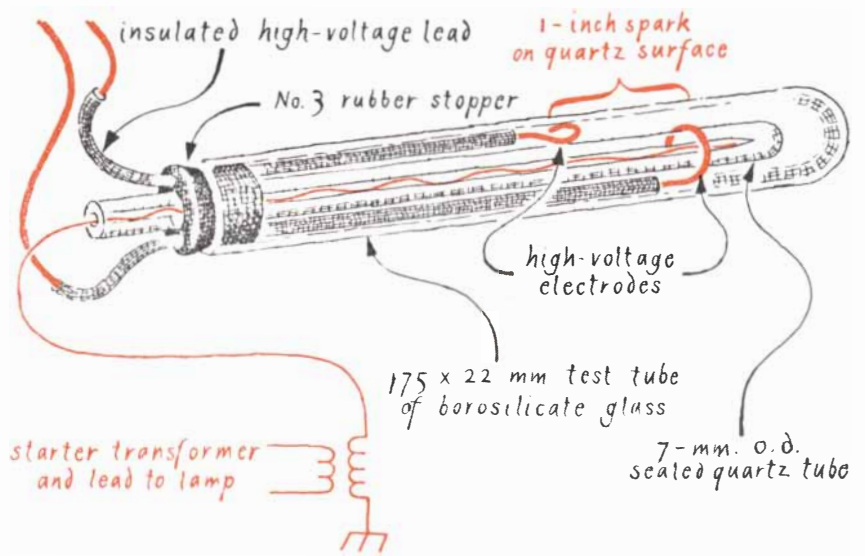


Assembly of colored slits *Slit images projected on straightedges*

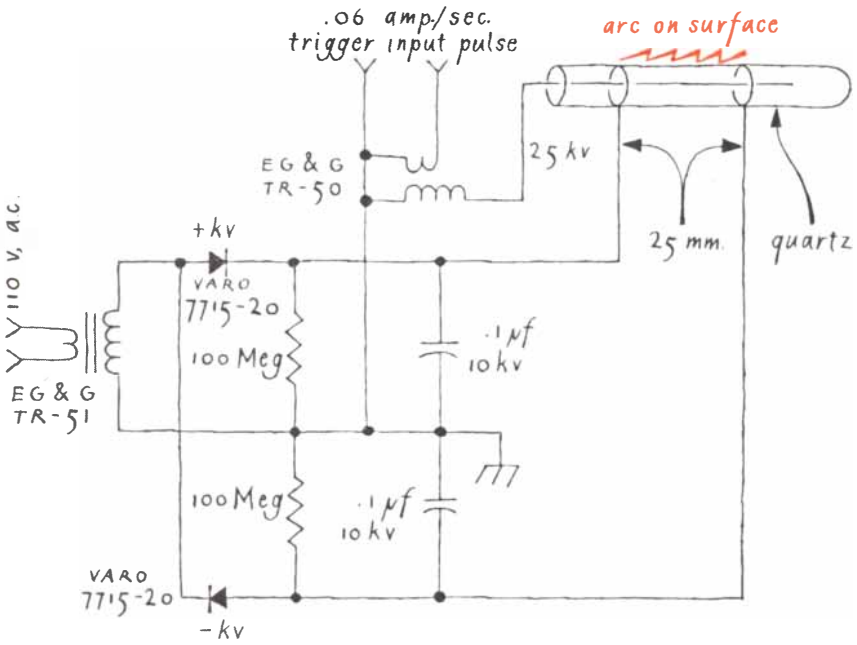
"As I have mentioned, systems for making schlieren photographs in color are based on the same optical principles but employ a more complex set of slits in color as sources. I made a square array of red, yellow, blue and green by taping to a glass slide four triangles of the kind of colored filter found in stage lighting in theaters [*see illustration at left above*]. The edges of the triangles meet to form the diagonals of the square. Opaque portions of the assembly were made with black masking tape. As in the case of instruments with a single slit, the assembly is placed in the focal plane of the mirror or lens and illuminated from behind. The resulting light in the test section is a homogeneous mixture of all four colors and appears approximately white.

"The straightedge assembly consists of four independently adjustable blades that combine to form a hole .375 inch square. Images of the four colored slits fall on the opaque boundary of the square. A disturbance in the test section that deflects a portion of the filter image (up and to the right, for example) causes blue and green light to pass over the edges that form the bottom and left sides of the square. When the image is focused by a camera lens, a blue-green view of the disturbance will be recorded on the film.

