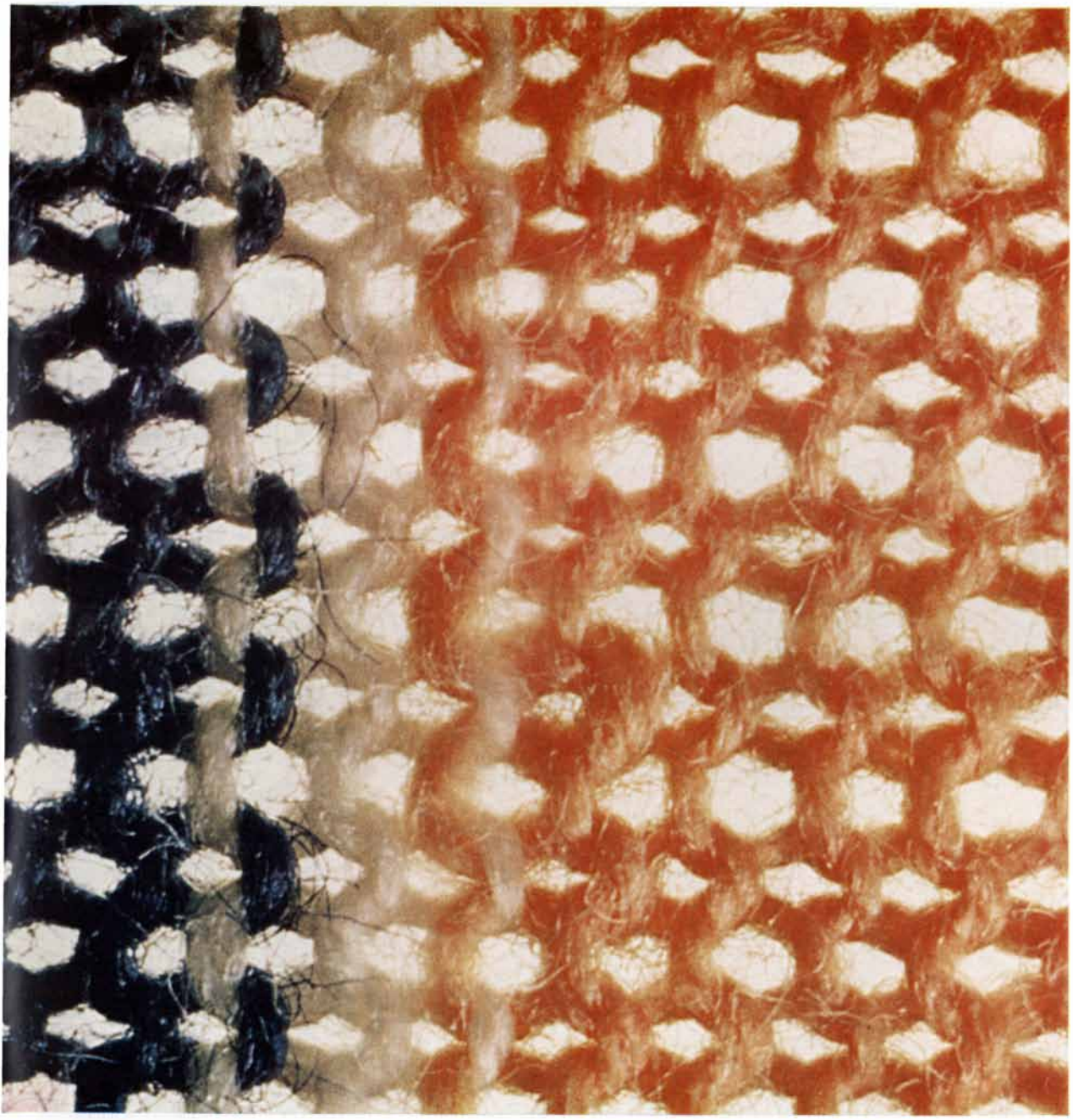
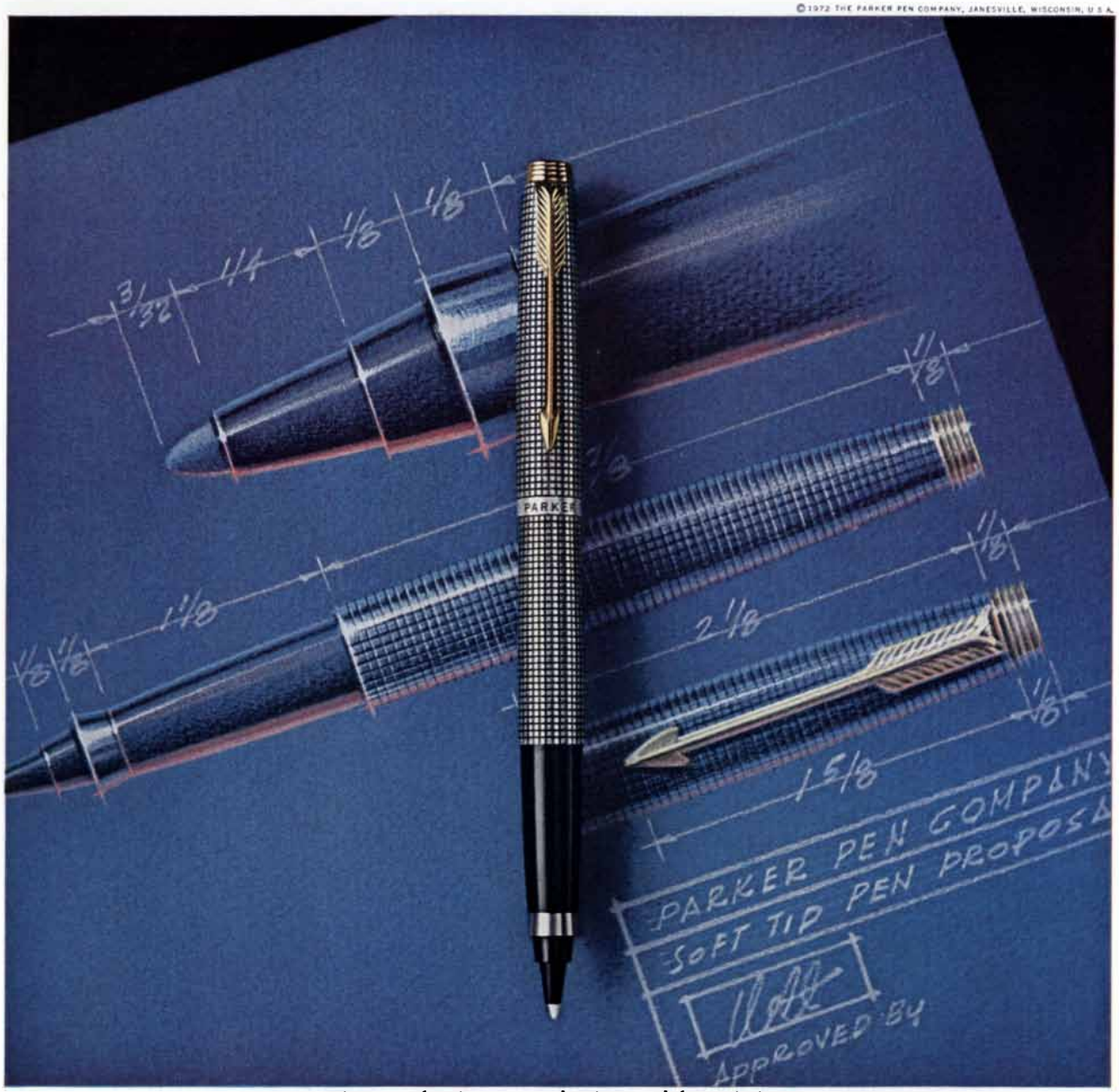
SCIENTIFIC AMERICAN



YARN FABRIC

ONE DOLLAR

December 1972



First soft tip pen designed for giving. The Parker 75

This is Parker's newest pen. Admittedly it's not one of the things that all the world has been waiting for. Crafted in solid sterling silver and priced at $20, it's an out-and-out luxury, which is exactly what we planned it to be. Special gift occasions and the very special "Thank you" are what this pen was made for.

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Go ahead, pick it up. The heft tells you it's solid sterling silver. Silver that grows more beautiful the more it is handled. And it gives the pen an almost ideal balance through hours of comfortable use.

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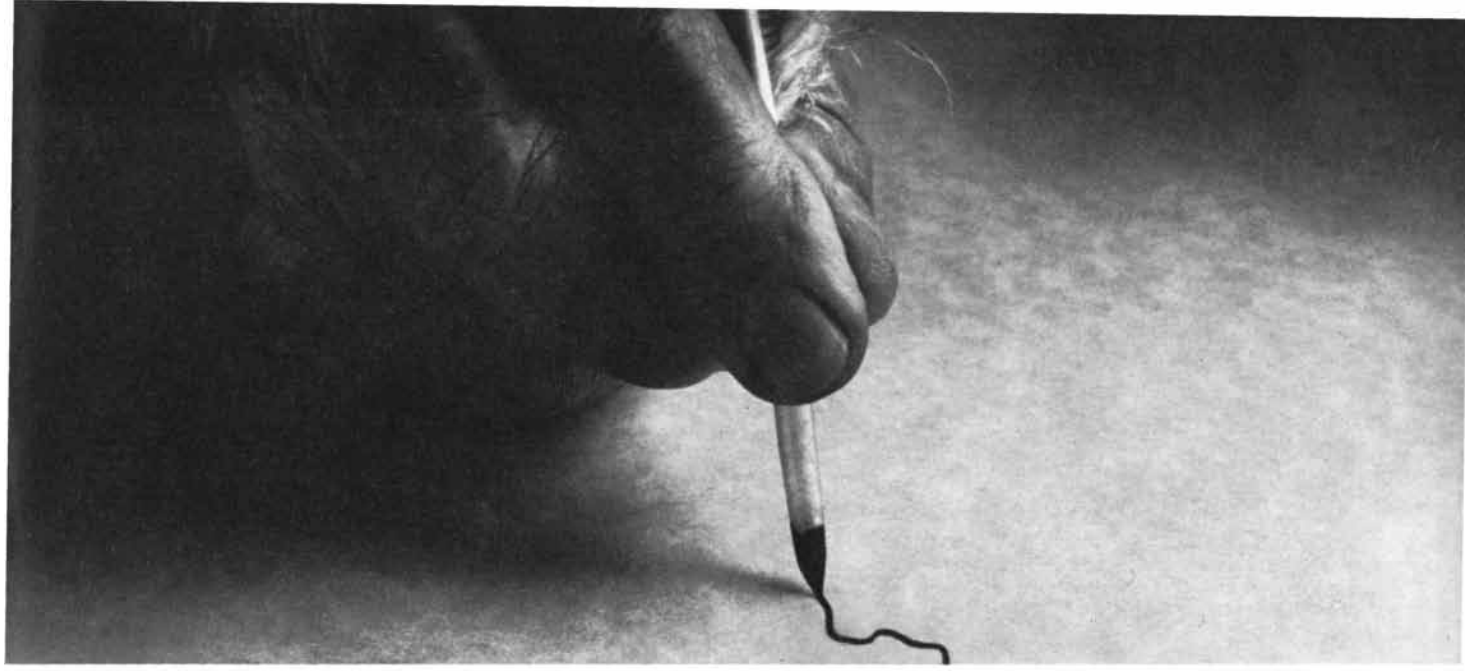
PARKER

World's most wanted pens

The Parker 75 Soft Tip Pen in solid sterling silver is $20. Also available in warm vermeil, $45; radiant 14K gold-fill, $30; dramatic titanium, $15. Matching ball pens and pencils. You'll find the famous arrow clip on every Parker, from the $1.98 Jotter Ball Pen to the $150 Parker 75 Presidential Pen.



Once maps were made by hand.

But why today?

Once, a man told another of what he'd seen and that man drew a map that all others could follow.

All of that was done by hand. That was then.

Today, a man takes a picture from an airplane of what he sees. And a second man prepares a manuscript from these photos. And then, this manuscript is transferred to film.

And then—incredibly—all of the lines that will make up the map (the rivers, the mountains, roads and streets) are *scribed* onto a negative master. By hand.

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We, CalComp, have told cartographers that our 745 flatbed plotter will scribe lines equal to the tolerances and standards of the most skilled mapmaker's hand.

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CALCOMP

IF WE GOT A CALL TODAY AT 3PM TO BUILD A MID-OCEAN TERMINAL, WE COULD GO TO WORK ON IT AT 3:05.

It's night. And an English container ship slips out of its berth for America. That same night an American container ship sails for England.

But part of the English ship's cargo will never reach America. And part of the American ship's cargo will never reach England.

Instead, both ships will dock in the mid-Atlantic.

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Today the world has plenty of seaports. And tomorrow there will be plenty of ports at sea.

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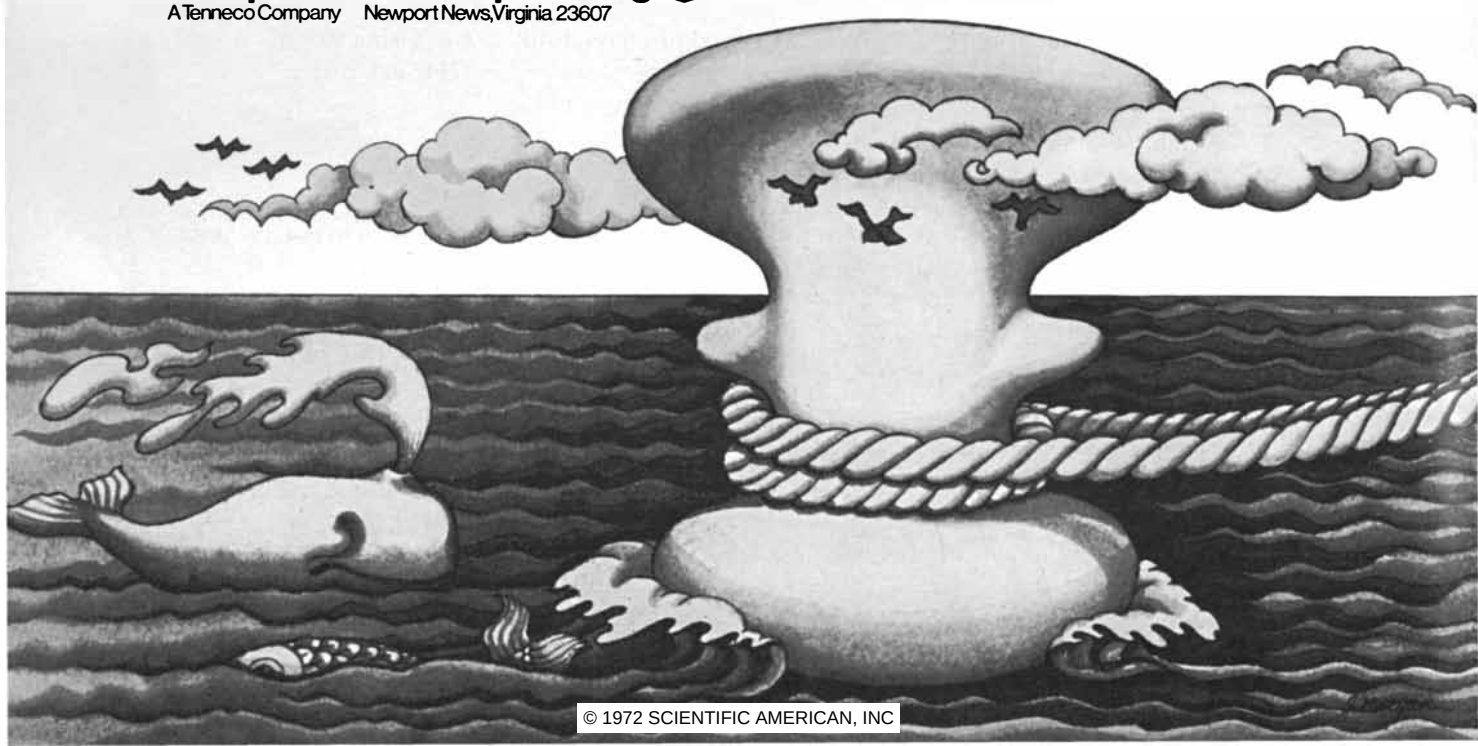

Established 1845 **SCIENTIFIC AMERICAN** December 1972 Volume 227 Number 6

ARTICLES

DEPARTMENTS

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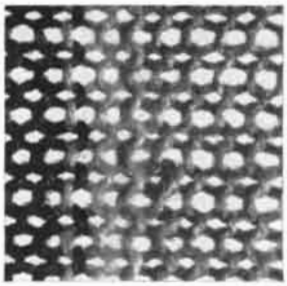

THE COVER

In the photograph on the cover a swatch of fabric is enlarged some 20 diameters, so that the individual strands of yarn of which it is made can be distinguished (see "Yarn," page 46). The fabric is a plain knitted jersey that was manufactured by the Galey & Lord Division of Burlington Industries. It was knitted on a circular knitting machine of a spun, staple yarn: a yarn composed of short lengths of natural or synthetic fibers that have been twisted together to make a continuous strand. In this case the yarn is a blend including equal proportions of cotton and polyester fibers.

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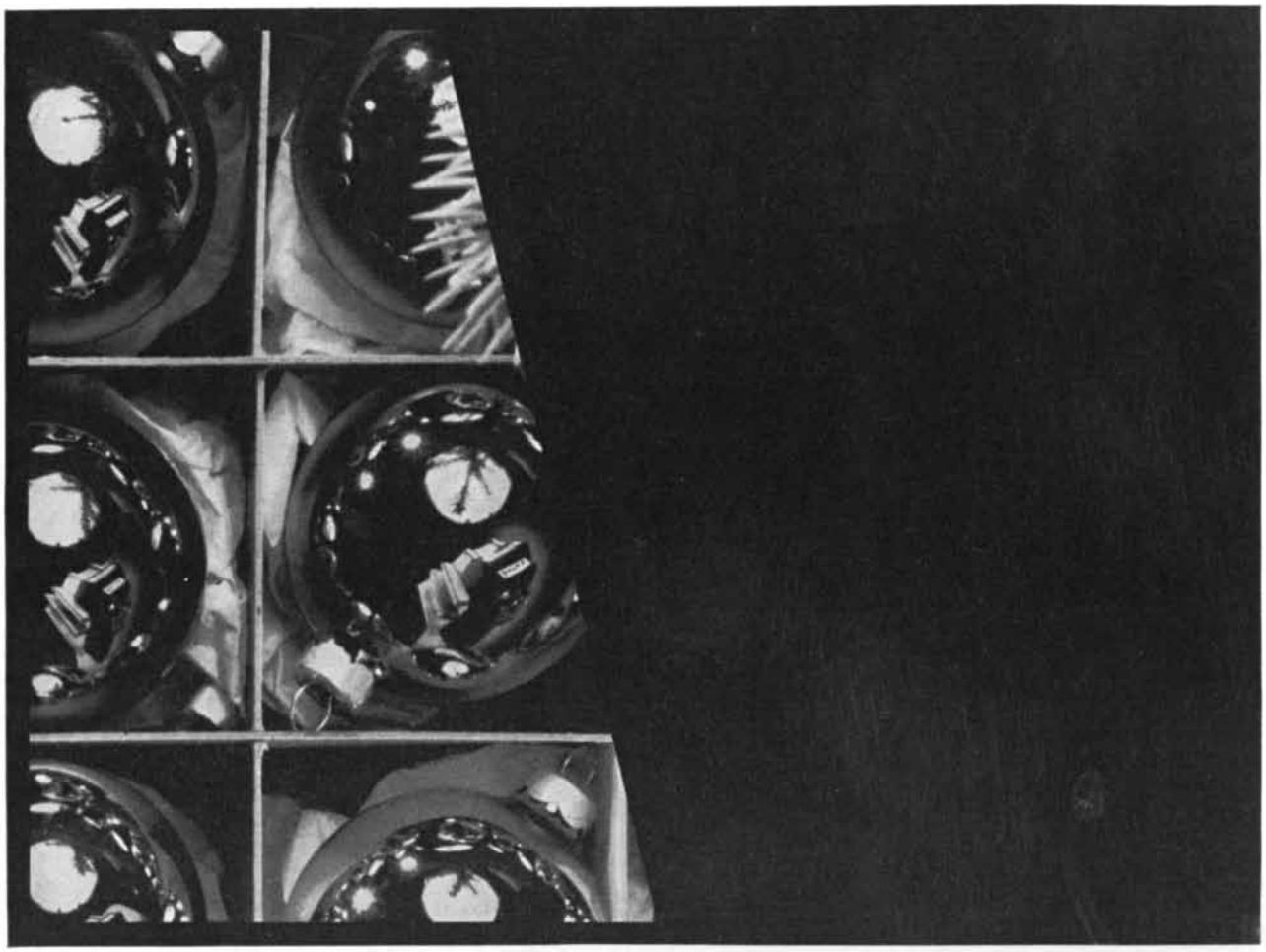
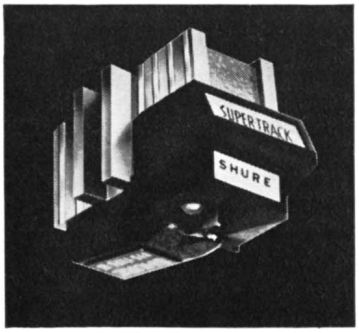


A cartridge in a pear tree.



A gift of the *Shure V-15 Type II* Improved stereo phono cartridge will earn you the eternal endearment of the discriminating audiophile who receives it. What makes the V-15 such a predictable Yuletime success, of course, is its ability to extract the real sound of pipers piping, drummers drumming, rings ringing, et cetera, et cetera. Stereo Review, in a test report that expressed more superlatives than a Christmas dinner, described the performance of the V-15 Type II Improved as ". . . . Unstrained, effortless, and a delight to listen to." All of which means that if you're the giver, you can make a hi-fi enthusiast deliriously happy. (If you'd like to receive it yourself, keep your fingers crossed!)

Shure Brothers Inc.,
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SHURE

LETTERS

Sirs:

When writing on a topic as general as animal communication, one must of necessity select material for presentation ["Animal Communication," by Edward O. Wilson; SCIENTIFIC AMERICAN, September]. However, selectivity does not necessitate bias. In choosing honeybee communication as a leading example in his article, Professor Wilson could well have mentioned the interesting controversy associated with this topic. Instead, the "dance language" is presented as fact without any mention of an alternative interpretation.

The theory of a symbolic "dance language" of bees has provided fascinating reading for many years. However, we fear that this fascination has too often led to an automatic rejection of other possibilities. The concept of a "language" among bees is an especially appealing one, it is true, but an alternative hypothesis has emerged from an ever growing body of evidence. It appears to us that honeybees may not be exceptional in their communication mechanisms after all, and that they may use odor in a manner similar to that of many other hymenopterans.

For those readers who are interested, a paper soon to appear in *Nature* contains our analysis of several challenges of our work and includes some new experimental results. Earlier aspects of the controversy are treated elsewhere (*The Bee Language Controversy: An Experience in Science,* Educational Programs Improvement Corporation, Boulder, Colo., 1971).

ADRIAN M. WENNER
LARRY JON FRIESEN

University of California
Santa Barbara

PATRICK H. WELLS

Occidental College
Los Angeles

Sirs:

I didn't mention the "controversy" over the honeybee waggle dance because I no longer feel that discussion of the subject even merits the word. While preparing my book *The Insect Societies* in 1969–1970 I studied the evidence in some detail, some of it in consultation with Professor Wenner, determined to reach an independent conclusion. The evidence, I came to conclude at that time (see pages 266–267), is overwhelmingly in favor of a communicative function for the waggle dance. A long series is now published of remarkable experimental results that have not been reasonably explained in any other way.

I have by no means taken a poll of experts on the subject but my impression is that Professor Wenner's rather intricate interpretations have been increasingly questioned and are now accepted by very few. The issue is not closed. (What issue ever is?) At this time it simply seems too tenuous to deserve mention in a general article on animal communication.

EDWARD O. WILSON

Harvard University
Cambridge, Mass.

Sirs:

Your August issue describes the use of hydrides of the lanthanum-nickel compound $LaNi_5$ and related alloys for the storage and purification of hydrogen ["Science and the Citizen," SCIENTIFIC AMERICAN, August]. These systems are indeed promising, but they are far from being the only ones, or the first ones, to be proposed for such an application. A group of us at Brookhaven National Laboratory have been working since 1966 on hydrogen storage in solids, and the results have been published in several articles and patents.

The program is oriented toward the long-range goal of providing small power sources, automobiles included, with nonpolluting synthetic fuels. Hydrogen is an obvious first choice, particularly since it does not require carboniferous raw materials for its production. At present they are its cheapest source, as in processes such as the steam-reforming of natural gas. Eventually they will become depleted, but hydrogen will still be available from the electrolysis of water by electricity of nuclear-reactor, perhaps fusion-reactor, origin.

A point worth noting is that different types of energy sources will require different hydrides as hydrogen reservoirs. Heat must always be supplied to decompose the hydride. Fortunately all energy-producing devices, whether fuel cells or combustion engines, produce waste heat as well, and it should be possible to utilize it for the decomposition. There must, of course, be a temperature match between the hydride and the device.... Still other criteria are obvious: high hydrogen content in the solid, by weight and by volume, and low cost. Much research remains to be done before the optimum hydride for each kind of energy producer has been found, but there are several that show promise besides the "AB_5" hydrides. For example, at room temperature vanadium dihydride (VH_2) will also supply hydrogen at a pressure in excess of one atmosphere, and it contains about 2 percent of available hydrogen by weight as compared with 1.38 percent for $LaNi_5H_6$. For devices operating above 250 degrees C., magnesium hydride (MgH_2) should be considered; its hydrogen content is 7.65 percent. Its heat of decomposition is high in relation to the waste heat from a typical engine, but one could afford to make up the deficiency by burning a fraction of the hydrogen and still show an advantage over systems of lower hydrogen content....

RICHARD H. WISWALL, JR.

Brookhaven National Laboratory
Upton, N.Y.

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NAME

NEW ADDRESS

OLD ADDRESS

SCIENCE/SCOPE

An advanced version of the successful Intelsat IV satellite has been proposed by a Hughes-led team of international companies under a Comsat study contract. The new satellite will have nearly twice the communications capacity and be operable with Intelsat's present ground-station network. At the present rate of growth, world communications traffic is expected to reach the capacity of the Intelsat satellite network in the Atlantic segment by 1975.

Two U.S. Navy aviators in an F-14A Tomcat became the first military crew in history to attack multiple targets simultaneously with multiple missiles from a single fighter aircraft when they launched two Phoenix missiles against two widely separated drones off Pt. Mugu, Calif., recently. The "double whammy" launch was a test of the multiple launch and guidance capability of the AWG-9 weapon control system. Both the Phoenix and the AWG-9 are built by Hughes. The Navy recently commissioned the first two F-14A squadrons.

Complex electronics systems for today's manned aircraft must withstand high G forces and considerable heat generated in critical units. To help solve these problems, Hughes is developing for the U.S. Air Force temperature-stabilized electronic mounting plates that use variable-conductance heat pipes in conjunction with phase-change heat-sink materials. Designed to improve component reliability, they can cool electronic units for as long as 30 minutes without using the aircraft's primary loop cooling because of a built-in emergency internal heat-sink capability.

Twelve long-range infrared devices that "see" at night are being built by Hughes for service testing under simulated combat conditions by the U.S. Army. Called NODLR (for Night Observation Device, Long Range), the portable, battery-powered device forms a TV-like image from thermal radiation of objects in view. It can be mounted on a ground tripod or installed on vehicles and will enable ground observers to detect people, vehicles, and field fortifications in total darkness.

Hughes has immediate openings for Field Engineers. Qualifications include U.S. citizenship, BSEE or Physics degree, willingness to travel, and experience in any of the following systems: electro-optical, infrared detection, laser ranging and target designation, or low-level-light TV detection. Please write: Professional Staffing, Hughes Aircraft Company, Field Service & Support Division, P.O. Box 90515, Los Angeles, CA 90009. Hughes is an equal opportunity employer.

An experimental laser communications system, developed by Hughes scientists under contract with the U.S. Army Electronics Command, provides a 5-megabit/second communications channel at 10.6 micron wavelength. With 1 watt output, and over the 8-kilometer path for which it was designed, the system is effective in all but the most severe weather. Keys to its high operating capability are the increased reliability and efficiency of the CO_2 laser in the transmitter and the optical heterodyne detection in the receiver. It has a potential in excess of 300-megabit data rate or 10 television channels.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1922: "According to Eugene Davenport, Dean of the Illinois College of Agriculture, the greatest future need of American agriculture is a fundamental national policy. One of our leading statisticians estimates that a century from now our population will amount to more than 225,000,000 people. The prophecy is startling because it suggests possible hunger and even famine as our future. At present, with less than half these numbers, our food production is only about equal to our domestic consumption. Unless we institute very revolutionary practices to enhance production, we may look for it to fall behind. Present indications are that we are rapidly slipping into the class of food-importing nations. This means that unless we are able to reverse the tide, we must readjust our social, economic and industrial organizations to accord with this new condition."

"While the sciences of physics and chemistry have become fine arts in which accurate measurements are not only possible but required, the attempts to measure the various capacities of the human mind have doddered along so far behind and remained so inaccurate that they have never been taken with too much seriousness. The best that psychological tests have been able to do in the past has been to show indications and determine rough averages. Out of the jungle of ignorance of ways and means for precise determinations of mental abilities great things are to come in the next few years. How much we can expect is shown by the excellent work done by Professor Carl Emil Seashore. His work in measuring musical talent is well-nigh flawless in so far as it goes—and he has gone much further than the layman can have dreamed possible. He is able to test any given subject and to say definitely how much musical talent that person has in relation to the average talent possessed by the group of persons already tested and numbering more than 5,000. This is far different and far more important than determining the average talent of the 5,000."

"The past month has been an eventful one as regards astronomical observation. Some of the parties that observed the total solar eclipse in August had favorable weather, including the Lick Observatory party on the northwestern coast of Australia. When their photographs have been measured and the calculations completed, the world will probably be in possession of decisive evidence, beyond the possibility of cavil, regarding the relativistic deflection of rays of light that pass near the sun."

"Radio broadcasting in its present form was built up overnight. Due to its complex nature, the lack of precedent or parallel to go by and other deterrent factors, it was to be expected that this hastily and poorly erected institution should be inherently weak and unsatisfactory to the radio industry and the public alike. It should be taken down to its very foundations and reconstructed along safe and sane lines. There are too many poor broadcasting stations and not enough good ones. The latest figures indicate that on October 5 there were 546 broadcasting stations in the U.S., very spottily distributed throughout the country, and up until recently all these stations have been operating on one and the same wavelength, 360 meters, giving rise to endless confusion. Broadcasting caught our legislators unprepared. The present radio law was designed before radio telephone existed in everyday form. There is a bill in the House and Senate at the present time which, if passed, will give to the Secretary of Commerce regulatory powers, and this bill should be brought up for public hearing without delay. The proper radio laws, giving several bands of wavelengths for different classes of stations, might do much to increase the possible number of broadcasting transmitters with a minimum of interference."

SCIENTIFIC AMERICAN

DECEMBER, 1872: "Dr. Ludwig Buechner, the German naturalist, lately delivered a lecture in New York on the origin of man, in connection with the theory of the origin and development of life. After explaining the Darwinian theory of the origin of life, the lecture characterized the hypothesis that man is a descendant of the monkey and the ape

as absurd. The higher classes of apedom—the gorilla, the chimpanzee and the orang-outang—were, Dr. Buechner said, only our cousins, and there was some satisfaction that these ugly animals were not our ancestors. But there was no doubt that they descended from the same ancestor that was the forefather of man. The origin of man must be looked for in a tropical region, probably southern Asia or Africa, during the Tertiary period. This means that the time of the origin of man must be traced back hundreds of thousands of years."

"The town of Easthampton, Mass., has an excellent plan for a local fire department, which may be advantageously copied by communities that do not desire to maintain steam fire engines in connection with a reservoir. The Valley Machine Co. are building a large bucket-plunger steam pump with a capacity for discharging 500 gallons per minute, from which pipes have been laid through the streets, connecting with hydrants placed at suitable distances apart. These pipes are always kept full of water by means of a small auxiliary pump. The large pump is to be connected with a boiler in one of the manufacturing establishments of the town, where steam is always kept up, so that a stream of water can be obtained in a moment, in case of fire, merely by coupling the hose to a hydrant."

"There is at last a fair prospect of the permanent establishment in New York of a Metropolitan Museum of Art—a museum similar to the South Kensington museum in London: a collection of works of art, original and copies, free to the study and inspection of the public. A site for the building has been obtained, on the corner of 79th Street and Fifth Avenue. In addition to the fine paintings that have been placed in the present temporary gallery, duplicates of the best specimens of the splendid collection in the abovementioned English museum are to be added."

"The object glass of the Allegheny Observatory at Pittsburgh, Pa., which was mysteriously stolen three months ago, has been found and restored to its place in good order. Its value was $4,000. It was carried off by an intelligent sort of thief who probably expected that a reward would be offered for its return, enabling him to make a little money by the operation. He deposited it in a stable, and his pal stole it from him. It finally came into the possession of the police and was carried home."

THE AUTHORS

RAPHAEL TSU ("High Technology in China") is a member of the research staff of the International Business Machines Thomas J. Watson Research Center, where he is involved in both theoretical and experimental studies in the broad area of semiconductor and solid-state physics. Born in Shanghai in 1932, Tsu (whose Chinese name is transliterated as Chu Chao-shiang) left China for England in 1951 after two years of study at St. John's University Medical School (now merged with Aurora University Medical School to form the Second Medical College in Shanghai). He spent a year of graduate study in nuclear physics at the cyclotron laboratory of the Carnegie Institute of Technology before moving on in 1957 to Ohio State University, where he obtained his Ph.D. in 1960.

JAY S. ROSENBLATT ("Learning in Newborn Kittens") is professor of psychology and acting director of the Institute of Animal Behavior at Rutgers University. Rosenblatt's academic training, which began in 1940 at the College of the City of New York, was interrupted during the closing years of World War II by service in the U.S. armed forces. After the war he resumed his studies at New York University, earning a B.A. in 1947, an M.A. in 1950 and a Ph.D. in 1953. He taught psychology and did research on animal behavior at both C.C.N.Y. and N.Y.U. for a number of years before joining the Rutgers faculty in 1959.

KENNETH J. HSÜ ("When the Mediterranean Dried Up") is an experimental geologist on the faculty of the Swiss Federal Institute of Technology in Zürich. A native of Nanking, Hsü was graduated from the Chinese National Central University in 1948. He went on to obtain an M.A. from Ohio State University in 1950 and a Ph.D. in geology from the University of California at Los Angeles in 1954. He became a U.S. citizen in 1963. Before moving to Switzerland in 1967 he did industrial research (for the Shell Development Company) and taught (at the State University of New York at Binghamton and at the University of California). He writes: "My hobby is reading, and I am particularly fond of history books. I became a geologist—a scribe of earth history—only after I was persuaded that a historian, in the strict sense, had a hard time earning a living in China."

STANLEY BACKER ("Yarn") is professor of mechanical engineering and head of the Fibers and Polymers Division at the Massachusetts Institute of Technology. His association with M.I.T. has been a long one: he acquired all his academic degrees there (a B.S. in business and engineering in 1941, an M.S. in textile technology in 1948 and an Sc.D. in mechanical engineering in 1953) and has been a member of the faculty there since 1951. Backer holds six U.S. patents and is the author or coauthor of some 50 publications in his field, which he summarizes as "the mechanics of textile structures and the dynamics of textile processes."

ROBERT E. APFEL ("The Tensile Strength of Liquids") is assistant professor of engineering and applied science at Yale University. After graduating as a Phi Beta Kappa from Tufts University in 1964, Apfel went to Harvard University, where he received an M.A. and a Ph.D. in applied physics respectively in 1967 and 1970. He stayed on at Harvard for another year as a postdoctoral research fellow before joining the Yale faculty. In 1971 he was awarded the A. B. Wood Medal and Prize by the Institute of Physics in London for his work on cavitation phenomena. Apart from his interest in liquid physics, Apfel writes, "I have a strong interest in acoustics. As a physics major at Tufts and a member of the college chorus, I was challenged by the chairman of the department of music to come up with some answers about the poor acoustics in the auditorium in which we performed. This led to an undergraduate thesis on that topic.... At Yale I have expanded my interest in architectural acoustics (I'll be teaching a course on this subject in Yale's School of Art and Architecture) and have continued my research in liquids. I am now trying to apply some of the information learned about bubble formation in liquids to the practical problem of understanding decompression sickness ('the bends')."

BARBARA GORDON ("The Superior Colliculus of the Brain") is assistant professor of psychology at the University of Oregon. As an undergraduate at Radcliffe College, her primary interest was in experimental psychology. "As I learned more about sensory physiology," she writes, "my interest shifted to neurophysiology." Accordingly, after ob-

taining her B.A. in psychology from Radcliffe in 1963, she went on to work on the habituation of the spinal cord as a graduate student at the Massachusetts Institute of Technology, obtaining her Ph.D. in physiology in 1966. She began her work on vision in the laboratory of David H. Hubel and Torsten N. Wiesel at the Harvard Medical School, and has continued this line of inquiry since moving to Oregon in 1969. Most of her papers on the work have been published under the name Barbara G. Wickelgren.

GUNTHER S. STENT ("Prematurity and Uniqueness in Scientific Discovery") is professor of molecular biology and of bacteriology at the University of California at Berkeley. This is Stent's second article this year for SCIENTIFIC AMERICAN; he also wrote "Cellular Communication" in the September single-topic issue on communication. Concerning the genesis of the present article, he writes: "In May of 1970 the American Academy of Arts and Sciences held a small conference in Boston on the History of Biochemistry and Molecular Biology at which I was asked to make a few brief comments following an account by Salvador Luria of the origins of molecular genetics. I intended to speak for about five minutes, a time I thought was more than enough to point out the relevance of the prematurity and the uniqueness concepts to Luria's reminiscences about Oswald Avery and James Watson. But the conference participants—both scientists and historians—kept on interrupting me, and my 'brief comments' eventually lasted twice as long as Luria's lecture. This article is the product of that vigorous discussion, and among the discussants I am especially indebted to Robert K. Merton and Harriet A. Zuckerman of Columbia University for helping me to focus my ideas more sharply."

ELLIOT A. LAPAN and HAROLD J. MOROWITZ ("The Mesozoa") work together at Yale University, where Lapan is a postdoctoral research associate and Morowitz is a professor in the department of molecular biophysics and biochemistry. Lapan, who has just completed his doctoral studies at Yale, where he devoted his efforts to taming mesozoans as laboratory animals, is also associated with the Institute of Molecular Embryology at Arco Relice in Italy. A graduate of Temple University, he spent two years as a marine physiologist in France and taught high school for a year before going to Yale in 1968. Morowitz received his Ph.D. from Yale in 1951.

CUTLASS SALON BY OLDSMOBILE.

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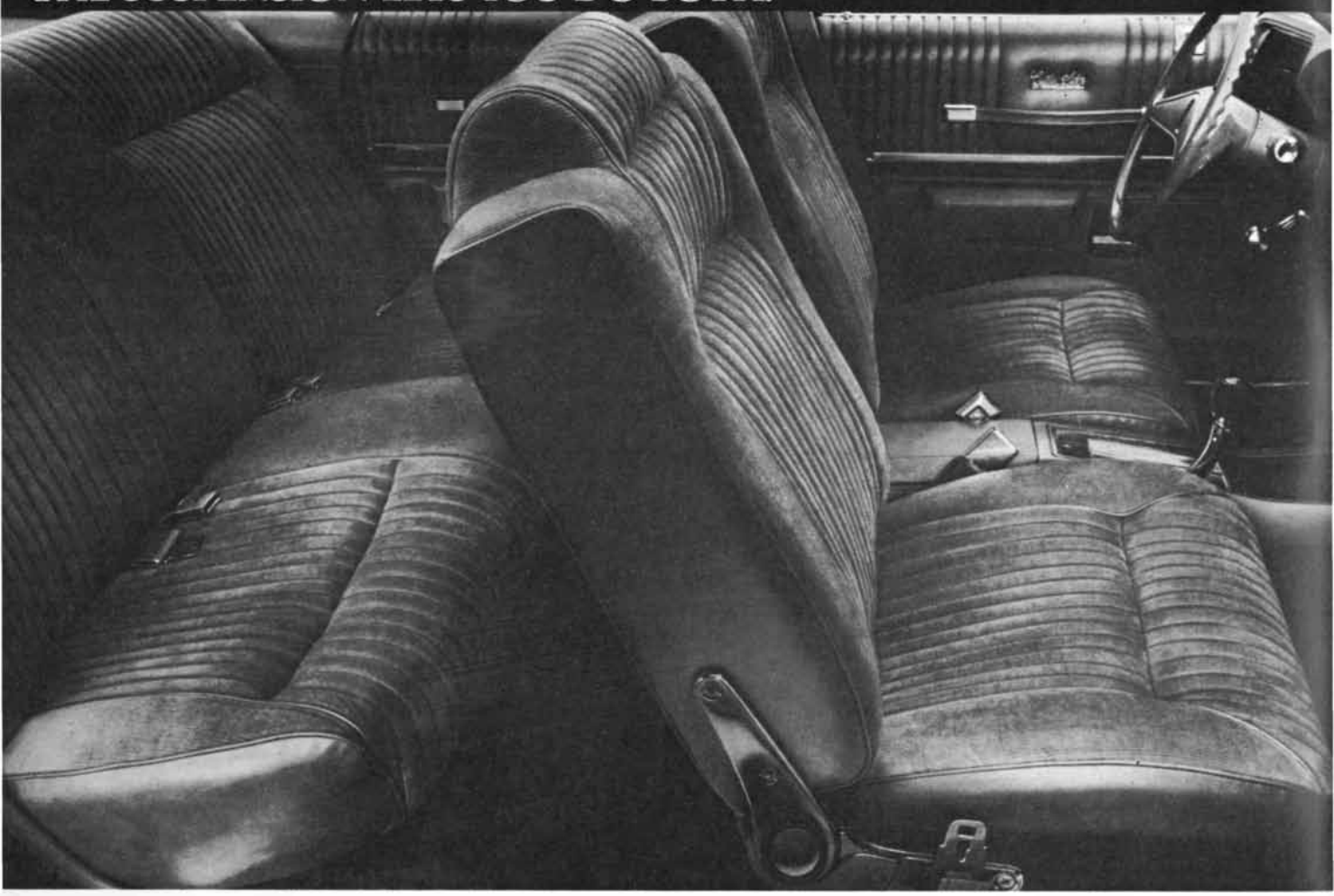

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High Technology in China

A report on a visit to China in which the author observed the state of such fundamental areas of modern industrial development as electronics, computers and instrumentation

by Raphael Tsu

The traditional prerequisites for rapid industrial growth include political stability, an energetic population and access to raw materials. In China these preconditions are met, and for some time it has been clear that China was developing a substantial heavy industry. What may be less well known is that the Chinese have recognized that modern industry is grounded in advanced technology, that blast furnaces and even machine tools no longer suffice to ensure the development of a nation with significant industrial status. In the course of a visit last summer to Chinese universities, research facilities and industrial plants I became convinced that the country is building the technological foundation it needs. There is high technology in China, including specifically the computers, control systems and instrumentation that make a modern industrial society function. The technical competence and (to a lesser degree) the hardware I saw in many cases approach what we are accustomed to seeing in the U.S.

Before reporting on China's high technology I shall briefly describe China's attainments in what might be called conventional industry, to some extent bringing up to date a report presented in this magazine six years ago [see "Technology in China," by Genko Uchida; SCIENTIFIC AMERICAN, November, 1966]. On the basis of values projected from 1971, one can expect for 1972 a gross national product of some $145 billion and the production of about 25 million metric tons of steel, 30 million metric tons of oil and 150 billion kilowatt hours of electric power. These figures are not high compared with those for the U.S., which produces about five times as much steel and 15 times as much oil. One cannot compare the two countries, however, without taking into account their different ways of life. Here we consume large amounts of steel in order to make automobiles and large quantities of oil in order to run them. China has an insignificant number of automobiles; it can husband its limited amount of steel and petroleum for more basic industrial purposes. Last year, for example, China had to import only a few million tons of steel and actually had a surplus of oil.

With ample supplies of coal and hydroelectricity China should be able to devote much of the oil now flowing from the Ta Ching fields in Manchuria to a petrochemical industry. I visited the Peking Oil and Chemical Complex, which is now producing 8,000 metric tons of refined oil per day. Like most modern refineries it is automatically operated; it has a 30-foot control panel covered with the familiar recorders, meters and switches. (The plant's waste water, incidentally, is treated by advanced biological degradation methods, and the treated water is used for irrigation.) The complex includes some 35 plants employing 11,000 workers. Another 11,000 workers are building a new petrochemical plant, scheduled for completion next year, for the synthesis of plastics, fertilizers and Dacron.

There were many other signs of a maturing heavy industry. One accomplishment is a 12,000-ton hydraulic press, reportedly one of only 10 machines of that size in the world. At the permanent Shanghai Industrial Exhibit there is a model of a 300,000-kilowatt high-temperature, high-pressure turbogenerator, a number of which are said to be in operation; one of its advanced features is water-cooled inner conductors for the rotor as well as the stator. The Shanghai exhibit also includes a 200-ton extruding machine, a 250-ton power press, a half-size model of a large vacuum refining furnace and milling machines, lathes and other machine tools. Shipyards in Dairen and Shanghai are turning out 20,000-ton vessels with automatic navigating equipment.

What are some of the attainments that place a country among the high-technology industrial powers? Among them are such great-power status symbols as jet aircraft, nuclear weapons and missiles. China has been building copies and variations of high-performance Russian MIG fighters for some time, according to *Aviation Week & Space Technology;* it does not produce commercial jets. China exploded a fission device in 1964 and a fusion device in 1967, and it has tested several hydrogen bombs since that date. For the production of uranium 235 China has built a number of gas-

centrifuge plants, according to an article by Francis James in *The Sunday Times* of London; the method has not been used industrially in the West, although its feasibility has been demonstrated in the laboratory. Chinese physicists are said to be working on controlled fusion with laser-heating methods as well as the older plasma-pinch ones; they are said to have reached the stage of detecting a flux of neutrons, but this has not been confirmed by analysis of the neutron spectrum. As for rocketry, in 1970 *Aviation Week & Space Technology* reported that China had become the fifth nation to launch a satellite of its own, and it has been testing military missiles fairly regularly.

In none of these fields is it possible to succeed without an array of high-technology systems and components: computers, automatic-control systems, semiconductor and microwave devices and sophisticated instrumentation. Because I am a solid-state physicist, my interests and knowledge lie primarily in these fields, and it was on these technologies that I concentrated during my tour as a guest of the Chinese Academy of Sciences.

There was a period during which China relied on foreign sources, particularly the U.S.S.R., for much of its basic technology. After the break with the U.S.S.R. early in 1960, disagreement over how long the country could put off self-sufficiency in these areas was one of the crucial factors in the ideological and economic clash that led in 1966 to the Cultural Revolution. From that time on the emphasis has been on self-sufficiency in technology as a basis for industrial growth. In laboratories and industrial plants one often sees a large poster that reads: "Maintaining independence and keeping the initiative in our hands and relying on our own efforts."

The Chinese recognize the central importance of semiconductor technology. One demonstration of this recognition came during the 1970 National Day celebration: a large float was paraded through Tien En Man Square in Peking carrying a control terminal and a single-crystal "puller," a crucible for the production of pure silicon semiconductor; at the top of the display was a model of a silicon single-crystal ingot and beside it hundreds of workers paraded carrying other model ingots. For the past two years the Shanghai Scientific and Technological Exchange Committee has sponsored a propaganda team to promote the importance of electronic and semiconductor technology. Since 1970 the electronics industry has diffused outward from the traditional centers to outlying cities.

Electronic research and development and the manufacture of electronic components are carried out in China by a combine of specialized institutes, universities and industrial plants. The Institute of Semiconductors of the Academy of Sciences was organized in 1958 under the direction of Wang Shou-wu, who wrote a dissertation on the cohesive energy of metals at Purdue University in 1949. Its research workers began investigating germanium in 1958, silicon in 1961 and integrated circuits in 1963. The laboratory has four divisions: materials science, solid-state circuits, microwave devices and lasers; it employs 900 people, 300 in research.