"The sensitivity of the instrument can be controlled by making each of the four



Harold E. Edgerton's air flash lamp



Circuitry of the lamp

straightedges independently adjustable. I frequently retract one straightedge somewhat, thus allowing light of a particular color to flood the picture. When yellow is admitted, for example, the blue-green image of a disturbance is superposed on a background of yellow, which not only improves the contrast but also may result in a more pleasing image.

"As indicated by the calculations, the size of the image in the camera can be adjusted by varying the focal length of the camera lens. In my system, which has mirrors 10 inches in diameter with an eight-foot focal length, a camera fitted with a telephoto lens having a focal length of 400 millimeters projected a 45-millimeter image on the film. The depth of the field varies inversely with the diameter of the square aperture formed by the straightedge. Reducing the aperture requires a comparable reduction in the size of the colored slits at the light source, which in turn reduces the light and increases the time of exposure.

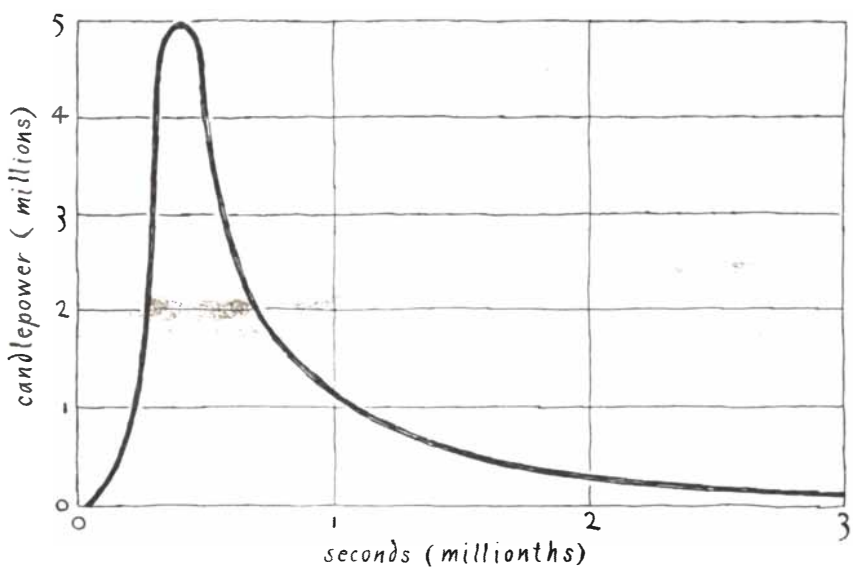
"Keep the diaphragm of the camera wide open. The size of the effective aperture is determined by the length of the straightedges. Place the camera lens about half an inch behind the straightedge assembly.

"Motion of the subject can be stopped only by short exposures, which require bright light. Each of the four colored slits of my instrument is 5/8 inch long and 1/8 inch wide—quite large compared with the dimensions cited in the technical literature. By using 'Sun Gun' lamps of the tungsten-halogen type with built-in reflectors of the kind designed for slide projectors, I could make photographs 45 millimeters square with exposures of a sixtieth of a second. This exposure is not fast enough, however, to stop motion as slow as hot air rising from a flame if the camera has a 400-millimeter lens.

"The solution of the problem of stopping fast action lies in an electronic flash lamp. The duration of most 'strobe' lamps owned by amateurs is about 5×10^{-4} second, which is sufficiently brief for many events of interest. The flash unit is placed behind and close to the colored slits, as is the alternative incandescent lamp. Indeed, the schlieren apparatus can be made with a rotatable fixture for conveniently interchanging an incandescent lamp and an electronic flash unit. The continuous source serves for composing the picture and is replaced by the flash for making the exposure.

"The simplest technique for taking photographs is to black out the studio, open the camera shutter and trigger the flash. For photographing bullets in flight a microphone can be employed to pick up the passing shock wave and trigger the flash. Timing difficulties are avoided by opening the shutter of the camera in advance. The color photographs reproduced in this article were made with a 35-mm. camera having a zoom lens of 170-mm. aperture and a maximum focal length of 410 mm. I used ASA 160 high-speed Ektachrome film and a Microflash unit manufactured by EG&G, Inc. (35 Congress Street, Salem, Mass. 01970).

"This unit generates white light of remarkable intensity by discharging a capacitor in 3×10^{-7} second through an air gap arranged so that the resulting arc adheres to the outer surface of a slender quartz tube. As first described by Edgerton in 1961, the flash unit consists of a power supply that charges a .05-microfarad capacitor of low inductance to a potential of about 18,000 volts. The flash is generated by discharging the capacitor through a spark gap consisting of two conductors in contact with the surface of the quartz [*see bottom illustration on preceding page*]. This assembly is housed in a Pyrex test tube about an inch in diameter and six inches long. The quartz tube and the electrodes are supported by a rubber stopper that, along



Output of light by the lamp

with the test tube, tends to suppress the noise of the spark.

"An appropriate electronic circuit for developing the spark consists essentially of a step-up transformer of 6,500 volts, a pair of solid-state diodes designed for service at 20,000 volts (such as the Varo Type 7715–20) and a pair of .1-microfarad capacitors of extraordinarily low internal inductance [*see top illustration on opposite page*]. Such capacitors are made by interleaving sheets of conducting foil with sheets of insulation and connecting the many alternate conducting sheets at the edges. The fabrication technique is costly, and the capacitors are also expensive.

"Edgerton found that the shortest flashes could be developed by discharging the capacitors in air. Gases such as krypton and xenon, which are found in conventional discharge lamps, continue to glow strongly for a substantial period of time after the electric current has ceased. Edgerton also learned by experiment that contact with the quartz tube tends to cool the arc and quench it quickly. He noted that the extended air spark over quartz has a higher resistance than an open gap. A critically damped spark must present to the circuit a resistance of about 13 ohms, whereas the resistance of an open spark is a small fraction of one ohm. The guided arc helps to damp out the oscillations in the circuit and reduce the flash duration. Moreover, the guided arc is more efficient for producing actinic (ultraviolet) radiation. The design generates a flash of about five million candlepower within an interval of less than 300 nanoseconds [*see bottom illustration on opposite page*].

"Triggering the spark to catch the action at the desired instant can pose a problem. In the case of a speeding bullet the problem has an interesting solution. Position a microphone to pick up the shock wave as the bullet speeds toward the target. After amplification the resulting pulse of current can be applied to a spark coil, such as the EG&G Type TR-50 trigger transformer. The output, at a potential of some 25,000 volts, is applied to a bare wire in the bore of the quartz tube. The resulting ionization initiates the discharge on the outer surface of the tube.

"The energy stored at 18,000 volts in the low-inductance capacitors is dangerous. The capacitors must never be touched until they have been short-circuited with a length of bare copper wire fastened to the end of an insulating handle at least a foot long. The triggering transformer, however, is no more hazardous than an automobile ignition coil."

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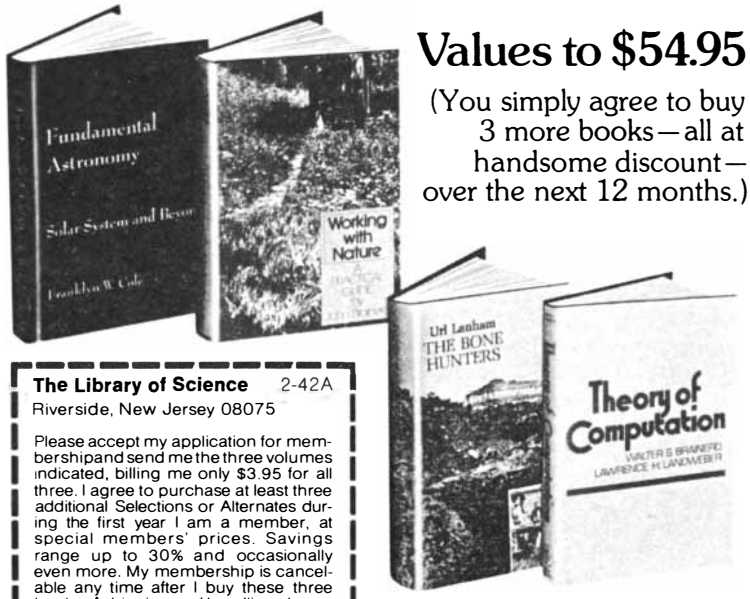