The scope of the work of this laboratory and others is indicated by the range of publications in the field. There is *Electronics News,* published by the Chinese Electronic Society; *Electronic Technology* and *Electric World,* published by the Shanghai Electronic Society; the *Semiconductor Device Handbook,* prepared in 1971 jointly by the workers of the Hsu-wei District Commune in Shanghai and Chiao-Tung University. In 1970 the Scientific Publishing Company translated a textbook well known in the U.S.: *Introduction to Large Scale Integration,* by A. J. Khambata. In 1971 the National Defense Industry Publishing Company translated a number of foreign articles and published them in a book titled *Large-Scale Integration.* More recently a number of books in these fields have been published, including *Microwave Integrated Circuits* and *Lasers.* China also has access to most Western publications; during my visit to Tsinghua University in Peking I noticed a student reading a recent issue of the American journal *Applied Optics.*

A simple list of some of the devices and processes mentioned in the *Semiconductor Device Handbook* will suggest, at least to specialists in the field, what their Chinese contemporaries are working on. Among diodes are point-contact, Zener, rectifier, variable-capacitance, tunnel and photodiode types. Transistors include the alloy junction, diffused junction, unit junction and MOSFET types. Integrated circuits include diode-transistor logic, transistor-transistor logic, amplifiers and both thick-screen and thin-screen elements.

The Chinese diode-transistor logic element uses a method of packaging (developed in the U.S.) called the TO-5 package; the transistor-transistor element uses what is called flat pack. There is reason to believe they have progressed beyond this stage, perhaps to the faster emitter-coupled logic. The silicon planar transistor incorporated in many of these devices has a seven-decibel noise figure

PORTABLE OSCILLOSCOPES manufactured in this workshop are lined up on the table; they appear to be simple instruments, probably suitable for use in the field. Electronic equipment is manufactured in China in factories, technical institutes and even universities.

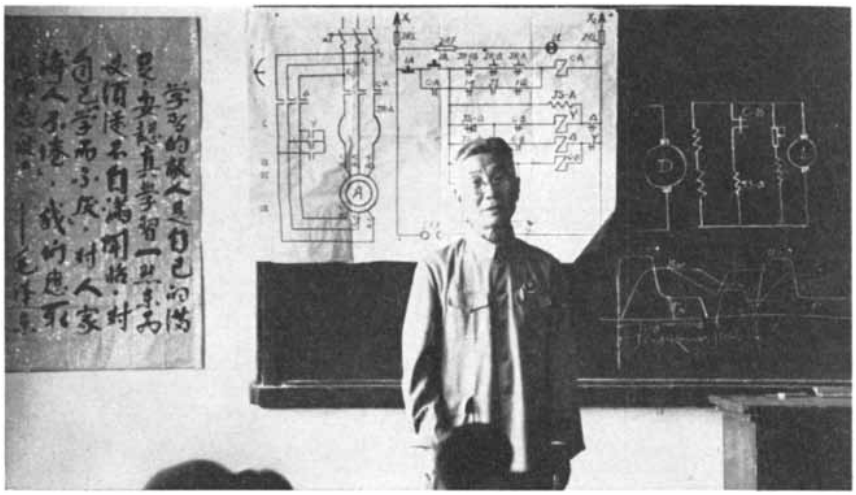
at 400 megahertz, which compares favorably with elements commonly available in the U.S.

To my surprise I found that the work at the Institute of Semiconductors is more oriented toward basic research than the activities at Tsinghua University are. The universities (and even the high schools) do quite a lot of the actual fabrication. I visited the section of Tsinghua University's large physics building where work on integrated circuits is conducted. The chip I was shown under a microscope was an integrated circuit employing bipolar transistors. A young woman manipulating an ultrasonic bonder connected 10 wires to it in about a minute, which is a good pace.

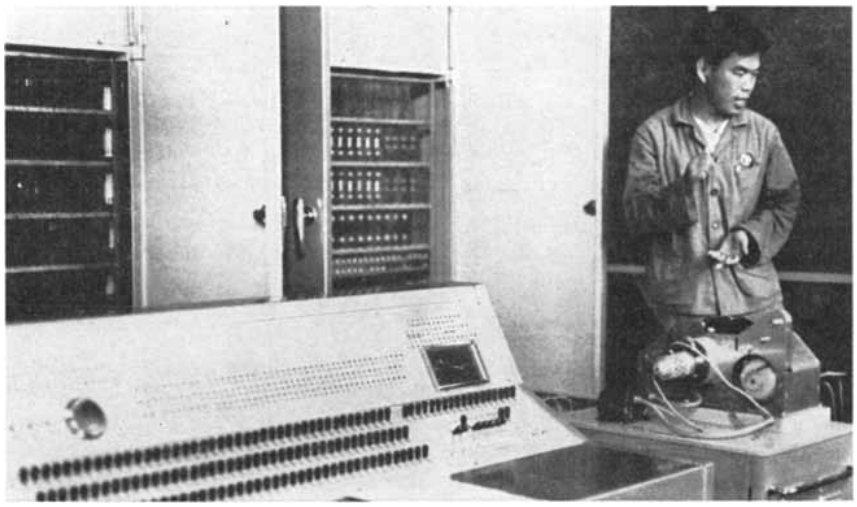
All the equipment for integrated-circuit work, including the photoreduction microscope and the ultrasonic bonder, was of Chinese manufacture. The silicon wafers were cut from single-crystal ingots grown by specialized factories such as the Single Crystal Factory operated by the Peking Engineering College. The crucibles in which these large crystals are grown, Czochralski crystal pullers, are made in China. They turn out a three-kilogram crystal ingot two feet long by two inches in diameter. It appears that each workshop (such as the one at Tsinghua University) making a solid-state device grows its own silicon epitaxial layer on the wafers. Most of the epitaxial ovens they use are built by a Peking "neighborhood factory," the cooperative Western District No. 1 Semiconductor Factory. The plant was organized in 1958 (by housewives, it is said) to make simple balances and other measuring instruments. In 1965, in response to a government request, some of the factory's workers were trained, in two months at Tsinghua University, to make ovens. Now 360 workers produce 100 diffusion ovens and 100 epitaxial ovens per year. These ovens have a spatial temperature uniformity of ± 1 degree Celsius and a stability of control of $\pm .5$ degree, specifications that compare with those of the best U.S. ovens.

At the factory I was told that none of the employees has more than a high school education. It was pointed out that higher education is really not necessary for many technical jobs. I should add that a Chinese high school graduate, even one not intending to go on to college work in a technical field, has at least a year of chemistry, physics, algebra, trigonometry, coordinate geometry and solid geometry, and some calculus.

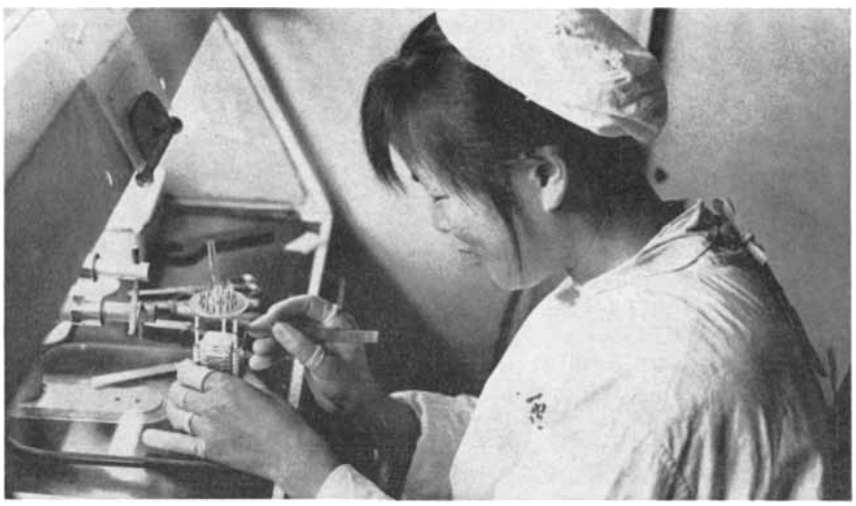
At Peking University physics courses are more advanced than those given at Tsinghua University, including such



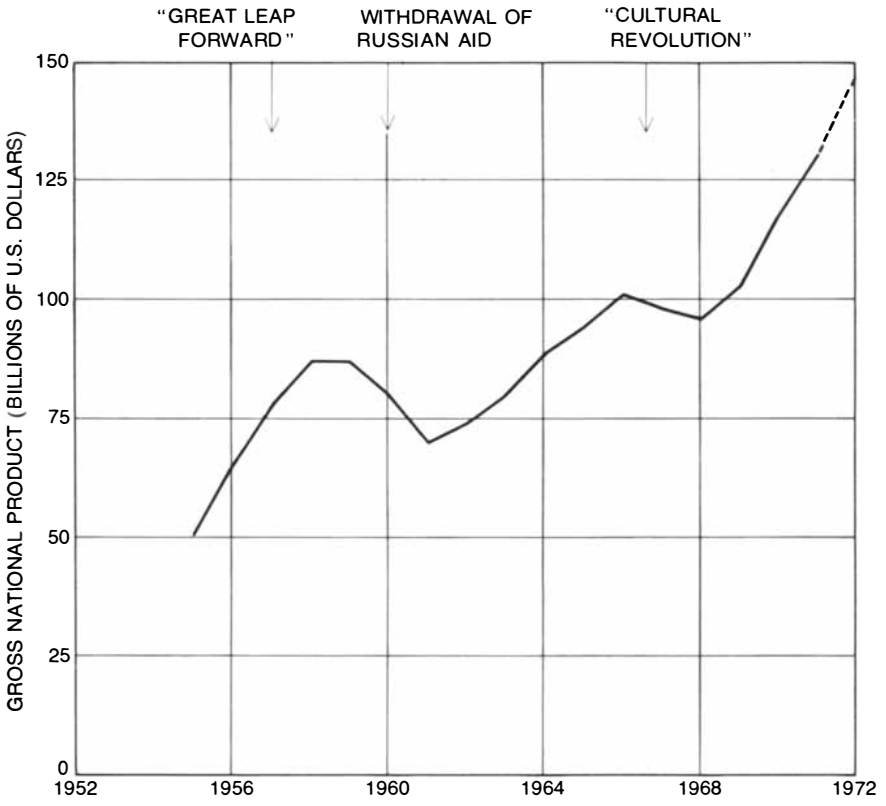
CHIAO-TUNG UNIVERSITY is a school of technology at Sian in northwestern China. A professor of electrical engineering is teaching electric-power control. The poster (*left*) carries quotations from Mao Tse-tung, including "The greatest enemy of learning is self-satisfaction" and "The beginning of serious learning is dissatisfaction with oneself."



COMPUTER CLASS at the university is instructed in the use of the Type 701 computer. The computer console is in the foreground and the central processing units are at the left rear.



PHOTOMULTIPLIER, an important research tool, is being assembled by a young worker in a university workshop. Self-sufficiency in such equipment is a major goal in China now.



GROSS NATIONAL PRODUCT of China has shown steady growth since the Cultural Revolution. G.N.P. figures are not issued by China but are estimated by foreign analysts.

basic solid-state subjects as low-temperature physics. Still, the emphasis is on applications. That is in line with Mao Tse-tung's dictum that "education must serve proletarian politics and be combined with production labor." (As a matter of fact, it seems to me that even a theoretical physicist can be strengthened by some contact with practical matters. British physicists, I have often felt, have an edge over their American counterparts because there is more serious laboratory work in the undergraduate curriculum in Britain.) The distinguished theoretical physicist Huang K'un, who was at the University of Bristol and who wrote *Dynamical Theory of Crystal Lattices* with Max Born, is professor of physics at Peking University. He told me that although he is teaching a course on semiconductor physics, his main preoccupation is running a university-associated pilot plant where 20 professional staff members and 100 technicians work on integrated circuits.

Peking University is rapidly enlarging its student body after a sharp decrease in enrollment during the Cultural Revolution. The president of the university (he is actually called the vice-chairman of the university's Revolutionary Committee) is Chou P'ei-yuan, who did his doctoral dissertation on symmetry in Einstein's general theory of relativity in 1928 at the California Institute of Technology. He considers it a good thing that all professors are required to do some manual work, whether it is merely helping to tend vegetables in the university garden or "joining the workers" to learn the needs of industry (usually in activities not unlike the consulting work that many American professors do). Chou stressed the necessity of there being a clear relation between research and practical problems, a position that seems reasonable for China in its present stage of industrial development.

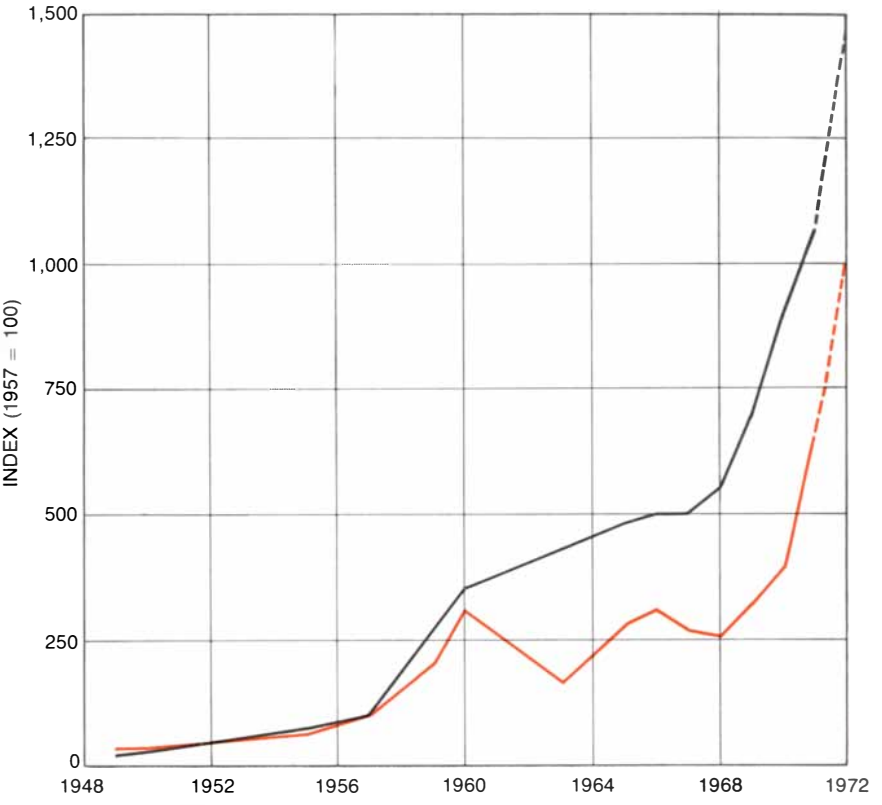
A full range of sophisticated instruments and other laboratory equipment is basic to electronic technology. These items are now manufactured in China. I saw a 100-megahertz digital counter, a 50-megahertz oscilloscope and a sampling oscilloscope with a rise time (in effect a time resolution) of 44 picoseconds (trillionths of a second). There was an electron microscope capable of 400,000-diameter magnification and a resolution of seven angstroms. I was shown a two-meter diffraction-grating spectrograph with a resolution of eight angstroms per millimeter in the wavelength range from 2,000 to 10,000 angstroms, and a mass spectrograph with a cylindrical electric field and a constant magnetic field. I was impressed by an ion pump, which is used for creating high vacuums very quickly, that is capable of pumping at the rate of 14,000 liters per second. By way of comparison, the best sampling oscilloscope made in the U.S. has a rise time of 28 picoseconds. Our mass spectrographs are generally built with a quadrupole lens. Our ion pumps are operated, when it is necessary, in conjunction with a titanium sublimation pump, which I was told does not exist in China. In general, however, one is hard put to think of a significant research instrument that is not being manufactured in China.

I examined a number of computers. One, at the Institute of Computers of the Academy of Sciences, was built there in 1968. It is a transistorized model with the following specifications: two-microsecond access time; magnetic cores with an inside diameter of .8 millimeter and an outside diameter of 1.2 millimeters; a 32,000-word main memory and a 64,000-word drum memory. (This computer is almost identical with the model DJS-6 that the Chinese exhibited at the Canadian National Exhibit in Toronto this fall.) The computer's input element is a photoelectric paper-tape reader that handles 1,000 "marks" (punched holes) per second. The output system includes a rapid printer working at 1,200 lines per minutes and 15 marks (letters) per line; a wide-line printer working at 300 lines per minute and 160 marks per line, and a "plate tracer," or plotter, that executes .25-millimeter steps at 400 steps per second. Again by way of comparison, the memory unit of the IBM 370's new Model 158 will use MOSFET's instead of magnetic cores and will be at least 20 times faster than the Chinese memory unit. I saw no evidence of disk memory units or of computer time-sharing. The Institute of Computers may not, however, be the place to see the latest Chinese computers, since it is involved more in software development than in component research. Chinese computer engineers are apparently engaged in substantial programs on large-scale integration and are encountering the same kind of problems we faced here a few years ago. For example, the relatively poor quality of some of their materials makes it difficult to achieve high enough yields to build sophisticated memory units with this novel technology. They seem, however, to be establishing a foundation that will within a few years enable them to master the art of large-scale integration.

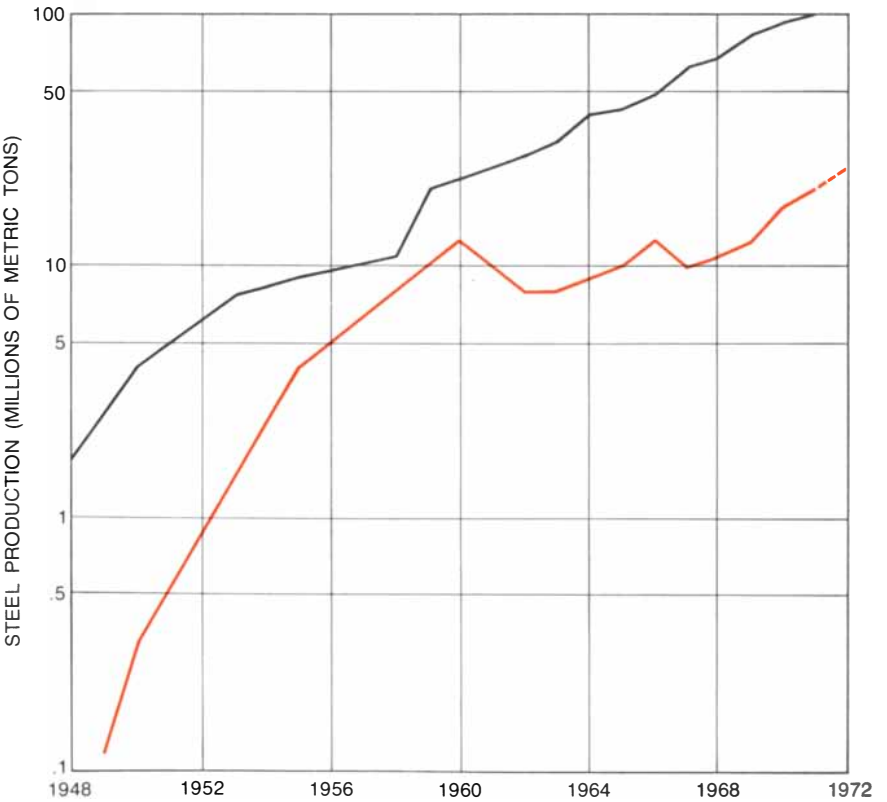
In China semiconductor technology has penetrated far beyond the laboratory and a narrowly construed electronics industry. Indeed, it would be fair to speak of an electronic revolution in many fields. For example, in Shanghai the Song-Chiang County Commune and the 29th Radio Factory, working together, developed a portable ultraviolet (3,600-angstrom wavelength) insect killer for farms. A shoe factory developed an electronic device for scanning and computing the area of irregular pieces of leather. A book-size transmitter-receiver and amplifier is available that can drive a 25-watt speaker or 40 small speakers. Silicon rectifiers are used as control elements in electric steel furnaces and to convert alternating current to direct current for operating a new electric train. As for microwave technology, I saw workers at the Peking Communication Equipment Factory, where S-band repeaters are made, building silicon Schottky diodes and traveling-wave amplifiers, and as usual growing their own epitaxial films.

One of the aspects of Chinese industry that impressed me is the evidence of local autonomy in technological development under general guidelines established by the government. In the U.S. our large corporations also set overall objectives at central headquarters for execution by various divisions and local plants. The difference, of course, is in the degree of complexity: a government needs to take more factors into consideration than a corporation does.

Foreign observers often point out that industry is "unbalanced" in China. To be sure, it is said, they make a few good computers, but Japan produces 12 million television sets per year and China has only half a million. As I suggested at the beginning of this article, such comparisons are not meaningful. Of course China is not turning out consumer goods at a high rate. Of course its per capita income is still very low. After 50 years of industrialization the U.S.S.R. is still not effectively meeting its population's demand for consumer goods. Japan, the third industrial giant of the world, still has a per capita income below that of most European countries. Given China's present needs and its form of society, the country's industrial development may well be correctly "balanced." Having developed a scientific base for the support of technology and having committed its technology to the propulsion of rapid industrial development, China is on the way to becoming an advanced industrial power.



PRODUCTION of crude oil (*black*) and electric power (*color*) has risen rapidly since discovery of the Ta Ching oil fields. The figures for 1957, which is the base year for the index, were two million metric tons of crude oil and 15.5 billion kilowatt hours of electricity.



RATES OF GROWTH of steel production in China (*color*) and in Japan (*black*) are compared. Scale is logarithmic, so that parallel segments of curves represent equal growth rates.

LEARNING IN NEWBORN KITTENS

A series of experiments demonstrates that, although kittens seem virtually helpless at birth, they quickly learn to find their way to their favorite nipple and their home territory

by Jay S. Rosenblatt

The young of many species of mammals appear to be almost totally helpless at birth. Indeed, a well-known hypothesis of mammalian development is that such newborn mammals are not even capable of learning until they enter a critical period when they have attained a certain level of sensory and motor development. At the Rutgers University Institute of Animal Behavior we have been looking into suckling and homing behavior of newborn kittens. We find that these particular newborn mammals are quite capable of learning immediately after birth. Moreover, such learning plays an important role in the animal's growth and development.

During its first weeks of life a kitten develops a rich repertory of behavior, which makes it a favorable subject for investigating early development. In collaboration with the late T. C. Schneirla of the American Museum of Natural History, Gerald Turkewitz and I began an experimental study of behavioral development in kittens. Our first objective was to observe and describe the normal course of social development in kittens in our particular laboratory conditions. The kittens lived with their mothers in cubical cages that were three feet on a side. We observed the activities of the kittens and mothers for a three-hour period each day during the eight-week nursing period.

After we had observed a large number of mothers and their litters, certain regular features in the behavioral development of kittens became apparent. Suckling begins within a few minutes of birth and is initiated by the mother: she lies on her side and guides the kittens to the nipple region. The mother continues to initiate nursing for the next three weeks. During this period nursing takes place only in a part of the cage we call the home area. The mother approaches the kittens, which are huddled together in the home corner, arouses them by nuzzling and licking them and then lies down on her side so that her nipples face them. Her body and outstretched hind limbs and forelimbs encircle the kittens.

The kittens' eyes open at the end of the first week after birth, but they do not make any use of the visual sense until the end of the second week. After the third week the kittens begin to wander from the home area. They also begin to approach the mother when they want to nurse. She stands still until the kittens begin to suckle, and then she lies down. After the fifth week the mother becomes less willing to nurse, but now the kittens are able to pursue her around the cage until they can get hold of a nipple, after which the mother allows them to nurse.

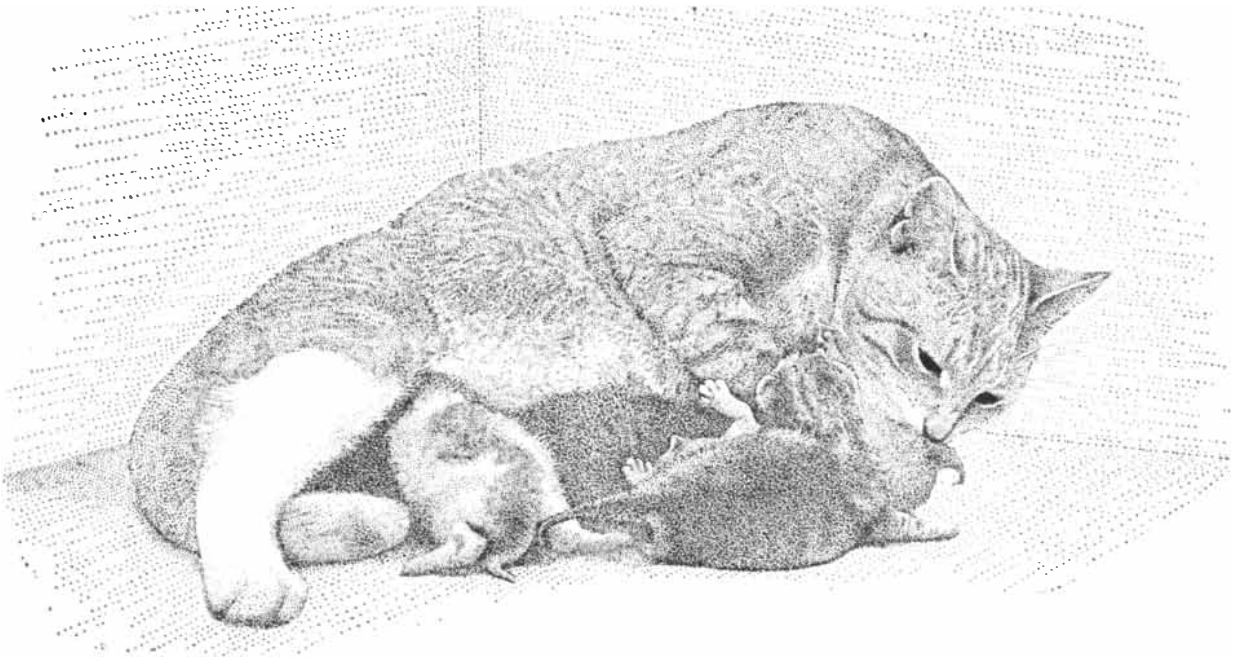
The play activities of the kittens—mouthing, pawing, hugging, rolling and licking—are primarily directed at other kittens, but the mother often is an unwilling subject. The kittens paw and climb over her face or leap on her back when she is lying down. When they paw at the mother's face, she often moves her tail to divert their attention. Simple forms of play among kittens appear as early as the third week. The more active forms of play—chasing, rolling and hugging—appear in about the fourth week when the kittens begin to move out of the home area.

We noted a definite relation between the behavior of the kittens and the behavior of the mother as the kittens matured. The behavior of both changed, and the changes gave us a hint of how kittens are weaned, or in other words why mother cats gradually act in a less maternal way toward their young. There was a shelf in the cage that the mother could jump onto to escape her kittens. Except for a brief period during the first week after the birth of the litter, the mother did not spend any time on the shelf until after the third week. The mother was always on the floor of the cage near her litter. As the play activity of the kittens increased the mother spent an increasing amount of time on the shelf beyond the reach of the kittens. Nursing periods became less frequent and of shorter duration, and at about the fifth week the kittens began to eat and drink from dishes that had been placed in the cage. Once the process of weaning had begun, it progressed rapidly, even though suckling did not stop entirely. By the end of the eighth week the kittens were virtually weaned, but they continued to suckle on occasions when they could grasp a nipple. When there was only a single kitten in the litter, weaning tended to take longer because there was less play activity to disturb the mother.

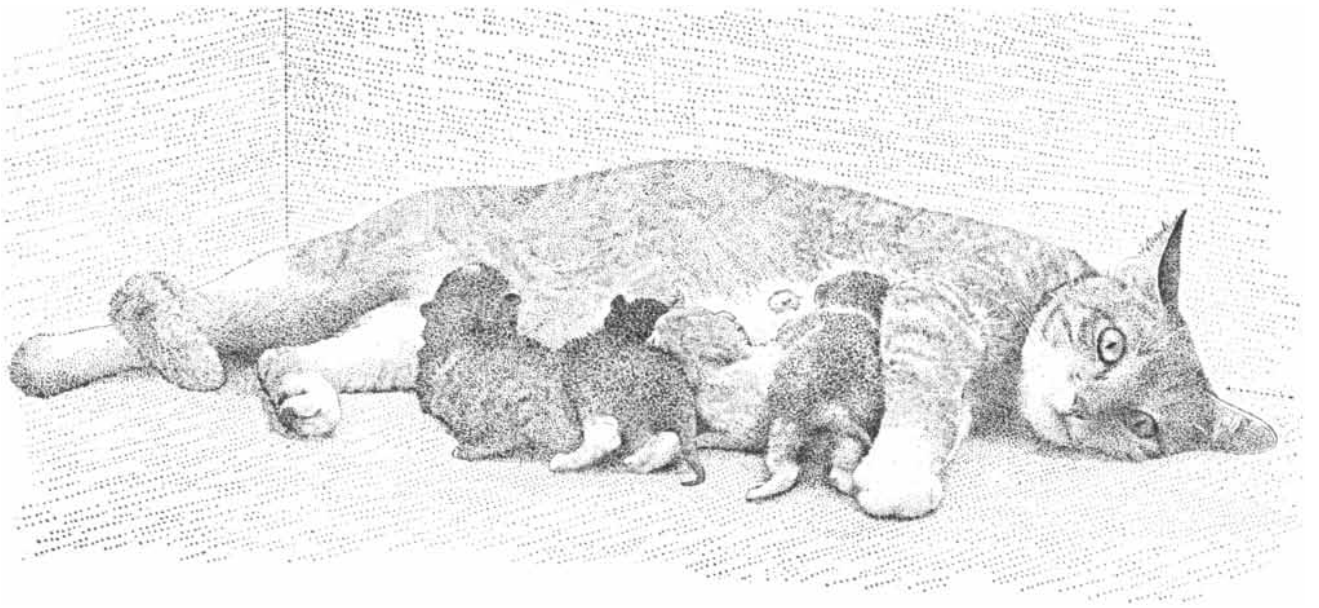
After we had established the normal course of kitten development in the cages, we began to remove individual kittens from litters at birth and to place each kitten alone in a brooder with an artificial mother consisting of a soft cloth and a small rubber nipple. At the end of a week each kitten was returned to its natural mother. At first the kittens were disoriented and could not find the mother; they huddled in a far corner of the cage. Eventually they made contact with the mother, and then they remained near her. It took several hours for them to find a nipple to suckle. After they had learned to nurse they also were able to learn to find the home area when they had been placed outside it.

At the time these studies were done the prevailing view was that newborn mammals cannot learn until they reach a critical age that can be anywhere from a few days to several weeks, depending on the species. That view was based on studies where attempts to form conditioned reflexes in newborn puppies were unsuccessful until the puppies had reached an age of two or three weeks. In those studies the conditioned reflex was lifting the foreleg in response to an auditory, visual or olfactory stimulus. Working with the more natural behavior of newborn animals, such as suckling and home orientation, we found that one could come to quite another conclusion.

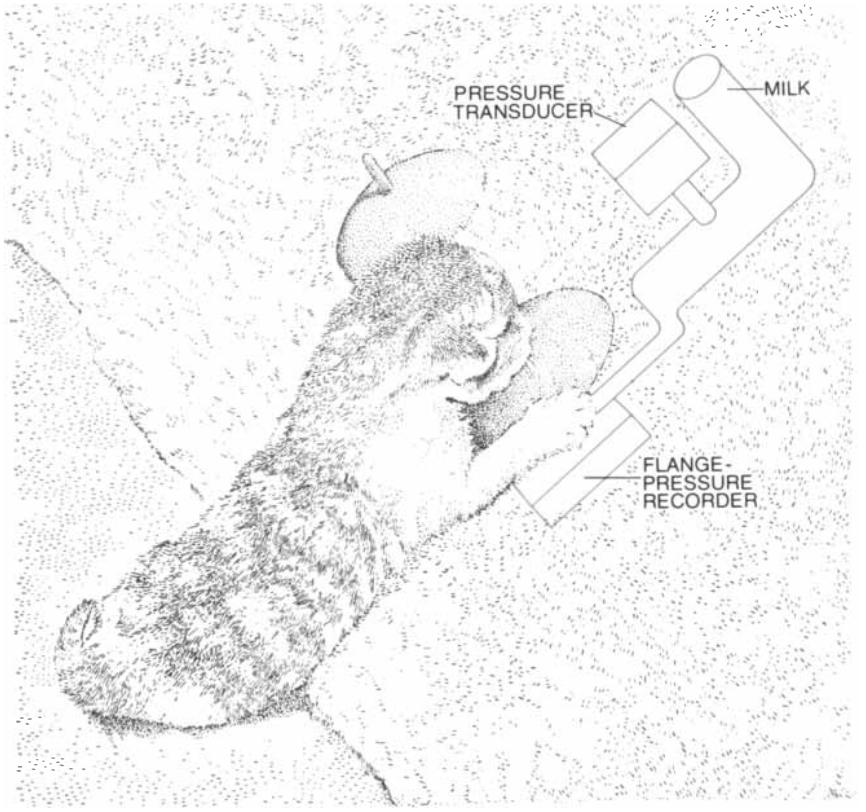
With normal litters we had observed that the kittens line up at the mother's nipples in an orderly way to suckle and that each kitten has a preferred nipple position. Kittens tend to develop a preference for the nipple on which they suckle during the first and second day. At the end of the third day more than 80 percent of the kittens we observed suckled from a single nipple position at



NURSING IS INITIATED by the mother cat shortly after the kittens are born. She lies on her side to expose her nipples and licks the blind kittens, which orients them to her body. They crawl to her, nuzzle in her fur and while maintaining constant contact with the fur move along her body to the nipple region. There nuzzling changes into gentle nose-tapping until a nipple is touched. The touch of the nipple stimulates the kitten to make mouthing movements that change into sucking when the nipple is grasped.



NIPPLE PREFERENCE is developed by the kittens within a few days. They show rapid improvement in the speed with which they find the preferred nipple. When a kitten accidentally takes another kitten's nipple, it readily abandons that nipple when the rightful owner nuzzles it. When a kitten is sucking from its preferred nipple, it will hold on tenaciously when another kitten tries to take it.



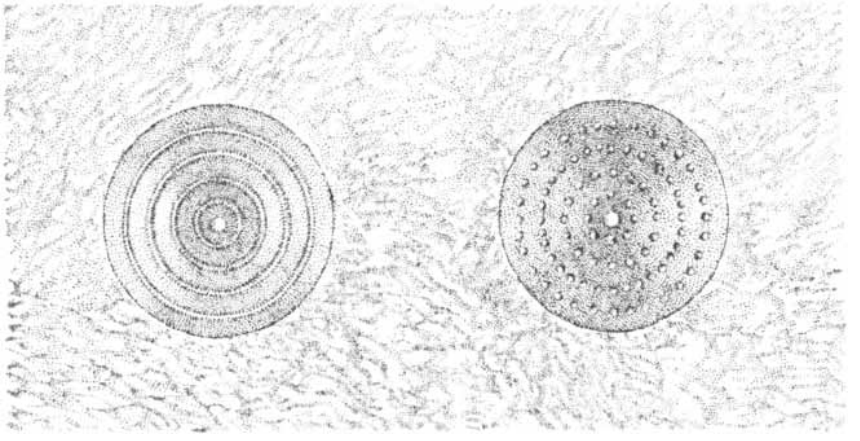
ARTIFICIAL MOTHER consisted of a carpeted board with two nipples, each surrounded by a rubber flange. Pressure-sensitive devices recorded how much the kitten touched each flange and sucked on each nipple. Only one nipple provided milk; the other was sealed.

each feeding. The rate at which nipple preference is established is independent of the size of the litter. When a kitten takes the wrong nipple, it may suckle on it until the rightful owner nuzzles at it. A kitten readily abandons a wrong nipple, but when it is at its own nipple, it holds on tenaciously when an intruder tries to nuzzle in.

How do kittens identify the preferred nipple out of the array of four pairs of nipples that are available to them? To find out Robert J. Woll and Natalie Freeman, graduate students at the Institute of Animal Behavior, have been conducting experiments with kittens exposed to an artificial mother and to natural mothers whose nipple region has been washed or shaved. Here the artificial mother consists of two rubber nipples mounted on a carpeted board. Around each nipple is a two-inch rubber flange. One nipple provides milk; the other is sealed but is filled with water. Each nipple and its flange are linked to pressure sensors that record how much the kitten nuzzles at the flange and sucks at the nipple.

Kittens are removed from the litter at birth and are fed by syringe for the first day and a half. They suck on a small nipple at the tip of the syringe, and behind the nipple is a rubber flange corresponding to the milk nipple they will encounter later on the artificial mother. Some of the flanges are textured either with raised dots or raised concentric rings; others are smooth and are scented with men's cologne or oil of wintergreen. Thus when the kittens are fed, they are exposed to a particular tactile or olfactory stimulus. They associate the stimulus with feeding from the first day, and when they are placed in a cage with the artificial mother, they tend to nuzzle the flange and nipple with the associated tactile or olfactory stimulus much more than a control flange and nipple. They suckle almost exclusively at the correct nipple.

After the kittens have learned to identify the milk nipple they begin to make a path to the nipple along the carpeted surface of the artificial mother. The path consists of an area that is matted by the kitten's repeatedly crawling over it. Very likely it also has a distinct odor left by the kitten itself. An effort was made to study the path's texture and its odor independently, but the kittens always managed to introduce the other stimulus. It was possible, however, to show that the kittens could identify the milk nipple by texture alone. The entire area surrounding both nipples was washed, and in a series of tests the position of the milk nipple was shifted from one side to the other.



TEXTURED FLANGES, one with a raised-dot pattern and the other with raised concentric circles, were used in a study to determine the learning ability of newborn kittens. To obtain food a kitten had to learn to associate the milk-filled nipple with one of the two textures.

Nipple-preference experiments were much more difficult to perform with a natural mother. Not only were the odors and textures of the mammary surface subtler but also there were differences in the temperature gradients around the nipples to which the kittens could be sensitive. When the mammary surface, including the fur, of a mother cat was washed to remove odors, the kittens began to suckle at random nipples, but within a day or two they returned to their preferred nipple position. When we shaved portions of the mother's mammary region, the kittens were much less confused and continued

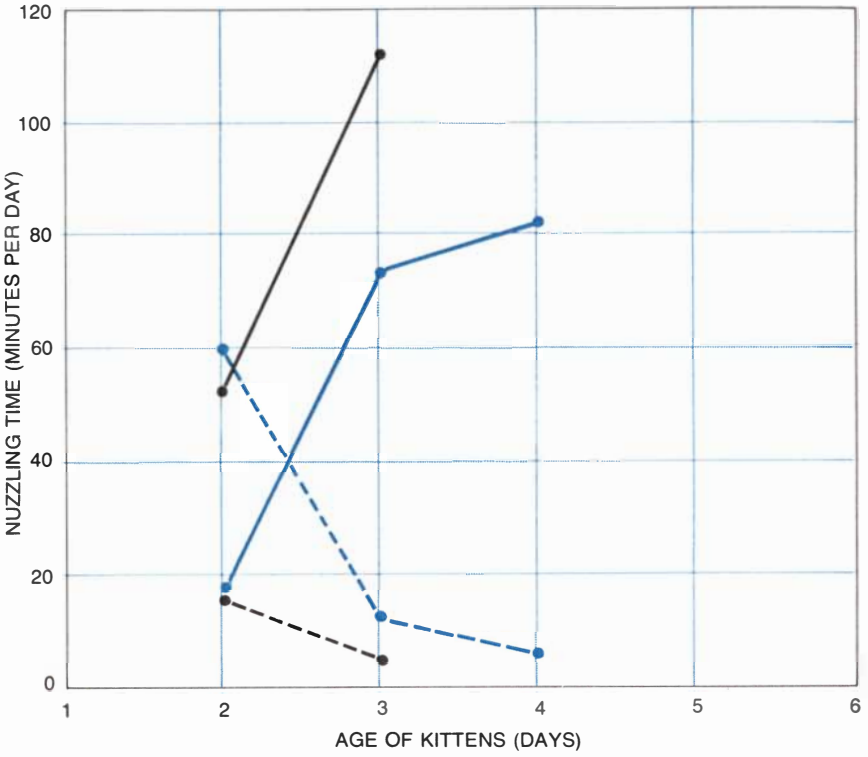
to suckle from their preferred position. It seems that texture may not play an important role when odors are present. As the kittens matured, particularly after the third week, visual cues began to play a part in the initiation of suckling.

In our observations of normal laboratory litters we noted that kittens appeared to be able to recognize their home cage even before they made contact with their mother or their littermates in the home area. Kittens removed from their cage for weighing began to cry immediately, and the crying stopped abruptly when they were returned to the same cage. We also found that the kittens seemed to know whether they were in the home area of the cage or in some other area. A kitten placed in the corner adjacent to the home area would crawl to the home area and not stop until it had reached it, whereupon it usually fell asleep.

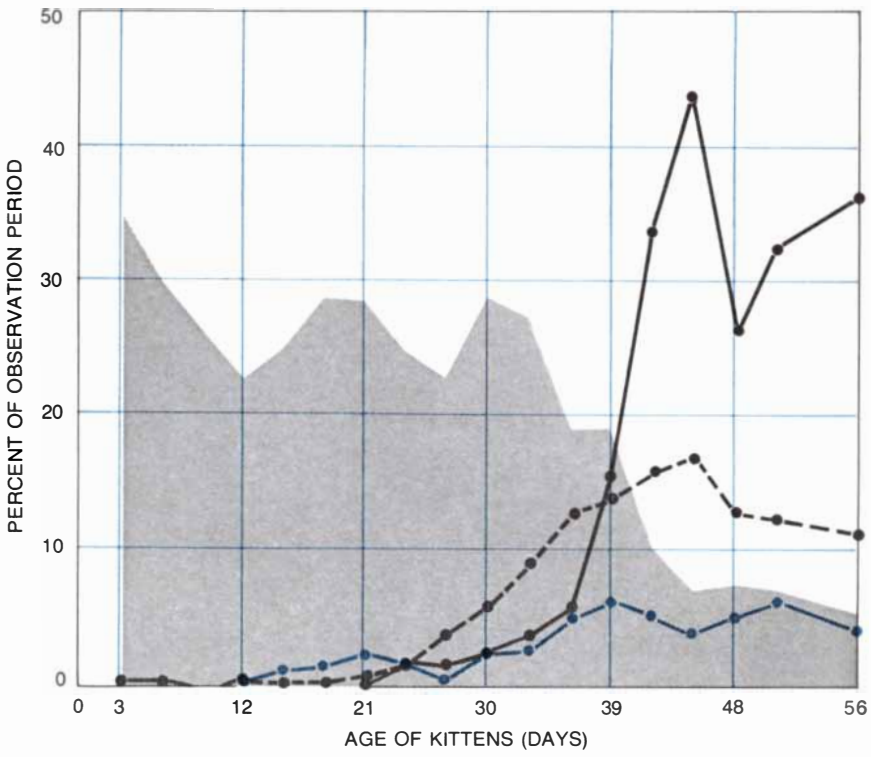
Even before a kitten is able to see it is able to divide its home cage into identifiable regions. When the kitten is placed in an area of the cage other than the home corner, it is able to find its way back to the home corner. When the kitten is put into a strange cage that is physically identical with the home cage, it immediately begins to cry and often backs into a corner.

In order to trace the development of home orientation in kittens we tested a large number of animals daily from birth to 22 days of age. The test kitten was placed in a strange cage, which we called a field, for two minutes and its reactions were observed. Then the kitten was placed alone in the home cage, either in the home corner or the adjacent corner or the diagonal corner, and its behavior for three minutes was recorded. During the various tests the kittens cried to a greater or lesser extent. As the kitten crawled about the floor of the cage, the intensity of its crying was scored on a scale of from one to four.

For the first few days after birth the crawling behavior of the kittens remains the same regardless of where they are placed. They tend to crawl in a circular path around the starting point. As they grow older their pattern of movement begins to change depending on where they are placed. In the home corner they crawl in circles and then fall asleep. In the corner adjacent to the home corner they crawl randomly at first but after a short time head for the home corner. Once they enter the home area the kittens sniff the floor and soon fall asleep.



IDENTIFICATION OF A MILK-FILLED NIPPLE by the texture or odor of the surrounding flange is rapidly learned by newborn kittens. The kitten nuzzles the textured flange around the milk-filled nipple (*solid black curve*) much more than the textured flange around a sealed nipple (*broken black curve*) and learns to feed itself independently at the age of three days. It needs more time to learn to discriminate the odor of the milk-filled nipple (*solid colored curve*) from the odor of the sealed nipple (*broken colored curve*).



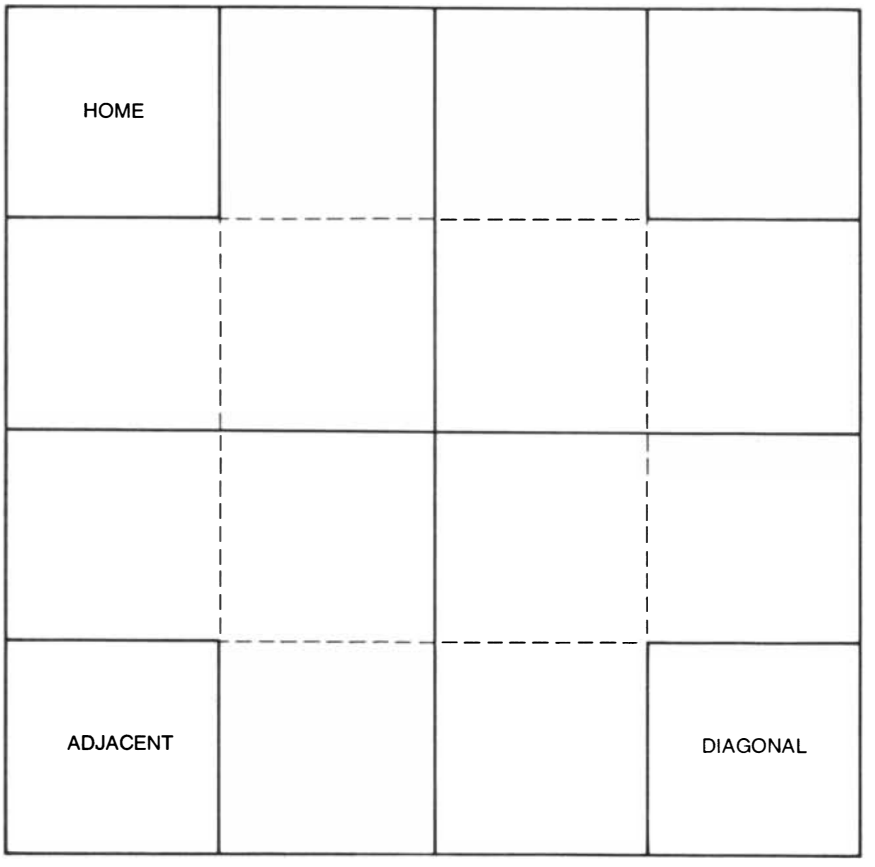
PLAY ACTIVITIES of kittens directed toward the mother (*colored curve*) and toward each other (*broken curve*) increase from about 30 days after birth, and at the same time the mother begins to spend more time on a shelf out of reach of the kittens (*black curve*). The amount of nursing during the daily observation period is shown by the shaded area.

By the age of five to seven days nearly three-quarters of the kittens find their way home from the adjacent corner. Kittens usually do not learn the way home from the diagonal corner until they are from 14 to 16 days of age. Instead of crawling directly to the home corner from the diagonal corner, the kittens first crawl to the adjacent corner and then turn homeward. There is little change in the animals' behavior in a strange cage until they are 19 days old.

The kitten has a distinct response, which we call the settling reaction, when it reaches the home area. The same response is seen in newborn kittens when they regain contact with the mother after having been separated from her. The kitten's movements slow down and its vocalization becomes softer and gradually stops. The kitten relaxes and soon lowers its head to the floor and falls asleep.

Kittens are able to distinguish between a strange cage and their home cage from the first day after birth. When they are placed in a strange cage, their crying becomes more intense; when they are placed anywhere in the home cage, the crying immediately becomes less intense. The rate at which the crying declines in intensity and the final level that is reached are different for each of the home-cage corners. The initial decline in the intensity of crying when the kitten is placed in the home cage indicates that the kittens recognize the home cage. By the time the kitten is five days old it is able to distinguish what area of the cage it is in. After an initial decline in crying the kittens react to the specific region they are in. In the home area crying remains at a low level throughout the test. In the other corners, however, after the initial decline in crying the kittens begin to vocalize louder. The farther the corner is from the home area, the louder are the kittens' cries.