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BOOKS

J. Bronowski's "The Ascent of Man," and some playful aspects of the scientific life

by Philip Morrison

THE ASCENT OF MAN, by J. Bronowski. Little, Brown and Company ($15). "For Art and Science cannot exist but in minutely organized particulars," wrote William Blake. Dr. Bronowski knows his Blake, critically appreciates the arts and is an active scholar in realms ranging from mathematics to biology, by way of operations analysis. With evident delight he has presented here some marvelous particulars from the history of how human beings have come to an understanding of the world, in order to generalize for us "the way in which man's ideas express what is essentially human in his nature." His 13 personal and expressive chapters span that journey, from the ash layers around Lake Rudolf to the life of John von Neumann: our ascent, as he proudly sees it. We are still climbing his "sequence of cultural peaks." The handsome volume is the lightly edited spoken script of his ambitious television series; the book's origins in television (both that television-series number, 13, and the more than 200 illustrations) are evident. Although the ideas are his own, along with the engaged and open warmth and the quite personal conclusions, the resources brought to bear are more than any writer on the philosophy of nature has ever disposed of. The resources, skills and energy of the British Broadcasting Corporation made the films (which will be shown in this country during the fall on the Public Broadcasting System) possible and remain visible in the book, in special experiments, computer graphics, distant landscapes and the varied labors of gifted research assistants. Most of the illustrations that enrich the text are fresh, their meanings tightly linked, their form as attractive as it is unexpected. Familiar images are not neglected: we expect and deserve a bison of Altamira, the golden heads of emmer and wheat, four stages of the chick embryo, a prism and its spectrum and a spiffy young Einstein in the patent office. We also see, in context, a computer screen displaying two outline drawings in rotated views, the one a loop of DNA helix, the other a chalice by Uccello; the baths of the harem in the Alhambra; a helicopter view of a single tree flaming purple in the green canopy forest; Josiah Wedgwood's trial bits for the color and glaze of his 1776 jasper ware, and eight attractive man-and-wife couples: the Watsons, the Pasteurs, the Curies, the Einsteins, the Borns, the Boltzmanns, the Bohrs and the von Neumanns.

Dr. Bronowski's success is clear: at his best he welds his high general theme with the vivid details of our history. In the usual book, a less personal work, we expect to gain an easier middle ground, neither so wide nor so particular; such books treat of individual disciplines, such as "history of Renaissance science" or "comparative ethnography." A few examples cannot in any way exhaust Bronowski's kind of story but can suggest it. Blood groups alone make it clear that two waves of migrants came, rather late in the history of our species, into the unpeopled Americas. We see their dwellings today, from Arizona to the Andes, and we can distinguish two kinds of architecture. One was made by molding—the mud house; the other was made by the assembly of parts—stonemasonry. Both arise here, as they did elsewhere in the world. For our author, one form merely "reflects the cupped hand"; the shape of the hand fixes the shape of the clay pot and the pit house. The controlled modular splitting of wood or stone is analytic; by it we divide and reassemble the world in blocks, making a kind of new "crystal," forms never before found in nature. Not every craftsman will agree, but the depth of the argument shows plain.

Again, take the Alhambra, "last and most exquisite monument of Arab civilization in Europe." Its Sala de las Camas was the intimate chamber to which the harem girls came after the bath, while blind musicians played and eunuchs padded about. No doubt in classical and in Christian palaces the room would be embellished with erotic representations of the female form, but here in Islam we find instead ingenious and colorful geometric designs in tile, exhausting the symmetries of the plane. In this civilization "the artist and the mathematician... have become one."

It was through western Islam that most of the classical legacy was forwarded to Europe. With it came the perception of the "one really original scientific mind that Arab culture produced"—Alhazen, we call him—who first realized how a cone of rays represents light coming from an object to the eye. On that insight the Christian artists, freed to draw the "irrepressible life" of the world, at last constructed perspective. In the cities of northern Italy the painters came to portray the world as it appeared, projected into the eye. This conquered depth at last, but that dimension was not the only gain: still more, it captured time. Before perspective things were rendered as they were known to be, ideally, seen from many shifting viewpoints—time-averaged, as it were. The perspective artist caught that single fleeting moment when his gaze was directed to the vanishing point, more an instant of time than a special position. From that power arose the analysis of motion. As the High Renaissance gave over to the 17th century time appeared in our vision of nature, not merely the uniform, ineffable circling of Aristotle but Kepler's rhythmic ellipses and finally the powerful successive snapshots of Newton and Leibniz.

So dazzling a thread quickly spun out of the short-staple facts is not always strong enough to support the philosopher, but it is the sense of risk and daring that gives the book its special appeal, no less perhaps for the general reader than for the scientifically trained one. It is overall a master weaver's effort to make us all a warm cloak against the world's dark, explicitly fearing that unless "an understanding of man's origins, his evolution, his history, his progress" becomes a "commonplace of the schoolbooks" we shall not endure 50 years more. The key to our hopes is a "democracy of the intellect," not the aristocracy of the mind

that the author's brilliant friend von Neumann loved and served. This book and the films are Dr. Bronowski's offering to that end; if a doubtful detail enters, if relativity, say, is not made quite obvious, if a magnificent Shang bronze owl and one text page alone present all of great China, we all share that human finiteness, just as we admire human courage and richness. The measure of this work will be the reflection and discussion it must ignite, for its pages are bright and warm at the same time. Read, and watch!

A RANDOM WALK IN SCIENCE, an anthology compiled by R. L. Weber. Edited by E. Mendoza, with a foreword by William Cooper. Crane, Russak & Co., Inc. ($12.50). TWO CYBERNETIC FRONTIERS, by Stewart Brand. Random House Inc. ($2). Weber's wide-ranging anthology includes up-to-date selections from *The Worm Runner's Digest, The Journal of Irreproducible Results,* the *Journal of Jocular Physics* and a real find, the Russian volume *Physicists Continue to Laugh,* published in Moscow by MIR in 1968. It offers more: Jonathan Swift and Mason-Dixon, James Clerk Maxwell and R. W. Wood, John Dalton and Ludwig Boltzmann, with cartoons and even excellent photographs of ancient clockwork and of unlikely church-steeple crystals seen with the scanning electron microscope. Initially a "collection of jokes about physics," it has been enlarged in scope and tone to present a more humane picture of scientists than their usual papers convey, to include some playful items from other sciences, with some "dramas and tragedies from the past." These augment the modern parodies and (mostly clever) puns, the cynical appraisals of colleagues, the disillusion with granting agencies and even a few exercises in cruelty. The English novelist William Cooper supplies a troubled foreword that recognizes the "set of clever men... having a high old time with rational concepts," but he is distressed that these same physicists at play have not "comprehended that irrationality is our basic natural state." This worldly fun is more conceptual, he says, than human: heedless pleasuring in an endangered time when the two poles of culture are not just science and letters but mind and antimind.

Yet the darker side of human existence informs these quips and crotchets more than Cooper will allow. Consider the pointed tale told of Niels Bohr. On a visit to the U.S.S.R. he replied to the question on how he had created such a first-rate school of physicists: "Presumably because I was never embarrassed to confess to my students that I am a fool." Later a well-known Russian theorist misquoted Bohr's remark to go very differently: "... to declare to my students that they are fools." The speaker apologized for his slip of the tongue after the audience's animated reaction. The thoughtful Peter Kapitsa did not see the event as a slip of the tongue at all but as "the principal difference between the schools of Bohr and of Landau." Nor can we laugh except in despair at the 1931 review of the German book *100 Authors against Einstein,* even when its critic is at his wittiest; antimind has carved the decades between too deeply.

Compiler, editor and designer have done well. Here are the classic pieces: the double-talk engineering report on the turboencabulator, the verse about Dr. Edward Anti-Teller in his distant streak of antimatter, the oracular aria "Take away Your Billion Dollars" (every volt I make is pure!), the original paper on Murphy's iron law, the pioneering 1955 study "On the Feasibility of Coal-driven Power Stations," the random knowledge generators of 18th-century Laputa and of today's CERN, the erudite prewar Princeton parody on the mathematics of lion-hunting in all mathematical styles "by H. Pétard" ("the Dirac method... left as an exercise for the reader") and the story of the paper by Alpher, Bethe and Gamow. There are some 100 items, from many pages long to a few lines; given some tolerance for those stubbornly wrought puns (for example 10^9 los is one gigalo), there is something between laughter and tears for every reader in the know. Entry is limited, however, by language and subject matter to the initiate, for here is an honest display of our common humanity expressed within a coterie, albeit one that spans many lands and some centuries.

The "two frontiers" of *Two Cybernetic Frontiers,* a little paperback, are described in reworked magazine pieces by a sensitive analyst of science and technology, the originator of the *Whole Earth Catalog.* Here only the second of his essays will receive much attention; the first is a sketchy if enthusiastic introduction to the person and the subtle thought of the philosophical psychologist and anthropologist Gregory Bateson.

The second essay (improved and enlarged from the rock periodical *Rolling Stone!*) is of one cloth with Brand's earlier prescience. He visits, appraises and portrays the computer hacks: the technicians of the discipline, a legion in support rather than in research whose energy and devotion infuse what is now one of the largest industries in the world. They are young men and women who are "brilliant but not very interested in conventional goals," artisans of the mind, "fanatics with a potent new toy. A mobile new-found elite, with its own apparat, language and character, its own legends and humor." Witness the number-halftone printers, the wild geometric displays, the playful computer-music programs; half of these people, Brand says, are "heads."