Was the home orientation of the kittens possibly the result not of normal development but of the kittens' daily experience in the tests? To examine this possibility a number of kittens from various litters were not tested daily with their littermates. Some kittens were tested for the first time at about one week of age and others at about two weeks. In both cases the naïve kittens showed the same patterns of movement and vocalization as their littermates that had been tested every day from birth. Therefore the daily testing of kittens was not the crucial factor in the development of home orientation.

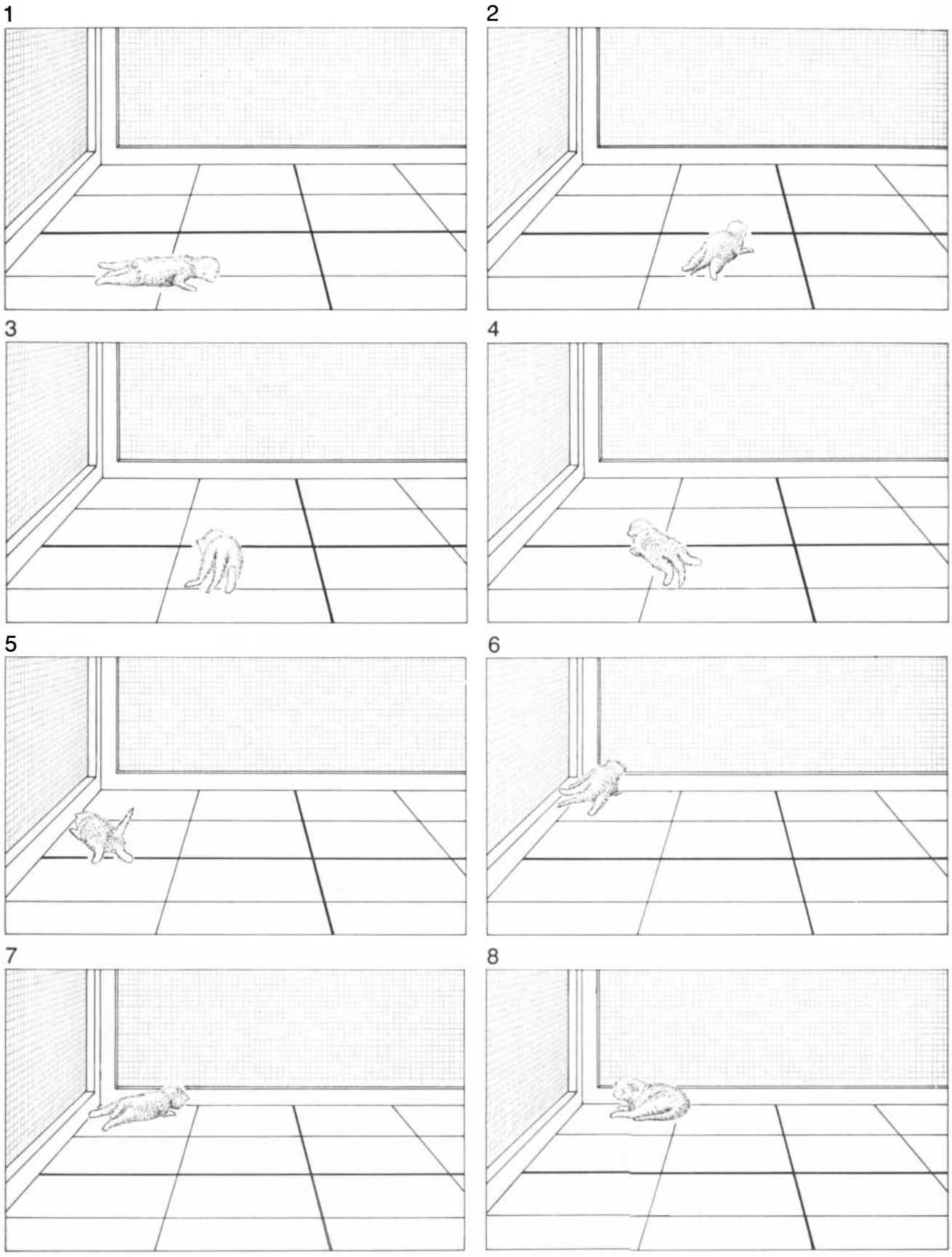


CAGE FLOOR PLAN shows the three major quadrants: home, adjacent and diagonal. The remaining quadrant contained litter material and was not used in the testing. Each 18-inch-square quadrant consisted of four smaller panels that could be individually removed.

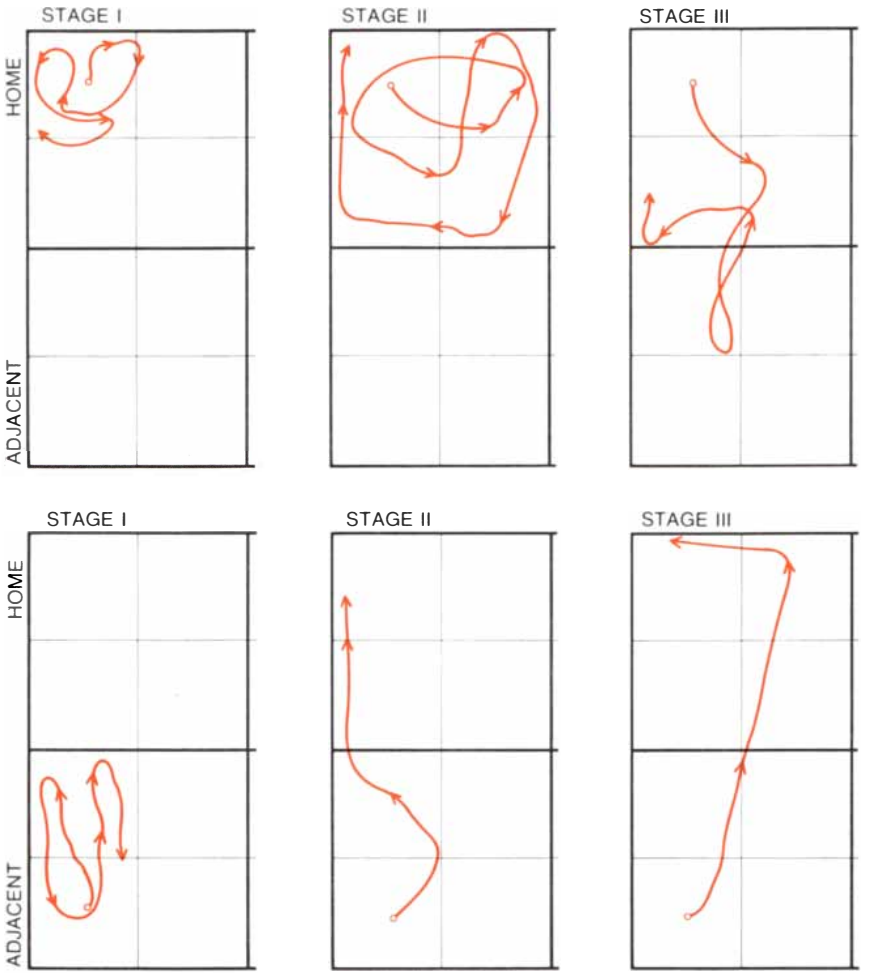
To determine whether or not a kitten had to grow up in the home cage in order to orient itself to its home area, we raised newborn kittens away from the home cage and prevented them from developing home-orientation behavior. After one week several of the isolated kittens were tested in the home cage of their littermates. None of the naïve kittens was able to distinguish the home corner from the other corners. For these kittens the home cage was only slightly different from the isolation cage. A kitten kept in isolation for two weeks also failed to orient itself to the home area when it was placed in its mother's cage. The isolated kittens were returned to their mother and after several days began to develop the typical pattern of home orientation. In other words, they had learned how to orient themselves to the home area.

In the home cage kittens are able to reach the home area from the adjacent corner when they are from five to seven days old and their eyes have not yet opened. This behavior indicates that nonvisual cues enable them to find their way. It seemed likely to us that the cues that enable the kittens to locate and identify their home area are odors. Presumably the odors are continuously deposited by the mother and kittens. The cages had removable floor panels, and in one study we took out the floor of the home corner and washed it to remove odors. We then tested kittens ranging in age from four to 18 days that already had proved they could return to the home corner from an adjacent corner. These kittens came to an abrupt halt when they reached the freshly washed home-corner floor. They backed away from the home quadrant and came to rest in the adjacent quadrant, where the odor was now most heavily concentrated [*see bottom illustration on page 24*]. When the kittens were placed on the freshly washed home-corner floor, they tended to crawl out of it to the adjacent quadrant.

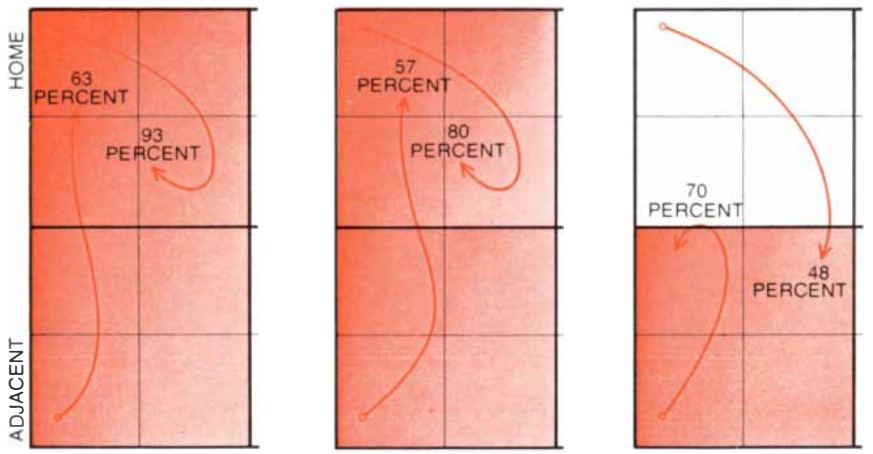
In the same study the home-quadrant floor was washed and then put back in place so that olfactory deposits from the mother and the kittens could accumulate again. When the kittens were tested the next day, they found the home area



HOME-FINDING BEHAVIOR of a blind five-day-old kitten is depicted in these drawings based on photographs. The kitten is placed in the adjacent corner of the home cage. It begins to crawl and moves its head from side to side sniffing the floor. At first the crawling is random, but the kitten soon heads in the right direction. Often the kitten's tail goes up after it enters the home quadrant, perhaps because it senses a strong home odor. The kitten continues to crawl to the home corner. In home area it relaxes and falls asleep.



EXPLORATORY BEHAVIOR from its home corner of a kitten during its first 22 days develops in three stages (*top illustration*). In the first stage the kitten tends to crawl in circles within the home corner. In the second stage it crawls along the border of the home quadrant but seldom leaves it. In the third stage the kitten makes exploratory forays outside the home quadrant. When the kitten is placed in the adjacent corner, its crawling is increasingly directed toward the home corner as it becomes older (*bottom illustration*). The arrows mark position and direction of a kitten at successive 15-second intervals.



ODORS DEPOSITED ON THE CAGE FLOOR enable kittens to identify their home corner. The gradient of odors is indicated by the intensity of the color. In the undisturbed home cage (*left*) 93 percent of the kittens remained in the home quadrant, and when placed in the adjacent corner, 63 percent crawled home. Later the home-area floor was washed and replaced so that odors could again accumulate. Kittens tested the next day (*middle*) found the home corner almost as readily as before. When kittens were tested on a freshly washed home floor (*right*), the lack of accumulated odors caused them to avoid the home quadrant.

almost as acceptable as the normal unwashed home area. The results confirmed our belief that the kittens follow odors deposited on the floor to find their way home. Removal of the home-area odors by washing does not prevent the kittens from crawling toward the home area when they are placed in the adjacent corner. This result suggests that they follow an odor trail that lies within the adjacent quadrant in order to reach the home quadrant. If the home quadrant lacks odors, the kittens return to the area with the strongest odor and remain there.

The use of olfactory cues gradually gives way to the use of visual cues when the kittens reach their third and fourth week. We tried several methods for determining the importance of visual cues in home orientation. In one method we put blinds on the inside walls of the cage to mask any visual cues the wall might have provided. In tests with kittens from 13 to 21 days of age there was a 30 percent increase in the failure of the kittens to orient themselves to the home from the adjacent and diagonal corners. When all the olfactory cues are removed, leaving only visual cues, successful orientation drops from 92 to 50 percent when the kittens begin in the adjacent corner, and it goes down from 83 to 25 percent when the kittens are put in the diagonal corner.

When the home area is made visually prominent by putting a black-and-white checkerboard pattern on the floor, three-week-old kittens are able to successfully orient themselves to the home area by means of the visual cue alone. In one test the home checkerboard floor was left in place but all the other floor panels were removed and replaced with freshly washed panels. Even in the absence of odor trails the kittens were able to find the home corner. They were equally successful when the home floor was replaced with a freshly washed panel that had the checkerboard pattern.

The growth in the relative importance of visually based orientation eventually leads to a change in the behavior of the kittens. Beginning at about 16 days of age kittens will voluntarily leave the home area, although they return quickly. At the age of 22 days most of the kittens will leave the home area and will stay away for several minutes. Incidentally, we found that one reason kittens left the home area at this age was to investigate the investigator who was standing in front of the cage.

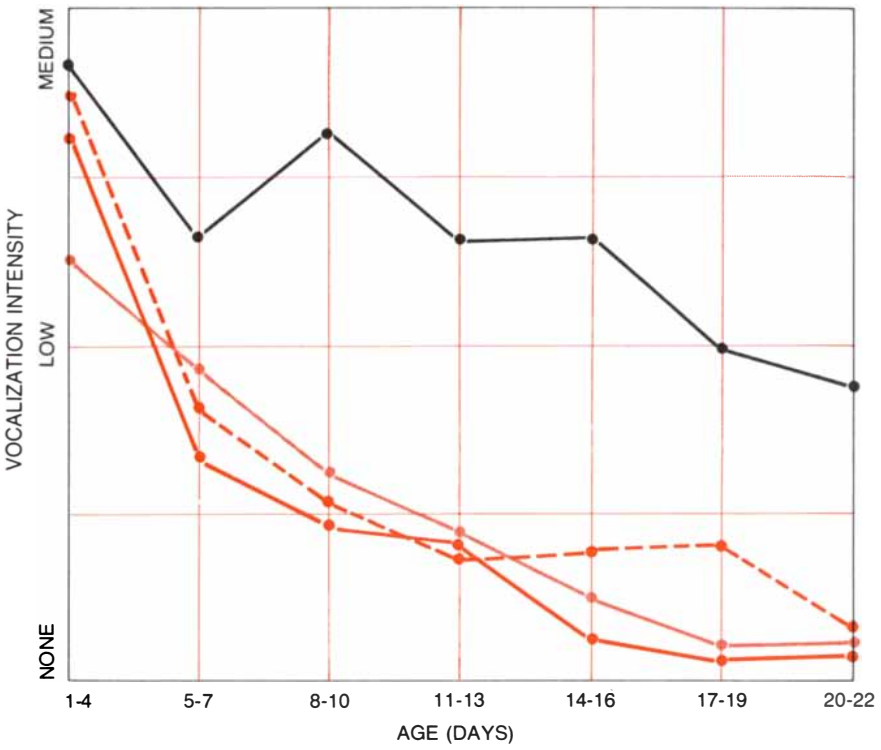
There is also a change in suckling at about this time. The kittens begin to pursue the mother to initiate feeding.

The kittens shift their orientation from the home area to the mother and to some extent to their littermates. The presence of littermates in a strange environment tends to calm the kittens. If the kitten is outside the home area and becomes distressed during the period when it is dependent on odors to identify the home area, it is not calmed until it has returned to the home area. When the kitten can use vision to identify the home, it can take the most direct route home and later can remain outside the home area and still retain the emotional security provided by the home area.

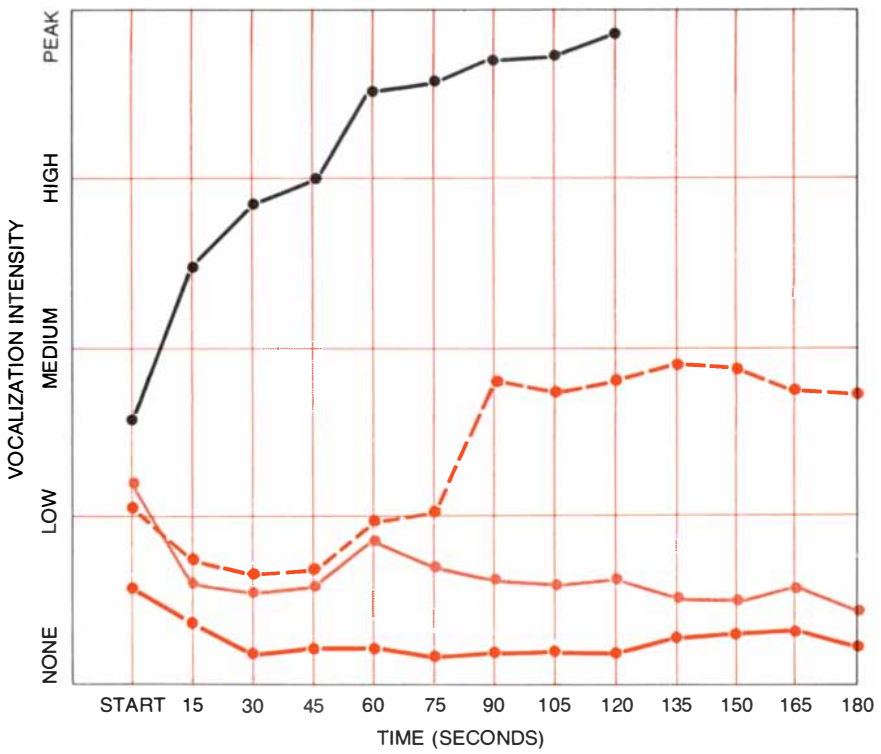
Our studies thus show that learning plays an important role in the behavioral development of newborn kittens. Such learning, however, is closely related to the maturation of sensory and motor processes and cannot be studied apart from such processes. Specific behavior patterns arise from a fusion of experience and maturation. Therefore behavior patterns will vary according to the circumstances in the life situation of the newborn animal.

The similarity of behavioral development in the young of many animals indicates that there may be a general pattern of infantile development. Young rats show signs of recognizing nest odors by the ninth day after birth and strong home-orientation behavior appears when they are from 12 to 16 days of age and before their eyes have opened. In several species of herbivores (such as sheep, deer and cows) the young can see and walk shortly after birth and rapidly develop a strong orientation toward the mother. The importance of bodily contact in the emotional development of infant monkeys has been well established by the experiments of Harry F. Harlow at the University of Wisconsin. Studies with human infants show that the infant can orient itself toward its mother at a very early age.

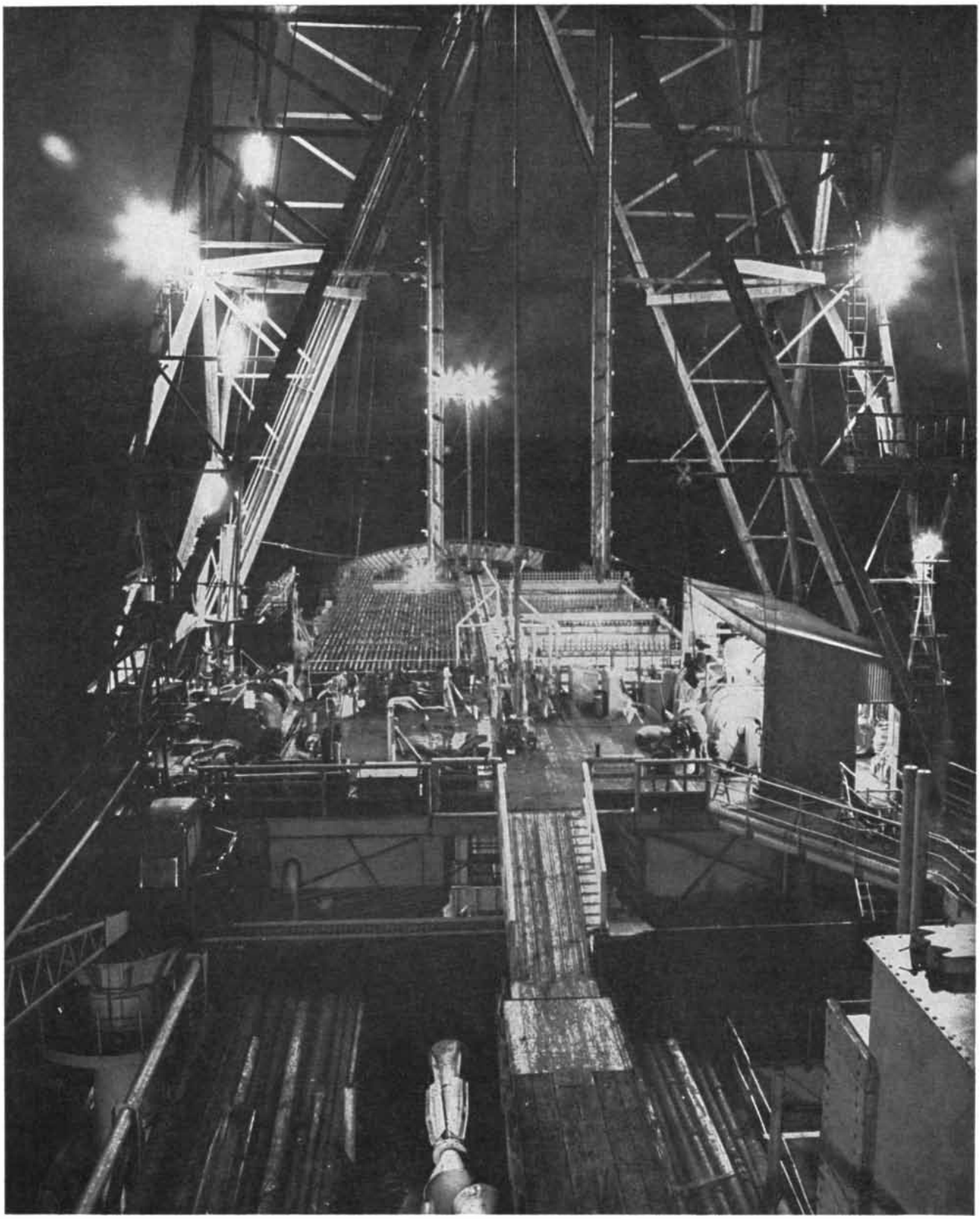
With kittens the learning of home orientation has the function of keeping the kitten in the home area while the mother is away. In other species comparable forms of early orientation learning serve to keep the young in the safety of the nest or close to the mother. The infant builds a zone of emotional security within which it develops its capacities first to cope with nearby features in its environment and then to deal with more distant features. By maintaining contact with its home base the growing infant lessens the emotional impact of the new and strange environment it must enter as it becomes independent of its mother and its original home.



INTENSITY OF VOCALIZATION in kittens was rated at the start of the tests as a measure of their distress. Within a week the kittens cried much less when they were put anywhere in the home cage (*colored curves*) than when they were placed in a strange cage (*black curve*). Crying decreased equally in the home (*solid color*), adjacent (*light color*) and diagonal (*broken curve*) corners, indicating that the kittens recognized the home cage.



ABILITY TO DISTINGUISH REGIONS of the home cage is evident in kittens that were tested at five to seven days of age. Crying is lowest when kittens are placed in the home corner (*solid colored curve*). It takes the kittens about a minute to distinguish between the adjacent corner (*light color*) and the diagonal corner (*broken*). When the kittens are placed in a strange cage, the intensity of their crying steadily increases (*black curve*).



NIGHT VIEW FROM THE BRIDGE of the *Glomar Challenger* shows, straddling the middle of the ship, the lower legs of the 142-foot drilling derrick, the vessel's most conspicuous structural feature. Beyond the derrick, on the foredeck, is the automatic pipe-racker, where 24,000 feet of drill pipe can be stored. The length of pipe suspended vertically above the derrick floor is the top end of a 15,000-foot drill string, which at the time the photograph was made was in the process of boring through the floor of the Mediterranean Sea 80 miles west of Sardinia. As the photograph suggests, such drilling and coring operations are carried out 24 hours a day. At present the *Glomar Challenger* is the only drilling ship capable of operating in the open ocean. It uses a dynamic positioning system to keep virtually stationary over the borehole, even in a stormy sea. The ship, which is owned by Global Marine Inc. and is operated by the Scripps Institution of Oceanography under a contract with the National Science Foundation, is named after the world's first full-time oceanographic research vessel, H.M.S. *Challenger*, which was launched in December, 1872, exactly 100 years ago.

WHEN THE MEDITERRANEAN DRIED UP

Evidence acquired on a recent cruise by the deep-sea drilling vessel *Glomar Challenger* has revealed that six million years ago the Mediterranean basin was a desert 10,000 feet deep

by Kenneth J. Hsü

Six million years ago a biological revolution swept across the Mediterranean Sea. The ancient marine fauna of the Mediterranean, descendants of mixed races from the Atlantic and Indian oceans, effected an unorganized mass exodus to find a refuge west of Gibraltar. Those that remained were soon to face annihilation, except for some hardy species that could tolerate the deteriorating environment. Thus ended the Miocene epoch, the less recent of the two dynasties that preceded our own Quaternary period. With the dawn of the Pliocene, or more recent, epoch the refugees returned, bringing with them new species from the Atlantic. They are the ancestors of the present marine fauna of the Mediterranean. This dramatic event, as recorded by fossils in certain sands and marls of Italy, did not escape the attention of Sir Charles Lyell, one of the founders of geology. The end of the revolution, signaled by the establishment of a new faunal dynasty, was chosen by Lyell in 1833 as the historical datum dividing the Miocene and Pliocene epochs. What was the cause of this revolution?

Near the end of the 19th century a deep gorge buried under the plain of Valence in southern France was discovered during a search for ground water. The gorge was cut into hard granite to a depth of hundreds of feet below sea level. Filling the gorge are Pliocene oceanic sediments, which in turn are covered by the sands and gravels of the Rhône river. When the gorge was first discovered, it was found to extend for some 15 miles between Lyons and Valence. Eventually the buried channel was traced for more than 100 miles downstream to La Camargue in the Rhône delta, where the valley was reached by drilling 3,000 feet below the surface. Obviously the modern Rhône is a lazy weakling compared with its ancestor, which sculptured a system of gorges almost comparable in size to the Grand Canyon of the Colorado. What caused the deep incision of the Rhône?

In 1961 the American oceanographic-research vessel *Chain* sailed to the Mediterranean with newly developed seismic equipment to explore the sea floor. The CSP, or continuous seismic-profiling, device aboard could be considered a super echo-sounder. Besides recording bottom reflections (the acoustic signals bounced back from the sea bottom), the instrument picked up signals transmitted by sound waves that were able to penetrate beyond the bottom and be reflected by hard layers hundreds of feet below. The new tool made possible a new discovery: it was found that the Mediterranean floor is underlain by an array of pillar-like structures, each a few miles in diameter and hundreds or thousands of feet high, protruding into the beds of sediments [*see top illustration on next page*]. Geophysicists were familiar with structures of this type; they looked very much like salt domes.

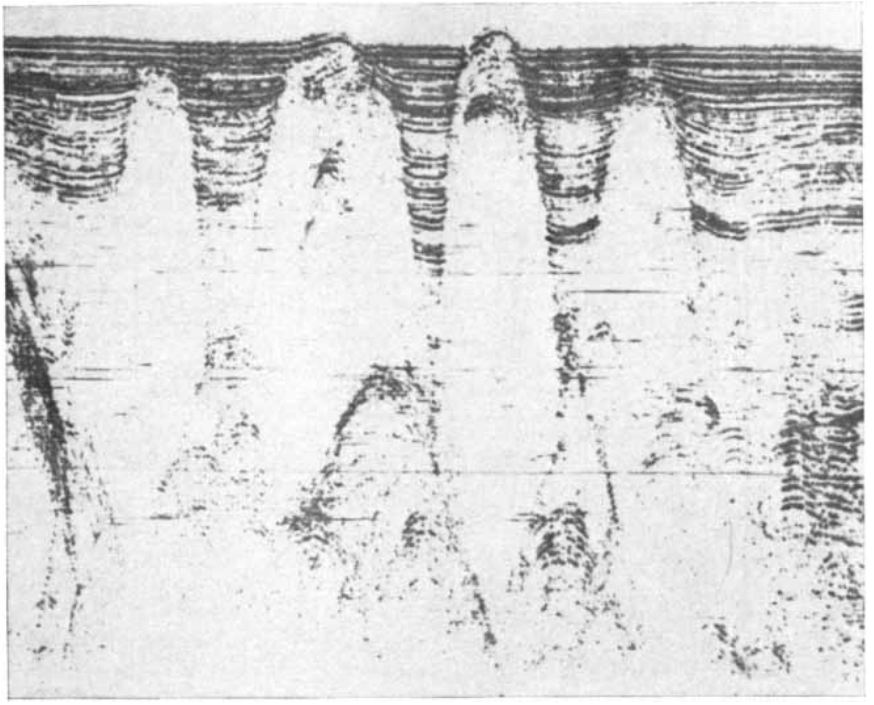
Salt domes are formed after rock salt from a deeply buried mother bed has forced its way upward into overlying sediments. Salt domes are common, for example, along the U.S. Gulf Coast, where many oil fields have been located around the domes. To find salt in coastal sediments is not unexpected, because geologists have long thought that the rock-salt formations were precipitated in coastal salinas, or lagoons. It was entirely unexpected, however, that salt domes would be discovered under the abyssal plains of the Mediterranean. Where could the salt have come from? Or are those structures indeed salt domes?

The exploration continued in the 1960's. William B. F. Ryan of the Lamont-Doherty Geological Observatory, a participant in four cruises to the Mediterranean, and others working in the area were soon impressed by the presence of a strong acoustic reflector everywhere in the Mediterranean [*see bottom illustration on next page*]. This reflector, the *M* reflector, is commonly found a few hundred feet below the sea bottom, and its geometry closely simulates the bottom topography.

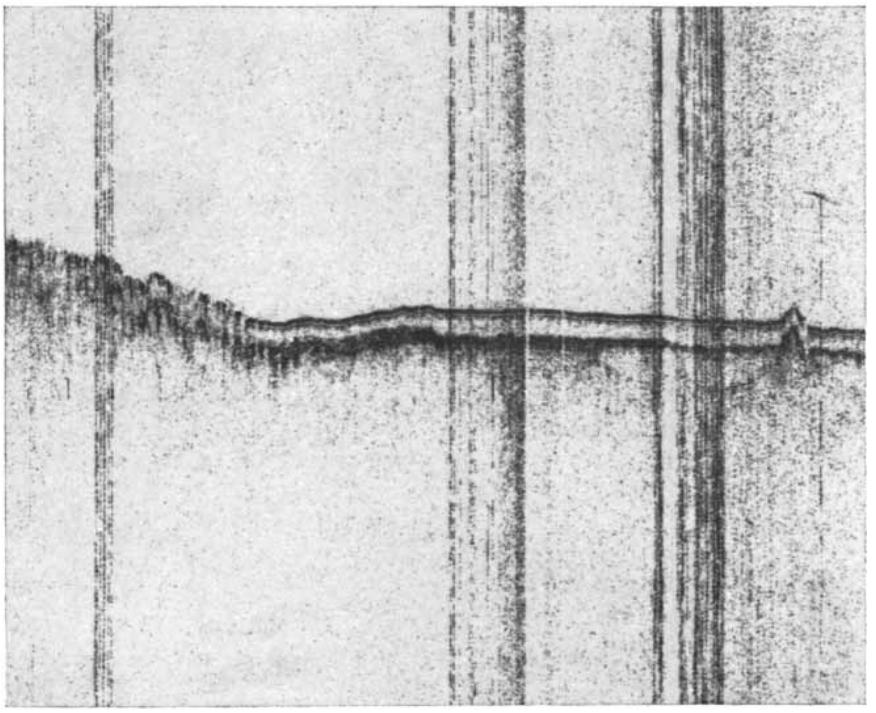
A layer that could send back distinct echoes must be very hard. Yet ocean sediments are commonly soft oozes made up of minute skeletons of the small organisms called foraminifera and nannoplankton. What could this hard layer be? Why should such a hard rock be down there under the Mediterranean?

To solve these and many other puzzles a group of investigators constituting the Mediterranean Advisory Panel of the Joint Oceanographic Institutions for Deep Earth Sampling program (JOIDES) in 1969 recommended to the Deep Sea Drilling Project (which is funded by the National Science Foundation and administered by the Scripps Institution of Oceanography) that the deep-sea drilling vessel *Glomar Challenger* be sent to the Mediterranean. The proposal was approved, and a two-month cruise in the fall of 1970 yielded the surprising answer to our mysteries: The biological revolution of the Mediterranean, the deep incision of the Rhône and the oceanic salt are all silent witnesses to an event six million years ago when the Mediterranean was almost completely dry. The hard-rock layer serving as the strong acoustic reflector is composed of the inorganic residues left behind by the desiccated Mediterranean: minerals known as evaporites.

The *Glomar Challenger* left Lisbon on August 13, 1970, for the 13th cruise



PILLAR-LIKE STRUCTURES, believed to be salt domes, are evident under the sea floor in this continuous seismic profile of a 10-mile-wide section of the Balearic abyssal plain in the western Mediterranean. The continuous-seismic-profiling device records not only reflections from the sea bottom but also signals transmitted by sound waves that penetrate beyond the bottom and are reflected by hard layers below. Some of the domes protrude as knolls above the sea floor; others are completely buried. The discovery of these pillar-like structures was the first hint that vast salt deposits are located under the Mediterranean floor.



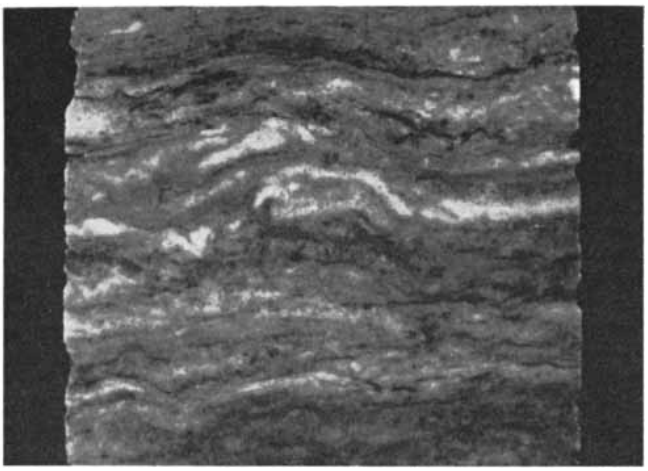
***M* REFLECTOR, a strong acoustic reflecting layer, underlies much of the Mediterranean floor. The relief of this layer (*lower dark contour*) closely simulates the bottom topography (*upper dark contour*). Drilling has shown that the *M* reflector corresponds to the top of an extensive underground evaporite formation consisting of inorganic residues precipitated from brines when the Mediterranean was isolated from the Atlantic Ocean some six million years ago. This continuous seismic profile was obtained by the *Glomar Challenger* as she worked her way northeastward (*right to left*) from a point southeast of Sicily toward Crete.**

of the Deep Sea Drilling Project. The vessel is unique because of its ability to keep virtually stationary in a stormy sea. Guided by a system of radio beacons and computers, the four thrusters of the vessel can position her above the drill hole within a circle with a diameter of about 100 feet. Ryan and I were co-chief scientists on this cruise, heading an international team of 20 investigators and technicians. On the evening of August 23 we arrived at a spot some 100 miles southeast of Barcelona. After positioning our vessel above a buried submarine volcano we were ready to tackle the problem of identifying the *M* reflector.

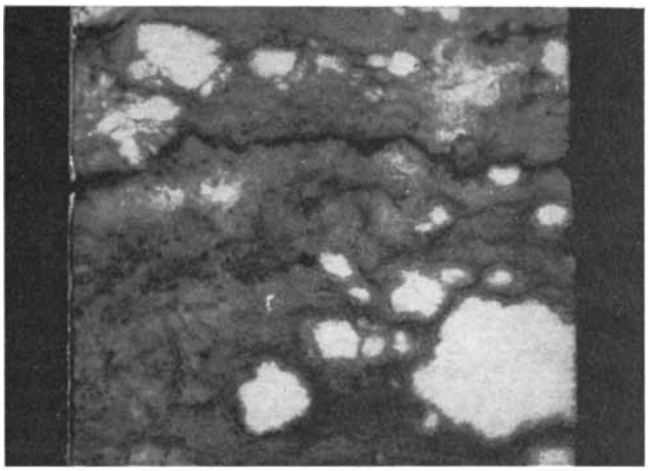
The drill string was lowered to the bottom at a depth of 6,000 feet, and we bored some 600 feet into the sediments. According to our seismic record, we should have been hitting our goal and reaching the top of the hard layer. Since we had penetrated the oldest Pliocene sediments, the hard layer should date back to the late Miocene: some six million years ago. At the critical juncture, however, while we all waited eagerly for the next rock sample to come up, we ran into trouble: the core barrel got stuck inside the drill string. There was nothing to do but to haul all the drill pipes back on deck and pull the core barrel out of the pipe at the end of the string. Furthermore, we were advised to find another drill site; we could not expect to dig deeper at this spot.

Neither Ryan nor I slept that night as we supervised the drilling details. Now that the core barrel had come up, it was found to be buried in a tube full of sand. The sand was brought in a bucket to our shipboard laboratory. All morning long on the 24th Ryan and I busied ourselves sorting pea gravel out of the sand; we were too tired to work and too keyed up to sleep. We needed the menial labor to ease the tension. As the morning wore on, however, we became more and more amazed by what we saw.

Gravels are rare in the oceans. Submarine slumping can generate an underwater current, known as a turbidity current, that can transport coastal sands and gravels to deep abyssal plains. One would expect gravels of this type to be composed of many different kinds of rock, derived from erosion on land. As our pickings accumulated, however, we noticed that our gravel was made up of only three different types of rock: oceanic basalt, hardened oceanic ooze and gypsum. In addition there was an unusual dwarf fauna of small shells and snails. We found no quartz, no feldspars, no granites, no rhyolites, no gneisses, no



CONVEX-UPWARD LAMINATION of the sedimentary rock shown in this photograph of a Mediterranean *M*-reflector core obtained by the *Glomar Challenger* has what geologists refer to as a stromatolitic (literally "flat stone") structure. Stromatolites are typically layered carbonates that owe their origin to the fact that blue-green algae tend to grow in a succession of thin mats on certain coastal flats. Since the very existence of the algae depends on photosynthesis, the presence of a stromatolitic structure is considered evidence of shallow-water deposition, the deep-sea bottom being too dark to allow the survival of such photosynthetic plants.



LIGHT-COLORED NODULES evident in this Mediterranean rock core are composed of anhydrite: a high-temperature form of calcium sulfate that can only be precipitated from brines at temperatures higher than 35 degrees Celsius. At lower temperatures the low-temperature form of the sulfate, gypsum, is precipitated. Anhydrite is formed today almost exclusively in the sedimentary layers of the hot and arid coastal deserts called sabkhas, where it is precipitated in the pore spaces of sediments near the ground-water table. The high-temperature form typically grows as irregular nodules, similar to the limy concretions one finds in arid soils.

schists, no quartzites, no sandstones. In fact, we found no trace of anything that could be identified as coming from the nearby continent. The gravels could not have been brought out here by turbidity currents from the Spanish coast. What was the meaning of this unusual gravel?

Toward the evening of the 24th the drill bit was brought in. Caught in the teeth of the bit, which had been stuck near the top of the hard layer, were fine aggregates of anhydrite, an anhydrous calcium sulfate. Anhydrite is a common mineral in evaporites, which represent the inorganic residues left behind by evaporated brines, and ancient evaporites are commonly lithified (converted into rock). Now we had the first solution to our mysteries: The *M* reflector, the hard layer under the Mediterranean, is a late Miocene evaporite.

This solution only deepened the mystery. Evaporites should be the deposits of coastal lagoons or of deserts. Why should we find an evaporite formation under the Mediterranean at depths of thousands of feet below sea level?

The gravel provided the clue. The fragments of gravel could not have come from land, only from a dried-up ocean. Was it possible, then, that the Mediterranean had been isolated from the Atlantic and had changed into a desert basin during the late Miocene?

One could imagine the gradual shrinkage of the Mediterranean and the increasing salinity of its waters, with the death of all normal marine animals except for some dwarf species of clams and snails tolerant of supersaline conditions. The inland sea would eventually be changed into a salt lake, like the Dead Sea, where the brine would be dense enough to precipitate gypsum. Continued evaporation would eventually have laid bare the Mediterranean bottom. The submarine volcano would be converted into a volcanic mountain, and the oceanic ooze on its flank would become lithified. Streams draining such a desiccated ocean bottom would produce an unusual gravel such as the one we had found.

It seemed preposterous to make up such a story on the flimsy bit of evidence we had. The Mediterranean abyssal plains are more than 10,000 feet deep and the basin holds almost a million cubic miles of water. It was unthinkable that this beautiful blue ocean should disappear and be replaced by a series of Dead Seas and Death Valleys.

Or was it so unthinkable? A few facts and figures showed that it would be rather easy to dry up the Mediterranean. The climate of the Mediterranean region is arid. The annual evaporation loss is approximately 1,000 cubic miles. Only a tenth of the loss is compensated by rainfall and by the influx of fresh water from rivers. The Mediterranean manages to maintain its normal marine salinity through an exchange of water masses with the Atlantic. If the Strait of Gibraltar were to be closed today, the annual evaporative loss could not be compensated, and the Mediterranean would be dried up in about 1,000 years.

Still, was it necessary to invoke such a drastic explanation? Many geologists had speculated that salts could be precipitated from a deep brine pool when the salt content in the brine exceeds the saturation concentration. The distribution of the evaporite layer indicated to us that this sedimentary formation was deposited in a deep Mediterranean basin. Is it not possible that the basin was filled to the brim with brines? True, a deep-water theory could not explain the genesis of our unusual gravel, but there should be more convincing evidence for desiccation.

The Arabic word sabkha is used in the Arabian Gulf countries to denote arid desert flats, particularly that part of a desert coastal plain situated slightly above the high-tide level. Sabkhas became an object of considerable interest to geologists soon after it was realized that certain types of ancient rock formation are practically identical with the sabkha sediments; both are characterized by the presence of nodular anhydrite and stromatolitic dolomite.

Anhydrite is a variety of calcium sulfate formed at high temperatures. At temperatures below 35 degrees Celsius in the presence of a brine that is saturated with sodium chloride (NaCl) an-

hydrite would be hydrated to form gypsum ($CaSO_4 \cdot 2H_2O$). (The hydration temperature would be higher if the brine were less salty). Since deep brine pools rarely exceed 35 degrees C. in bottom temperatures, anhydrite is formed today almost exclusively as a mineral in sabkha sediments. Since it is precipitated in the minute pore space of sediments near the ground-water table, it tends to grow as irregular nodules rather like the concretions one finds in arid soils.

Stromatolite (literally "flat stone") is a laminated carbonate that owes its genesis to the growth of algae [see "The Evolution of Reefs," by Norman D. Newell; SCIENTIFIC AMERICAN, June]. A dense growth of blue-green algae forms a thin mat on coastal flats. After a severe storm the mat may be buried under a thin cover of sediments, but the algal growth persists and a new mat is constructed. This alternation ultimately results in the laminated rock called stromatolite. Stromatolite is common under the sabkhas of the Arabian peninsula, where nodular anhydrite also grows.

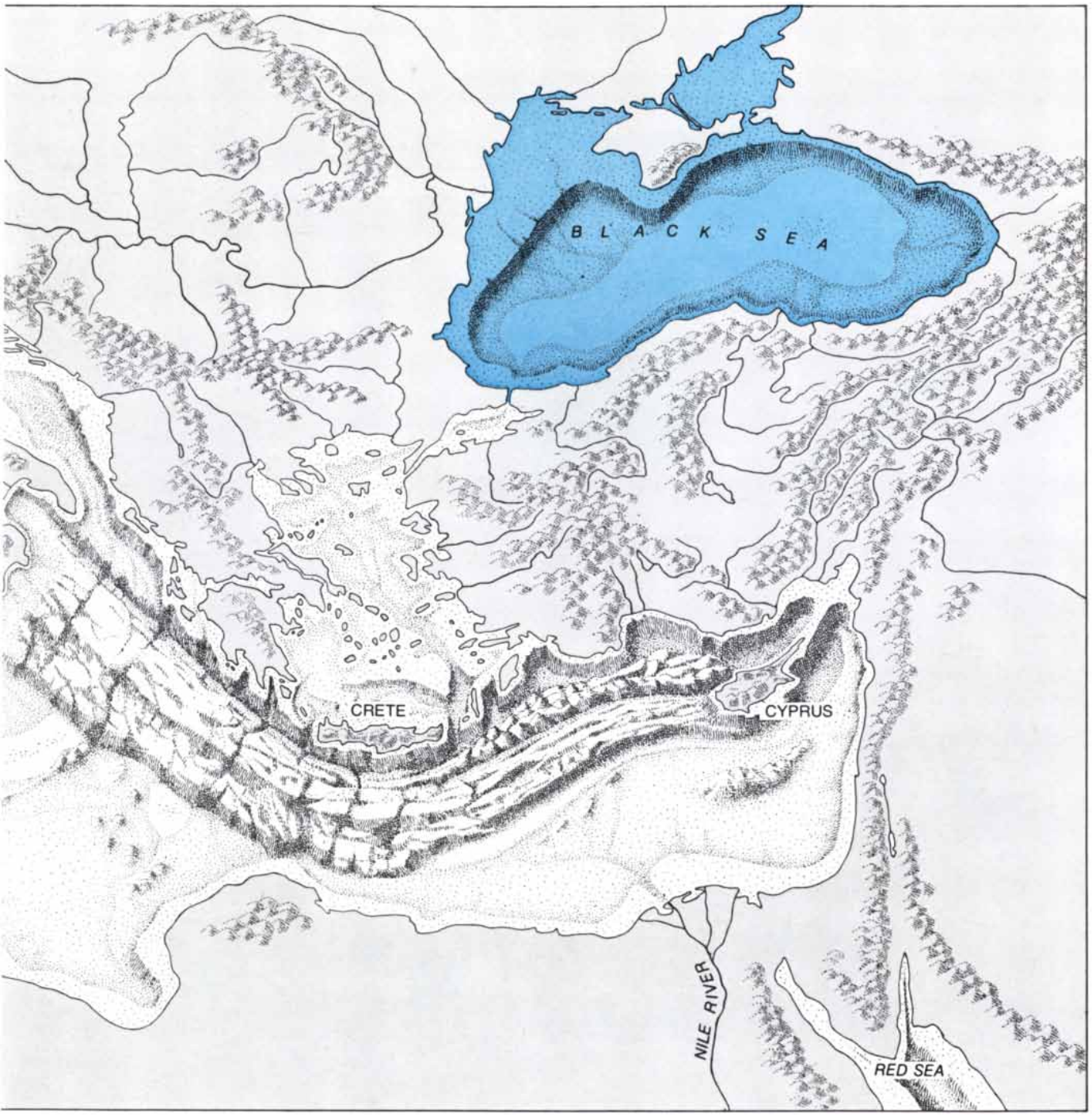
To return to our narrative, we sailed

DESICCATED MEDITERRANEAN is represented by this panoramic drawing of the modern submarine topography of the Mediterranean basin. The Mediterranean must have looked something like this approximately six million years ago, when the basin was a great interior desert lying 10,000 feet below sea level. The Balearic abyssal plain was then a salt lake where evaporite minerals, including rock salt, were precipitated. Meanwhile nodular anhydrite grew in the soils on the lake shore. Gravels and variegated silts were

our vessel on August 27 to the Balearic Sea south of Majorca. Our drill site was positioned slightly north of the abyssal plain of the Balearic basin; our precision depth recorder registered 1,417 fathoms. The drill penetrated 1,000 feet of soft oozes before reaching the top of the hard layer. The core came up, and it was a late Miocene evaporite, as we expected. What was surprising, at least to those who advocated deep-water salt deposition, was the sampling of nodular anhydrite and stromatolitic dolomite [*see illustrations on page 29*].

Stromatolite cannot form in deep water because the growth of algae requires sunlight. Moreover, one could not expect the bottom of a deep-water Mediterranean to ever get as hot as the 35 degrees C. (95 degrees Fahrenheit) needed to precipitate anhydrite. Later a detailed petrological investigation by G. M. Friedman of Rensselaer Polytechnic Institute confirmed our prognosis that the Mediterranean evaporites were deposited on a desert flat; such sediments could not possibly have been deposited in several thousand feet of water.