Notable hacks include "The Unknown Glitch." "One of the guys wrote a program... which at random intervals would wake up, print out I AM THE UNKNOWN GLITCH. CATCH ME IF YOU CAN, and then it would relocate itself somewhere else in core memory, set a clock interrupt, and go back to sleep. There was no way to find it." More social than that solitary adventure is Spacewar, the game program that displays spaceships as blips on the television screen and provides means for firing controllable space torpedoes that occasionally strike and remove the target, which disappears "in an attractive explosion." It was invented at the Massachusetts Institute of Technology in 1962 by Steve Russell; now, in much-elaborated versions, it engulfs hundreds of hackers from coast to coast every night, "locked in... combat for hours at a time, ruining their eyes, numbing their fingers..., joyously slaying their friends and wasting their employers' valuable computer time." Dazzling graphic programs abound in every center "but the only one you find everywhere is Spacewar." In San Francisco there is now a people's computer, a donated computer set up and operated by a loose volunteer community of 200. "Spacewar serves Earthpeace"; it is a parable for the still optimistic Brand, this "enthusiasm of irresponsible youngsters." Can this symbolic death lead somehow to a moral replacement for war? In this too brief article, with the faces of the players, the look of the screen and the addresses of real people who can tell you more, Brand has once again set out how a generation feels that is not passive before the machine. Their stance has its own irony: addiction, like the gambler's.

A WORLD OF STRANGERS: ORDER AND ACTION IN URBAN PUBLIC SPACE, by Lyn H. Lofland. Basic Books, Inc., Publishers ($9.50). A stranger falling among the Bedouin can count on the most hospitable of receptions. The Tiwi, who lived as hunters on two small islands just within sight of the northern coast of Australia, were "consistently and implacably hostile" to the point of murder of any

outsider who appeared, whether he was an Australian mainlander not unlike themselves or a Malayan fisherman castaway. Human beings have lived in small, intimate groups up to the size of villages for the entire life of our species; strangers have therefore always been rare, and have been dealt with as rarities in one way or another. In the past five millenniums, maybe more, a new social relationship has arisen: We who live in cities live in a world of strangers, surrounded by other humans "personally unknown . . . but visually available." How have we made the transition to groups of 10,000 or more, in which we perforce surrender personal identification of the faces we see?

That is the unexpected problem set in this readable volume, a weaving of widespread historical citations with direct observation and experience by a California sociologist. She sees the world of strangers in the public spaces of the city, where anyone can go—at the price of encounter with strange faces. Follow the city into time. The preindustrial city (a few pages of description here evoke the omen and chiaroscuro of Federico Fellini's ancient Rome) ordered its people not in space but by their costumes and behavior. The street singer, the curbside merchant, the open-air classroom, the blind beggar, the mutilated malefactor being whipped along the road, the sudden burst of flame and the spontaneous fire fighters, the enclosed litter with its powerful hidden passenger guarded and borne on the burly shoulders of uniformed men—all these crowd you in the open street, in noise, dirt, filth and fright. Too many people, too many odors, too many sights. So it was in the past. Public space was mainly integrated, but people's dress, markings, bearing and groupings displayed the social order and categorized all the strangers bustling by.

In the modern city most of this kind of order has vanished. No criminal is legally marked or mutilated. Special places enclose behind doors the schools and the punishments, the markets and the latrines. The sedan chair of the few has become the automobile flood of the many; in the automobile public space becomes private as one rolls through unvisited and emptying streets "in a cocoon of privacy." It was the not so wealthy middle class, as it grew in numbers and power, that fostered the spatial order. Police and fire forces, zoning and a variety of other legal and "humanitarian" institutions arose to maintain the class and task structure of the city through spatial division. Then the mass production of clothing dealt "the most crucial blow to the dominance of the appearential order." Now the poor could look like the elite. Given, then, the new class in power and the massive influx of rural people ignorant of the old ordering scheme, the modern spatially differentiated city was bound to arise.

The latter half of this stimulating argument addresses itself to the behavior of people in cities as they operate the varied systems that "code" their world of strangers. There is a long education in this art, begun in childhood and leading to such subtleties as one novelist's Greenwich Village woman, who sits at the drugstore counter with the Stendhal novel she had read up to page 50 and "carried now only for effect." This effort to signal one's role by appearance is constant, but it is as ephemeral as the bumper strip you can change overnight with the headline. Here are the means of making a piece of public space into home territory. One example is the pensioners on the bus-depot bench, who never travel but act as host to the casual traveler. Another is the groups that turn a given district into a village or a once public bar into the hangout of a particular coterie. Mobility and change fight the tendency to disassemble the city's unity into a network of urban villages, and the automobile in a way superimposes on the map of the metropolis a dispersed "village" of semiprivate spaces, different for each driver.