More sophisticated methods of research led to the same conclusion. For



deposited around the edge of the basin at the foot of the steep slope, which is now the continental slope. At the end of the Miocene epoch, some 5.5 million years ago, an opening was breached at the Strait of Gibraltar. The inrushing water of the Atlantic constituted a great waterfall, which probably had a discharge rate 100 times greater than Victoria Falls. Within a few thousand years the desiccated Mediterranean would be filled to the brim, and deep marine sediments would again be deposited on the Balearic abyssal plain.

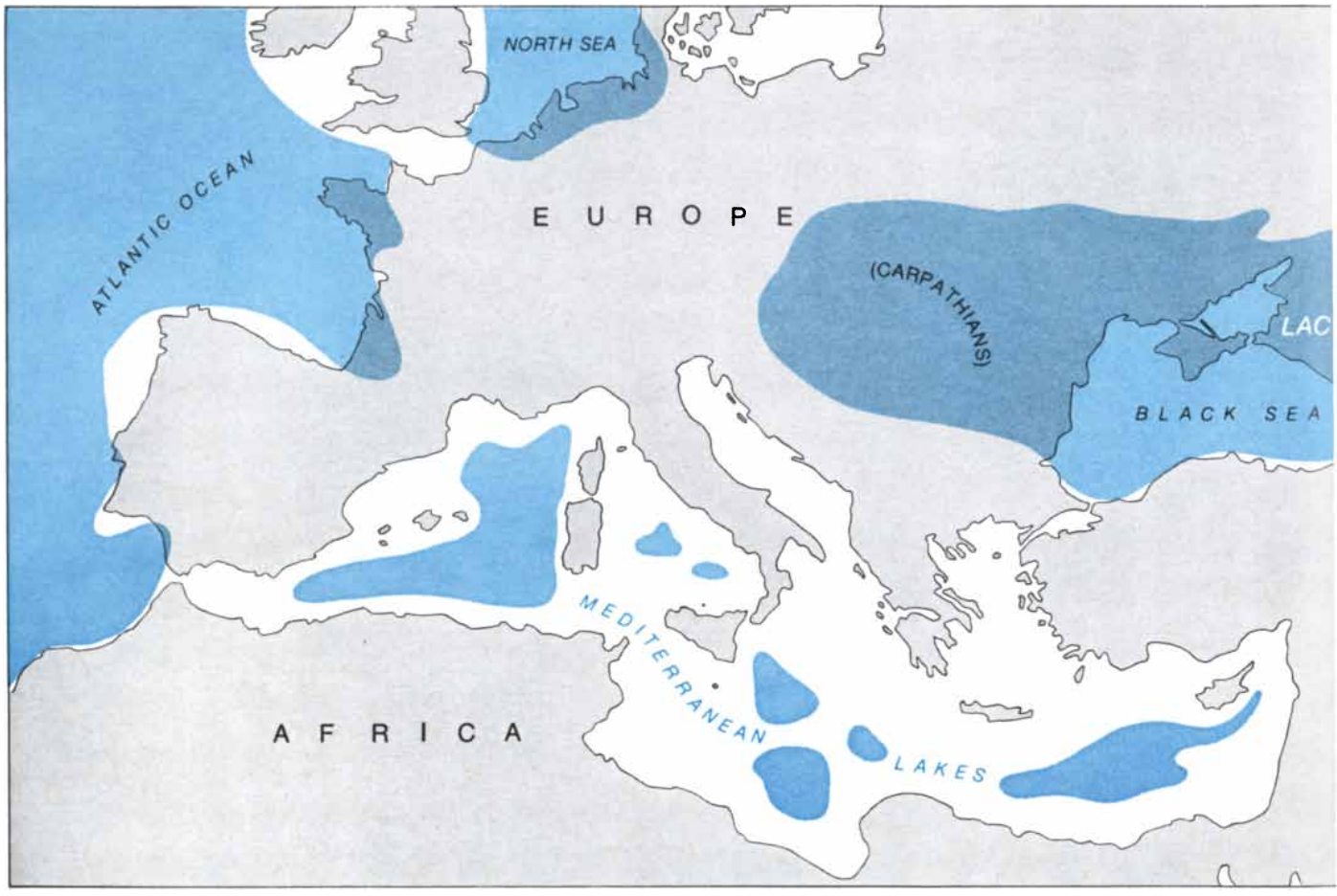
example, we know that the oxygen in sulfates and carbonates consists of two isotopes: oxygen 16, the common isotope, and oxygen 18, the heavy isotope. The ratio of oxygen 18 to oxygen 16 in a sample could reveal its genesis. Evaporites precipitated from evaporated seawater have a narrow range of isotopic compositions. In contrast, those deposited on playas, or desert lakes, have a wide range of values. Analyses of our samples by R. M. Lloyd of the Shell Oil Company laboratory in Houston showed a high variability of isotopic composition and thus provided additional confirmation for their playa origin.

Thus the anhydrite was deposited on a desert flat, but what a desert flat it must have been! The flat is now buried 9,000 feet below sea level. Do we have any unequivocal evidence that the floor of the Mediterranean basin was so very deep?

In fact, we do. Maria Cita of the University of Milan, one of our shipboard paleontologists, studied the microfossils in the marine sediments above and below the anhydrite. She told us that the sediments are normal deep-ocean ones. Clearly the basin was deep and submerged under marine waters when it was open to the Atlantic, but it turned into a deep hole when the floodgate was shut and the basin dried up. Because we discovered several oceanic sediments interbedded with the evaporites, we concluded that the floodgate swung open and shut repeatedly during an interval of about a million years.

After six weeks of drilling we were able to confirm that the *M* reflector is an evaporite everywhere. Nonetheless, we had sampled only evaporative carbonates and sulfates and not the rock salt. Some doubted that a piece of salt could ever be brought on deck before it had been pulverized and dissolved by the drilling. We were aware of the fact that we might be searching in the wrong places. The distribution of saline minerals in desert playas shows a bull's-eye pattern [*see illustration on page 34*]. The less soluble carbonates and sulfates, being the first to precipitate, are found at the edge of a salt pan, whereas the more soluble rock salt is usually deposited in the more central, deepest part of a basin, where the last bitter waters were concentrated. Our earlier drill sites had been on the peripheral, slightly elevated parts of the basin. To find rock salt we had to search under the abyssal plain. It was now October and we were heading home. A last borehole was spudded on the abyssal plain some 80 miles west of Sardinia. After drilling through 1,100 feet of soft oozes we hit pay dirt. The driller brought in a cylinder of shining, transparent crystals. Their bitter taste left us with no doubt that we had found rock salt 10,000 feet below sea level.

Interbedded in the salt layers are some windblown silts. This aeolian detritus includes land-formed quartz as well as the broken skeletons of forami-



SEVEN MILLION YEARS AGO the geography of Europe was quite different from what it is today. Most of northeastern Europe was covered by a very large fresh-water-to-brackish-water lake that extended from the vicinity of Vienna eastward to beyond the Aral Sea. This great inland water body was named the Lac Mer by the French geologist Maurice Gignoux. At that time the Mediterranean was already separated from the Atlantic. Just before the uplift of the Carpathian Mountains, which took place roughly seven million years ago, the Lac Mer drained into the Mediterranean, supplying fresh and brackish waters to form a series of large inland lakes there. Laminated diatomites were deposited in such lakes. Eventually the Carpathians rose and formed a barrier, depriving the Medi-

nifera. Those tiny marine creatures flourished in the Mediterranean during the intervals when marine conditions prevailed. After the sea was isolated and desiccated the dead skeletons were blown across the desert flat by dust storms and laid down on the shore of a salt lake, to be buried eventually in rock salt. Bearing testimony to the alternate wetting and drying of the playa are nodular anhydrite and salt-filled mud cracks.

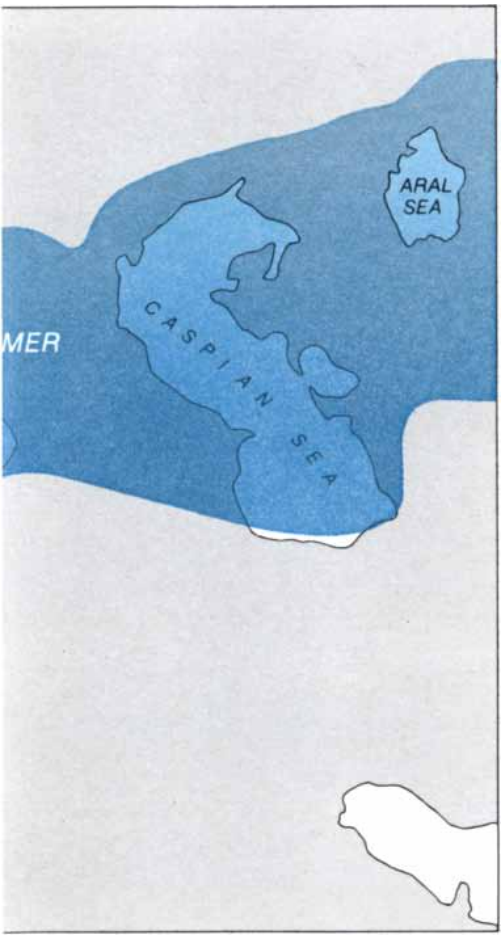
Examined under the microscope, the rock salt showed evidence of repeated solution and recrystallization, much like the salt in the modern coastal salinas of Lower California or in parts of Death Valley. The analogy to Death Valley can be carried a step further. We sampled red and green floodplain silts and well-rounded arroyo gravels from a nearby site. Those were carried to the base of an exposed continental slope by flash floods from the mountains of Sardinia and were deposited as alluvial fans fringing the salt pan. The similarity ends when one recalls that whereas Death Valley lies nearly at sea level, the floors of the Mediterranean desert basins were some 10,000 feet lower.

Our drilling had barely scratched the top of a huge salt deposit. The Mediterranean salt should be 5,000 or 6,000 feet thick, according to geophysical surveys. This estimate is probably not too far off the mark, since we were told that late Miocene salt formations are present in Sicily and are several thousand feet thick. We now believe the Sicilian evaporite represents a segment of the Mediterranean sea bottom that was pushed up by mountain-building movements a few million years ago.

After the salt came the deluge. The evidence is unmistakable from our drill cores. We obtained the geological record from three drill sites (in the Balearic, Tyrrhenian and Ionian basins), showing that the separate parts of the Mediterranean were simultaneously flooded and submerged under deep marine waters at the end of the Miocene epoch some 5.5 million years ago. The first deposit is a dark gray marl five inches thick, deposited when the basin was being filled up, followed by a white ooze with local patches of red ooze.

One can picture the desiccated Mediterranean as a giant bathtub, with the Strait of Gibraltar as the faucet. Seawater roared in from the Atlantic through the strait in a gigantic waterfall. If the falls had delivered 1,000 cubic miles of seawater per year (equivalent to 30 million gallons per second, 10 times the discharge of Victoria Falls), the volume would not have been sufficient to replace the evaporative loss. In order to keep the infilling sea from getting too salty for even such a hardy microfauna as the one found in the dark gray marl the influx would have had to exceed evaporation by a factor of 10. Cascading at a rate of 10,000 cubic miles per year, the Gibraltar falls would have been 100 times bigger than Victoria Falls and 1,000 times more so than Niagara. Even with such an impressive influx, more than 100 years would have been required to fill the empty bathtub. What a spectacle it must have been for the African ape-men, if any were lured by the thunderous roar.

By the time the first Pliocene white ooze was deposited the Mediterranean must have been filled to the brim. Then the present system of exchange with the Atlantic would have been in operation. The white ooze is a typical oceanic sediment, made up almost entirely of the skeletons of microfossils and nannofossils. In addition to floating creatures bottom-dwelling organisms were found. William E. B. Benson of the National Science Foundation has examined the marine ostracods and Orville L. Bandy of the University of Southern California has studied the benthic foraminifera. They have both concluded that at that time the bottom of the Mediterranean was either colder or deeper than it is today. Those new immigrants from the Atlantic crawled through the deep gash at the western end of the Mediterranean. Eventually the cold-water bottom fauna died out when the Strait of Gibraltar was sufficiently shoaled to prevent the inflow of deep Atlantic waters, a condition that has persisted until today.



terranean of its water supply from the Lac Mer and turning the entire Mediterranean basin into a vast desert. The large fresh-water and brackish-water lakes were reduced to shallow lakes and playas, where salt and various other evaporites were precipitated.

As we drilled through the evaporite formation we encountered an unusual laminated sediment. In addition to organic materials and minute crystals of dolomite the sediment contains fossil diatoms, whose skeletons consist of silica (SiO_2). Herbert Stradner of the University of Vienna, another of our shipboard paleontologists, recognized that some of the diatoms could only have lived in bodies of fresh or brackish water. This identification was later confirmed by Marta Hajós of the Hungarian Academy of Sciences; she found not only floating species but also bottom-dwelling ones. Later, at an eastern Mediterranean drilling site south of Crete, we sampled a late Miocene ostracod fauna. As Arredo Decima of the University of Palermo, an expert on ostracods, told us after he had examined our specimens, these tiny creatures also could have lived only on the bottom of brackish-water lakes.

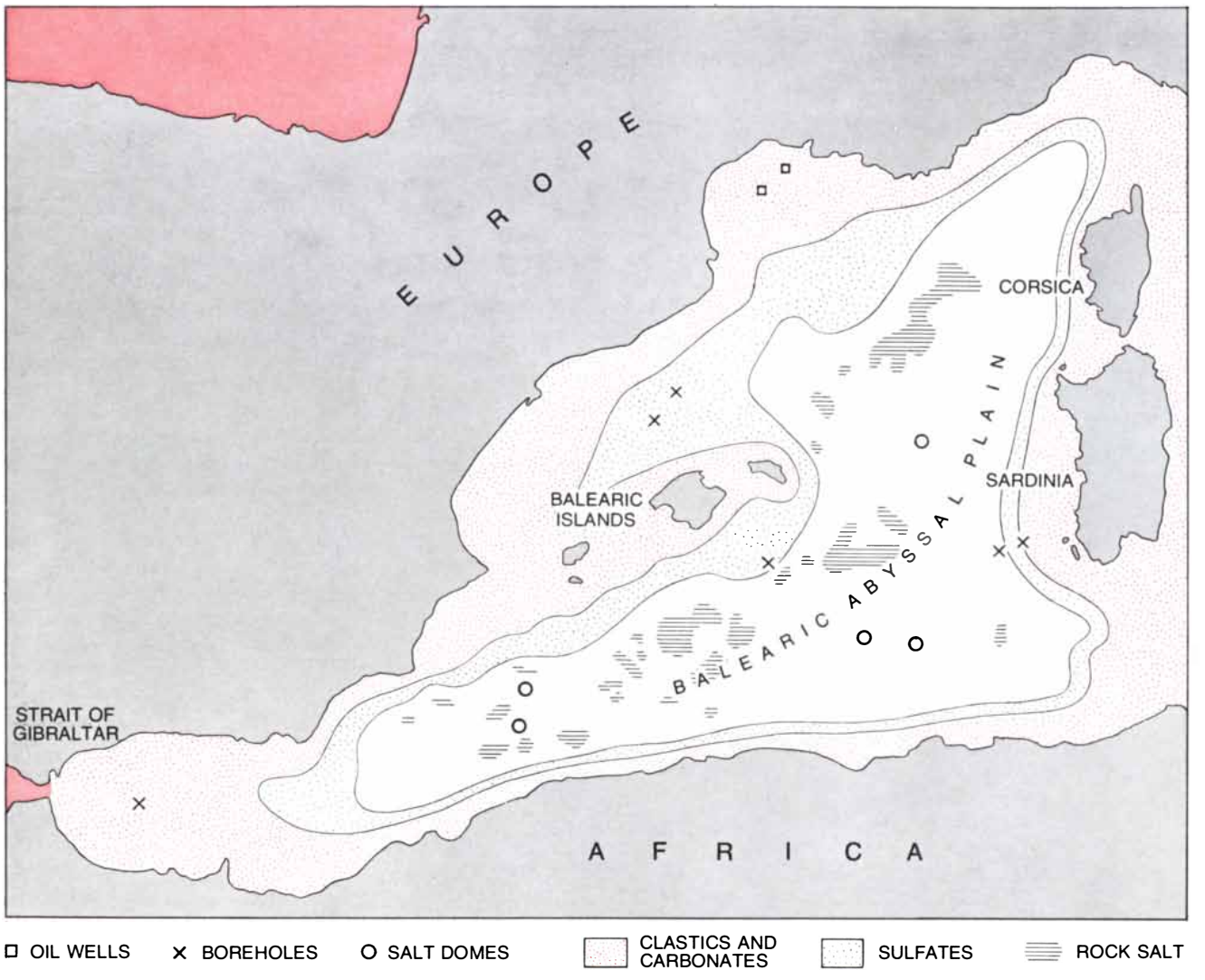
We were puzzled by this discovery. Where could all that fresh water have come from? There was absolutely no reason to assume that the Mediterranean climate had been much more humid six or seven million years ago, nor could we find any evidence for sudden and drastic changes in precipitation or in evaporation that would have converted great lakes into Death Valleys. The mystery was resolved when we talked to our Austrian and Balkan colleagues, who told us about the Lac Mer. Apparently a large part of eastern Europe was covered by fresh or brackish waters during the late Miocene and the Pliocene. At one time a giant lake, called by the French Lac Mer, extended from Vienna to the Urals and the Aral Sea; its last descendants are the Caspian Sea and Black Sea of today. This body of water, collecting all the excess precipitation from the then wet and cold northeastern Europe, was draining into the Mediter-

ranean during the earlier part of the late Miocene, some seven or eight million years ago. Shortly thereafter tremendous earth movements led to the uplift of the Carpathian Mountains and a radical reorganization of the drainage system. The Lac Mer now found an outlet to the north. The eastern faucet to the Mediterranean was turned off. Cut off from its major supply of fresh water, the arid Mediterranean suffered the fate of desiccation.

From the eastern Mediterranean boreholes we obtained a series of middle Miocene cores. Aided by the outcrop section on Sicily, we were able to reconstruct the history of the Mediterranean during the past 15 or 20 million years. The Mediterranean was once a broad seaway linking the Indian and Atlantic oceans. With the collision of the African and Asiatic continents and the advent of mountain-building in the Middle East, the connection to the Indian Ocean was severed. Meanwhile Africa was also advancing toward Europe, and communication to the Atlantic was maintained by way of two narrow straits, the Betic in southern Spain and the Riphian in North Africa. We saw evidence in our cores of the gradual deterioration of the Mediterranean environment, the advancing stagnation of its waters, the inevitable extinction of its bottom-dwellers, the struggle for existence by its swimming and floating population and the evolution of a hardy race that could survive widely changing salinities. We saw a change from an inland sea to a series of great lakes, and we saw their desiccation and the complete extermination of the fauna and flora at the bottom of the Miocene Death Valleys, 10,000 feet below sea level. We saw also the deluge, the establishment of a new faunal dynasty and the changing marine population leading up to the population of the present.

The discovery of the Mediterranean desert was made possible by deep-sea drilling. The first people acquainted with the discovery were the shipboard investigators who were selected for qualifications other than their mastery of local geology. Hence the full impact of the discovery was only appreciated after the *Glomar Challenger* returned to Lisbon and the drill results were communicated to the public by press conferences in Paris and New York.

If the Mediterranean had indeed been emptied, the coastal plains of the sur-



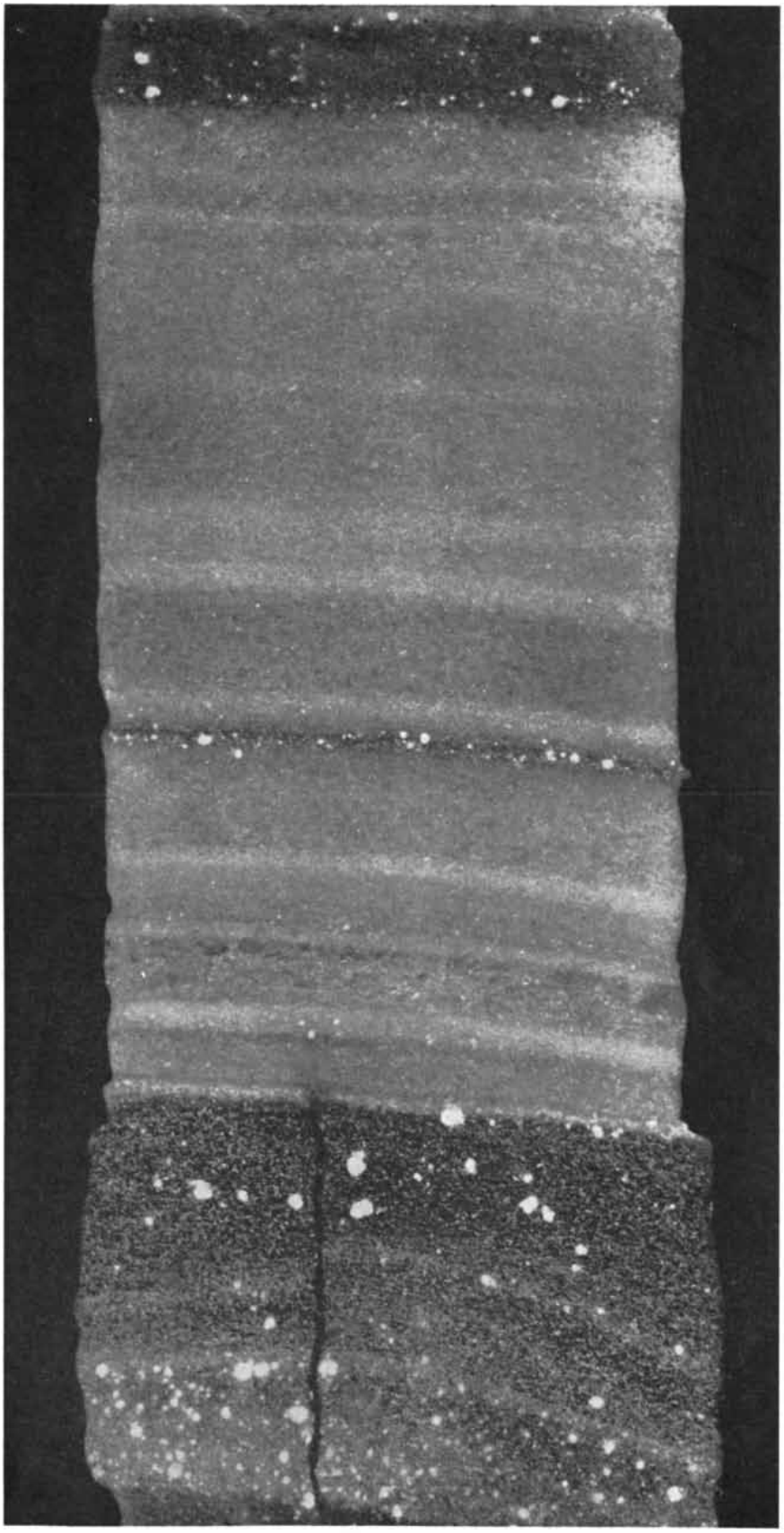
DISTRIBUTION OF EVAPORITES under the Balearic Sea shows the characteristic bull's-eye pattern one would expect in a completely enclosed basin. The less soluble carbonates and sulfates, being the first to precipitate, are found around the periphery of the basin; anhydrite and gypsum are found in a narrow ring just inside this outermost region, whereas rock salt, being the most soluble, is present only under the central, deepest part of the abyssal plain, where the last bitter waters must have been concentrated.

rounding lands would have become high plateaus, and islands would have been lofty peaks. The first response to a lowering of the water level would be rejuvenation of streams: a marked increase in their down-cutting power. The buried Rhône gorge, first discovered 80 years ago, should thus be one of the many surrounding the Mediterranean. Where are the other buried gorges?

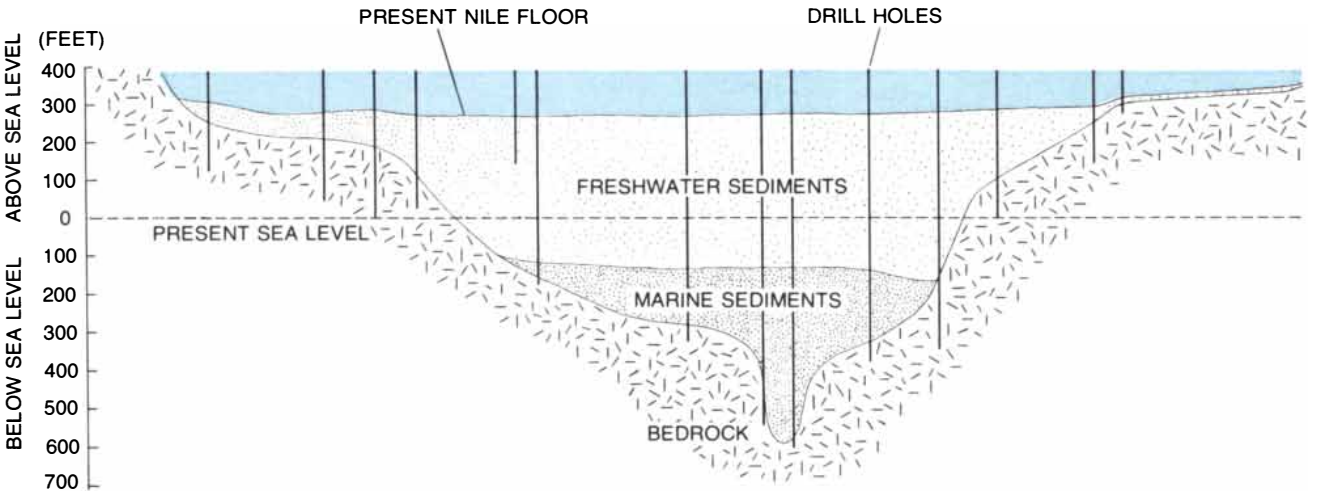
Soon after we returned to port Ryan received a letter from a Russian geologist, I. S. Chumakov, who had learned of our findings through an article in *The New York Times*. Chumakov was one of the specialists sent by the U.S.S.R. to Aswan in Egypt to help build the famous high dam. In an effort to find hard rock for the dam's foundation 15 boreholes were drilled. To the Russians' amazement they discovered a narrow, deep gorge under the Nile valley, cut 700 feet below the sea level into hard granite [*see illustration on next page*]. The valley was drowned some 5.5 million years ago and filled with Pliocene marine muds, which are covered by the Nile alluvium. Aswan is 750 miles upstream from the Mediterranean coast. In the Nile delta boreholes more than 1,000 feet deep were not able to reach the bottom of the old Nile canyon. Chumakov estimated that the depth of the incision there might reach 5,000 feet, and he visualized a buried Grand Canyon under the sands and silts of the Nile delta.

Chumakov was not the only one who had been puzzled. Oil geologists exploring in Libya had also had their share of surprises. First, their seismograms would register anomalies; there were linear features underground transmitting seismic waves at abnormally high velocities. Drilling into the anomalies revealed that they are buried channels incised 1,300 feet below sea level. The geologic record tells the same story: vigorous downcutting by streams and sudden flooding by marine waters at the beginning of the Pliocene. Frank T. Barr and his coworkers of the Oasis Oil Company, based at Tripoli in Libya, concluded in a report that the Mediterranean must have been thousands of feet below its present level when the channels were cut. They could not get their manuscript published in a scientific journal, since no one would accept such an outrageous interpretation.

Still other buried gorges and channels have been found in Algeria, Israel, Syria and other Mediterranean countries. Rivers emptying into a desiccating Mediterranean not only would have in-



DEEP-SEA SALT CORE, the first of its kind ever obtained, was retrieved from a borehole drilled by the *Glomar Challenger* through some 1,100 feet of soft oozes underlying the Balearic abyssal plain about 80 miles west of Sardinia. The sea bottom in this region is about 10,000 feet deep. The vertical crack in the lower part of the core is believed to be a desiccation crack, further evidence that the Mediterranean was dry down to 10,000-foot level.



DEEP GORGE under the upper Nile valley near Aswan in Egypt was discovered by a team of Russian geologists while drilling test boreholes preparatory to the construction of the Aswan high dam. The narrow, deep central portion of the canyon cuts some 700 feet below the present sea level. The incision was apparently carved when the Mediterranean was dry. When the Mediterranean was flooded again at the beginning of the Pliocene epoch, the canyon was also drowned and marine sediments filled its lower section.

cised deeply on land but also would have continued on down across the exposed continental shelf and the continental slope to the flat bottom of the abyssal plain that was turning into a playa. In the course of a lecture at Yale University devoted to a discussion of the results of our expedition a student in the audience called my attention to such an eventuality and asked if such channels exist.

They do indeed. Extensive oceanographic surveys have been carried out by the French in the Balearic basin. The late Jacques Bourcart of the University of Paris reported in 1950 the discovery of numerous submarine canyons indenting the continental margins off the coast of France, Corsica, Sardinia and North Africa. The canyons are typically river-cut and are filled with alluvial gravels. Most of them can be related to a river on land and can be traced to a depth of 6,000 or 8,000 feet at the edge of the abyssal plain. They too were drowned by the early Pliocene deluge. Similar canyons have since been found in all parts of the Mediterranean. Their genesis had never been satisfactorily explained until it was realized that the Mediterranean was desiccated six million years ago.

The key opens the door to the solution of other mysteries. For example, one can now begin to understand the origin of the extensive caverns in the circum-Mediterranean lands and the peculiar karst topography of Yugoslavia, where sinkholes and pinnacles abound. One can also provide an answer to the long-standing question of why ground-water circulation once penetrated 10,000 feet below sea level in a mid-ocean island such as Malta. Not only the geomorphic changes but also the biological ones were catastrophic. Giuliano Ruggieri of the University of Palermo, an authority on the evolution of the shallow marine fauna of the Mediterranean, recently sent me a reprint of an article he wrote in 1955, in which he surmised that the Mediterranean must have been desiccated in order to explain the biological revolution six million years ago. Lyell's historical datum marked the return of marine waters to this inland basin.

To remove all the water from the Mediterranean and pile it elsewhere would raise the sea level of the world ocean by 35 feet, an event that would drown many of our coastal cities. The magnitude of the negative load on the desiccated Mediterranean was comparable to the weight of the Fennoscandian ice sheet on Europe during the last ice age. The resubmergence of the Mediterranean must have led to the subsidence of the basin and the uplift of surrounding lands. Oceanographers and geologists began to see such evidence in their records. The presence of a hot desert where the Mediterranean is now should have had a heavy climatic impact. Indeed, European paleobotanists have noticed a change toward warm aridity in central Europe during the late Miocene, when the Vienna woods were changed into steppes and when palms grew in Switzerland. With the return of marine waters to the Mediterranean in the Pliocene epoch the central European climate again became wet and cold and deteriorated gradually into the ice age. It is also interesting to note that the Arctic polar ice cap began to build up in the late Miocene. Was this a coincidence, or was the initiation of glaciation triggered by the drying up of the Mediterranean?

Was the disappearance of a large inland sea a unique event in the geological history? Probably not. The existence of large saline deposits indicates that there have been other desiccated oceans. The famous Zechstein salts of northern Europe may have been the residues of an inland sea that dried up 250 million years ago. The giant salt and potash deposit of Alberta and Saskatchewan, some 350 million years old, may have had a similar origin. In fact, the discovery that a small ocean basin can be converted into desert has led us to reexamine the entire problem of salt genesis. Geologists used to worry about the occurrence of oceanic salt deposits under the Gulf of Mexico, under the South Atlantic off the coast of the Congo and Angola and under the North Atlantic off the coast of Nova Scotia. We can now postulate that those salts were formed when the Gulf and the Atlantic were isolated inland seas undergoing desiccation.

It must of course seem somewhat farfetched to imagine the Mediterranean as a deep, dry, hot hell. We ourselves were reluctant to come to that conclusion until all other explanations had failed; the facts left us with no alternative. As Sherlock Holmes once remarked: "It is an old maxim of mine that when you have excluded the impossible, whatever remains, however improbable, must be the truth."

We want to be useful ...and even interesting

Wetlands telebotany

Little by little the public overcomes its ancestral antipathy to swamps and marshes. The need to extirpate them in the interest of public health, safety, and progress is no longer accepted as self-evident, even though the botanist who took this picture to illustrate spikerush *(Juncus roemerianus)* inadvertently stepped on the back of a five-foot Sapelo Island (Georgia) alligator in doing so.

The University of Georgia Marine Institute

There was no alligator hazard in southern Maine, where another botanist did this illustration of wiregrass *(Spartina patens)* in salt meadow. On the Louisiana coast that same botanist finds the association of these same two species to be a reliable indicator of the otherwise difficult-to-locate intertidal zone. Down there the pesky salt marsh mosquito *(Aedes sollicitans)* lays its eggs on non-submerged soil, but the eggs hatch only in water. Therefore, to control this pest with least waste of insecticide either on higher ground or on shallows that do not drain out and contribute significantly to the primary food supply of the whole Gulf, it is well that charts should accurately indicate the labyrinthine intertidal zone in the vast expanse of flat Gulf coast.

The gentleman who frightened the alligator reports that on *his* coast *J. roemerianus* occurs mostly in pure stands. His particular salt marsh research can guide land use, such as major highway construction, to avoid areas of high biological productivity, as represented in stands of *J. roemerianus* and *Spartina alterniflora.*

Still other investigators, working on the New Jersey coast, find *S. patens* growing almost exclusively *above* areas of daily tidal inundation. The contrast with *S. alterniflora,* which needs tidal flooding for vigor, provides an easily interpretable key for drawing a mean high tide line to submit in litigation.

Obviously the wetlands botanists have a big job ahead of them, too big to do on foot. Which is why they have to know a lot about aerial photography and why, as a manufacturer of technical color photographic products, including color infrared film for detecting plant signatures from aloft, we call attention to the 320-page "Proceedings of a Symposium on Coastal Mapping" published by American Society of Photogrammetry, 105 N. Virginia Ave., Falls Church, Va. 22046.

Deeper and deeper in liquid crystals

Only ten years ago a man exploring liquid-crystal phenomena at a large technology-based company risked boring his boss or, somewhat worse, being suspected of having fun on company time. Today he has an outside chance of simultaneously earning a high honor in Stockholm for himself and honors from the investment community for the business sagacity of his company's management—a rare conjunction of honors. Liquid crystals generate such visions.

Only nine months ago Kodak announced "Nematic Mixture, Dynamic Scattering." We advertised that when a 12μm thickness of this product is hit with more than 4 volts dc, it turns turbid; that at 60 Hz, 200 v peak-to-peak, only 0.1% of the light flux in an entrant parallel beam remains within the forward $f/34$ cone of solid angle, as compared with 78% where there is no field. The resulting contrast between field and no field yields "sophisticated" means of graphic display with ambient light and of image formation. Very convenient as long as the temperature stays above 5°C.

Now we offer "Nematic Mixture, Dynamic Scattering, II" (EASTMAN 11880). That 5°C changes to −20°C. Important for devices that ought not give up on a frosty morning in Minnesota. The upper limit is above 100°C. Another big improvement occurs in contrast, provided excitation is done with 30-Hz square waves at only 30 v peak-to-peak. They are as readily come by in tiny packages today as sine waves. Where higher voltage can be provided, higher contrast is realized than with our original product, and as before, rise time shrinks to a few milliseconds.

"Nematic Mixture, Field Effect" (EASTMAN 11900), with a working range from −7°C to 100°C, is new and works by a different principle. Without field it rotates the plane of plane-polarized light; with as little as 4 v dc across the 12.5μm film thickness, rotation is prevented. Resistivity being some fivefold that of the dynamic scattering mixture, power drain is proportionally more negligible. Hence "field effect." Furthermore, some think the display is better-looking, at the expense of adding two sheets of polarizer to the train. We claim no credit for the discovery, aspiring only to supply a superior material for utilizing it.

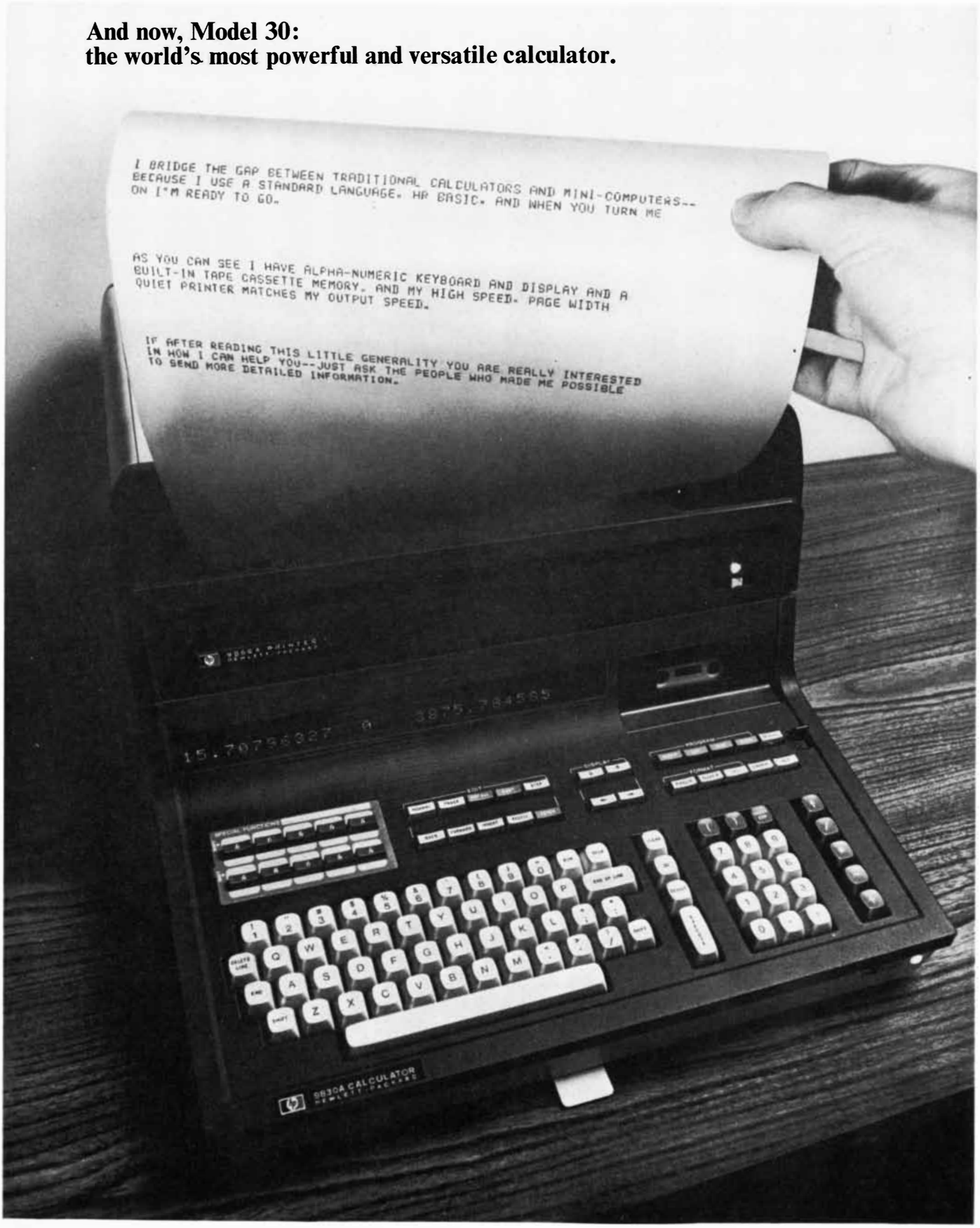
All this, we hope, is scarcely a beginning. Papers on liquid crystals are appearing at such a rate that our private bibliography in its various arrangements for convenient reference occupies a whole reel of microfilm. If enough interest turns up, we might consider selling copies. More eagerly awaited are inquiries concerning commercial quantities of the two new mixtures and of liquid-crystal preparations to customer-specified parameters and specs. Such inquiries, perhaps preceded by requests for data sheets, should be directed to Richard Hapeman, Eastman Organic Chemicals, Kodak, Rochester, N.Y. 14650.

Kodak

Firm footing

Some things are changing for the better.

And now, Model 30:
the world's most powerful and versatile calculator.



Many people know us as an instrument manufacturer: we make more than 2,000 products for measurement, test and analysis. Others know us as a computer company: more than 10,000 own our calculators and computers. We prefer to think that our business is to serve your measurement and computation needs.

A way to manage airport noise.

Aircraft engine noise — from more and bigger planes taking off and landing more frequently — is now a bona fide environmental problem. As the volume of air traffic grows and our population expands to surround previously remote airport areas, the need for effective noise control is essential.

The ideal solution is to stop this noise at its source by designing quieter engines, or by retrofitting the world's current fleets with noise-suppressing engine nacelles, but this will take time to implement.

Until then, many airports are finding an interim solution by developing noise abatement techniques for landing and take-off operations. To help establish and validate these techniques, some major airports with acute noise problems are using HP Aircraft Noise Monitoring systems.

These systems operate automatically and around the clock. Special microphones monitor noise from different locations in the airport vicinity. This information is relayed to a central location where the data is continuously analyzed and reported so that airport operations can immediately advise pilots of noise irregularities and violations.

HP noise monitoring systems are now operating at international airports in Los Angeles, Sydney, Geneva, Zurich and Stuttgart (and soon, in London and Manchester).

If you have any relationship to this issue of airport noise, we'd be happy to send you information on our system. The noise won't go away, but our system will help make it more manageable.

A typical noise violation report generated by HP's noise monitoring system.

SINGLE EVENT NOISE VIOLATIONS

DATE	TIME	NMS	RANGE	SETNL	MNL	LIMIT	SENEL	COMMENT
1:23:72	0:13:25	4	60	85	102.5	105	114.7	Flight KL 147
1:23:72	0:13:54	7	80	85	104.8	105	113.2	
1:23:72	0:14: 8	10	60	85	97.7	100	104.3	
1:23:72	0:17:45	12	80	85	121.8	105	116.9	
*								
VC								
1:23:72	0:18: 0	1	80	90	84.9	110	96.3	CAL
1:23:72	0:18:12	14	60	85	99.6	100	107.0	
1:23:72	0:18:55	11	80	85	104.7	105	112.7	
1:23:72	0:19:25	2	80	90	85.3	110	96.8	CAL
1:23:72	0:20: 0	8	40	70	92.0	95	100.5	

NMS: microphone location by number.

RANGE: indicates the lowest value in dB of the dynamic range at microphone location.

SETNL: the threshold noise dB level. If a noise event occurs at or above this level, a report is generated.

MNL: the maximum dB which occurred during the noise event.

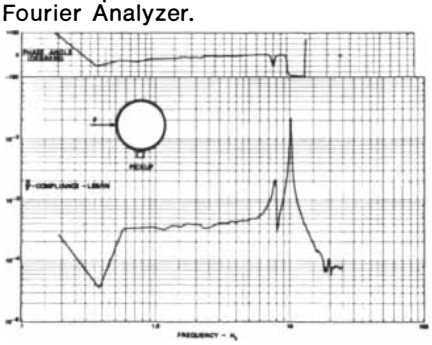
LIMIT: when this dB noise level is exceeded in a single event, audible and visual alarms are initiated.

SENEL: noise exposure level for the event: a time period/dB relationship.

You can detect the real cause and true effect of vibrations and noise.

A trained ear can pinpoint the pitch of a pure note within a few cycles per second. But, given a complex mixture of sounds or other types of signals — like an automobile vibration, or an underwater sound — it takes more than a trained ear to identify the basic frequencies that make up the mixture. Scientists and engineers find it highly useful, and sometimes essential, to trace or identify a low frequency signal through a mechanical structure. And they often need this information on the spot — in real-time as an event is taking place.

It is now possible to bring real-time signal analysis to the lower frequencies of vibration and sound with computers and the fast Fourier transform: HP's Fourier Analyzer.



Send a vibration through a pump with a known force (such as a hammer equipped with a load cell); obtain the output (from an accelerometer); display the transfer function on an HP Fourier Analyzer and you immediately learn the natural resonant frequencies of the pump, (see the above diagram). With this information, you can redesign to avoid resonance (vibrations) problems which might loosen connections or cause failure.

Here are a few practical examples of how it can be used.

- Testing mechanical components such as axles, differentials, and motors to assure their quality.
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- Analyzing structures, i.e., buildings, bridges, vehicle frames, airplane wings for improvement in design and resistance to failure.

If you think you have a problem that might yield to the HP Fourier Analyzer, ask for a free brochure.

For more information on the products described in these pages, fill out the coupon or write to: Hewlett-Packard, 1503 Page Mill Road, Palo Alto, California 94304.

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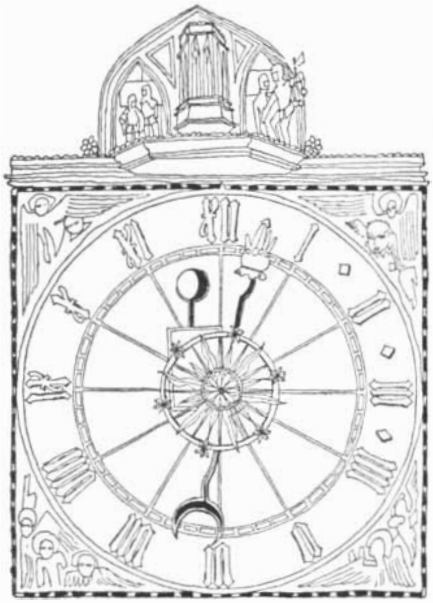
SCIENCE AND THE CITIZEN



Grains of SALT

The almost universal approbation that greeted the announcement in Moscow last May of the results of the first round of the strategic-arms-limitation talks (SALT I) between the U.S. and the U.S.S.R. was tempered somewhat by the concern expressed in various quarters that the immediate effect of the SALT I agreements might be merely to divert the arms race from a primarily quantitative competition to an equally costly qualitative one. The ensuing actions of the Nixon Administration, which has since pushed ahead strenuously with a variety of new strategic-weapons programs not expressly prohibited by the Moscow pact, have tended to focus attention on such fears.

Now an independent, detailed analysis of the SALT I accords, with particular reference to their probable impact on the future of the arms race, not only has elaborated on many of the initial reservations regarding the actual accomplishments of SALT I but also has called into question the value of the entire approach of seeking to limit strategic arms by means of bilateral "big power" negotiations, at least as such bargaining sessions are currently constituted. The analysis, in two parts, was published recently by the Stockholm International Peace Research Institute (SIPRI).

Part I of the SIPRI report, prepared by Jozef Goldblat of the institute's research staff, reviews and interprets the terms of the two principal SALT I documents: a treaty limiting anti-ballistic-missile (ABM) systems and an interim agreement freezing offensive strategic missiles at roughly their present levels. Conceding at the outset that in purely political terms the Moscow arms-control agreements, along with several other documents adopted during President Nixon's visit to the U.S.S.R., "may signify the beginning of a steady rapprochement and closer cooperation between the two powers," Goldblat asserts that such an outcome "would bring direct benefits to the powers themselves, and indirect positive repercussions for the cause of international peace insofar as the likelihood of a world war, started by design, has been reduced." Nonetheless, he cautions, "from the point of view of disarmament, in the proper sense of the term, the value of the Moscow agreements is less obvious."

Juxtaposing the activities explicitly prohibited by the agreements with those explicitly allowed or simply not covered, Goldblat finds the prohibitions "less than impressive." For example, he notes that the ABM treaty "will result in the deployment by both countries of missiles that were not operational at the time the Moscow agreements were concluded." Furthermore, he states, "the overall number of submarine-launched missiles will rise," and although a stop will be put to "the excessive proliferation" of land-based intercontinental ballistic missiles (ICBM's), the importance of fixed ICBM's "is diminishing as compared to sea-based deterrence." In addition "mobile land-based ICBM's and bombers are not prohibited."

The "concrete net gains" of the SALT bargain are summed up by Goldblat as follows: "Cancellation of the U.S. 12-site anti-ballistic-missile program—probably a matter of primary concern to the U.S.S.R. . . . and discontinuance of the deployment of Soviet land-based launchers for 'heavy' SS-9 missiles—a matter of primary concern to the U.S." In any event, the balance of terror remains unchanged: "Whatever the relative nuclear strength of the U.S. and the U.S.S.R., and whatever standards are used to measure it, the destructive power accumulated in their arsenals is already more than sufficient to cover every significant target on their territories, and even a retaliatory . . . nuclear strike would completely devastate either of them."

On balance, then, Goldblat's assessment is that the rapid transformation of the nuclear-arms race "from a race for quantity to a race for quality" not only continues unabated but also is "encouraged and even legitimized" by the SALT I agreements. "The competition in arms will be fueled by new technological advances," he concludes, and "limitation may well turn into escalation."

Part II of the SIPRI report, prepared by George Rathjens of the Massachusetts Institute of Technology, covers much of the same ground as Part I and arrives at similar conclusions. Rathjens, however, focuses more on the motivations underlying the strategic-arms race. Thus he views official statements of the past few years about the possible vulnerability of U.S. forces to a Russian "first strike" more as rationalizations than as reasons to acquire new weapons, and he gives special emphasis to what he perceives as an accumulation of evidence indicating that in spite of a great deal of official rhetoric to the contrary, "it seems clear that the Nixon Administration has unequivocally rejected strategic sufficiency, at least as conventionally defined, as a basis for its policies, believing that Soviet superiority in strategic strength is unacceptable, and that, at least as regards the state of technology, U.S. superiority is imperative." (The doctrine of strategic sufficiency, which appeared to be gaining widespread acceptance among U.S. military planners during the late 1960's, holds that what is necessary and sufficient for U.S. strategic forces is an "assured-destruction capability," that is, an ability to inflict with high assurance an unacceptable level of damage on the U.S.S.R. in a retaliatory attack.)

In Rathjens' view "the whole approach to SALT I would have been entirely different if strategic sufficiency, conventionally defined, had been accepted by both parties, or even by one, as a basis for policy. The nuclear-arms race would have been treated more as the problem of cancer than as a contest in which relative advantage is of importance. But, of course, the approach to SALT has been very much in the latter vein, and spokesmen for the Nixon Administration have made much of the necessity for a strong position from

which the U.S. could bargain with respect to both SALT I and SALT II. Yet it seems likely that the 'bargaining chip' argument, like the arguments relating to accidents, the China threat and the first strike, has been exaggerated in the interest of securing support for programs the major incentives for which really lie elsewhere: in concern about Soviet counterpart weapon systems; in the desire of the military establishment to acquire new weaponry; in pressures from industry, and perhaps above all in the rather generalized belief that increasing strategic strength is advantageous, regardless of arms-control negotiations."

Rathjens concludes that although "there would seem to be a basis for highly qualified optimism that SALT II might produce an agreement of unlimited duration relating to offensive delivery system levels that would be broader in scope than the interim agreement... there is less basis for optimism about substantial reductions, significant limits on strategic weapons development or limitations on defensive systems other than ABM.... Meanwhile the strategic arms race will go on fueled by commitments made to secure support for the SALT I agreements and by demands made for bargaining chips for SALT II.

"If very encompassing agreements are the result of SALT II, perhaps the price will have been worth paying. However, the events of the last several years provide enough basis for pessimism to suggest that the unilateral exercise of restraint, with the hope that there will be some reflection in adversary actions, may be a more promising approach to strategic arms control and disarmament than continued formal negotiations, the ancillary benefits of the latter notwithstanding."

The Nobel Prizes

The 1972 Nobel prizes in science and economics have been awarded to a total of 10 investigators, all but two of whom are Americans. For the first time in the history of the awards a prize has been given a second time in the same field to one individual. Marie Curie and Linus Pauling had previously won two Nobel prizes but they were given in different fields. The new double winner is John Bardeen, who shared the 1956 Nobel prize in physics for discoveries leading to the transistor. Bardeen now shares the prize with Leon N. Cooper and John R. Schrieffer "for their jointly developed theory of superconductivity, usually called the BCS theory."

The 1972 Nobel prize in physiology or medicine went to Gerald M. Edelman and Rodney R. Porter "for discoveries concerning the chemical structure of antibodies." The prize in chemistry went to Christian B. Anfinsen, Stanford Moore and William H. Stein for "fundamental contributions to enzyme chemistry." The prize in economics went to Kenneth J. Arrow and John R. Hicks for "their pioneering contributions to general economic equilibrium theory and welfare theory."

Bardeen, Cooper and Schrieffer published their theory of superconductivity in 1957, when all three men were colleagues at the University of Illinois. Cooper is now at Brown University and Schrieffer is at the University of Pennsylvania. The Dutch physicist Heike Kamerlingh Onnes discovered in 1911 that when certain metals are cooled to the vicinity of absolute zero (−273 degrees Celsius), their electrical resistance vanishes. After the development of quantum mechanics it seemed likely to a number of physicists that superconductivity was a macroscopic manifestation of the unusual kind of behavior that quantum mechanics ordinarily allows only for events on the atomic scale.

The BCS theory shows explicitly how quantum behavior becomes manifest on a macroscopic scale. In brief, the motion of electrons becomes coupled to the vibrations of the crystal lattice of a metal that has been cooled to temperatures a few degrees above absolute zero. When an electric current flows in the metal, a large fraction of the electrons start traveling in one direction in tightly bound pairs, all of which have nearly the same momentum. Although individual electrons may collide with imperfections in the crystal, the strength of the bond between electrons is sufficient to keep the colliding electron from moving off in the opposite direction. In fact, one cannot break up a single pair without perturbing all the other pairs. This behavior requires an amount of energy that exceeds a critical value: the value corresponding to the temperature at which superconductivity disappears.

Edelman and Porter are respectively professor of biochemistry at Rockefeller University and professor of biochemistry at the University of Oxford. Working independently, they unraveled the structure of the commonest of the many thousands of antibodies that circulate in the blood and provide resistance to infections and disease: immunoglobulin gamma. When Edelman and Porter began their work in the late 1950's, practically nothing was known about the structure of antibody molecules. The variety of such molecules was so enormous that the prospect of analyzing the complete chemical structure of any one of them seemed only a faint hope.

In 1959 Edelman found that immunoglobulin molecules could be separated into two kinds of polypeptide chain: "heavy" and "light." The heavy chains consist of about 430 amino acid units, about twice as many as are found in the light chains. At the same time Porter showed that the enzymes papain and pepsin would cleave the antibody molecule in distinctive ways that provided clues to how the heavy and light chains were put together. It turned out that each molecule contains two heavy chains and two light chains paired so that the molecule resembles a *Y* in which each member is doubled. The two heavy chains side by side form the base of the *Y*, and one heavy chain extends up each arm; each arm also comprises a light chain parallel to the segment of heavy chain.

In 1962 Edelman and one of his students, Joseph A. Gally, demonstrated that patients with multiple myeloma, a malignant disease of the plasma cells, excrete in their urine large amounts of a single variety of the light chain. It thus became feasible to determine the amino acid sequence of a pure component of immunoglobulin. Subsequently Edelman and his co-workers established the chemical structure of the complete molecule, consisting of 19,996 atoms, a structure far larger than any protein successfully analyzed up to that time. Further work by Edelman, Porter and others has shown that each of the four chains in the immunoglobulin molecule has a constant region and a variable region. The exact sequence of amino acid units in the variable region determines the molecule's ability to bind to a particular antigen (see "The Structure of Antibodies," by R. R. Porter, SCIENTIFIC AMERICAN, October, 1967, and "The Structure and Function of Antibodies," by Gerald M. Edelman, SCIENTIFIC AMERICAN, August, 1970).

Two of the winners of the 1972 prize in chemistry, Moore and Stein, are senior colleagues of Edelman's at Rockefeller University. Anfinsen, the third participant in the chemistry prize, is chief of the laboratory of chemical biology at the National Institute of Arthritis, Metabolism and Digestive Diseases. All three chemists worked with a variety of the enzyme ribonuclease obtained from the pancreas of beef cattle. The enzyme

degrades ribonucleic acid (RNA), which plays a central role in transcribing the genetic message coded in deoxyribonucleic acid (DNA) and making it available for the synthesis of proteins. Bovine pancreatic ribonuclease helps the animal to digest the RNA present in food.

Beginning about 1950 Moore and Stein set out to discover the sequence of 124 amino acids in the ribonuclease molecule. At that time the chemical structure of only a few proteins was known, and none were enzymes, the catalysts that engineer the complex chemistry of living cells. To speed their work Moore and Stein developed a number of new analytical methods, including an automatic amino acid analyzer now used in laboratories all over the world (see "The Chemical Structure of Proteins," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, February, 1961). After establishing the chemical structure of ribonuclease Moore and Stein were able to identify the "active site," the region of the molecule directly involved in cleaving RNA.

While Moore and Stein were working out the amino acid sequence of ribonuclease Anfinsen asked the question: Why does an enzyme or other protein molecule always fold itself into a unique three-dimensional structure? There seemed to be two general possibilities. The protein might fold itself spontaneously into a structure dictated solely by the sequence and properties of the amino acid units that form the molecule. Alternatively, the folding might reflect additional structural information that has to be supplied from outside, information that would therefore have to be coded in the genetic material of the cell along with the amino acid sequence of the protein.

Although the three-dimensional structure of ribonuclease had not yet been established, it was known that the molecule's chain of 124 amino acid units is tied together at four points by disulfide (sulfur-sulfur) bonds. Anfinsen showed that the four bonds could be split by a certain chemical environment, rendering the molecule "denatured" and inactive. If the denatured molecule was returned to a favorable environment, the disulfide links would spontaneously reform, folding the molecule into its active configuration. Anfinsen and his coworkers subsequently demonstrated similar spontaneous folding with other proteins.

The economics prize was first awarded in 1969. One of this year's two winners, Sir John Hicks, who recently retired from the University of Oxford, made his major contributions in the 1930's. The Nobel citation credits him with providing "a complete equilibrium model with aggregated markets for commodities, factors of production, credit and money." He published *The Theory of Wages* in 1932 and his major work, *Value and Capital,* in 1939.

Arrow, the other winner of the economics prize, moved to Harvard University in 1968 after nearly 20 years at Stanford University. He first won prominence in 1951 with his doctoral dissertation at Columbia University: "Social Choice and Individual Values." That paper contained a powerful insight known to economists as the "impossibility theorem." It has been compared to Gödel's proof, the demonstration by Kurt Gödel that every formal system of mathematics must contain undecidable propositions. In "welfare" economics one would like to show that an economic system can be designed to satisfy the needs and wishes of the majority of people. One might think that one could ask individuals to rank various possible economic states and arrive at a consensus. Arrow's theorem shows that such a consensus is technically impossible.

Rubella and Autism

The outbreak of rubella ("German measles") in 1964 was one of the most costly epidemics in American history. An estimated 30,000 infants carried by mothers who had contracted the disease during pregnancy were born with congenital abnormalities such as deafness and cataracts. It now seems likely that the abnormalities include the childhood psychic disorder known as autism. This grave syndrome, which is characterized by almost total withdrawal from interaction with other people, has been ascribed to various psychogenic and organic causes. Until recently, however, the neurological damage done by rubella did not rank very high among the possibilities.

According to surveys in Britain and the U.S., the rate of autism in the general population is less than five cases per 10,000 live births. For a group of 243 "rubella children" being investigated at the New York University Medical Center the rate is a thousandfold higher, equivalent to 412 cases per 10,000. A smaller group being studied at the Baylor University College of Medicine shows a rate twice that of the New York University group.

One of the participants in the New York University studies, Stella Chess, professor of child psychiatry at the Medical Center, has found that 20 percent of the 243 rubella children escaped organic damage of any kind and that nearly 50 percent show no evidence of psychiatric disorder. Nine of the 243, who also exhibit various degrees of mental retardation, are autistic, and one unretarded child is autistic. Partial autism is evident in one unretarded child, in six who are retarded and in one with combined cerebral dysfunction and mental retardation. Noting that 65 others in the group are more or less severely retarded but that none of these children is autistic, Chess judges that the overlap between retardation and autism is coincidental. The fact remains that 10 of the 243 are autistic and eight are partially so.

Chess notes that the New York University studies clearly imply the existence of a link between rubella and autism, even though the exact mechanism whereby the organic damage manifests itself behaviorally remains to be determined. She speculates that the link was largely overlooked by most medical workers in the U.S. until after the 1964 epidemic and suggests that mothers of autistic children be routinely questioned about a possible history of rubella during pregnancy.

Sludge-eating Sludge

The key process in most modern sewage disposal systems is biological treatment, whereby the organic contaminants in waste water are metabolized—used as nutrients—by bacteria that are naturally present in the sewage. A new biological-treatment system has been developed that produces much cleaner effluent water than present methods and in the process consumes essentially all the solid organic contaminants in the waste water. The new method, invented by John W. Klock of Arizona State University, is described in *Research and Invention,* a publication of the Research Corporation.

Conventional biological treatment is the secondary stage of sewage treatment. (The first stage is the mechanical separation of suspended solid matter.) Either in filtration beds or in "activated sludge" units the water is aerated to maintain its oxygen content as it is repeatedly exposed to "hungry" bacteria that metabolize the organic matter. The bacteria, multiplying, form a sludge, some of which is cycled through the process. The excess sludge, together with the solids removed by primary treatment, is partially decomposed by fermentation in digesting units; the solids that remain

at the end—perhaps 1,500 pounds per million gallons of sewage treated—must be disposed of somehow, for example by drying and conversion to fertilizer, by dumping or by burning. The fermentation process also emits gases, primarily carbon dioxide and methane. And the treated water, although it has lost perhaps 80 or 90 percent of its organic contaminants, is still not suitable for, say, bathing, irrigation or industrial purposes.

Klock's "submerged filter" process gives promise of doing the job now done by both primary and secondary treatment including fermentation, producing usable water and just about no sludge. It depends on a careful but simple arrangement of a number of cells, each containing trays, tubes and baffles on which bacteria collect and proliferate and over and through which the water is slowly recirculated. The result is that different types of bacteria are allowed to metabolize various contaminants, including dead bacterial cells. There is little or no excessive buildup of bacterial sludge. The process can handle even the gross solid matter that is ordinarily removed in primary treatment. It emits primarily carbon dioxide and the effluent water. This final effluent has a "biochemical oxygen demand" (the amount of oxygen required for bacteria to digest the remaining waste) of only one to five parts per million, compared with an ideal minimum of about 20 parts per million for conventional plants. Submerged-filter plants have been tested for some five years on raw sewage; one has operated for two and a half years with no perceptible buildup of sludge. A 500,000-gallon-per-day plant has just gone into operation in Phoenix, where it provides tertiary treatment: further purification of the effluent from a conventional plant. The water it produces will be used to irrigate cropland.

Who Marries Whom

It is well known that an experimental animal's experiences at certain critical periods early in its life can profoundly affect its social and sexual behavior as an adult. Are some aspects of human behavior similarly determined? When it comes to the selection of a sexual partner the answer may well be yes, according to a study of the premarital sexual activity and marriage patterns of persons raised from birth in Israeli kibbutzes, or collective farms.

According to Joseph Shepher of Haifa University, children in the kibbutz are cared for from infancy in small, one-age peer groups by trained personnel. They live apart from their parents for most of the day and in most kibbutzes during the night as well. Sexual play in early childhood is intensive and is generally not interfered with. By the age of 10 sexual inhibitions appear and relations between the sexes often become tense. The tension disappears with the onset of adolescence. Members of a peer group have strong emotional bonds and share in each other's joys and sorrows as brothers and sisters would.

A survey of second-generation kibbutz adolescents and adults conducted by Shepher revealed that among 2,769 marriages contracted by members of the group there were none between individuals who had been members of the same peer group from birth. In one kibbutz where Shepher worked for several years all heterosexual relations of whatever intensity that involved adolescents and adults in the second generation were recorded. Not only were there no cases of marriage between members of the same peer group but also there were no instances of heterosexual activity between peers. The avoidance was completely voluntary, since there were no formal or informal pressures against such activity.

In the marriage census Shepher found 13 apparent cases of marriage between peers. These couples were asked for detailed information about their childhood. In all cases, Shepher found, there had been an interruption in peer-group membership before the age of six. This suggests, he concludes, that there is a critical period between birth and age six during which exposure to other children will "define with whom one will not fall in love."

Ahead of His Time

If Thomas Edison had pursued a passing interest in the accurate measurement of heat, the long list of his achievements might well have included the founding of infrared astronomy. Almost a century ago he invented an instrument that could detect changes in temperature to the unprecedented accuracy of one millionth of a degree Fahrenheit, and with it he successfully measured the heat radiation of the sun's corona. Possibly because so little was known about the corona, and perhaps also because Edison made his observations as part of a recreational trip to the Rockies, the true importance of his achievement was not recognized at the time.

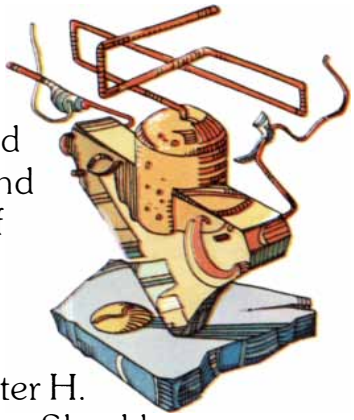
In 1878, writes John A. Eddy in *Journal for the History of Astronomy,* Edison was working on various improvements in the telephone. In the course of experimenting with buttons of compressed powdered carbon as a transmitting element he discovered that the buttons responded to the heat of his hand; they were thus sensitive detectors of infrared radiation. Never one to let such an observation go to waste, he built an instrument that he named the tasimeter, from the Greek for "extension" and "measure." A horn focused radiant heat onto a rod in contact with a carbon button. As the rod expanded, it altered the electrical resistance of the button; the change was recorded as a deflection in the needle of a galvanometer. The tasimeter was so sensitive that, in the words of a contemporary newspaper correspondent, "let a person come into the room with a lighted cigar and it will drive the little animal wild."

Edison was invited to join an expedition organized by the astronomer Henry Draper to observe a total eclipse of the sun on July 29, 1878. Edison welcomed the chance for an excursion and took along his tasimeter. The expedition set up its observing station at the frontier town of Rawlins in the territory of Wyoming. Three nights before the eclipse Edison aimed the tasimeter through a telescope at the star Arcturus and was rewarded with "five uniform and successive deflections." On the day of the eclipse he recorded the heat radiation from the corona during the last moments of totality and found it to be 15 times more intense than the radiation from Arcturus. On the basis of modern measurements of Arcturus' radiation Eddy concludes that Edison was justified in his assertions about the extraordinary sensitivity of his instrument. Moreover, Eddy has shown that Edison's measurement of the heat radiation from the solar corona is of the correct order of magnitude.

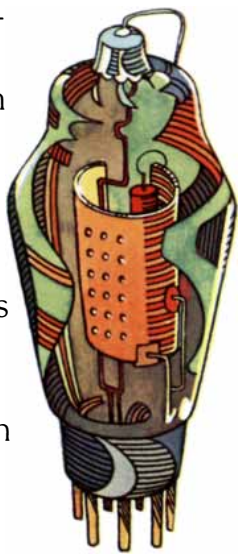
After the eclipse interest in the tasimeter at first grew. Edison proposed a plan to attach the device to a large telescope and explore the sky at infrared wavelengths as well as visible ones. The scheme was never put into effect. In its original form the tasimeter was erratic, slow to respond and gave unrepeatable results; in short, it was unsuited for making accurate physical measurements. Interest in the instrument faded, and astronomers returned to less sensitive but more reliable devices. Since Edison was not an astronomer, he had no real motivation to continue his work on the tasimeter. The development of infrared astronomy awaited the arrival of new kinds of infrared detectors after World War II.

Since Bell Labs invented the transistor,

On December 23, 1947, a team of Bell Laboratories scientists demonstrated that they could manipulate the behavior of electrons in a crystal of germanium and thereby amplify an electric current and the sound of a voice being carried by the current. This invention, the transistor, revolutionized communications and affected the lives of just about everybody in the world. For their work, John Bardeen, Walter H. Brattain, and William Shockley received a Nobel Prize.

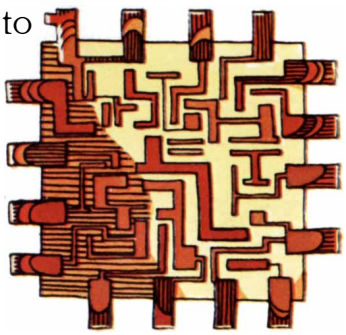


The story of the transistor began in the late 1930s. Telephone equipment used vast numbers of vacuum tubes and relays, but seemed to have inherent limitations for handling the ever-growing, ever more complex communications needs of the future. Devices without the shortcomings of tubes and relays were needed. Bell Labs scientists sought to find the answer through research in semiconductor materials. World War II interrupted their efforts until 1945 when the quest was resumed. Out of this research came the discovery of the transistor effect—the amplification and control of the flow of electrons in a solid material.



Bell Labs immediately mounted a major effort to understand fully the new phenomenon, devise new transistor structures, and develop methods for preparing and purifying germanium, and later silicon. The early "point-contact" transistor was soon followed by the "grown-junction," the "diffused-base," and the "field-effect" designs, and more recently by the combining of large numbers of transistors, diodes, and resistors on a single chip of silicon to form the "integrated circuit."

Western Electric in turn set out to apply its broad manufacturing expertise to producing economically the large numbers of transistors needed for telephone uses. Methods were required to refine semiconductor materials to extreme levels of purity, to grow perfect single crystals out of them, to diffuse appropriate "impurity" atoms into the semiconductor for altering its properties, to form individual devices, and to encapsulate them. Western Electric had to design and build factories where this work is done under microscopes in hospital-clean, dust-free environments.



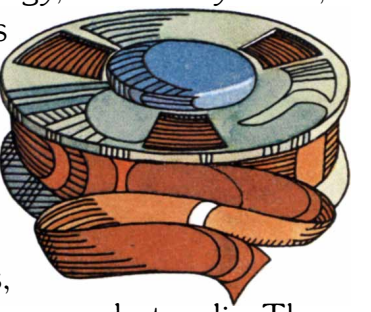
In the Bell System, transistors and other semiconductor devices have made possible Touch-Tone® dialing,

your world has never been the same.

high-speed data transmission, and highly reliable undersea cables. These devices have increased enormously the capacities and dependability of buried coaxial cables for carrying communications across the country. They have also made possible new switching machines for rapidly connecting telephone callers and providing such new services as automatic call transfer. Without the transistor—and its minute size, heat-free operation, and high reliability—many of today's and tomorrow's communications services would not be possible.

It was evident early that the transistor would also have wide applications outside the telephone business. So, Western Electric and Bell Labs made information about it available to other companies, universities, and the Federal Government through technical talks, publications, and symposia. As a result, a large effort in research, development, and manufacture of transistors soon got going outside the Bell System.

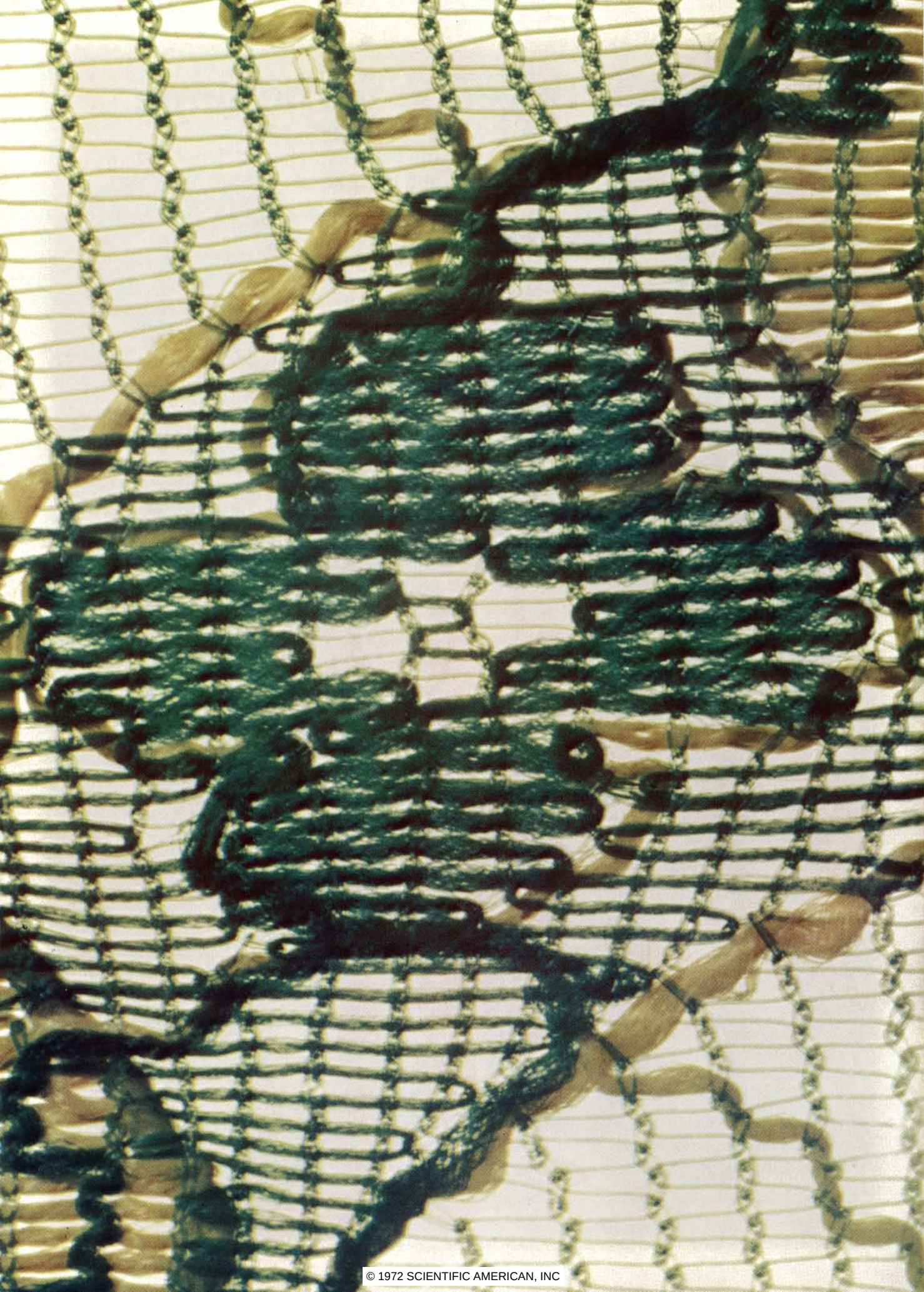
Today, transistors are widely used in space exploration, satellite communications, medical technology, defense systems, and in hundreds of such diverse products as television sets, hearing aids, automobile ignition systems, and the ubiquitous pocket radio. The transistor revolutionized the computer industry by making possible millions of accurate calculations in less than a second.



The transistor spawned a whole new industry of "solid-state electronics." Worldwide sales of semiconductor devices are estimated to add up to $2.7 billion this year. In the USA, nearly 8 million people are employed in the manufacture of equipment using these devices.

All this started 25 years ago. The same philosophy of technical innovation that created and made practical the transistor continues to operate today in Bell Labs and Western Electric. They are working together to bring you better communications services at lower cost through your local Bell operating company. At the same time, spin-offs from their creativity are benefiting all mankind.

Bell Labs
Western Electric



YARN

The age-old technology of twisting fibers to make a yarn changes as new fibers are developed, some designed to look and feel like cotton, wool or silk and others to have entirely new properties

by Stanley Backer

In common usage yarn is the material that knitted goods are made of. In the textile industry yarn is an assemblage of natural or man-made fibers or filaments that are twisted together to form a continuous strand, which can be used in knitting, weaving, braiding or pleating or can be made into a textile in some other way. As might be expected from the antiquity of the practice of making textiles, some yarn technology is very old. Some of it is also quite new. What is surprising, in view of the fact that everyone uses knitted and woven goods, is how little is known about yarn technology outside of the textile industry.

The work done to make yarn out of the hairlike fibers of cotton (each only an inch or so long) illustrates the basic processes. Cotton from the bale is put through machines that open, clean and partially separate the fibers to produce a fairly thick and clumpy sheet known as lap. The lap goes through a carding process: a revolving cylinder covered with fine hooks or wire brushes pulls it against a moving segmented belt that has similar hooks or brushes. The operation further opens and separates, then partially straightens and aligns, the fibers, producing a thin web that is put through a funnel-like device to yield a round, ropelike mass called a card sliver. (If fine yarn is the aim, the fibers are further straightened and made parallel by a combing process that yields comb sliver.) Several slivers are combined into a thick, parallel array that is put through a number of stages of drawing out on a series of rollers, which produces longer and thinner slivers. Further drawing, together with a small amount of twisting, produces roving: a cylindrical stock about 3/32 inch in diameter. Roving, on bobbins, is put into spinning frames, where it receives a final drawing out and the twisting necessary to make it into yarn. Twisting gives a short-fiber yarn its strength by diverting part of any tensile load on it into lateral pressure among the fibers that keeps them from slipping past one another.

Textile Fibers

It is thought that the first human attempts to make rope and cordage consisted of intertwining or twisting together vines and long-fibered plants. Many such fibers still constitute the raw material for textiles: jute in carpet backing and agricultural bags; flax in linen; hemp in twine and cordage, and manila and sisal (which are leaf fibers) in cordage. Considerable use has also been made of asbestos, a natural mineral fiber, in pipe insulation, wallboard and heat-resistant clothing.

Fine yarns, however, depended for many centuries on hair fibers, notably cotton (which is seed hair) and wool. Cotton was king in the U.S. until quite recently; until 1967 the consumption of cotton exceeded that of all other fibers put together. Now cotton has lost its lead to man-made fibers.

Wool was the second raw material of significance to the U.S. textile industry for a long time, but it too has declined. During the past 10 years it has accounted for only about 5 percent of the national consumption of fiber. Technically, however, wool is a fascinating fiber with unique properties that are often simulated by man-made fibers. It has a high extensibility (25 to 30 percent when room-dry, in contrast to the 8 to 10 percent of cotton) and high recovery from extension. Its surface has a coefficient of friction that varies with the direction of rubbing, a difference that contributes importantly to the ability of wool to migrate and squirm within a fiber assembly so as to promote the local entanglement of fibers called felting. Wool also has a bilateral swelling and shrinking behavior arising from structural differences in its cortex cells. Accordingly the wool fiber, like the bimetallic thermostat, bends in response to changes in ambient conditions. Self-bending of a long bilateral strip that is under restraint at the ends results in a reversing helical-coil crimped configuration. Fibers with this helical crimp yield an open, low-density yarn structure with desirable softness, elasticity and bulk.

The cost of wool made it an early target of research on man-made fibers, so that in the past 20 years wool has been steadily displaced by synthetic fibers, first in blends and now in fabrics that are entirely synthetic. The synthetic fibers that replaced wool in clothing were not, however, made in the continuous-filament form in which man-made fibers were first extruded. Instead they were prepared in the form of cut staple (short fibers) and then spun into yarns by methods used for cotton and wool. The development of filaments in continuous

THREE KINDS OF YARN are combined in the complex lace fabric that is enlarged about 20 diameters in the photograph on the opposite page. One is the green nylon monofilament that forms the open sections of the pattern. The second is a green nylon yarn made of many filaments that have been textured, or crimped, in order to increase the yarn's bulk and opacity. The third is a yellow, conventionally twisted viscose rayon yarn. The fabric, which is produced on a Raschel warp-knitting machine, is made by the Takeda Lace Company.

form followed an entirely separate path: the path of the silklike fibers and fabrics.

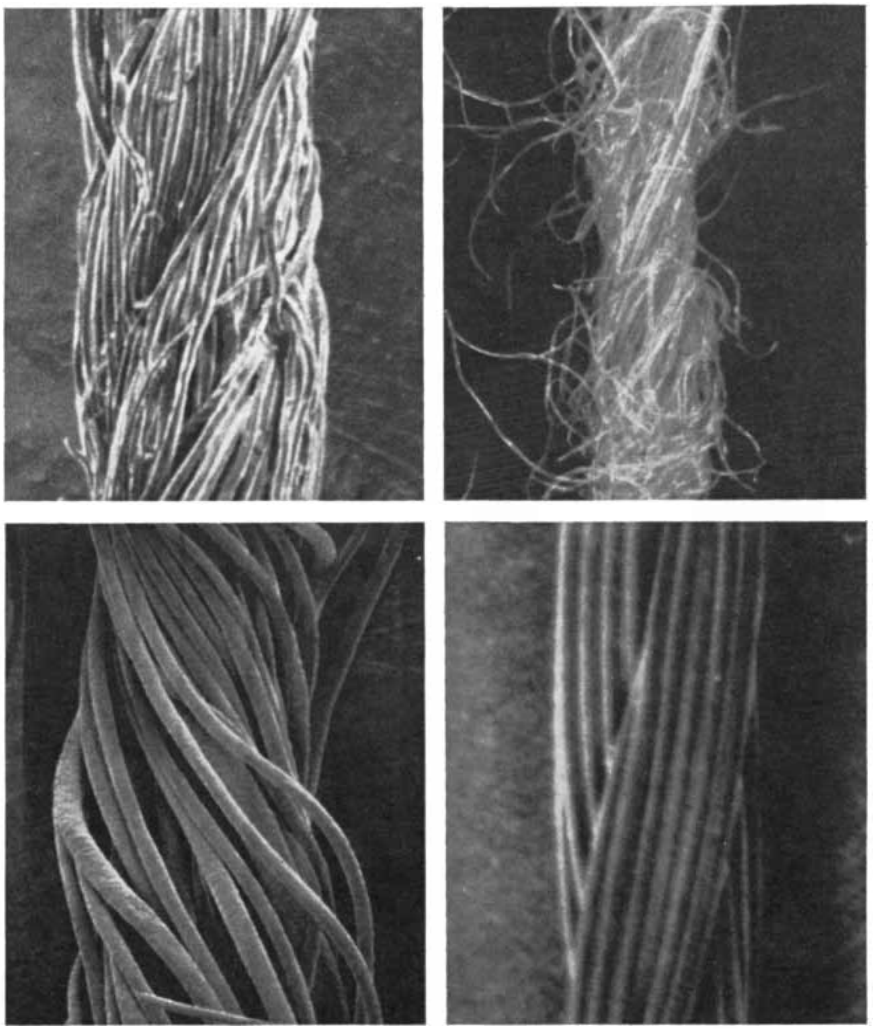
Silk is extruded by the silkworm *Bombyx mori* in forming its cocoon. Silk is a double filament of triangular cross section, extruded by the worm in virtually infinite lengths. Textile weavers and spinners have been familiar with its properties for centuries. The direct impact of silk on the textile market today is negligible, but in terms of its effect on the development of modern textile products its importance is great. Spinners handling silk learned how to convert continuous filaments into yarns and fabrics without breaking or cutting the individual filaments. Many of the first man-made fibers were retained in continuous-filament form and were made into fabrics derived from the industry's experience with silk, as reflected in the typical acetate lining of a man's suit coat.

The early man-made fibers were essentially recast molecules of cellulose originating in wood fibers or cotton linters (very short fibers). As extruded they were straight and untwisted. Although the lustrous, smooth appearance of fabrics made from such filaments and their cool, slippery surface were ideal for jacket linings, evening gowns and the like, they were in many cases not acceptable as everyday outer fabrics. Consumers tended to favor the rougher, hairy, nonlustrous appearance of fabrics made from yarns consisting of discontinuous natural fibers having some crimp. Accordingly the industry chopped up many of its continuous filaments, having imparted to them a crimp, and fed them into textile plants that had formerly produced yarns from staple natural fibers. The resulting products bore a close resemblance to the conventional fabrics made of cotton and wool. (Continuous-filament viscose rayon is still used in tire cords, and continuous acetate figures in gowns, lingerie and linings.)

Glass fibers appeared commercially in 1934. At first they had little impact on the apparel market, but because of their high tensile strength, dimensional stability and resistance to chemical, photochemical and microbiological degradation they soon found wide application in such products as reinforced plastics, heat insulation, filters and electrical insulation. More recently they have taken a good share of the drapery market and have been introduced into belted bias-ply tire structures. Lately the development of fine glass yarns, having less than a tenth the diameter of other commercial textile fibers, has brought glass fibers into such products as bedspreads and covers for ironing boards.

The appearance of the first wholly synthetic fiber, nylon, in 1939 opened a new era in fiber and textile technology. Some 10 different basic types of nylon are now produced, and the worldwide consumption of these polyamide fibers exceeds four billion pounds per year (mostly nylon types 6 and 6.6). Polyester fibers, developed in 1941, now account for about a fourth of the worldwide production of synthetic fibers. Nylon, mostly in filament form, makes a smooth, lustrous yarn that has performed well in lingerie and women's hosiery and in tire cord and industrial fabrics. Polyester fibers have gone into yarn in both staple and filamentous forms, the former at one time in blends with wool in suits and with cotton in shirts, the latter in dresses, lingerie, tire cord, sailcloth and (most recently) double-knit suiting material.

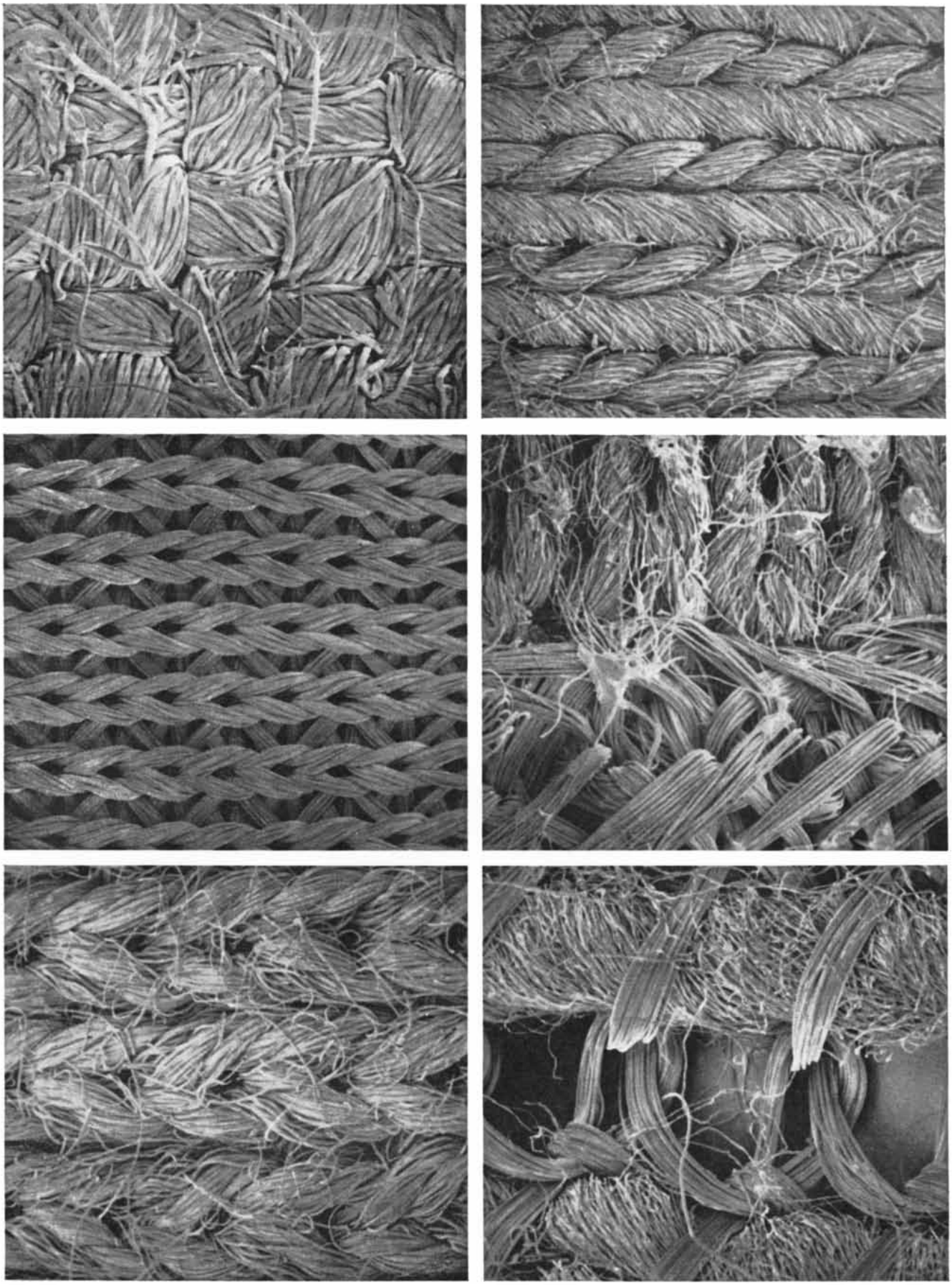
Another important group of fibers is the acrylics, which were first produced about 25 years ago. Because of its warm and luxurious feel, most acrylic fiber goes into staple-fiber yarns for apparel and floor covering. Synthetic fibers that have appeared in recent years include saran (vinylidine chloride), noted for its resistance to weather and abrasion; spandex (of polyurethane origin), noted for its rubber-like properties; vinal (of vinyl alcohol origin); olefin (as polyethylene or polypropylene); vinyon (of vinyl chloride origin), and triacetate, known for its good looks, ease of care and capability of being set by heat.



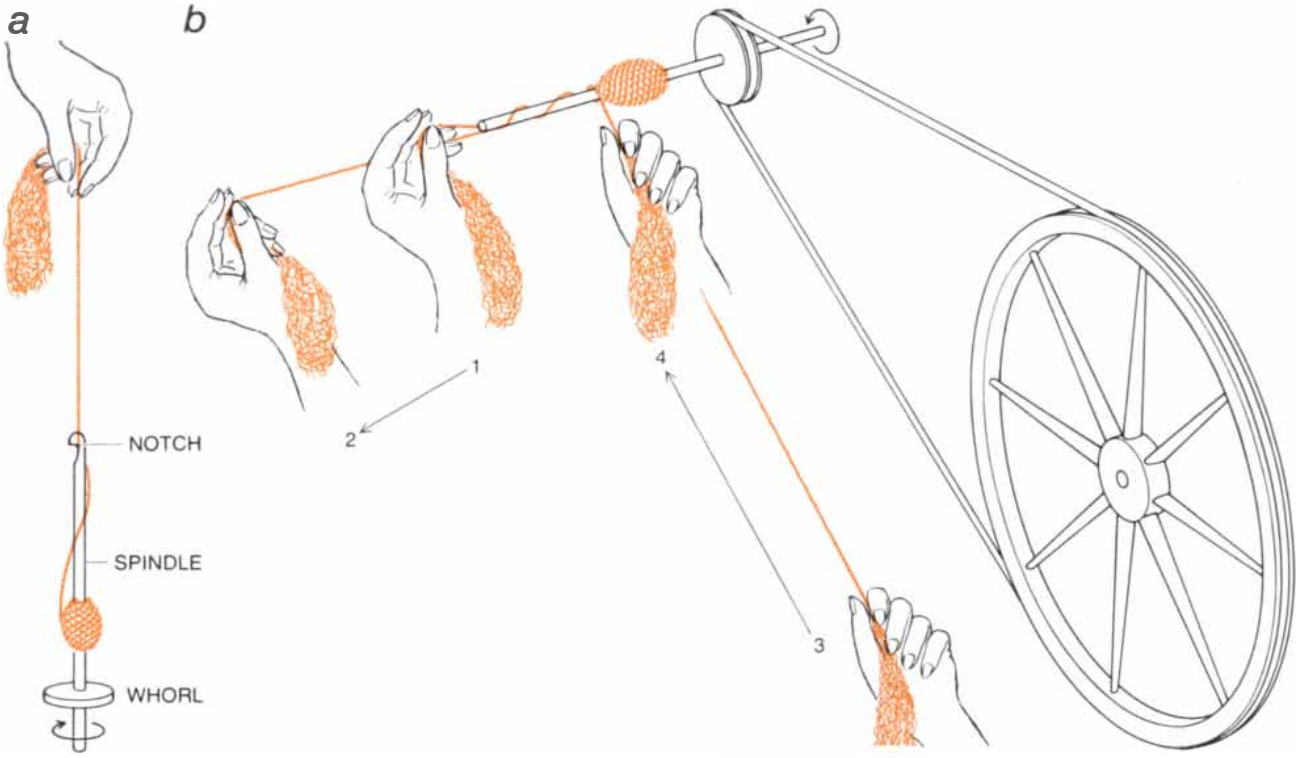
CLASSICAL YARN STRUCTURES are illustrated: spun cotton (*top left*), spun woolen (*top right*), spun woolen worsted (*bottom left*) and polyester continuous filament (*bottom right*). The first three are staple yarns: short lengths of fiber twisted together to make strands. A continuous-filament yarn is a sheaf of essentially endless fibers. The enlargements vary; individual natural or synthetic fibers are between .001 and .002 inch in diameter.

Spinning Yarn

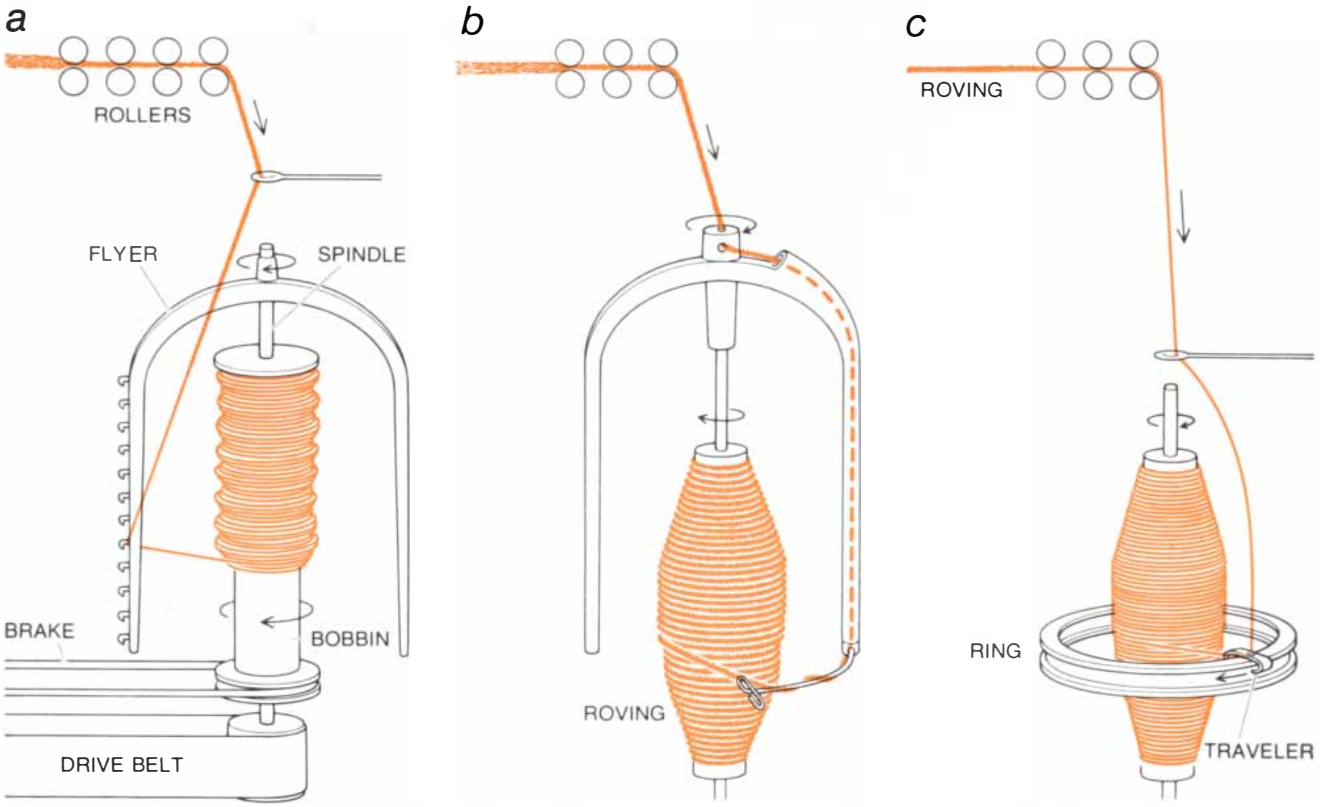
The technology of yarn-making is usually closely related to the properties of the fibers that make up the yarn.



COMMON FABRIC STRUCTURES are illustrated. The plain-weave, flat cotton fabric (*top left*) is enlarged about 75 diameters. The other samples, all enlarged about 25 diameters, are a knitted cotton jersey (*top right*), a nylon tricot knit (*middle left*), a tricot knit bonded to a regular knit (*middle right*), a double knit of spun yarn (*bottom left*) and a stitch-bonded fabric (*bottom right*).