Sometimes a single venturer must enter public space, unable to enforce any change on the space filled with strangers. Such a person, drawing on a lifetime of experience, uses "body management" to transform the space symbolically into a private one. He cases the place, eyes wandering, while he delays his entry with some small plausible task: taking coins from a pocket or shifting a purse from one arm to another. Concentration on objects, thereby avoiding contact with a stranger's focused eyes, is one important step. "Nesting" oneself in a corner, impassivity, sunglasses, the "middle-distance stare," flight and disattention represent various loners' adaptations to the world of strangers. "That all this skill should be put to such a negative use is perhaps one of the great ironies of city life." Finally, some people seek adventure in the strangers' world, hunting, "passing" and performing—and pretending, a spontaneous version of the last two arts. "In the friendly darkness of the anonymous bar, how easily does the teaching assistant become a professor . . . , the lowly private out of uniform, a man of substance."

Professor Lofland is an "unashamed cityphile." She cannot foresee any retreat from the city, retreat either into the pseudotribalism of the urban village, dispersed or contiguous, or into the small town, the rural commune or the community. There are too many of us now, and we must face the world of strangers as a permanent home. She has certainly raised a set of fascinating and central issues, although her use of entirely secondary historical sources and her somewhat sketchy account of modern experiences leave the reader with no conviction that the book has solved or even finally outlined these problems. There is more work to be done—in understanding social behavior, in securing economic change and in modifying national structures—before we can build a city of unafraid strangers.

MAN-MADE CRYSTALS, by Joel E. Arem. Smithsonian Institution Press ($15). The happy rock hound and the merely curious file past the cases of the great mineral collection of the Smithsonian, in proper admiration now of the indigo glow of the Hope diamond, now of green tourmaline bars as big as Thermos bottles. Nature has bred such crystals out of the symmetry of the electron orbits and the incessant search of diffusing atoms for thermodynamic balance. In the same halls the author of this colorfully illustrated book has recently established a new archive, the National Synthetics Collection, recording our human emulation of the slow processes of the earth. The crystals brought together there document the insight, cunning and patience of crystal growers, bearers of a 20th-century technology; these beauties were formed not deep in the veins of the Minas Gerais or in the Kimberly Pit but in the superhigh-pressure machines of Schenectady or the rotary autoclaves of Massachusetts.

Let us sample this account of a collection. In 1877 Edmund Frémy of Paris crystallized thin, fragile plates of ruby from alumina melted with the right flux. His assistant Auguste Verneuil went beyond his master when, by 1902, his rubies made by the flame-fusion method came on the world market. Nowadays melt-grown gemstones are made by the ton worldwide by that method, to serve as ornaments and in instruments. A schematic diagram shows how the feed powder drops down through the tip of the inverted oxyhydrogen flame, to fall as droplets of rain onto a slowly turning ceramic rod that is gradually lowered as the drops solidify into a single crystal. The high temperature and the freedom from any wall impurities allow a most

orderly growth, given precise control of the entire process and a final careful annealing. An even cleaner modification involves growth in a vacuum, the heat coming from the focused image of a high-intensity arc. A hundred substances are now grown by flame-fusion methods. Here one can see in color the little Frémy rubies alongside of nine-inch carroty boules of modern ruby and cakes of ruby good for flat plates, made by collecting the droplets on a rotating disk. A pure snow white alumina feed grows clear, colorless boules, "white sapphire" to the trade, used for instrument bearings; chromic oxide makes rich rubies; a mixture of iron and titanium, blue sapphire. (The producers offer a wide range of colors: red, pink, orange, yellow, green, blue, brown and purple!) If you want stars, add a little titanium dioxide in the feed; when the formed boules are reheated, needles of rutile precipitate within the crystal along the sixfold crystallographic axes; the magnificent star gem results. High-quality synthetic corundum is as fine in color and regularity as any natural gem; since the round bubbles and curved striae of the natural stone can be detected under the microscope, synthetic corundum remains distinguishable from, and much cheaper than, the rare gift of the Ceylon sands.

Corundum can also be grown by the Czochralski "pulling" technique, in which the crystal grows on a rotating rod that is slowly withdrawn from a melt. Twelve-pound crystals are known from this technique; big white sapphire plates have been made into light body armor and bulletproof helicopter windows. Extruded shapes can be grown too, by pulling films of the melt out through dies to make elegant tubes and plates of various kinds; the trade name of such material is Saphikon.