SPINNING OF YARN, a twisting process, was long done by hand. In the suspended-spindle process (*a*) the spindle is twirled, with the whorl acting as a flywheel, by one hand while fibers are fed from a loose mass held in the other hand. From time to time the spun yarn is removed from the notch and wound on the ball. With a spinning wheel (*b*) the spindle is horizontal and is driven by the wheel. With the mass of fibers held at the end of the spindle (*1*) the spindle's rotation twists the fibers into yarn; fibers are fed from the hand, which is moved away from the spindle until an arm's length of yarn is spun (*2*). The length of yarn is shifted, becoming perpendicular to the spindle (*3*); now spindle rotation winds the yarn on the ball (*4*). Then the entire process is repeated.



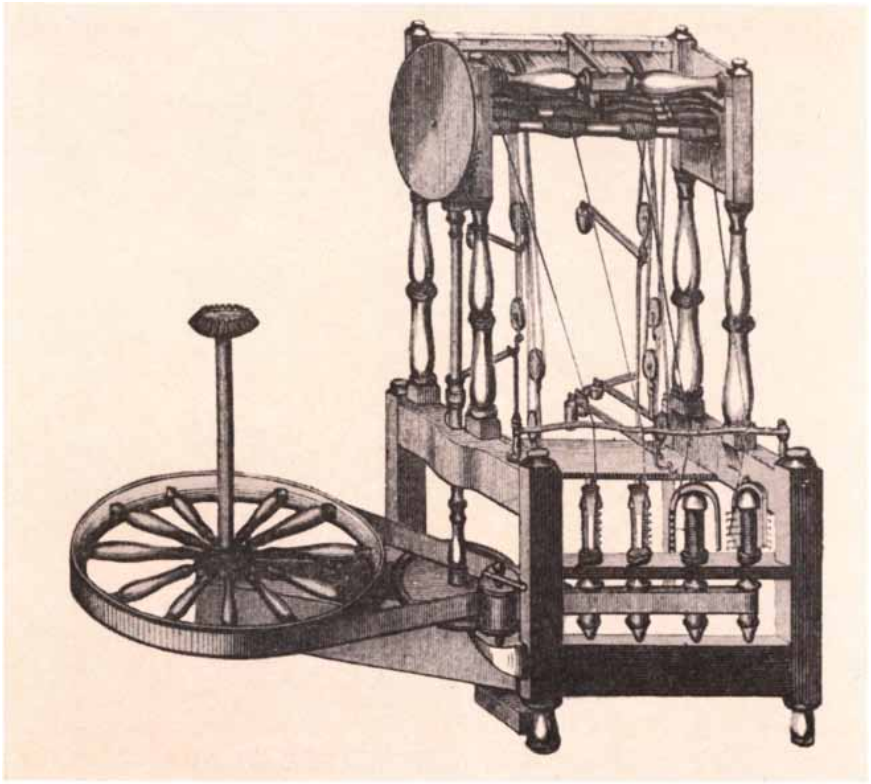
CONTEMPORARY SPINNING METHODS combine drafting and twisting processes. Richard Arkwright's water frame had a set of rollers for drafting and a *U*-shaped flyer for twisting (*a*). The flyer was driven; the bobbin tended to follow and its rotation was braked to provide more twist per winding. The various hooks on the flyer provided fairly even winding. In a modern roving frame (*b*) rollers moving at increasing speeds draft the loose bundle of fibers into a thinner, firmer strand. The flyer spindle and the bobbin are driven separately. The resulting roving is drafted and twisted further in a spinning frame (*c*). Here the bobbin is rotated; the traveler is pulled around the nonrotating ring, which is raised and lowered continuously to provide for even winding.

Since in the presynthetic era only a few fibers had any economic significance, the early spinners of yarn had few variations of fiber property to contend with. Probably the earliest spinners (as long as 15,000 years ago in Asia or 12,000 in North Africa) had little knowledge of fiber properties beyond what they saw and felt. Such a spinner was able, however, to select the staple fibers that could be pulled out as a bundle from a loose fibrous mass, drawn or extended by slipping fibers longitudinally past one another and finally twisted into a cylindrical assembly: the yarn. This process of hand spinning can be done by anyone after some practice. The loose-fiber mass is held in one hand and the other hand partly pulls out a small bundle and draws it to yarn size while rotating the free end, thereby twisting the attenuated fibers into a strand.

It was a natural evolution to facilitate the rotation of the free end by attaching it to a small spindle, which in turn was fastened to a small weight or whorl. The spindle-whorl combination was then sharply rotated by hand; acting as a flywheel, it continued to revolve for a time, twisting the yarn in the process. Early spinners also developed the distaff, which held the unspun fibers.

Perhaps 1,000 years ago the spinning wheel was developed in India. Rotated by hand, the wheel moved a belt or cord mounted on the rim. The cord drove a spindle-whorl combination mounted on a frame with a simple bearing. A single turn of the wheel resulted in many turns of the whorl. After twisting an arm's length of yarn the spinner moved her hand, changing the angle at which the yarn approached the spindle, and wound the newly twisted length onto a bobbin. This simple two-stage process (drafting and twisting, then winding) served mankind's textile needs for many centuries.

The productivity of weaving was greatly enhanced by the invention of the fly shuttle in 1733, creating pressure for more productivity in spinning. Still, some of the spinning inventions that resulted simulated the intermittent action of the hand spinning wheel. James Hargreaves in his spinning jenny of 1762 (named after his daughter) initially provided eight spindles on a frame, each driven by a cord from a common roller actuated by a large wheel turned by the spinner. The fiber, in the form of eight loose rovings, was fed to a clamp mounted on a carriage. The carriage was pushed back and forth by the spinner, one way during the drawing-twisting operation and the other way during windup. Later models of this machine had as many as 100 spindles.



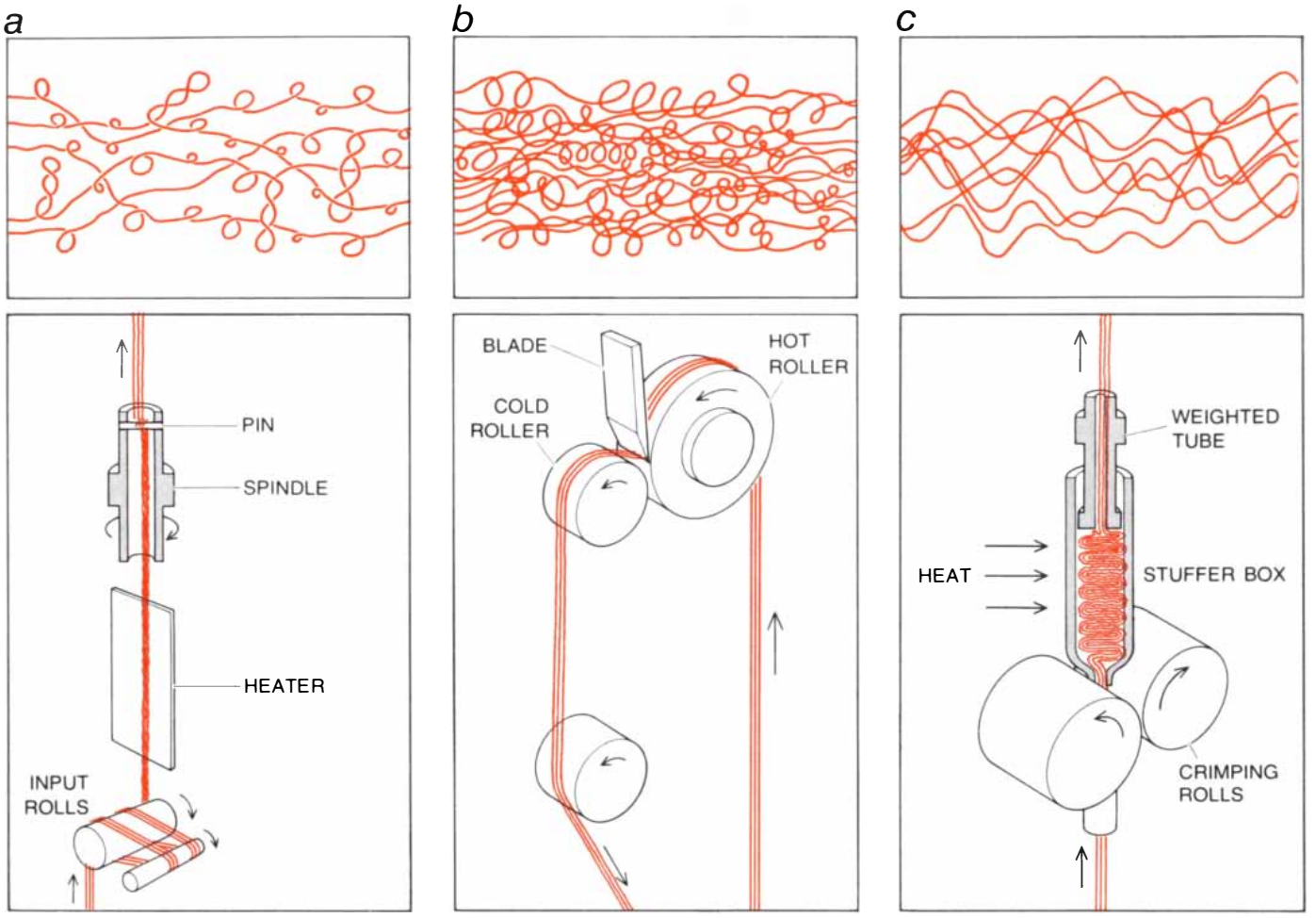
ARKWRIGHT'S WATER FRAME, the first continuous spinning machine, combined roller drafting and twisting in one device driven by waterpower. The sets of rollers are at the top. The firmed rovings are led from them down to a set of flyers driven by a single belt.

The intermittent, two-phase process of hand spinning was carried over to Samuel Crompton's mule jenny of 1779 (so named because it combined in hybrid form the Hargreaves jenny and the roller form of drawing invented by John Wyatt and Lewis Paul in 1738). The basic principles of this machine are evident in the powered mule spinners producing high-quality, fine-spun yarns in some parts of the world today. In the U.S. mule spinning is seldom seen because high-speed, continuous-process spinning is preferred to the slower and intermittent mule process.

Continuous Processes

The problem of simultaneously twisting and winding in a continuous process was solved by providing an inverted *U*-shaped flyer that revolved coaxially with the main bobbin but at a different angular speed. Newly drawn yarn was fed in at the apex of the flyer and then down along one of its arms and over to the bobbin. The difference in angular speed between the bobbin and the flyer, together with the diameter of the bobbin, determined the rate at which yarn was wound on the bobbin, and the rate at which the flyer rotated per unit length of yarn wound dictated the twisting. Both operations proceeded simultaneously.

The need for a drawing process of constant velocity to serve as a continuous input for the spinning process was solved by the simple method of using two sets of rollers, one going faster than the other, for drawing out the loose sliver. It was Richard Arkwright who first combined roller drafting with spinning by bobbin and flyer in his water frame of 1769. (Water was the source of power.) That was the first continuous spinning process, and its principles are present in all major modern spinning systems: the flyer spinning frame; the cap spinning frame, in which the bobbin is driven and the yarn is whirled around in a balloon to insert twist and also drags along the edge of the cap to achieve a difference in angular speed that yields a windup action, and the ring spinning frame, where the yarn is drawn by rollers and the bobbin is positively rotated, whirling the yarn in a balloon and dragging a small wire or plastic clip (the traveler) around a ring at the small difference in angular speed needed to effect windup [*see bottom illustration on opposite page*]. The ring



TEXTURING PROCESSES are illustrated along with the product of each, drawn schematically. Temporary twist (*a*) is imparted by a rotating spindle, which twists the yarn as far down as the input rolls; the twist is "set" in the yarn's molecules by heat, even though the yarn is untwisted as it passes through the spindle. Edge crimping (*b*) is done by the pressure of a sharp blade against heated yarn. (These first two methods can produce stretch yarns.) In the stuffer box (*c*) a fine crimp is introduced as yarn is compressed

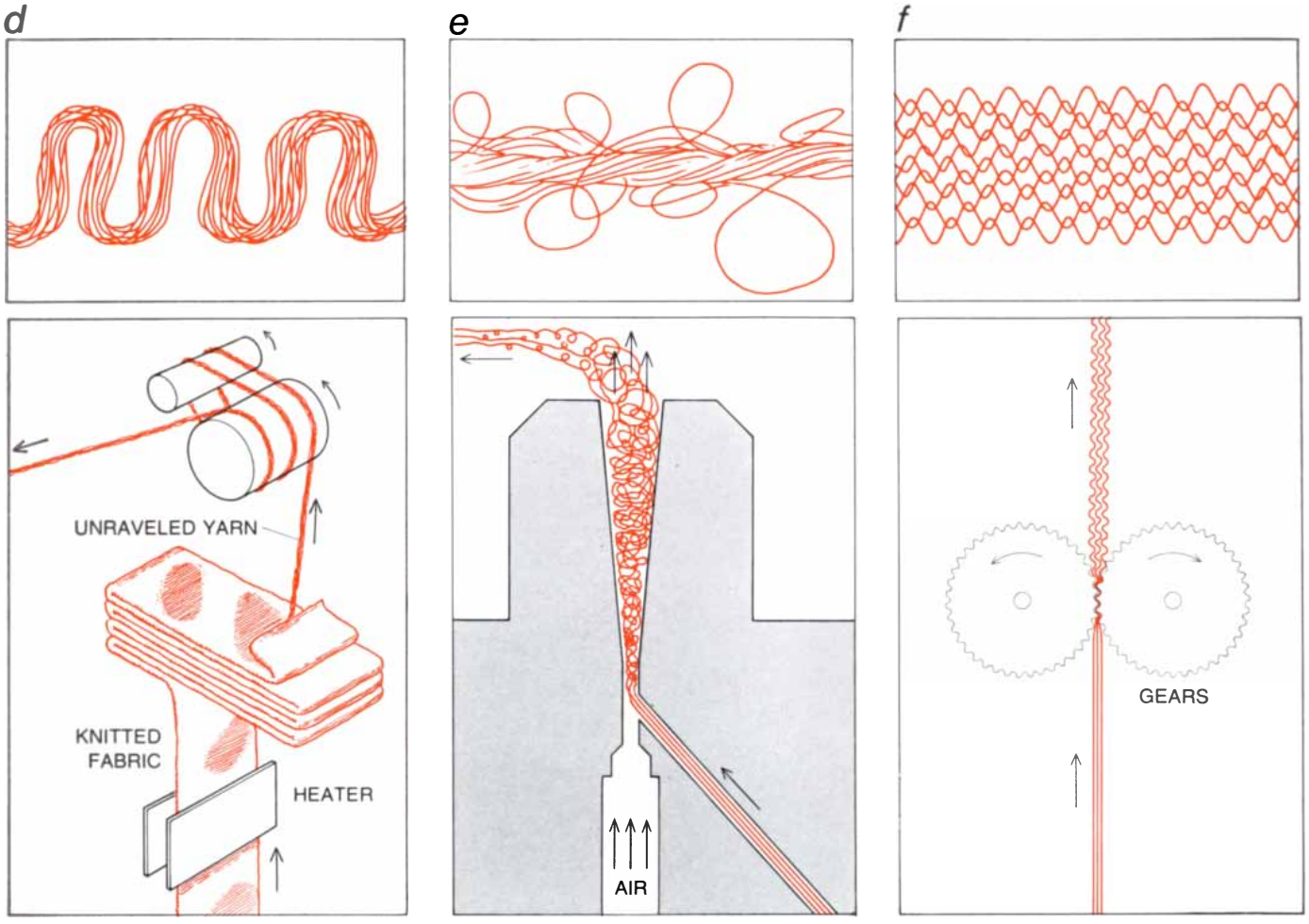
spinning process is now the most common one; it has been improved to a point where traveler speeds of two miles per minute and spindle speeds of 20,000 revolutions per minute have been reached. (Average production rates in the U.S. are considerably below these levels.)

Four basic yarn-preparation and spinning systems, which were developed before man-made fibers came on the scene, still dominate textile manufacturing. They are the carded-cotton system, the combed-cotton system, the woolen system and the worsted system. The two cotton systems were designed to operate with cotton-fiber lengths of an inch to an inch and a half; the woolen and worsted systems were set up to handle wool-fiber lengths of two to three inches and three to five inches respectively; the worsted process includes combing. Yarns prepared by these systems are still called by the old names, even if the fiber is acrylic or polyester. For example, one finds "worsted spun yarns" in men's suits made of 100 percent polyester.

One method of preparing man-made filamentous fibers so that they can be made into yarns resembling those made of cotton and wool is to sever a large number of filaments in a heavy parallel array known as tow. The bundle of cut filaments can then be handled much as a sliver of staple fibers is handled. Two important methods of converting tow have been developed in the past 20 years. In the cutting method a revolving spiral cutter presses against a uniformly spread sheet of fibers to yield a sliver of fairly uniform staple-length fibers. In the stretch-breaking method the filaments are stretched and broken by pulling the tow between two heavy sets of rollers. The filaments rupture independently of one another and in random lengths.

After tow is converted to sliver by one of these methods the sliver is usually crimped by stuffing it longitudinally into a narrow, slotlike box under pressure in the presence of dry or wet heat. The fibers buckle into crimps and waves as they are forced into the box, and they acquire a set in the crimped configuration before they are withdrawn from the box. The crimped fibers now respond well to the various kinds of drawing-out machine as they are made into yarn. Thus a staple-fiber yarn is produced by this method of tow conversion without the need for opening machines, blenders, pickers and carding machines (the messiest operations in a mill working on raw cotton and wool).

Tow conversion nonetheless has its drawbacks, notably the fact that the size of the starting assembly (from several thousand to several hundred thousand fibers) makes it necessary to draw the resulting sliver several times before the yarn can be twisted. The challenge to the industry has been to achieve the softness, bulk, reduced luster and even hairiness of the staple-fiber yarn structure while making the yarn directly from continuous filaments. The response has been the introduction of "textured" yarns, meaning continuous filaments treated in such a way as to achieve in a fabric the kind of texture characteristic



against the weighted mass of yarn in the box. The knit-deknit process (*d*) involves actual production on a knitting machine of a tubular fabric; the geometry of the knitted loops is set in the yarn by heat and then the yarn is unraveled. In air-jet texturing (*e*) the yarn is drawn in through the high-velocity, low-pressure region of the tube; then the channel widens, the airstream becomes turbulent and the filaments are whipped about, looped and entangled. The gear crimper (*f*) simply deforms fibers between intermeshing teeth.

of wool or cotton fabrics [*see illustration above*].

Texturing Processes

One method of texturing involves imparting a temporary twist to the filament. A three-step process for doing so was devised by Swiss yarn makers some 40 years ago. In the first step a filament was given a high degree of twist. The twist was then set by heat or a chemical. In the third step the filament was untwisted and wound onto a package for fabrication into a knitted or woven structure. When the fabric was dyed and finished, the filaments tended to resume the helical configuration of their twist-set state. Since then the process has been improved to a point where one sees temporary-twist (or "false twist") machines that operate continuously, rather than in steps, at speeds exceeding 600,000 r.p.m.

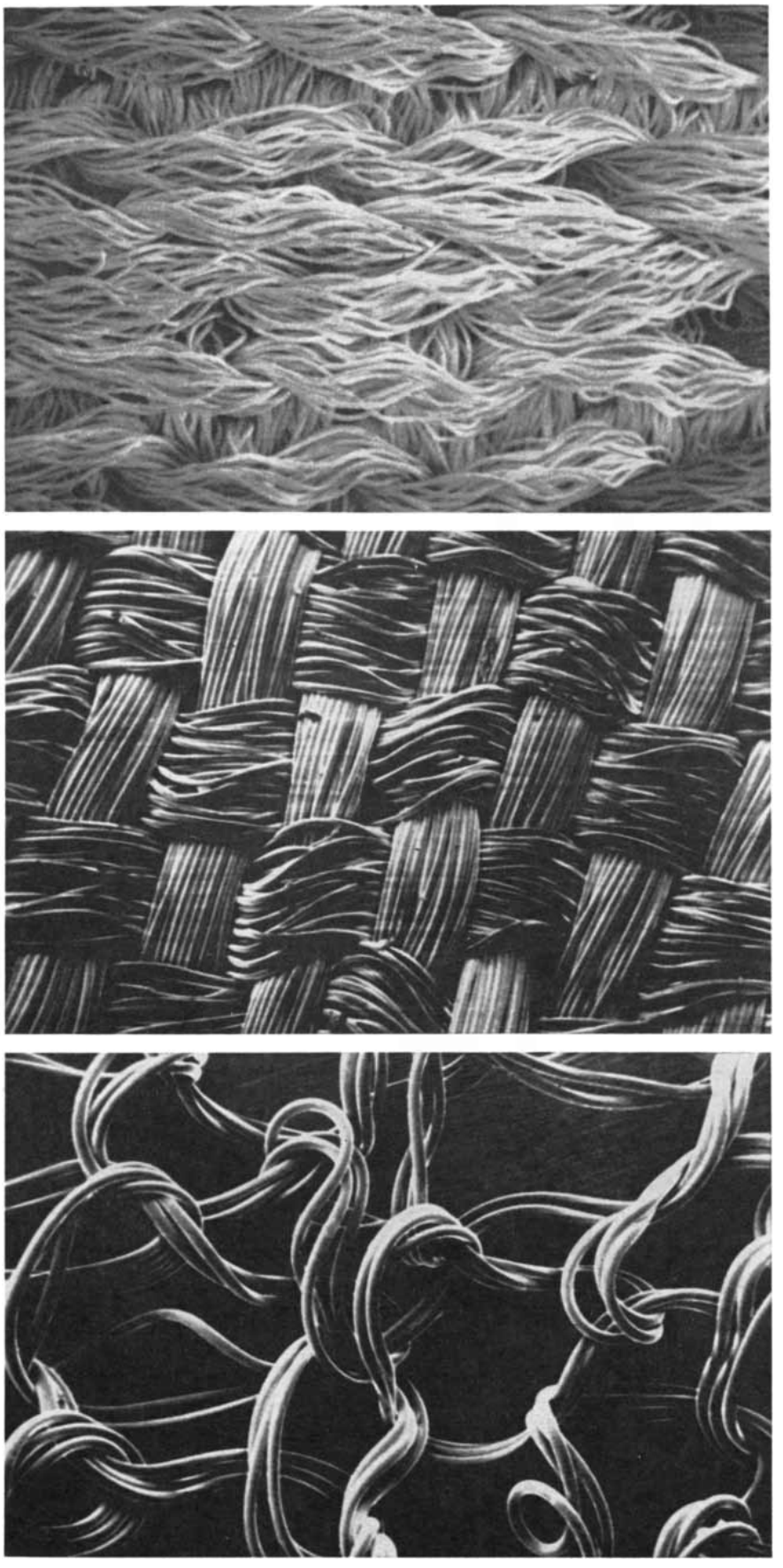
Another texturing process is edge crimping, which was developed as a commercial process in about 1955. It employs the principle often used by people wrapping gift packages when they scrape the ends of the ribbon over a sharp edge in order to curl them. Yarns produced by this process, which was developed independently in Britain and the U.S., are known commercially as Agilon yarns. The process is similar to other texturing schemes in that it deforms the yarn filaments from their straight configuration and employs heat to relax the fiber and to redevelop stress-free molecular bonds in the deformed state. The application of heat simply improves the permanence of the deformation under subsequent stresses, heat and moisture.

A third method of producing modified continuous-filament yarns resorts to the stuffer-box technique that I have mentioned as a means of imparting crimp to staple fibers. The filaments are buckled into the stuffer box, where conditions of residence time and temperature are such as to effect a high degree of heat-setting of the imposed deformation. Fabrics and garments manufactured under the trade name Ban-Lon are made with yarns that have been textured by a stuffer-box method.

Texturing is also achieved by a remarkable process of knitting and deknitting to produce "crinkle-textured" yarns. Thermoplastic yarn is knitted in the form of a tubular fabric, which is set by heat. The yarn is then unraveled and wound on a package for incorporation in fabric. Some 10 million pounds of yarn textured in this way is produced annually in the U.S.

The fact that a manufacturer can, while remaining competitive, manufacture a fabric and then undo it (with the resulting yarn "remembering" its crimped form) suggests that circular knitting of filament yarn must be an efficient and low-cost process. It also suggests that other forms of texturing may be costly. In any event the market for crinkle or knit-deknit yarns, which impart a pebble or *bouclé* character to the surface of fabrics, is rising.

Air-jet texturing is still another means of modifying a continuous-filament



EFFECT OF TEXTURING is to give yarns increased bulk, fuzziness or stretchability. The double-knit fabric (*top*) is made with a textured polyester yarn; note the waviness of the filaments. The woven polyester fabric (*middle*) has a textured filling (horizontal yarn) and untextured warp. The stretch hosiery (*bottom*) is knitted of a textured nylon yarn.

yarn. Considering the high surface-to-volume ratio of textile fibers, it is not surprising that currents of air have been used for many years to transport loose fibers from process to process and also within a machine. More recently a number of processes have been devised for feeding filaments into air jets to achieve crimp. For example, the Taslan process feeds a filament into a rapidly moving airstream at the necked region of a nozzle. The channel of the nozzle widens thereafter, and the response of the filament to the subsequently turbulent air leads to the formation of loops in the filament and to entanglement among the loops. The result is a bulked yarn consisting of a fairly dense, somewhat entangled core and with numerous loops projecting from the surface. The dense core makes the yarn more resistant to extension than most textured yarns and directs its application to fabrics that require dimensional stability, considerable opacity and improved surface fuzz.

Gear crimping is a well-established method of imparting waviness to man-made fibers. Running tow or individual fibers between heated sprockets or gear teeth imparts a zigzag and more or less planar crimp and also tends to set it. A disadvantage of the planarity is that it yields yarns of less bulk and stretchability than yarns produced by methods that impart a three-dimensional crimp.

A few figures will indicate the extent to which texturing processes have come to figure in yarn-making. In 1970 the production of textured nylon in the U.S. was about 150 million pounds—113 million prepared by the false-twist process, 23 million by the stuffer-box process and eight million by the knit-deknit process. Textured polyester production in the same year was 205 million pounds, 95 percent of which was prepared by the false-twist method. In 1971 production of all types of textured synthetic yarn rose to 750 million pounds.

Trends in Yarn Technology

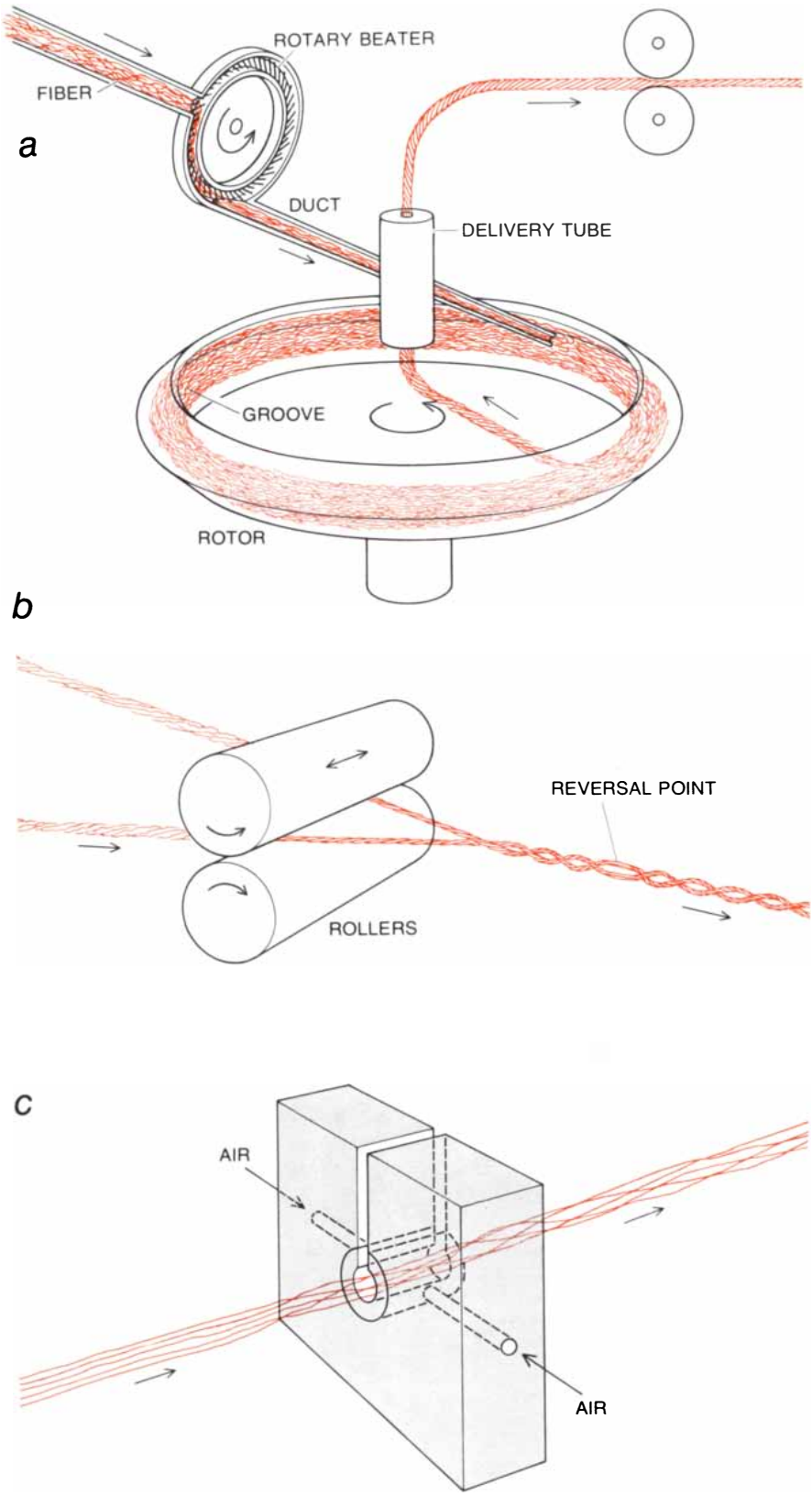
I have mentioned that the ring-and-traveler frame has become the most common means of spinning staple yarn. Although a great deal of research has gone into improving the efficiency of these machines, ring spinning remains one of the most costly processes in the textile industry. Accordingly the trend of recent developments in yarn technology is toward finding substitutes for the ring frame and also toward ways of providing twist substitutes and even of eliminating twist.

Many technologists consider twist essential, particularly for staple yarns. They have therefore tried to find a way of inserting real twist without rotating the entire package, which is a feature inherent in the ring-traveler system. Two approaches have been taken: open-end spinning and the self-twist method [*see illustration at right*].

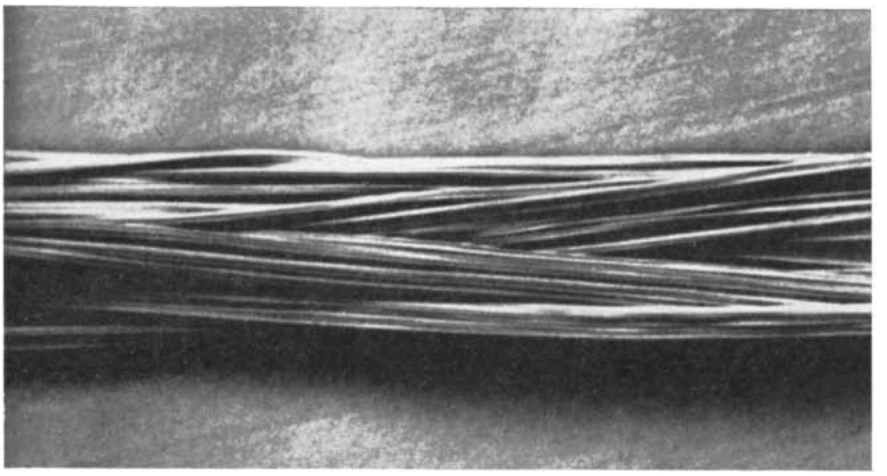
Open-end spinning has been the subject of intense development during the past five years. Commercial frames of Czechoslovakian and Japanese design have recently become available. The process, which is also called break spinning, differs from the typical kind of spinning in that the flow of fibers is interrupted at a point just ahead of spin-twisting. The interruption makes it possible to rotate the downstream end of the strand (the end just beyond the point of interruption) and thus to insert twist into the fiber assembly farther downstream. Then new fibers from upstream are transported (by air or electrostatic forces) to the downstream strand, where they are entangled with and twisted onto the end fibers of that strand.

Open-end spinning has yet to establish itself in the U.S. on a large scale, but it appears to have great potential. At the present stage of development it is two to three times faster than ring spinning. It is also less noisy and less dusty. In view of the fact that there are many millions of spindles operating on ring frames in the U.S. at a capitalization of more than $30 per spindle it is nevertheless unlikely that conversion to open-end spinning will take place soon, although there are moves to adopt this new method for certain yarns.

Self-twist spinning was developed in Australia, where a great deal of research is done on wools. Two lines of wool roving are carried between two rollers that have a double motion: a continuous rotational motion, as with conventional rollers, and a lateral shuffling motion. The latter motion compacts and twists the rovings as they are carried forward, giving each line of roving an alternating twist upstream and downstream of the contact point. When adjacent pairs of rovings are brought in contact with each other, they tend to intermesh to some degree and become entangled. When the contact pressure is released, the two rovings try to untwist, but because of their entanglement they ply over each other until the combined torsional and bending energies in the system are minimized and the now plied yarn reaches equilibrium. In one step this system converts loose rovings into a



RECENT DEVELOPMENTS eliminate ring spinning and thus improve windup efficiency. In open-end spinning (*a*) the fiber bundle is separated by a beater and the loose fibers are fed by an airstream into a rotor and thrown centrifugally into its *V*-shaped groove. The turning rotor drags the "open" end of the newly formed yarn around, twisting it; the yarn is lengthened as the open end entrains loose fibers in the groove. In self-twist spinning (*b*) a set of reciprocating rollers inserts alternating left-hand and right-hand twist in two strands of roving. Such strands tend to unwind under tension and, since they are contiguous, they become entangled, forming a self-twisted two-ply yarn. One twistless process (*c*) relies on an air jet that randomly tangles, or interlaces, continuous filaments in a bundle, forming a yarn.



INTERLACED YARN, made from acetate fiber by the air-jet process diagrammed in the illustration on the preceding page, is a straight, compact yarn that has no loops or crimping.

two-ply yarn without the need for twisting the entire package.

Whereas staple yarns require a substantial degree of twist to provide strength, filament yarns need only a low level of twist (1/3 to 1/2 turn per inch), enough to hold the bundle of filaments together during weaving or knitting. With the ring frame even these low levels of twist could be introduced no faster than at rates of 600 to 700 yards per minute, and so manufacturers were anxious to find other ways of providing cohesion in the bundle. One successful method relies on air nozzles that pass a stream of air through a bundle of filaments, separating filaments and groups of filaments from one another and then randomly intermingling them along the length of the yarn. Cohesion is thus imparted to the bundle, and a strand of yarn results. Production rates of more than 3,000 yards per minute have been reported, and the big, complex twisting frames have been replaced by small and rather simple air nozzles.

Fasciated yarns represent a new kind of structure. They take their name from the fasces of Roman times, which was a bundle of rods wrapped with ribbon and used as a symbol of authority. A fasciated yarn consists of a core of parallel and unusually long (five to six inches) staple fibers wrapped at intervals by a small fraction of the fiber components of the yarn. An aspirating jet pulls a long-staple roving into a torque jet, which strikes the periphery of the strand tangentially, thereby introducing a false twist. Since the strand is discontinuous, however, in contrast to the continuous filament on which the usual false-twist spindle operates, some of the upstream fibers are for the moment not twisted as much as the core fibers. On passing the jet, however, they are back-twisted more than the core fibers to achieve a localized wrapping over the core fibers, which the airstream has by now made parallel.

The structure of the fasciated yarn provides for unusual properties in a fabric, since the yarn has a filamentous character because of its long, parallel fibers and a spun-yarn character because of its wrappings. Fasciated yarns are cleaner, less fuzzy and more lustrous than ring-spun yarns. They are the product of advanced textile processing, and it will be interesting to see what impact they have on the market.

Bonded yarn, in which staple fibers are temporarily held together by an adhesive, is another form of twistless structure. The adhesive is removed after the yarn has been made into a fabric and has thus achieved strength from the interlacing of the weave. Fabrics produced of bonded yarn have had good strength, luster and softness and have performed well in wear and washing. The bonding process promises cheap and rapid production but appears to be some years away from manufacture on a large scale.

Yarn from Film

Yarn of a sort can also be made by slitting continuous sheets of polymeric film. The process rests on the fact that when a film made of a polymer such as polypropylene is stretched, it develops considerable strength along the direction of stretch while becoming quite weak in the transverse direction. The film can therefore be split or slit into tough, strong ribbons that are competitive with natural fibers (on a strength-to-cost basis) in industrial applications. A principal use for polypropylene slit tapes is in carpet backing; indeed, there is a good chance that within three or four years half of the carpets sold in the U.S. will have a polypropylene backing. Polypropylene coarse fiber or tape also serves as the artificial grass in most of the synthetic turf laid down in the U.S.

One also hears of film yarns that have been fibrillated, that is, made more fiber-like by a variety of mechanical means. They have not made much headway, however, because it is difficult to control their cross section and also because they tend to continue fibrillating after they have been incorporated in a fabric. Moreover, they have achieved less cost advantage than was originally expected.

Fibers derived from films are rectangular in cross section, and their fineness is accordingly dictated by the thickness of the original film and by the degree of drawing and fibrillation that can be achieved in commercial production. Yarns produced from film have not yet reached the level of fineness required for most textile applications.

A few years ago the splitting tendency of highly drawn polyethylene was put to work in a somewhat different manner to yield what are called network yarns. Such a yarn consists of fibers in the form of a network, much like chicken wire. The fibers interconnect at points about 1.5 centimeters apart. Their average diameter is less than four microns in contrast to the average of more than 20 microns for the fibers of yarns made into apparel. Network yarns as now produced can be woven or knitted (with or without twist) into fabrics that are acceptable to the eye and the touch. It remains to be seen whether or not their ease of manufacture (at speeds of 700 feet or more per minute) and the saving they achieve over the cost of processing conventional filament yarns will gain them a significant foothold in the market.

Composite yarns that have appeared on the market during the past year represent another method of producing a textile yarn at high speed and low cost. In such a system a synthetic polymer such as polyethylene is extruded at speeds well over 1,000 feet per minute and bonded by heat to conventional staple fibers that are fed into the stream. The result is in essence a hairy slit yarn that relies on its polymer core to provide strength without twist and yet has the fuzzy surface characteristic of spun yarn. The system accommodates a variety of extrudable resins as well as the entire spectrum of staple fibers.

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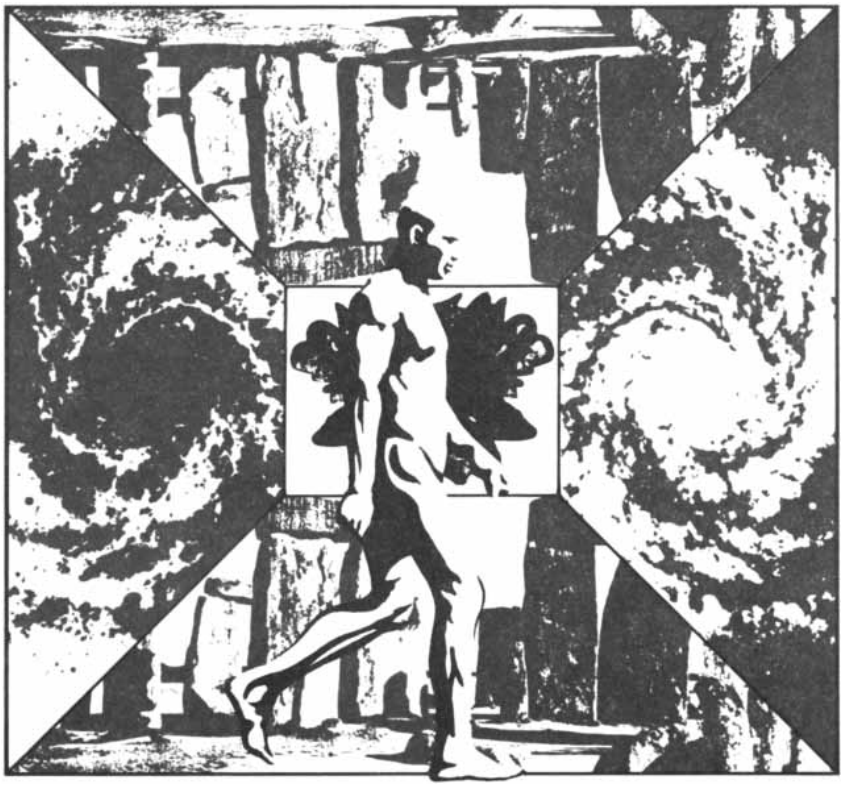

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The Tensile Strength of Liquids

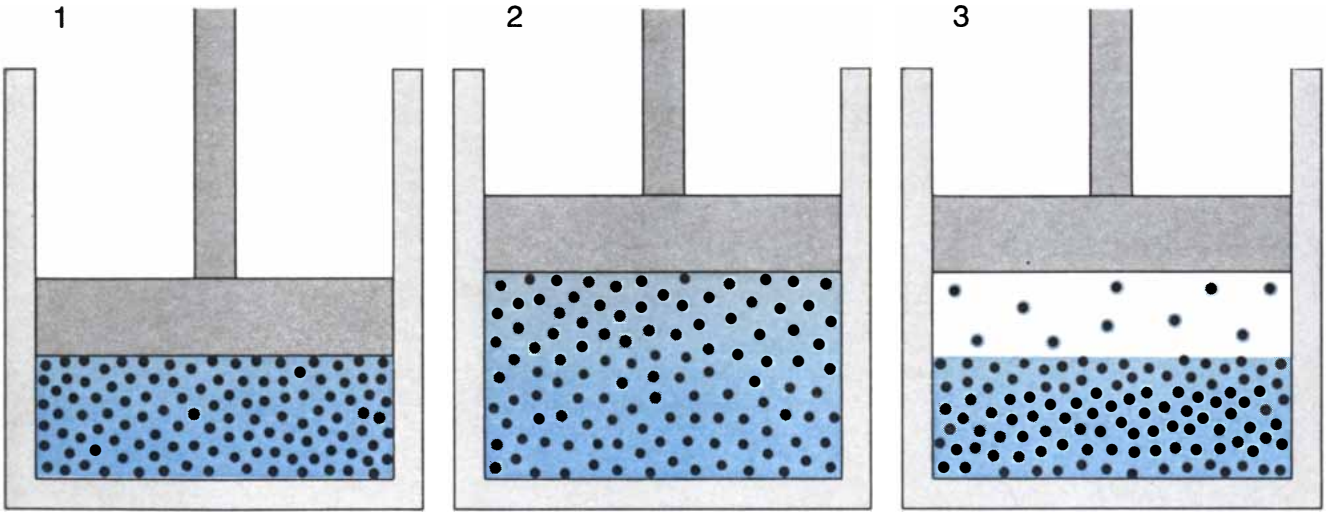
Like solids, liquids tear when they are placed under sufficient tension. Their strength has important consequences in nature and technology, and its measurement calls for special tactics

by Robert E. Apfel

Among the various properties of matter, one that is not commonly associated with liquids is tensile strength. The tensile strength of a metal, for example, can be measured by subjecting a piece of the metal to a strong, steady pull and noting the force needed to rupture it. Clearly it is not possible to make quite this kind of measurement with a liquid. The fact remains that liquids do have tensile strength, and it can be measured. Moreover, this tensile strength has significant natural and practical consequences.

The tensile strength of liquids is measured with the aid of the paradoxical-sounding concept of negative pressure. Consider the following experiment conducted by the 19th-century French chemist Marcellin Berthelot. He filled an evacuated glass tube with deaerated water, leaving a small space between the surface of the water and the top of the tube. Then he heated the tube gradually until the water had expanded enough to completely fill it. Contrary to what one might expect, when he allowed the water to cool, the tube at first remained filled to the top. Then when the water had further cooled to a certain critical temperature, it was suddenly and audibly transformed into a vapor. Berthelot reasoned that as the liquid cooled it was at a negative pressure, that is, it was under tensile stress. When the liquid reached the limit of its tensile strength, it "fractured" into a gas. From his experiments Berthelot estimated that the maximum value of the negative pressure for water was between −30 and −50 atmospheres. (One atmosphere is 14.7 pounds per square inch.)

A similar experiment is occasionally conducted by nature. In minerals there are tiny cavities filled with water and water vapor. Edwin W. Roedder of the U.S. Geological Survey has observed that freezing the water in such a cavity eliminates the vapor because frozen water occupies a larger volume than liquid water. He found that when the ice was allowed to melt partially, the vapor did not re-form when one might have expected it. In fact, the water in the cavity could be heated to as much as 6.5 degrees Celsius (43.7 degrees Fahrenheit), creating a negative pressure estimated at −1,000 atmospheres, before bubbles of vapor appeared in it.



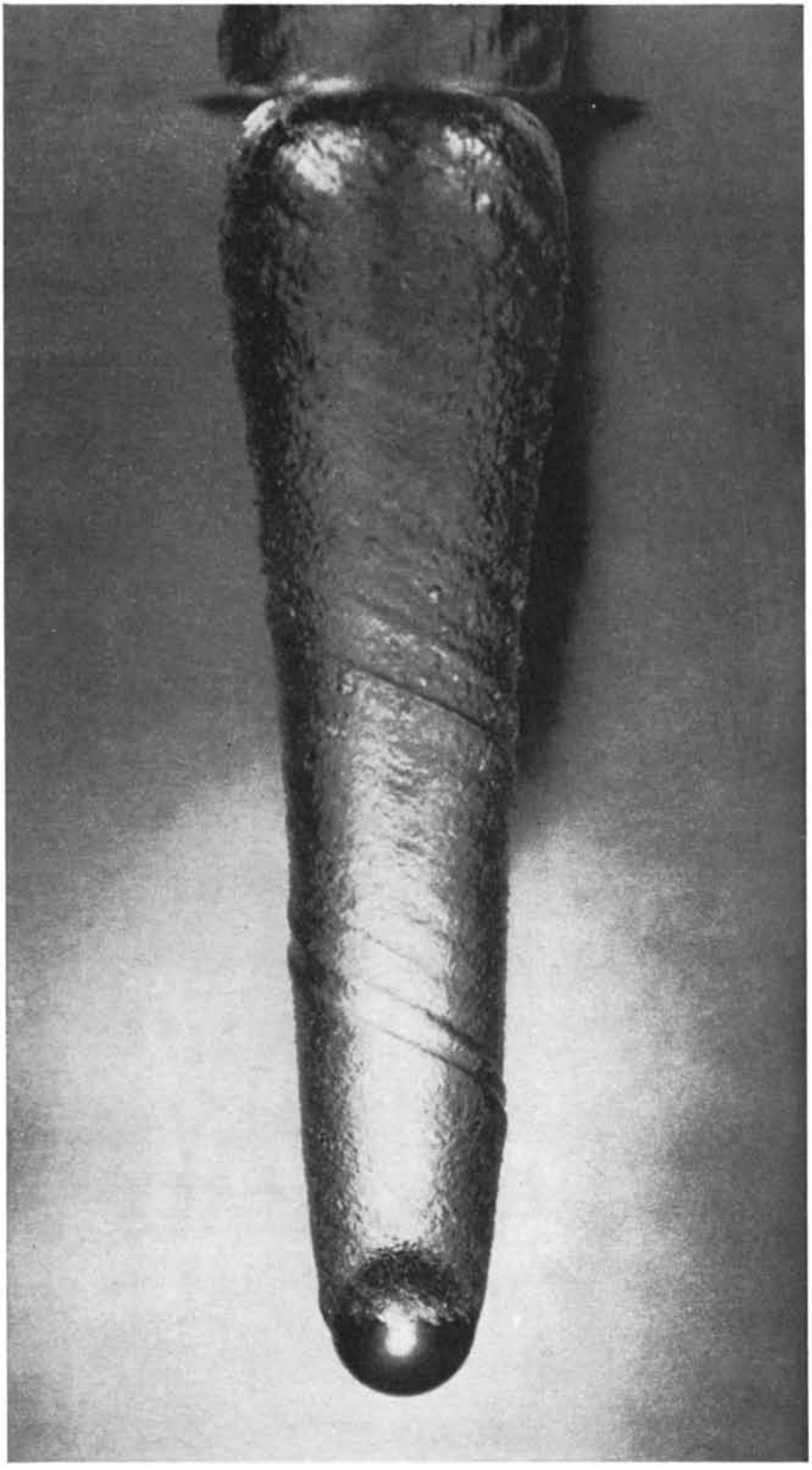
CYLINDER AND PISTON provide an idealized system for testing the tensile strength of a liquid. The cylinder is partially filled with a liquid; the piston is in contact with the liquid over its entire face (*1*). At the normal internal, or hydrostatic, pressure of the liquid the molecules (*black dots*) are a certain average distance apart and are held together by their cohesive attraction for one another (*color*). The liquid is stressed by slowly drawing the piston upward (*2*). If the liquid adheres sufficiently well to the piston face, its volume increases slightly as the pull on the piston increases the spacing of the molecules against the force of cohesion. If the pull exceeds atmospheric pressure, the liquid will be at a negative pressure. When it reaches the limit of its tensile strength (when the pull on the piston overcomes the force of cohesion between the molecules), it spontaneously separates into liquid and vapor phase (*3*).