The book is wide-ranging, in just this style. We read history, learn the techniques and the trade names, see excellent pictures of the crystals, learn of the uses—all at an entirely introductory and descriptive level. There are chapters on gems, on growth from vapor and solution as well as from the melt and on the meticulously pure axial forms grown for the electronic world: the smooth pulled bullet shapes of silicon and germanium. There are a dozen case histories, over the gamut of strange crystals found useful as laser mediums, light modulators, ferrite hosts for magnetic-domain ("bubble") memories, windows for infrared radiation, piezoelectric resonators and much else.

This is a first-class primer of a solid-

state art; it ought to open a new collector's domain. Diamond gets much too sketchy a treatment; in all other respects this is a very simple but encyclopedic initial reference. The trade names listed are useful for buyers; one wishes for a page or two of prices and production statistics. (Almost no numbers are given.) Our human principality of the glowing mineral kingdom finds here its first popular atlas.

THE PUZZLE OF PAIN, by Ronald Melzack. Basic Books, Inc., Publishers ($9.50). The house of our vulnerable body must have an alarm system, but clearly every urgent alarm can ring false, persist unduly and become itself a menace. Pain is a sensory experience, but assuredly it is more: effective, driving, sometimes overwhelming. "The pain of a toothache," wrote E. B. Titchener back in Theodore Roosevelt's day, "is localized... 'in the tooth'; but the unpleasantness of it suffuses the whole of present experience, is as wide as consciousness." The texts still like to simplify; generally we psychologize about the local event and regard the suffused experience as secondary. The model behind this view is as old as Descartes. Its latter-day version, developed by the physician Max von Frey in the 1890's, views our nervous circuitry in the simplest way, as so many color-coded wires, each color of wire bringing the similar pulse stimulus from a definite kind of transducer in the skin to a specific receiver in the brain. Today computer circuits no longer recall the wiring of the buzzers in the butler's pantry; they are branching and active, with feedback a commonplace, and when there is trouble, they often "ring." It is fitting, then, that we now begin to build a theory of pain based on a modest amount of pulse-tracing in the decerebrated cat, on a good deal of puzzling clinical material concerning human pain and on a model of message transfer in the time of System 370.

This brief, modest, readable and yet learned introduction to the modern view of pain is the work of a Montreal psychologist of wide experience (he has tried everything from finding what words people used to describe graduated degrees of pain to recording pulses from the brain neurons of cats) who is the coauthor (with Patrick D. Wall) of the most discussed current pain model. Anatomy and function are well linked in the book, which is illustrated with line drawings. There are block diagrams of conceptual schemes and drawings of oscilloscope traces, the most helpful of which schematize the hidden intricacies of the human nervous system with considerable clarity if not much realism.

The Melzack-Wall proposal is called the gate-control theory. One can hope only to suggest the complex conjectures in a limited space. The impulses from the various nerve endings in the skin are collected in a curious layer that runs the length of the spinal cord on each side. To this layer all inputs come, and it passes its processed results along to the deeper layers of the spinal cable leading up to the brain. This intermediate system tends to open a "gate" in the presence of certain identified patterns of input activity, to close it in the presence of other patterns. A central biasing and control mechanism in the brain can reach down to modulate the level of the gating. Given enough input from the right classes of fibers, with not too high a bias set on the gate, the transmission from the cord activates, in the midbrain above, "those neural areas that underlie the complex, sequential patterns of behaviour and experience characteristic of pain."

In such a scheme it is clear that pain is no blind result of a pinprick tipping off a single special pathway. Acupuncture anesthesia—even as strange a technique as inserting the current-carrying needles in the earlobe to block pain in stomach surgery—becomes at least credible. Hypnosis can in fact end pain, as can simple suggestion and even white noise! Perhaps one begins to understand the Scotch terriers reared in isolation who will sniff flame repeatedly and will orient toward pinpricks without withdrawal or arousal. Then there are the battle-wounded, whose pain is determined less by their injury's nature than by its significance. Only one in three of them asked for morphine; in a similarly injured group of civilian patients four in five did. The response to injury in the wounded soldier "was relief, thankfulness at his escape alive... even euphoria; to the civilian, his major surgery was a depressing, calamitous event." Now the curious phantom limb (for example the splinter under the nail that remained painful long after the entire hand had been lost in an accident) finds a closed-loop-circuit explanation. These notions seem somehow right in kind, although it would be rash to think that all the important mechanisms have already been teased out of the myriad interconnected fibers of the gray matter. The control of pain will not be single, biochemical or simpleminded, but the richer understanding reflected in this book means that it is on the way.

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