Negative pressure plays an important role in the columns of sap that transport water from the roots of tall trees to the leaves. The transpiration of water from the surface of the leaves draws the sap to the full height of the tree. A vacuum pump cannot pull a column of water beyond a height of 33 feet, corresponding to a pressure of one atmosphere. Since many trees are much taller than 33 feet, there must be a negative pressure in the column that transports the sap.

Technology takes advantage of negative pressure in a number of ways. For example, Alan Hayward of the British Government Scientific Service has demonstrated that one can build a simple negative-pressure pump much like nature's. Although the pump is inefficient, with modifications it could be useful in underdeveloped countries for extracting water from deep wells. The instrument called a galvanostalameter is a tension manometer (pressure gauge) that is used in electrochemical research as an extremely sensitive indicator of the first appearance of a gas bubble in a liquid. In the bubble chamber of the high-energy physicist subatomic particles are tracked by the bubbles they initiate as they pass through a liquid that is either heated beyond its normal boiling point or subjected to a tensile stress. High-intensity sound in a liquid produces brief periods of tension that can lead to the formation of short-lived bubbles; ultrasonic cleaners produce these bubbles to assist solvents in cleaning. Such bubbles can also act as a catalyst in certain chemical reactions.

There are also practical problems associated with cavitation in liquids subjected to tensile stress. The cavities that are formed in the water around propellers and in hydraulic turbines can greatly reduce the efficiency of these devices. The transmission of long-range sonar signals requires high-intensity sound and therefore can be limited by the bubbles that often form on the face of the transmitting transducer and in front of it. It is apparent from the nature of these problems that any navy has a strong interest in understanding the phenomena of tensile strength in liquids.

Since Berthelot's time several techniques for measuring the tensile strength of liquids have been developed. In most such measurements the results depend strongly on the way the sample of liquid is prepared. This fact suggests that something foreign to the pure liquid influences the process by which cavities form in the liquid. In order to minimize



WATER IS TORN by a spinning steel ball dropped from a height of 10 feet into a tank of water. When the ball enters the water, it is moving too quickly for the liquid to flow smoothly around it. The water is fractured into a cavity that surrounds the ball until a smooth hydrodynamic flow is established. In this photograph the ball was spinning at a rate of 56 revolutions per second. The experiment was conducted by G. G. Mosteller in a glass-sided tank at the Model Laboratory of the Naval Ordnance Test Station in Pasadena, Calif. A fixed-plate camera, shutter open, was focused on the tank in a darkened room. The falling ball, before entering the tank, interrupted a light beam that was directed on a photoelectric cell, triggering a microflash illuminating lamp. The brilliant flash of light, directed on the ball for about two microseconds, recorded on the camera plate the position of the ball and the characteristics of the cavity produced by its travel through the water.

such influences much care has been taken in recent experiments to avoid contamination of the liquid sample with suspended solid impurities, or motes, and to remove the sample from contact with the walls of the container. Since subatomic particles can initiate cavitation in liquids under tensile stress, as they do in the bubble chamber, in certain experiments radiation shielding has been needed.

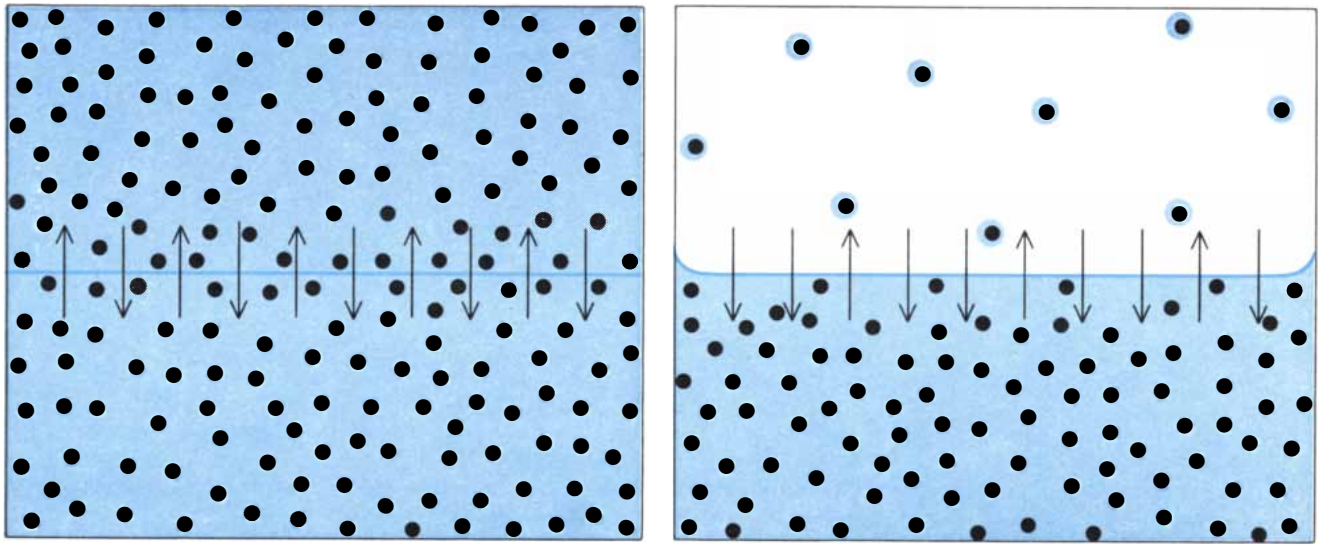
To understand the process of cavitation it is necessary to study the conditions under which the vapor phase and the liquid phase of a substance can coexist. The equilibrium pressure on the flat interface separating a substance's liquid and vapor phases is called the vapor pressure. The equilibrium is a dynamic one: in a given time the same number of molecules condense on the interface as evaporate from it. The vapor pressure varies with temperature. For example, the vapor pressure of water is equal to atmospheric pressure at the well-known boiling point of 100 degrees C. and is equal to about .025 atmosphere at the typical room temperature of 23 degrees C. The curve that describes the temperature dependence of the vapor pressure of a given substance is termed the coexistence line; at the states of temperature and pressure defined by this line the liquid can coexist in equilibrium with its vapor across a flat interface [*see bottom illustration on opposite page*].

In the absence of a flat liquid-gas interface the only way the vapor can form in the liquid is in cavities. Thus we can distinguish between two different types of vaporization. The first is evaporation from a liquid-gas interface, such as when steam rises from the surface of boiling water. The second is cavitation, such as when vapor bubbles are created within boiling water. In the second instance a new interface is formed.

Interfaces are characterized by the property of surface tension. Consider an imaginary horizontal flat surface within a liquid. Each molecule in the surface is attracted equally by molecules on both sides of the surface. If all the liquid above the surface is removed and replaced with a gas, the surface molecules will be subjected to an unbalanced force; they will be more strongly attracted by the molecules in the liquid, and if a state of equilibrium is to be maintained, some of them will be drawn into the liquid. The surface is somewhat depleted and is left in a contracted state rather like the state of a stretched elastic membrane. The analogy is a limited one, however. The interface is a transition layer of finite thickness (usually a few molecules thick) between the liquid phase and the vapor phase. If the area of the liquid surface were increased, the resulting larger interface would have the same number of molecules per unit area as the smaller one from which it had evolved. In forming the larger interface molecules must move from within the liquid to the surface against unbalanced inwardly directed forces. The thermodynamic definition of surface tension is the work done against these forces in forming a unit area of new interface. The thermodynamic approach to surface tension is largely due to the classic work of Josiah Willard Gibbs at Yale University late in the 19th century. This approach is crucial to understanding not only cavitation but also related phenomena such as the formation of liquid droplets in supersaturated vapors and the solidification of supercooled liquids.

Since work is required for the formation of the new interface of a cavity, the liquid can be subjected to pressures less than the vapor pressure without vaporizing. One can overexpand the liquid by reducing the pressure in it to below the vapor pressure, and even to negative pressures, until the liquid reaches the limit of its tensile strength and fractures, or vaporizes. Alternatively, one can superheat the liquid by heating it beyond its normal boiling point until it reaches its superheating limit and vaporizes. Whichever path is taken (heating the liquid, reducing its internal pressure or both), if the substance remains a liquid at a temperature-pressure state normally associated with the vapor, it is said to be in a metastable state. The limit of metastability represents the ultimate tensile strength of the liquid.

A spherical vapor cavity is in equilibrium if the inwardly directed stress and outwardly directed stress on the cavity interface are balanced. The inwardly directed stress is the sum of the pressure in the liquid and the force per unit area due to surface tension; the outwardly directed stress is the net force per unit area due to the vapor molecules in the cavity impinging on the liquid interface. The mechanical equilibrium of

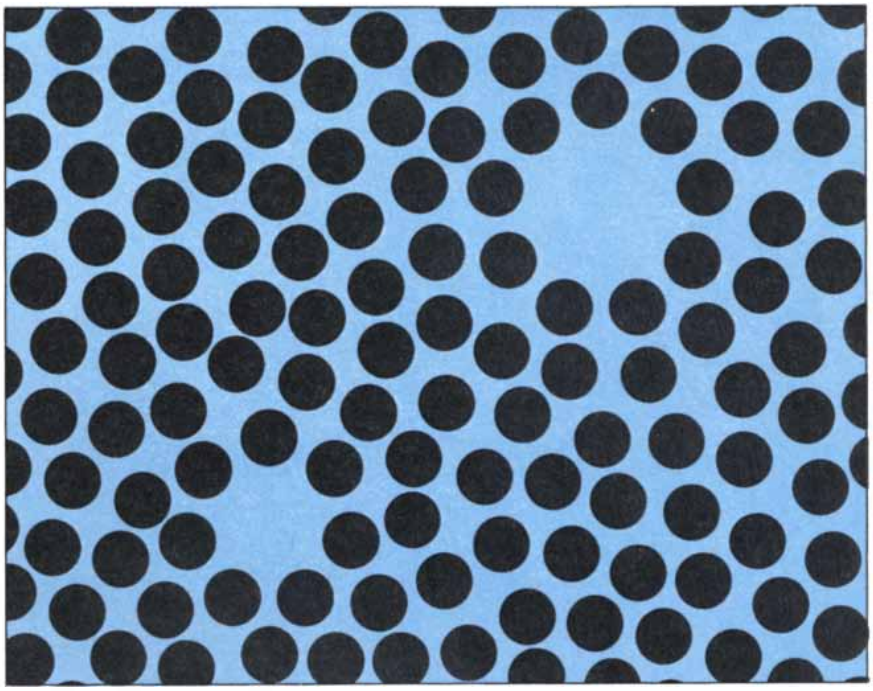


INTERFACES ARE CHARACTERIZED by the property of surface tension. In an imaginary horizontal flat surface within a liquid (*left*) molecules (*dots*) in the surface are attracted equally by the molecules on each side of the surface. If all the liquid above the surface is removed and replaced with a gas (*right*), the surface molecules will be more strongly attracted by the molecules in the liquid. If a state of equilibrium is to be maintained, molecules must be drawn into liquid, leaving the surface layer depleted.

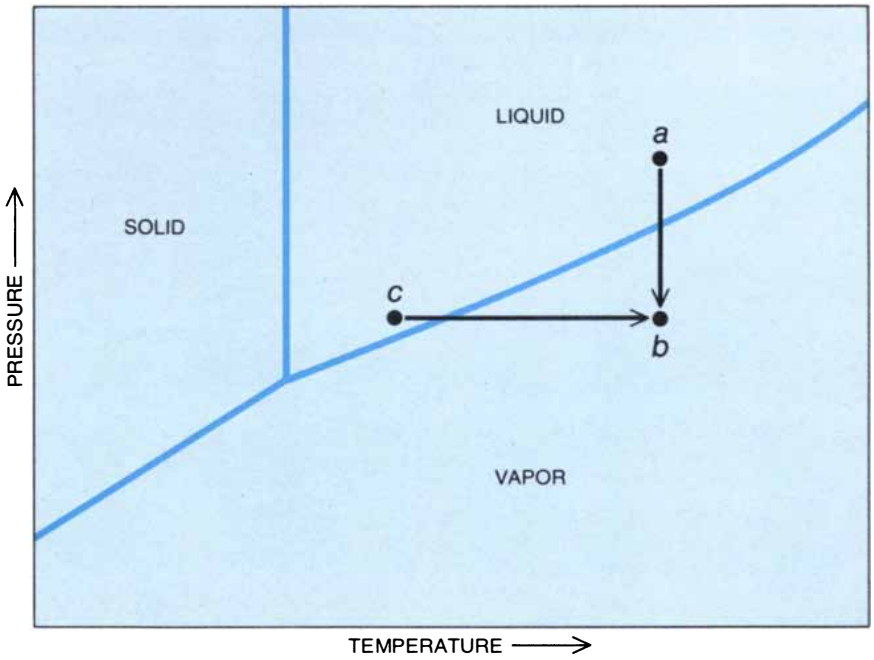
such a cavity, which is called a cavity of critical size, is unstable because the inwardly directed surface stress increases with the decreasing size of the cavity. If the cavity is made slightly smaller than the critical size, the inwardly directed surface stress will increase, upsetting the equilibrium and causing the cavity to collapse. If, on the other hand, the cavity is made slightly larger, the surface stress decreases. The cavity will grow to macroscopic size as long as the temperature, the pressure of the liquid outside and the pressure of the vapor inside the cavity remain constant.

How does a cavity of critical size form in a liquid that has no preexisting cavities? The theory of what is called homogeneous nucleation may provide an answer. Homogeneous nucleation refers to the appearance of minute embryos of the vapor phase in the pure bulk liquid phase. The theory, put forward by W. Döring in 1937, suggests that if we could focus a supermicroscope down to the molecular level, we would see that a liquid is in a highly dynamic state. The molecules vibrate back and forth some 10^{13} times per second, creating instantaneous local fluctuations in the density of the liquid. On the molecular scale density fluctuations are manifested as minute voids or vapor cavities that are continually formed and destroyed. As the temperature is increased or the pressure is decreased, or both, a snapshot would reveal that the cavities increase in number and in size. At some limiting temperature and pressure there is a reasonable probability that in a certain volume of the liquid and over a certain period of time density fluctuations will lead to the production of one cavity of the critical size.

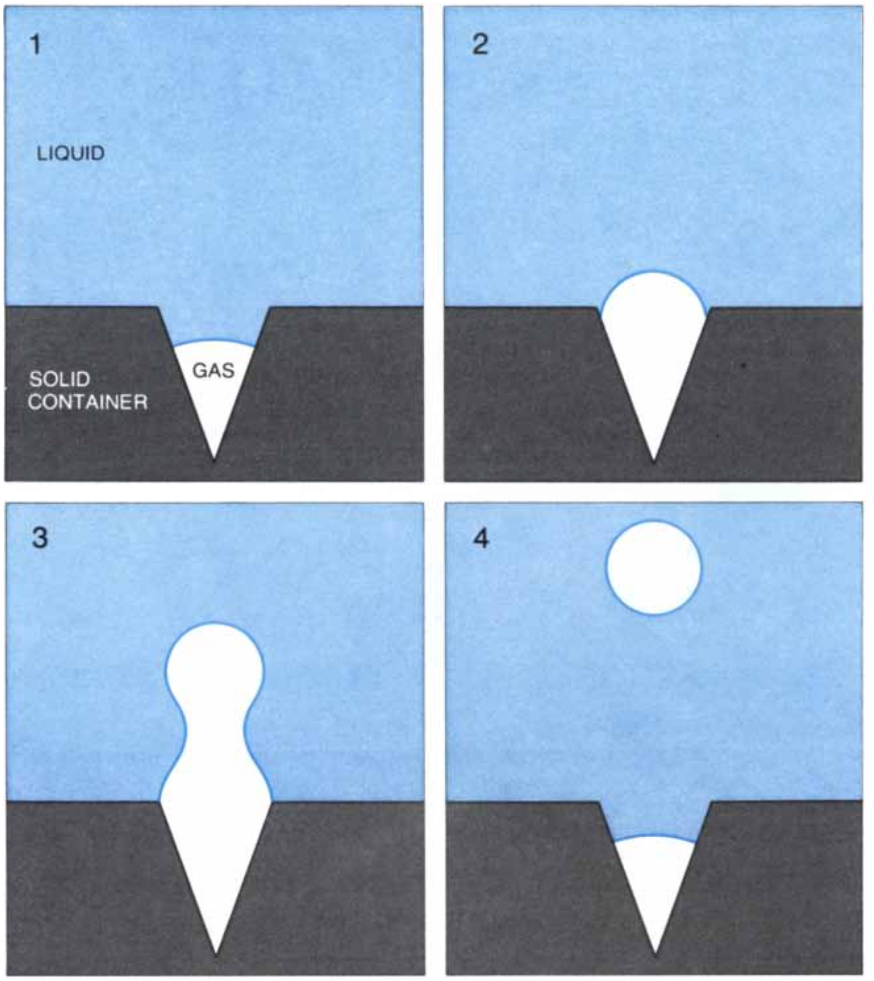
Since the cavity is in unstable mechanical equilibrium, it will grow to macroscopic size with an infinitesimal increase in temperature or decrease in pressure. The limiting temperature and pressure required to produce a cavity of the critical size determine the ultimate tensile strength of the liquid. The limiting temperature-pressure states depend somewhat on the experimental waiting time; the longer we wait, the greater the probability is that there will be a density fluctuation producing a cavity of critical size. As far as tensile-strength calculations are concerned, however, the effect is small: a millionfold increase in waiting time gives rise to only a 10 percent decrease in the predicted tensile strength. For water at room temperature the predicted tensile strength is between −1,300 and −1,500 atmospheres. Here



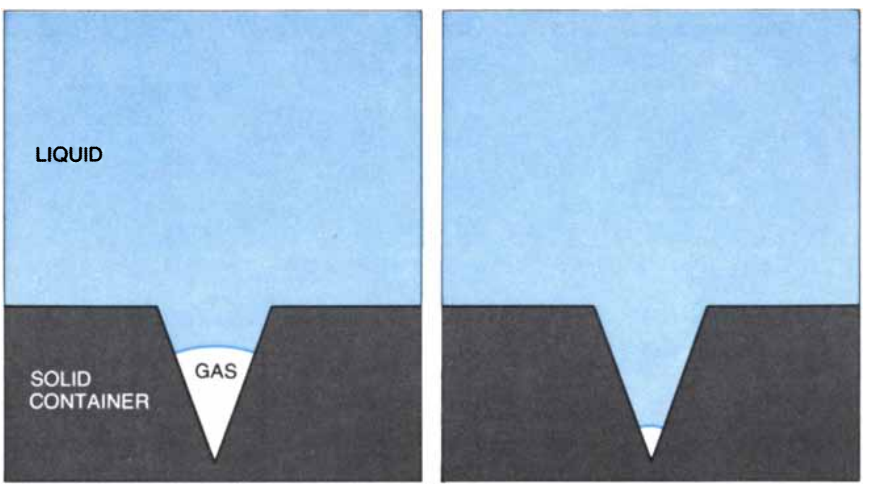
DENSITY OF MOLECULES in a liquid is not constant; the molecules (*dots*) vibrate back and forth some 10^{13} times per second, creating instantaneous local fluctuations in the density of the liquid. The fluctuations are manifested as minute vapor cavities that are continually formed and destroyed. Two such cavities are shown as larger open spaces between the molecules. As the temperature of the liquid is increased or the pressure is decreased, or both, the cavities increase in number and size until there is a reasonable probability that one will reach critical size and will ultimately induce the liquid to fracture into vapor.



PHASE DIAGRAM for a substance shows the state (solid, liquid or vapor) that a substance is usually in at various ranges of temperature and pressure. The liquid and the vapor can coexist in equilibrium on the portion of the curve (called the coexistence line) between the liquid phase and the vapor phase. Under certain circumstances the substance can be at the temperature and pressure of one region while having a form associated with another region. For example, a substance at the temperature-pressure state *b* would normally be a vapor. If the pressure in the liquid at state *a* were slowly reduced to a negative value, however, the resulting state *b* is below the coexistence line but the substance maintains its liquid state. Such a liquid is overexpanded. Similarly, a liquid can be slowly heated from *c* to *b*, again crossing the coexistence line without vaporizing. Such a liquid is superheated. Whichever path is taken across the coexistence line, a liquid at state *b* is metastable.



MINUTE CREVICES in the walls of solid containers can trap vapor and foreign gas (*1*), thereby limiting the tensile strength of the liquid in the container. As the liquid is subjected to a negative pressure the liquid-gas interface is drawn out of the crevice (*2*), grows (*3*) and eventually breaks off into the liquid (*4*) to form a cavity. Further negative pressure will induce the cavity to grow to a larger and possibly observable size in the liquid.



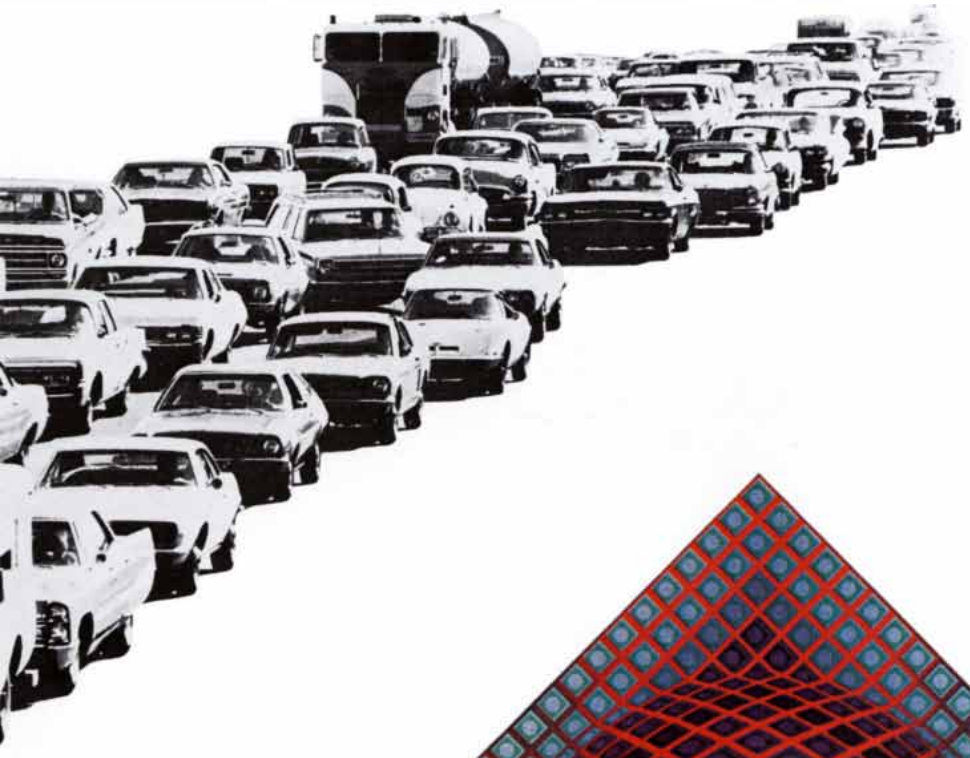
LIQUID CAN BE STRENGTHENED by applying a high positive pressure to it before conducting the tensile-strength experiment. Here the initial liquid-gas interface (*left*) is forced deep inside the crevice (*right*), and the gas slowly diffuses across the interface and dissolves in the liquid. The pocket of gas shrinks in size. After prepressurization a greater negative pressure is required for the interface to be drawn from crevice and form a cavity.

the critical size for a cavity is a radius of about 10 angstroms (10^{-7} centimeter). As the temperature increases, the predicted tensile strength decreases until it is zero at the superheating limit of water: approximately 300 degrees C., corresponding to a critical radius of some 50 angstroms. If there are vapor cavities or gas bubbles larger than the critical size in the liquid sample, the apparent tensile strength of that particular sample is determined by the largest cavity or bubble in it. Therefore unless great care is taken to eliminate all sources of impurities from the sample, it is very unlikely that homogeneous nucleation will be observed.

Let us now consider what happens to the liquid in a cylinder when the liquid is subjected to a strong pull by a close-fitting piston in the cylinder. The liquid will fracture into a vapor at one of two places: either within the bulk of the liquid or at the interface between the liquid and the wall of the cylinder or the face of the piston. The cavity will grow spontaneously and abruptly. If we push the piston in, condensing the vapor back into a liquid, and then pull it out again, the cavities will very likely form at the same sites as they did the first time. We see much the same thing in the home: a stream of bubbles comes from a few particular sites at the bottom of a pan of boiling water or on the wall of a bottle of carbonated beverage. If such cavitation sites could be eliminated, the tensile strength of the liquid would be increased.

We can eliminate the cavitation sites by applying a high positive pressure, say +1,000 atmospheres, to the liquid for about 15 minutes. Now when we release the positive pressure and pull on the piston, the liquid can withstand a much greater tensile stress before it cavitates. E. Newton Harvey and his colleagues at Princeton University observed a similar effect with respect to the boiling point of water: when the water was first subjected to high positive pressure and then returned to atmospheric pressure, it would not boil until it had reached a temperature as high as 202 degrees C., at which point the entire sample vaporized explosively. Such prepressurization effects imply that the liquids have memory: they "know" they have been prepressurized.

The explanation of this behavior lies in the solid surfaces touching the liquid. A microscopic examination of containers and suspended motes would show that the surfaces of these solids are not smooth but have many tiny cracks and crevices. Pockets of gas can be trapped



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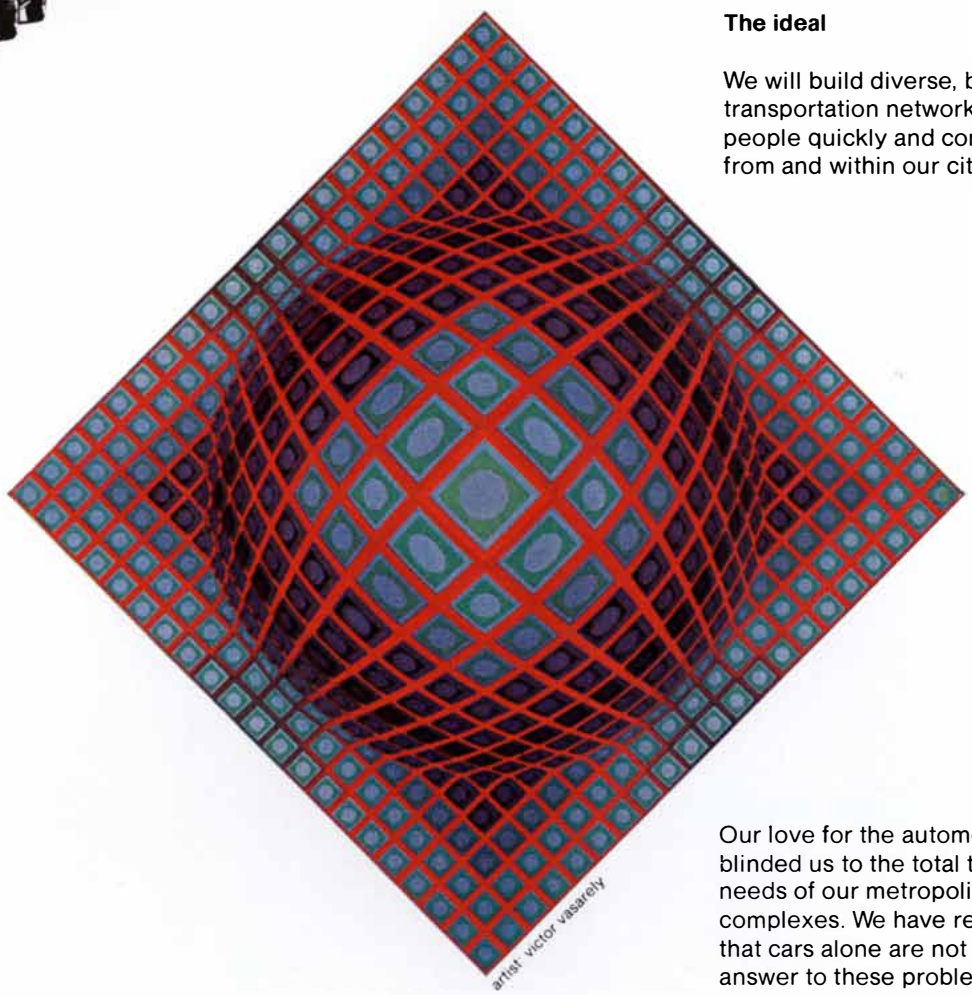
We will build diverse, balanced transportation networks that move people quickly and comfortably to, from and within our cities.



Our love for the automobile has blinded us to the total transportation needs of our metropolitan complexes. We have refused to see that cars alone are not the total answer to these problems.

It's time we opened our eyes to the urgent need for balanced mass and private metropolitan transportation networks. Developing them will take innovative planning, public support and cooperation among all levels of government.

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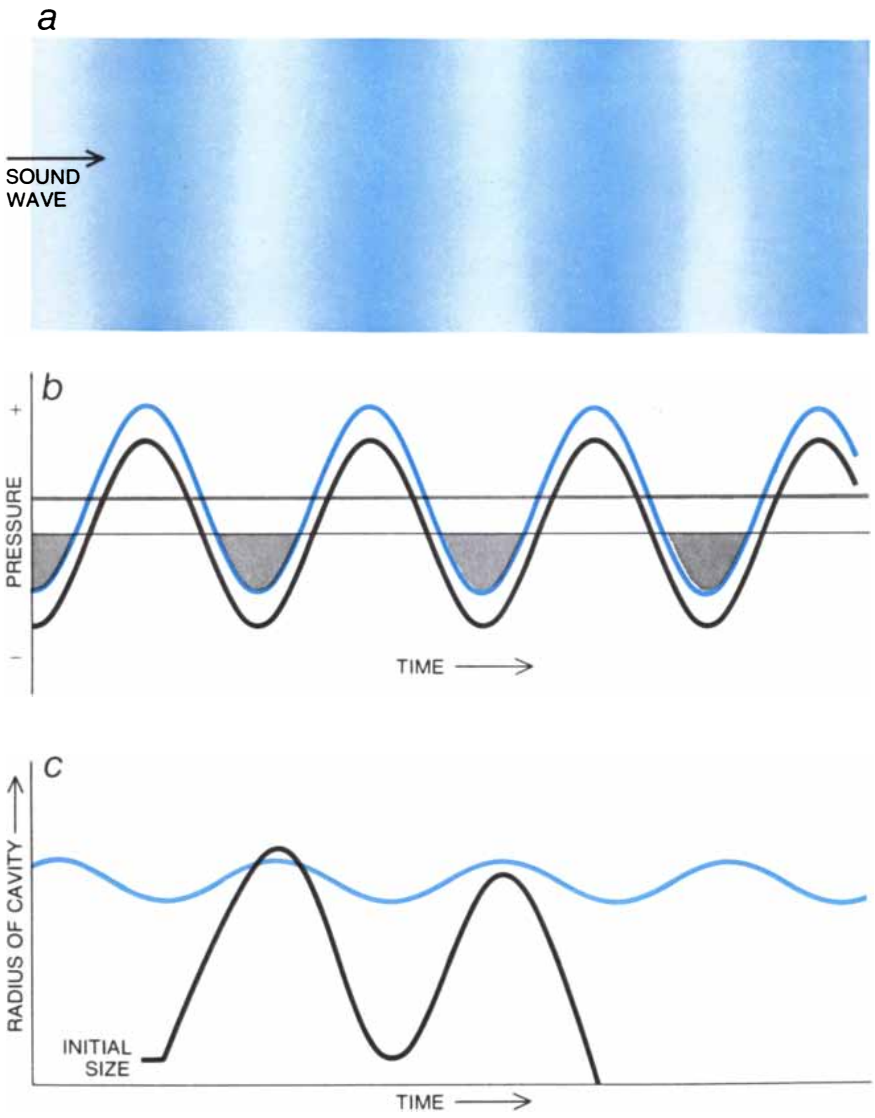
in such crevices. Unlike a free cavity that will either grow or collapse in the bulk liquid, the pocket of gas can exist stably in the crevice under certain conditions. The conditions depend not only on the properties of the liquid but also on the size and shape of the crevice and on the ability of the liquid to wet the solid.

On this basis it is easy to understand how prepressurization can affect the apparent tensile strength of a liquid. If the liquid is not prepressurized, then as the pressure is reduced it will eventually reach some critical tensile stress at which the pressure inside the pocket of gas and the negative pressure in the liquid can overcome the inwardly directed surface stress. The interface between the gas and the liquid moves out of the crevice and breaks free to form a cavity. If the liquid is prepressurized, the interface is forced deep into the crevice and the trapped gas diffuses across the interface into the bulk liquid. Now when the pressure is reduced to measure the tensile strength, the pocket of gas is smaller than it was when it was not prepressurized. A greater tensile stress is required to overcome the inwardly directed surface stress and cause a cavity to grow from the crevice.

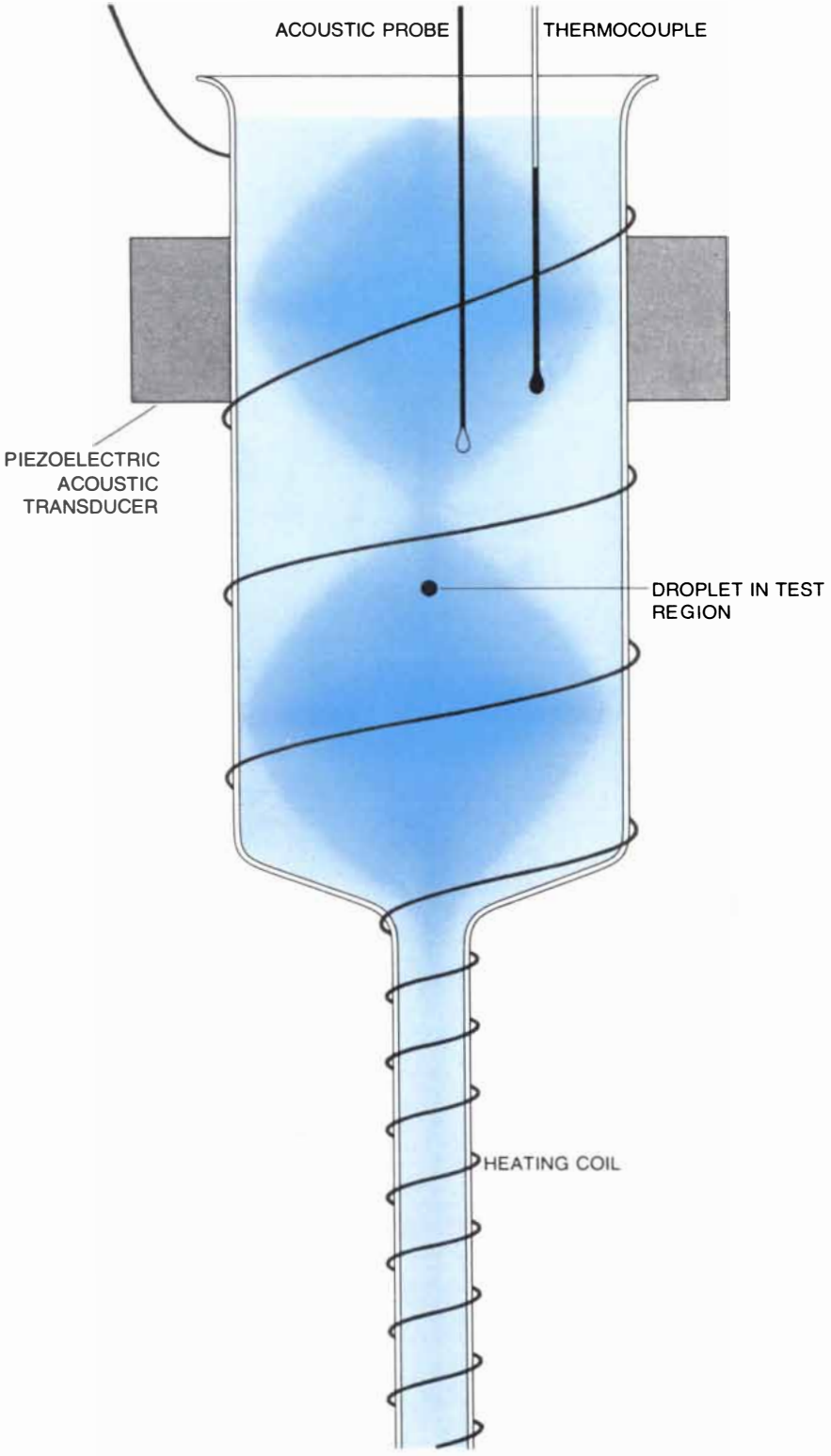
A cylinder and piston are convenient for discussing cavitation, but they are rather impractical for experimental purposes, primarily because it is difficult to avoid the formation of vapor cavities in the crevice between the side of the piston and the wall of the cylinder. Another method of creating large tensile stresses in liquids was developed by Lyman J. Briggs of the National Bureau of Standards. He filled a Z-shaped capillary tube with liquid and mounted it on a rotor. The rotor turned fast enough to cause the liquid to cavitate at the center of the tube, which is the point of maximum tensile stress. In Briggs's apparatus a sample of very pure water sustained a tensile stress of −277 atmospheres at 10 degrees C., the highest figure recorded for the tensile strength of pure water. This result, however, is a factor of five below theoretical predictions. Furthermore, it is likely that the actual site of cavitation was the interface between the tube and the water rather than within the water sample itself.

In order to avoid the undesirable effects of solid container surfaces, the tensile stresses must somehow be exerted in a region an appreciable distance away from the surface of the container. One way to accomplish this result is to focus high-intensity sound waves on some region within the liquid, generating a large alternating stress in it. As a sound wave propagates past any position in the liquid the pressure in the liquid alternates back and forth from a pressure greater than the hydrostatic pressure (the internal pressure of the liquid alone) to a pressure less than the hydrostatic pressure. During any part of one acoustic cycle the absolute pressure in the liquid is equal to the hydrostatic pressure plus the instantaneous acoustic pressure. For part of the low-pressure half of the acoustic cycle the absolute pressure in the liquid can be negative [*see illustration below*]. During this negative-pressure phase cavities may form within the liquid.

The tensile strength measured by sound waves is called the acoustic cavitation threshold. An acoustic cavitation event in a liquid well below its boiling point is often observed as a cavity darting away from the point of maximum acoustic stress. Since the negative pressure is of limited duration and is followed by the positive part of the cycle, the cavity is short-lived. A snapping or



HIGH-INTENSITY SOUND WAVES generate a large alternating stress within a liquid (*a*). The sound waves are longitudinal waves that create regions of high pressure (*dark color*) and low pressure (*light color*). At any point in the liquid at a given time (*b*) the absolute pressure (*color*) is the sum of the hydrostatic pressure (*gray*) and the instantaneous acoustic pressure (*black*). For part of the low-pressure half of the acoustic cycle the absolute pressure in the liquid can be negative (*gray areas*). A cavity can grow in response to this negative pressure (*c*); it can be a cavity of vapor (*black*) or a bubble of a gas that has been dissolved in the sample (*color*). The growth of the vapor cavity is limited because the negative-pressure phase is of limited duration and is followed by a positive-pressure phase. The collapse of the vapor cavity often gives rise to new cavities that repeat the process. A gas bubble is generally more stable than a vapor bubble; its size oscillates to a lesser extent in response to the varying acoustic pressure. It can last through several thousand acoustic cycles, whereas a vapor cavity usually collapses after only a few acoustic cycles.



GLASS COLUMN filled with filtered glycerin was part of the author's apparatus for measuring the tensile strength of superheated liquids. A droplet of ether or *n*-hexane was injected into the bottom of the narrow tube. As the droplet rose through the glycerin it was slowly heated until it was well into the superheated state when it reached the test region. A piezoelectric acoustic transducer established a standing-wave field of high-intensity sound (*color*) in the glass column. An acoustic probe revealed that the acoustic pressure decreased from the center of the column radially outward, and that it also varied cyclically along the axis of the column. When the magnitude of the acoustic pressure was increased to a certain value, the rising droplet stopped at a point somewhat above one of the acoustic-pressure maximums along the axis of the column. When the pressure was further increased, the droplet moved slightly closer to the pressure maximum. At a sufficiently high pressure the droplet reached the limit of its tensile strength and exploded into a vapor.

popping sound, associated with the shock wave produced during the violent collapse of the cavity, accompanies its disappearance. The acoustic cavitation threshold can be greater than the tensile strength measured by static means; not only must the cavity be formed during the brief period of tensile stress but also it must grow significantly while the pressure is negative. If it does not grow enough, it may collapse completely during the positive phase of the acoustic cycle before it gets big enough to be observed. Therefore if a cavitation event is to be observed, a maximum acoustic stress greater than the stress required to create the cavity may be needed. Under certain circumstances a gas dissolved in a liquid can form cavities under the influence of an intense acoustic field. The cavities grow slowly over many acoustic cycles as the gas is "pumped" from the liquid into the bubble. The trapped gas cushions the bubble against collapse.

Unfortunately measurements of the acoustic cavitation threshold of liquids made by different investigators tend to differ themselves, probably because of differences in the way each investigator prepared his liquid sample. Results for water vary from −1 or −2 atmospheres to more than −200 atmospheres. As these results imply, the role of motes can be crucial in determining acoustic cavitation thresholds. Martin Greenspan and Carl Tschiegg of the National Bureau of Standards have measured acoustic cavitation thresholds of more than −200 atmospheres in water after a particularly careful effort to filter out motes. Even then cavitation was probably initiated either by a residual mote or possibly even by a high-energy cosmic ray particle impinging on the sample. The importance of the filtering procedure can be appreciated when it is realized that even distilled water can contain more than 50,000 motes per cubic centimeter. The carefully controlled experiments of Greenspan and Tschiegg set a standard in the field of acoustic cavitation.

Because the problem of cavitation at container surfaces and at motes within the liquid is so difficult to solve, I decided to develop a different approach. I realized, as others had, that if the sample were reduced to a droplet less than .3 millimeter in diameter and suspended in an inert host liquid (a liquid in which the sample will not dissolve), I would dispose of two problems. First, the droplet would be so small that it might not contain any motes. Second,

its "container" would be the perfectly smooth surface of another liquid.

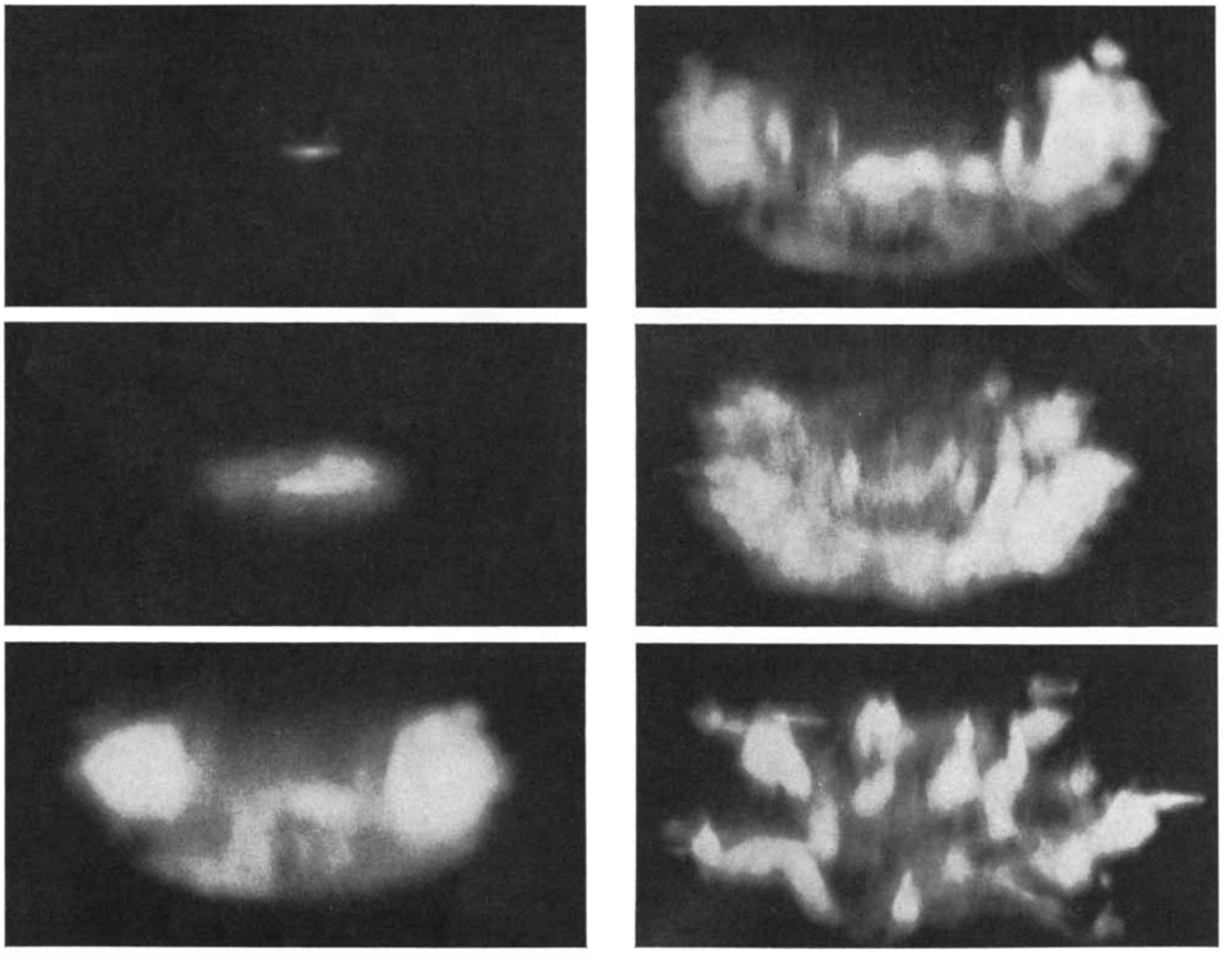
The droplet technique was used in 1958 by Hiromu Wakeshima and Kazuo Takata of the Kobe University of Mercantile Marine to measure the superheating limit of several hydrocarbons rising slowly in a host liquid of hot concentrated sulfuric acid. The measured superheating limits were quite repeatable from sample to sample of the same liquid and agreed well with Döring's theory of homogeneous nucleation.

With a similar technique I have also found good agreement with theory for liquids such as ether and *n*-hexane. The results for that difficult substance water, however, are not as repeatable and fall a bit short of theory, which predicts a superheating limit of about 300 degrees C. In 1922 K. L. Wismer reported that he had superheated water to about 270 degrees C. at atmospheric pressure. Milton Blander and Dennis Hengstenberg of the North American Rockwell Science Center, working with Joseph L. Katz of the Clarkson College of Technology, reported superheating water droplets in a silicone fluid to temperatures above 265 degrees C. and possibly approaching 280 degrees C. At the Yale University Department of Engineering and Applied Science I have recently measured a superheating limit of 279.5 degrees C. at atmospheric pressure for water droplets heated in a host of liquid benzyl benzoate. I believe that this higher result is due to my precaution of prepressurizing the water. Any motes present were more thoroughly wetted.

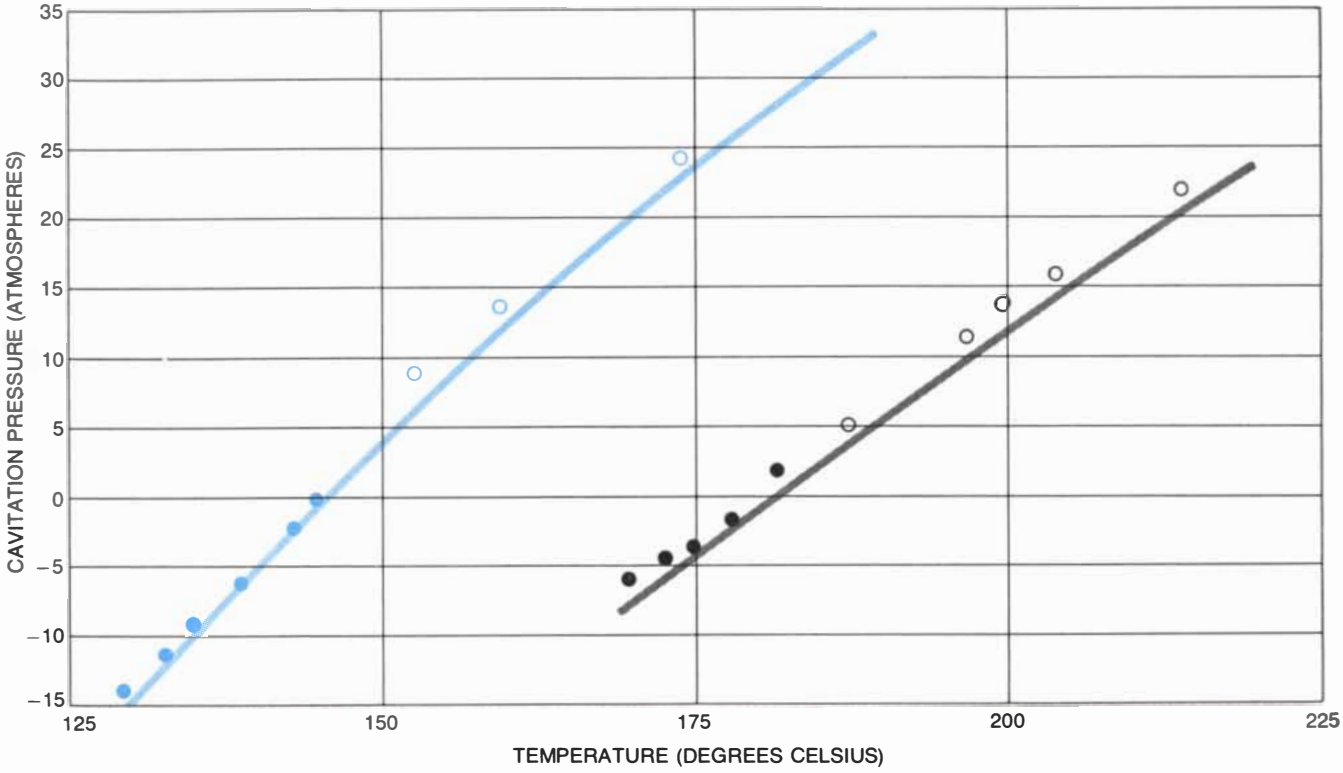
Before this most recent work with water, and while I was at the Harvard University Division of Engineering and Applied Physics, I had begun to adapt the droplet technique to the measurement of tensile strength. This technique was combined with the acoustic method to test the tensile strength of superheated liquids. Before these experiments were conducted it had not been demonstrated that a superheated liquid could even sustain a tensile stress. Moreover, laboratory measurements of the tensile strength of liquids had not come very close to predictions based on the theory of homogeneous nucleation.

It is difficult to produce tensile stresses between −200 and −1,000 atmospheres by acoustic means. (The predicted tensile strengths of many common liquids at room temperature are in this range.) I therefore decided to measure the tensile strength of liquids in the superheated state, where the predicted strengths are much lower than they are at room temperature. I also chose two liquids, ether and *n*-hexane, that were known in theory to have low tensile strengths.

A droplet of the sample liquid was injected into a glass column containing filtered glycerin, which acted as an



ETHER DROPLET EXPLODES into a vapor as a result of being simultaneously superheated to a temperature of 135 degrees Celsius and subjected to a large acoustic stress. The droplet is suspended in glycerin in the apparatus shown on the opposite page. The frequency of the acoustic excitation is 50,000 hertz, much higher than the speed of the film (about 3,300 frames per second), so that the average motion of the vapor cavity created by the explosion is seen here. Sequence of photographs runs top to bottom, left to right.



CONDITIONS FOR VAPORIZATION of ether (*color*) and for *n*-hexane (*black*) are plotted. The solid curve in each case represents the prediction of the theory of homogeneous nucleation, which describes the conditions for which vapor cavities are formed in a pure liquid. The normal boiling point of ether at atmospheric pressure is 35.6 degrees C. Tensile-strength measurements made at negative pressures by the author (*colored dots*) and at positive pressures by K. L. Wismer in 1922 (*colored open circles*) are in good agreement with theory. The normal boiling point of *n*-hexane at atmospheric pressure is 69 degrees C. Again, the measurements at negative pressures made by the author (*black dots*) and those made at positive pressures by V. P. Skripov and G. V. Ermakov of the S. M. Kirov Ural Polytechnic Institute in the U.S.S.R. (*black open circles*) agree well with theory of homogeneous nucleation.

inert host liquid. The host liquid was denser than the droplet liquid, which caused the droplet to rise slowly in the tube. A heating coil wrapped around the column established a stable gradient of temperature, so that the droplet was heated as it ascended. When it reached a certain height in the column designated the "test region," it was well into the superheated state. At this point it entered a standing-wave field generated by high-frequency sound pumped into the column. A cylindrical piezoelectric acoustic transducer was cemented to the wall of the glass column just above the test region. When an electric field is applied to a piezoelectric material, it produces a mechanical distortion of the material; an alternating voltage will cause the material to vibrate with a certain period. In this way one generates an acoustic signal. In order to get the maximum vibration out of the transducer and create the standing-wave field in the glycerin I adjusted the frequency of vibration to coincide with a resonance frequency of the entire transducer-glass-liquid system. The system resonated at a frequency of about 50,000 hertz (cycles per second). When I probed the pressure field of the standing wave with a miniature acoustic sensing device, I found that for this resonance condition the acoustic pressure decreased from the center of the column as the sensing device was moved radially outward. In addition the acoustic pressure varied cyclically along the axis of the column: it had a peak value about every four centimeters and fell away almost to zero midway between successive peak values [*see illustration on page 68*].

When the magnitude of the acoustic pressure was increased to a certain value, the rising droplet stopped at a point somewhat above one of the acoustic pressure maximums along the axis of the column. In other words, the droplet was levitated. At that point in the column the force of the acoustic pressure just balanced the droplet's natural buoyancy. The force of acoustic pressure represents the net force on an object as the result of a sound wave's impinging on it. It is usually a small effect, but when high acoustic pressures and pressure gradients are generated in a liquid, it can be significant.

When the acoustic pressure was increased even further, the droplet moved slightly to a new equilibrium position closer to the pressure maximum. Eventually, at a sufficiently high acoustic pressure, the levitation was interrupted by the droplet's exploding into a vapor. At some appropriate combination of superheating and acoustic stress the liquid droplet reached its ultimate tensile strength and vaporized. The experiment can be repeated for different test-region temperatures, thereby allowing the measurement of the trade-off between the amount of acoustic stress and the temperature of superheating as the causes of the droplet's vaporizing. The results of these measurements with the ether and the *n*-hexane gave us the tensile strength of these liquids as a function of temperature. I found that in the temperature range of the experiment the peak tensile strength of the liquid (the peak acoustic pressure minus the hydrostatic pressure) increases almost linearly as the temperature decreases. I believe the results would be the same for a static tensile stress of the same value as the peak tensile stress in the acoustic measurements. The reason is that the duration of the peak stress (about a millionth of a second) is long compared with the time it would take for a density fluctuation to produce a

cavity of critical size in the stressed superheated liquid.

It is interesting to compare these results for negative pressures with the results obtained by others who have measured the limit of superheating of the same liquids as a function of positive pressure. For example, in 1922 Wismer measured the limit of superheating of ether samples contained in capillary tubes and subjected to various positive pressures. His results for positive pressures lie along the same general curve as my results for negative pressures, and both results agree well with the predictions of Döring's theory of homogeneous nucleation. In 1964 V. P. Skripov and G. V. Ermakov of the S. M. Kirov Ural Polytechnic Institute in the U.S.S.R. measured the limit of superheating of *n*-hexane droplets rising in a heated host liquid of concentrated sulfuric acid that was subjected to various positive pressures by inert gas above the host. Here again the results for positive pressures are completely consistent with the results for negative pressures, and both are in good agreement with theory. This consistency has been achieved in spite of the different "containers" (glycerin, capillary tubes, concentrated sulfuric acid) for the samples.

These observations strongly suggest that for the liquids tested vapor cavities were formed within the sample itself and not at the liquid-liquid or liquid-solid interface. Moreover, the results lend strength to the sometimes controversial theory of homogeneous nucleation. Further experiments with other liquids are required for a more complete test of the theory.

The droplet-levitation technique has opened up new possibilities for studying the liquid state that we are now exploring at Yale. It should enable us to learn more about the properties of liquids in superheated, overexpanded or supercooled states. If the apparatus were modified, we could observe supercooled droplets solidify. It is known that water can be supercooled to −40 degrees C. or even below that temperature before solidifying. Water droplets in clouds are occasionally supercooled to this extent. We have superheated water to almost 280 degrees C. at atmospheric pressure; thus in addition to what is known of water between 0 and 100 degrees C. we should be able to learn much about the properties of water at atmospheric pressure between −40 degrees and 280 degrees C. Experiments of this kind should considerably enlarge our knowledge of the often mysterious liquid state.

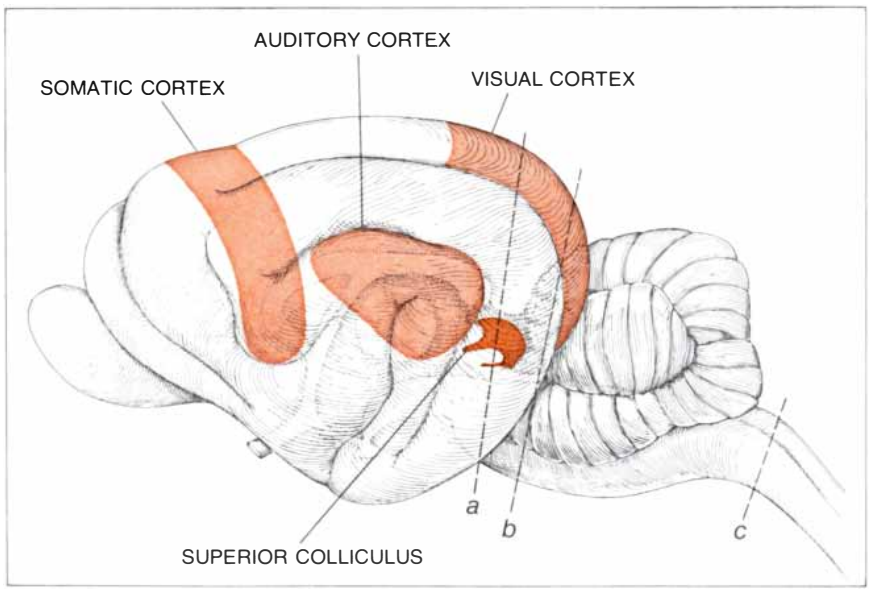
The Superior Colliculus of the Brain

The cells of this small region in the mammalian midbrain appear to help the eye detect and follow moving objects. They may do the same for the stimuli of hearing and touch

by Barbara Gordon

In order to survive an animal must be able to respond quickly to moving objects as soon as they enter its field of vision. The animal must rapidly determine the source of the visual stimulus and the speed and direction of its movement. Then the animal must move its head and eyes to hold the source of the stimulus in view. By the same token an animal must move its head and eyes to search for the source of a moving sound or an object brushing past its body. One might therefore predict that if one were able to identify the region of the brain involved in controlling the position of the head and eyes, one would discover that the region is responsive to different types of stimuli: visual, auditory and somatic.

Evidence is rapidly accumulating that one region of the mammalian brain intimately involved in the control of head and eye movements consists of two bumps on the upper surface of the midbrain long familiar to anatomists as the superior colliculus. (Colliculus means little hill.) By using microelectrodes to record the response of individual cells in the superior colliculus to various stimuli it has been found that this neural structure indeed receives sensory information from the animal's visual, auditory and somatic systems. In lower vertebrates the superior colliculus serves as the main visual center. In higher vertebrates much of the processing of visual information has been taken over by the visual area of the cerebral cortex. The superior colliculus, however, still receives nerve impulses directly from the optic nerve as well as impulses relayed from the visual cortex. In addition the deeper layers of the superior colliculus receive nerve inputs from the auditory and somatic systems. Recent experiments suggest that the deep layers of the superior colliculus may contain superposed topographic maps of the visual, auditory and somatic fields. Although these maps are somewhat crude, they may assist an animal in responding quickly and effectively to the ever changing stimuli presented by a complex three-dimensional environment.



SUPERIOR COLLICULUS is a receiving terminal for nerve impulses from the eye, the visual cortex, the auditory cortex, the spinal cord, the brain stem and the somatic cortex. The drawing shows a cat's brain from the side. The principal nerve pathways are shown in relation to sections *a*, *b*, *c* (plus a spinal-cord section) in the illustration on the opposite page.

In each sensory system the processing of information from the outside world begins when an electrical signal is generated in a suitable receptor by an adequate stimulus. Thus light activates the visual system, sound the auditory system and touch or joint movement the somatic system. This initial electrical signal is graded, that is, the stronger the stimulus, the larger the signal. If the electrical signal generated in the receptor is large enough, it eventually results in the generation of an action potential, or nerve impulse, in a nerve cell. Action potentials are the signals that are transmitted along the axon, the fiber of the nerve cell. Sometimes an action potential is generated in the same cell that produces the initial graded response to the stimulus. Sometimes the graded signal is transmitted across several cells before it reaches a cell that can generate an action potential. All action potentials carried by an axon are quite similar in shape and amplitude. Therefore all information about the stimulus must be coded by which cells fire and by the pattern of their firing.

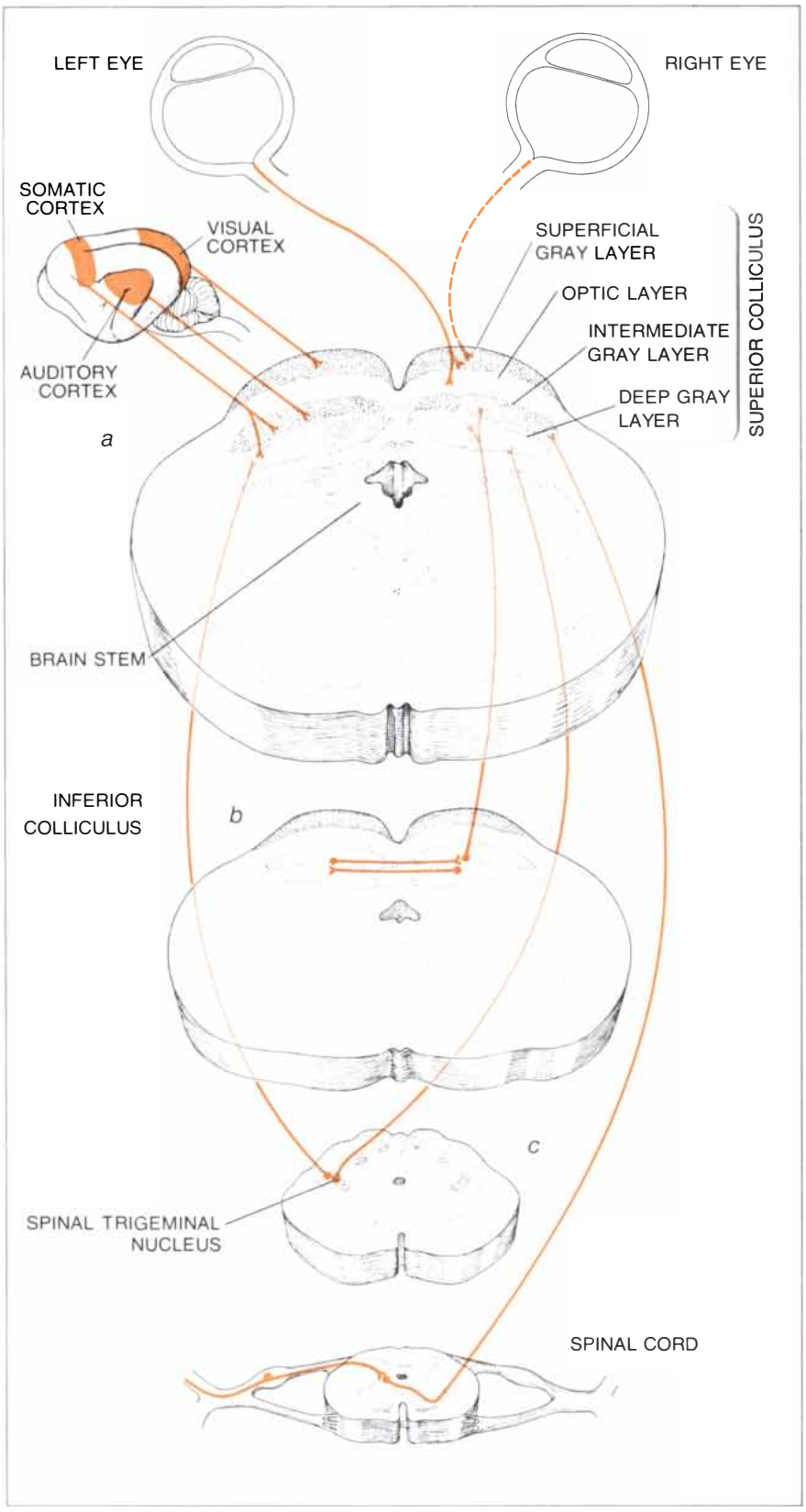
Most of the complex processing of sensory information goes on not within the sense organ itself but within the

brain and spinal cord. Sensory information is conveyed from the sense organ to the brain by action potentials traveling along axons. The terminal of each axon makes contact with other nerve cells in the brain at the junctions called synapses. At most synapses the arrival of an action potential results in the release of a small amount of chemical transmitter. The transmitter substance flows across the synaptic cleft onto the outer membrane of the next cell: the "postsynaptic" cell. The effect of this chemical substance on the postsynaptic cell can be either excitatory or inhibitory, that is, it can either increase or decrease the probability that the postsynaptic cell will generate an action potential.

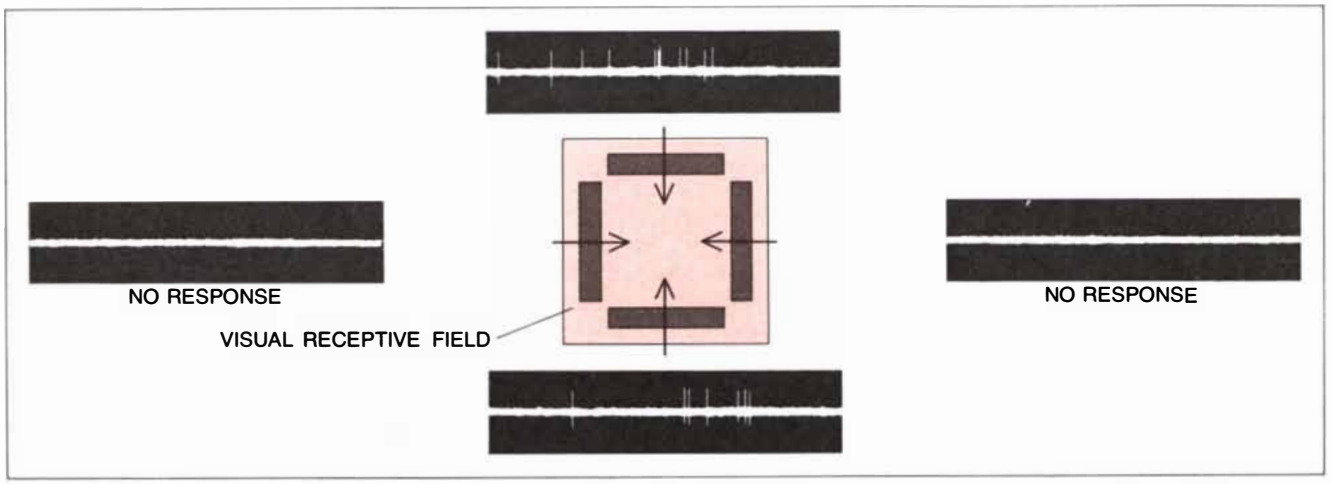
Information from each type of sense organ is processed along a separate sensory pathway. A sensory pathway consists of peripheral sense organs and several clusters of nerve cells called nuclei. Sensory information is processed in several stages, so that each nucleus receives input from the preceding one, processes the input and sends an output to the next nucleus.

Each primary sensory pathway ends in a specific area of the cerebral cortex termed a primary sensory receiving area. For most sensory systems we know quite a lot about how stimulus properties are coded by individual cells along the pathway from the sense organ to the cortex. (The auditory system is somewhat less well understood than the visual and somatic ones.) Little is known, however, about how the outputs of the cortical receiving areas are used by the remainder of the brain. The visual system is to some extent an exception: the functioning of two visual areas beyond the primary visual cortex is fairly well understood.

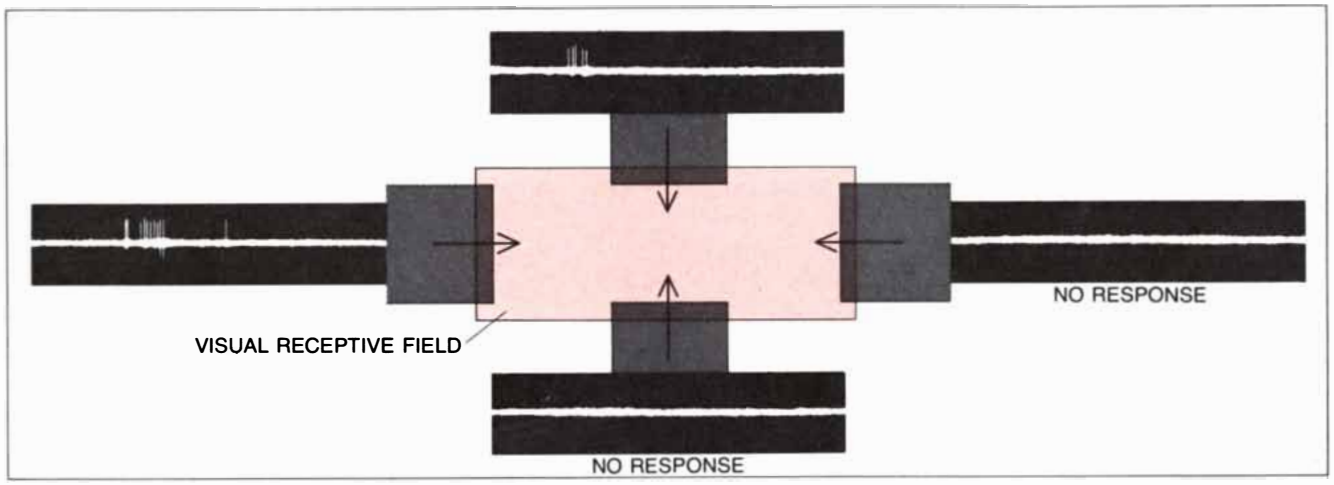
Since each cell along the sensory pathway can receive excitatory and inhibitory inputs from a large variety of sensory receptors and from a large variety of other nerve cells, the precise stimulus requirements for a cell can quickly become quite complicated. For example, visual information from the receptors is processed in a rather complex way before it ever leaves the retina [see "Retinal Processing of Visual Images," by Charles R. Michael; SCIENTIFIC AMERICAN, May, 1969]. The retinal ganglion cells, the cells sending their axons from the eye to the brain, represent the final stage in this processing. These cells receive their visual input, by way of several layers of retinal cells, from a large number of visual receptors. Retinal ganglion cells can be influenced



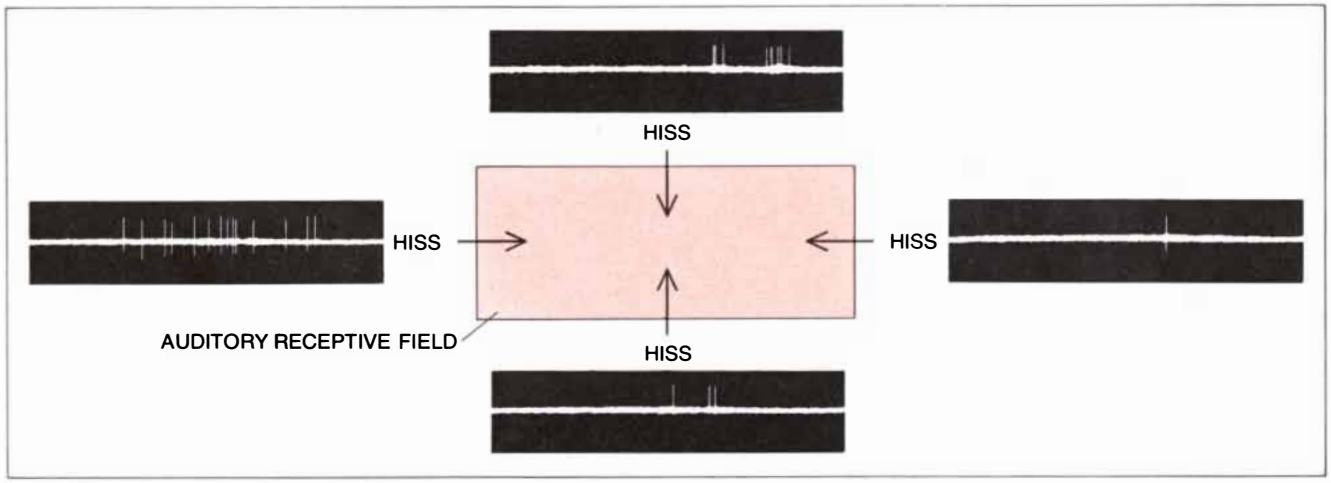
VARIETY OF SENSORY STIMULI converge on the superior colliculus, which is shown here in section (*a*). For simplicity and emphasis only one set of contralateral nerve pathways from the eyes and the spinal cord are depicted. The nerve projections from the spinal trigeminal complex (*c*), however, are bilateral and are so drawn. The retinal projection goes chiefly to the superficial gray layer and optic layer of the superior colliculus. A secondary projection from the ipsilateral eye is shown by a broken line. Nerve projections from the auditory cortex and the inferior colliculus (which is part of the auditory system) terminate chiefly in intermediate and deep gray layers. Projections from somatic cortex, somatic brain-stem nuclei and spinal cord also go mostly to intermediate and deep gray layers.



STUDIES OF VISUAL CORTEX of the cat led to the surprising finding that most of the complex cells in that part of the brain respond only to specific visual fields and only to specific stimuli entering those fields. David H. Hubel and Torsten N. Wiesel of the Harvard Medical School found, for example, that certain complex cortical cells respond strongly to a dark horizontal bar moved slowly up and down in the cell's visual receptive field (*colored square*) but not at all to same bar moved horizontally. Other cells respond to other shapes, orientations and movements. The author extended such studies to the superior colliculus (*see illustrations below*).



RESPONSE OF COLLICULAR CELL lying in the intermediate gray layer is distinctly different from that of a typical complex cell in the visual cortex. The cell responds strongly when a dark "tongue" is moved into the cell's visual receptive field (*colored rectangle*) from the left, responds less strongly when the tongue enters the field from above and responds not at all when it enters from either the right or the bottom. The visual receptive field is 10 degrees wide and four degrees high; tongue is three degrees wide.



AUDITORY RESPONSE is also exhibited by the collicular cell whose response to visual stimuli is illustrated above. The sound stimulus is the hiss of a partially constricted air hose that is moved across the auditory receptive field in direction indicated by arrows.

by light in a small, roughly circular region of the retina. That region is known as the cell's receptive field. The receptive field consists of two regions: a central circular region and a concentric surround. The firing of the cell is increased by a light shining on the central region and decreased by a light shining on the surround, or vice versa.

By the time visual information has reached the visual cortex, each cell has more complex stimulus requirements. For example, many cells in the visual cortex fire only when their receptive fields are stimulated by light or dark bars or edges with a specific orientation, a specific width and a specific length [see "The Visual Cortex of the Brain," by David H. Hubel; SCIENTIFIC AMERICAN, November, 1963]. Similarly, the auditory system incorporates cells that respond to a sound only if that sound is within a specific frequency band and is within a specific portion of the auditory field. Cells in the somatic system usually respond only to one kind of stimulus (touch, hair movement or joint movement) in one region of the body.

In summary, most cells that are part of a primary sensory pathway respond only to stimuli that meet fairly rigid requirements. Such cells are well designed to determine exactly what the stimulus is, for example how big, how wide or how long. Cells with rigid stimulus requirements are not well designed, however, to help an animal orient itself to a poorly perceived stimulus so that it can better determine the precise nature of the stimulus. A significant part of this task may be performed by the superior colliculus. Not only does the superior colliculus receive a great deal of precise sensory information but also it receives each kind of information over at least two pathways.

First, it receives input from cells that are also part of the pathway leading to the cortex. Second, it receives input from the cortical sensory receiving areas. Visual input reaches the colliculus directly from the retinal ganglion cells and from the visual cortex. Auditory input originates both in the inferior colliculus and in the auditory cortex. Somatic information reaches the superior colliculus directly from the spinal cord, from the dorsal-column nuclei and from the somatic cortex [*see illustration on page 73*].

It has been known for a long time that the visual information received by the superior colliculus is topographically organized. Each of the two bumps of the superior colliculus receives information from the contralateral visual field. In other words, the left colliculus sees the right visual field (that is, the entire visual field to the right of a fixation point) and the right colliculus sees the left visual field. The projections from the retina and the cortex to the colliculus are precisely organized. Each portion of the superior colliculus receives input from retinal cells and from cortical cells that respond to the same portion of the visual field. Cells in the front portion of the colliculus have receptive fields near the fixation point; cells in the rear portion of the colliculus have receptive fields in the peripheral regions of the retina. Cells in the portion of the colliculus nearest the midline of the brain have receptive fields in the upper portion of the visual field and cells in the portion of the colliculus nearest the side of the brain have receptive fields in the lower portion of the visual field. Recent experiments in my laboratory at the University of Oregon have shown that the auditory and somatic inputs to the colliculus are also topographically organized, although the topography is not as precise for these stimuli as it is for the visual input.

Many different types of experiment have been done in the attempt to find out how the superior colliculus of cats and primates processes sensory information and what kinds of information the colliculus provides to the rest of the brain. (Experiments on other species will not be discussed here.) Although most of these experiments have concentrated on the processing of visual information, they have also provided some knowledge about the way the colliculus utilizes auditory and somatic information.

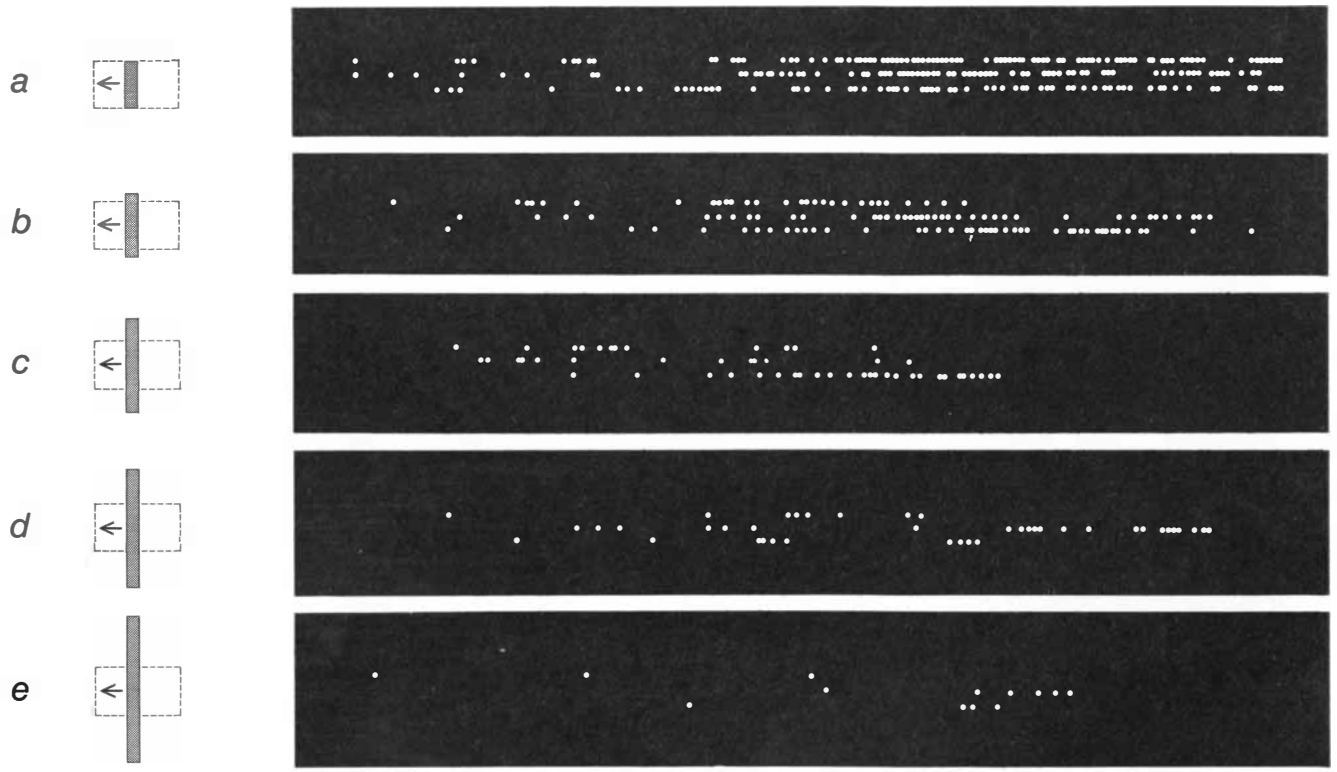
Perhaps the oldest method used is the lesion method. The colliculus can be eliminated from the brain of an experimental animal by removing it surgically or by passing large amounts of electric current through it. After making such a lesion one can compare the responses of normal and lesioned animals to a large variety of stimuli. The results of these experiments are difficult to interpret in detail for several reasons. First of all, it is difficult to make precisely the same lesion twice. Second, a lesion that removes the entire colliculus frequently invades surrounding areas, whereas lesions that are strictly confined to the colliculus frequently do not succeed in removing the entire structure. Third, the fact that a particular kind of behavior remains after a collicular lesion does not mean that the colliculus has no influence on that behavior. A few clear facts have nonetheless emerged from the lesion studies.

Tauba Pasik, Pedro Pasik and Morris B. Bender of the Mount Sinai School of Medicine have shown that removing the colliculus either unilaterally (on one side of the brain) or bilaterally (on both sides of the brain) does not eliminate eye movements. Although the animals showed some deficits in eye movement immediately after the lesion, one month later all the animals could move their eyes spontaneously in all directions and exhibited normal reflex eye movements in response to a particular kind of stimulation of the ear canal (flushing the canal with cold or hot water). Apparently normal eye movements were also obtained when the animals were placed inside a rotating drum lined with vertical black and white stripes.

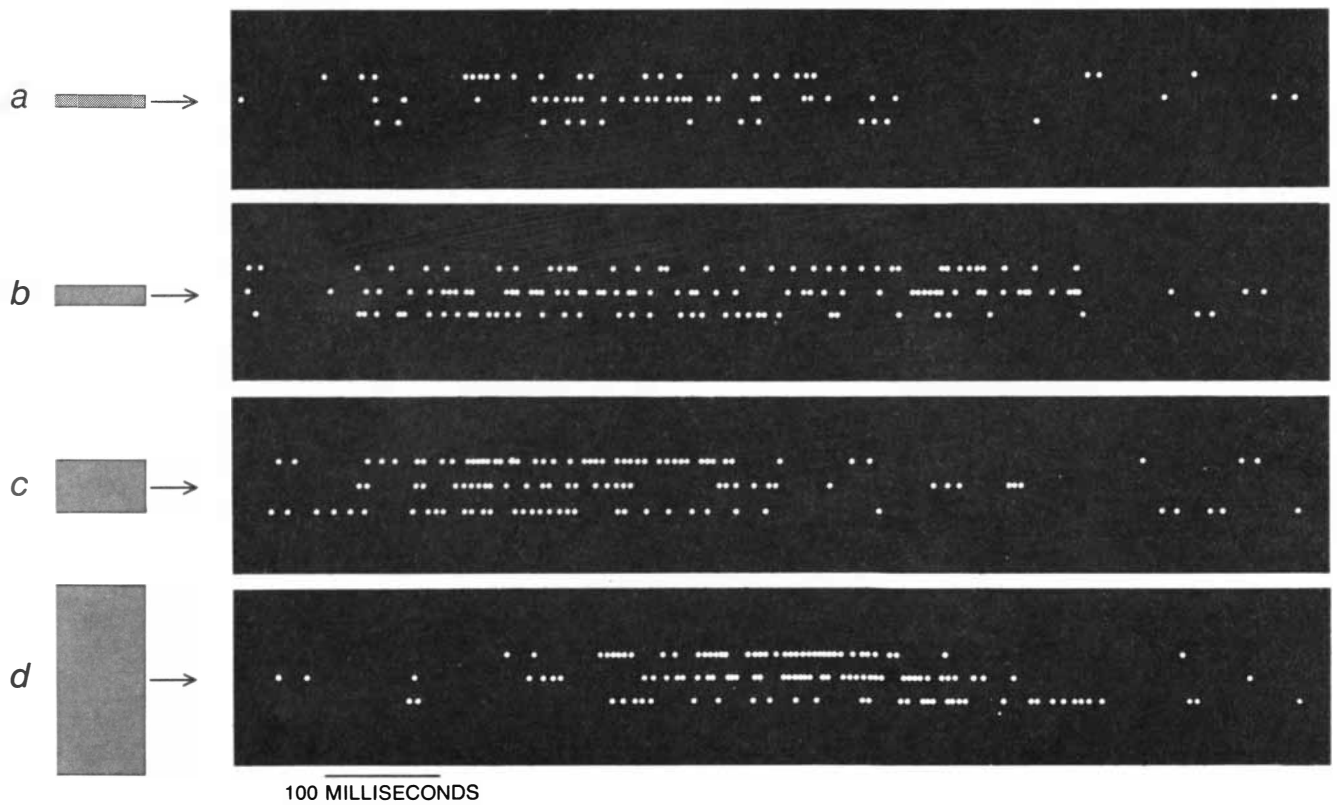
James M. Sprague and Thomas H. Meikle, Jr., of the University of Pennsylvania School of Medicine have done an extensive study on the effects of superior colliculus lesions in cats. They found that immediately after a unilateral lesion had been made the animals were completely unable to follow objects in the visual field contralateral to the lesioned colliculus, although they could move their eyes in all directions. (Remember that each colliculus receives visual information only from the contralateral visual field.)

A month later the animals responded to visual stimuli in the contralateral field if the stimuli were within 60 degrees of the midline. The animals rarely responded to stimuli presented beyond 60 degrees into the contralateral visual field. Immediately after the lesion had been made the animals failed to orient themselves consistently to sounds in the contralateral auditory field, and the pinna (the external ear structure) contralateral to the lesion did not move in response to sound. Although orienting responses to auditory stimuli gradually improved with time, they never became entirely normal. For the first month after the lesion had been made the animals were also unable to localize somatic stimuli on the contralateral side of the body.

Bilateral collicular lesions, like unilateral ones, did not eliminate eye movement. Even immediately after the lesions had been made the animals showed approximately normal eye movements in response to rotation of their bodies. The animals were unable, however, to visually locate small stationary objects or to follow them. They also had some difficulty in lifting their gaze above the horizontal. Although the



INCREASING SIZE OF STIMULUS, in this case a moving slit of light against a dark surround, evokes a smaller and smaller response from a cell in the superficial portion of the colliculus. The author has found that the maximum response results when the slit matches the width of the visual receptive field (*a*). When the slit is longer, it invades the suppressive region of the receptive field, and the response decreases. Each dot in the illustration represents a nerve impulse in three successive recordings for each stimulus.



RESPONSE OF CELL DEEPER in the colliculus is not suppressed when the size of the stimulus is increased. The deep cell also has a much larger visual receptive field than the cell whose response is shown in the illustration at the top of the page. The deep cell responds to any moving stimulus in the entire contralateral visual field, beginning in a region that is 11 degrees contralateral to the center of vision. This is not a general finding; more than half of the cells in the deeper layers do have suppressive regions.

ability of the animal to localize objects in space improved greatly during the second month following the lesion, it never became entirely normal. These experiments suggest that whereas the cat's ability to make eye movements does not depend on an intact superior colliculus, the superior colliculus does contribute to the animal's ability to use head and eye movements to localize sensory stimuli accurately and to follow them.

This general interpretation is supported by some quite recent experiments conducted at the National Institute of Mental Health by Robert H. Wurtz and Michael E. Goldberg. They have trained monkeys to sit in a chair and to move their eyes from one visual target to another. The monkeys were initially trained to fixate on a small light. When the light went off and a second light went on, the monkeys learned to shift their gaze to fixate on the second target. Wurtz and Goldberg then made a lesion in the portion of the colliculus containing the cells that responded to the second target. After the lesion had been made the animals were still able to move their eyes toward the second target, but the eye movements took from 150 to 300 milliseconds longer than they had before the lesion had been made. This deficit, like other deficits following collicular lesions, waned over a period of several weeks. Although the monkeys, unlike the cats, did not lose their ability to orient themselves to visual stimuli after collicular lesions had been made, they could not do so as efficiently after the operation as before it. The collicular-lesion experiments on cats and monkeys may not be entirely comparable, however, because Sprague and Meikle removed the entire colliculus of their cats whereas Wurtz and Goldberg made large but incomplete lesions in their monkeys.

If the superior colliculus aids an animal in changing its fixation point and in responding to visual stimuli, collicular lesions might be expected to impair performance in a pattern-discrimination task, if the task requires frequent changes in fixation point. Sprague and his colleagues have shown this to be the case in another series of experiments on cats. They found that superior colliculus lesions did not impair a cat's ability to discriminate between two patterns if the task was learned before the lesion was made but greatly impaired the animal's ability to learn new discrimination tasks of the same type.

Perhaps performing a previously learned pattern-discrimination task requires only a single shift of fixation point. The animal already knows what the correct stimulus looks like. If the first stimulus it inspects is incorrect, it has only to shift its gaze to the correct stimulus. When the animal is learning a new discrimination, it may have to shift its gaze from one stimulus to the other many times in order to determine what features distinguish the correct stimulus from the incorrect one. Collicular lesions seem to make the latter task much more difficult.

A second technique that has been used to elucidate the role of the colliculus in controlling eye movement is electrical stimulation. If electrodes are inserted into the colliculus and small amounts of electric current are passed through them, action potentials will be evoked in a large number of cells near the electrode. (The current must be kept small so as not to produce collicular lesions.) Electrical stimulation causes large numbers of cells to fire synchronously, whereas in response to natural sensory stimuli cells probably fire in precisely determined sequences. In spite of the abnormal firing patterns that must result from electrical stimulation, eye movements in any given direction can be evoked by stimulation of the appropriate location in the colliculus. Peter H. Schiller of the Massachusetts Institute of Technology has found that the current required to evoke eye movements by stimulating the superior colliculus is only between a third and a tenth of the current required to evoke eye movements by stimulating the visual cortex or the frontal eye fields (a more forward cortical area that may be involved in eye-movement control). This observation suggests, but does not prove, that the colliculus is more directly involved in eye movements than either the visual cortex or the frontal eye fields.

Schiller and David A. Robinson of the Johns Hopkins School of Medicine independently observed that the size and direction of eye movements evoked by the electrical stimulation of the colliculus depended on the exact location of the stimulating electrodes. The eye moved to the portion of the visual field that is mapped onto the stimulated portion of the colliculus. For example, stimulation of the medial colliculus evoked upward eye movements, and the more medial the stimulation, the larger the upward component of the eye movement. Increasing the duration of the stimulus did not increase the extent of the eye movement but resulted instead in a series of eye movements, each having the same magnitude and direction as the others. The eye movements resulting from collicular stimulation were independent of the initial position of the eye in the socket.

This result implies that the colliculus codes eye movement rather than eye position. Presumably the activity of cells in a particular part of the colliculus indicates the position of the stimulus with respect to the current center of gaze of the animal and not with respect to the center of the head. For instance, if an animal wants to change its fixation point to fixate on an object that suddenly appears in the visual field at a position 20 degrees above and 10 degrees to the right of the current point of fixation, it will have to make an eye movement with a vertical component of 20 degrees upward and a horizontal component of 10 degrees to the right. And of course the extent and direction of the eye movement must be independent of the initial position of the center of gaze with respect to the head.

A third method of studying the superior colliculus is to examine the sensory receptive fields of collicular cells and compare them with the sensory receptive fields of cells in the primary sensory pathways. This kind of study has been pursued most intensively with collicular cells that respond to visual stimuli, although some properties of cells that respond to auditory and somatic stimuli have also been investigated. A few years ago Peter Sterling and I, working in the laboratory of David H. Hubel and Torsten N. Wiesel at the Harvard Medical School, set out to study the receptive fields of cells in the superficial layers of the superior colliculus of cats. In our experiments the cat faced a screen 57 inches away. While a microelectrode was lowered through the colliculus, patterns of light and dark stimuli, such as light and dark bars and tongue-shaped figures, were shown on the screen. We attempted to find the receptive field for each cell we recorded from and to characterize the visual stimuli that were most effective in evoking action potentials from the cell.

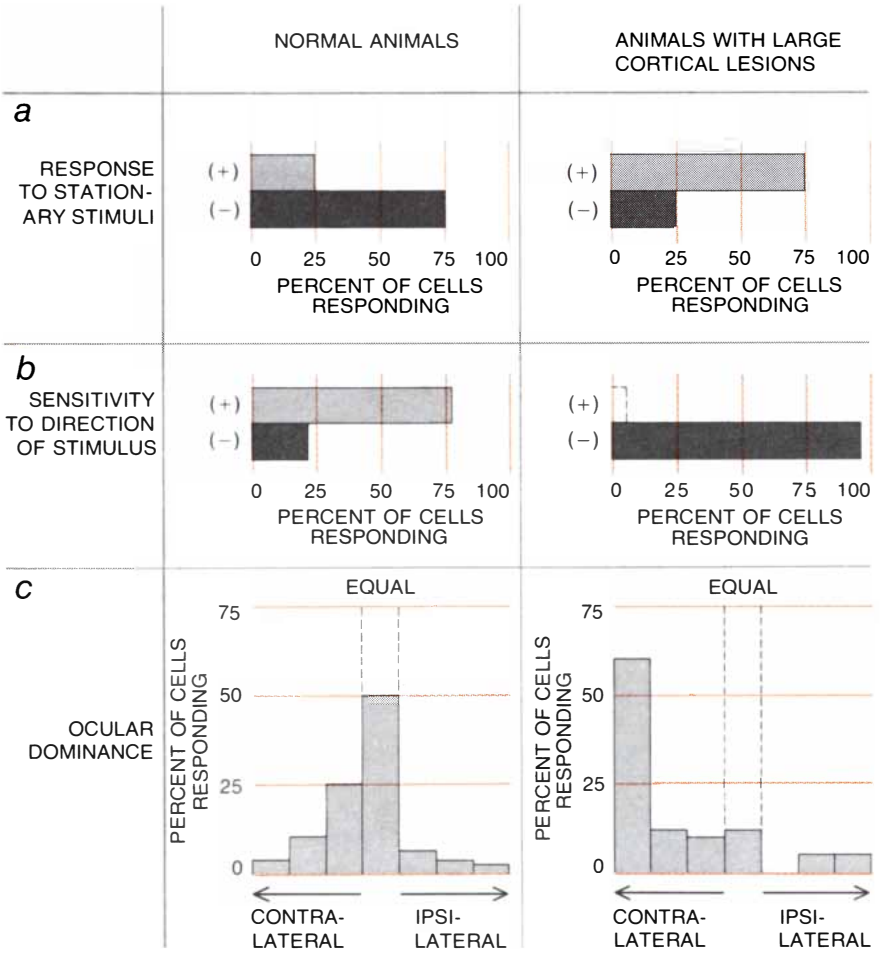
The first thing we noticed was that the collicular receptive fields were usually from two to four times bigger than the receptive fields of the visual cortex cells whose receptive fields are in the same portion of the visual field. We also noticed that most collicular cells responded only to moving stimuli. Stationary stimuli that were flashed on and off within the receptive field were al-

most completely ineffective for most cells. About three-quarters of the cells tested were also directionally selective. That means that they responded well to movement in one direction and poorly or not at all to movement in the diametrically opposite direction. Hubel and Wiesel had previously shown that many cells in the visual cortex are also directionally selective.

The directional selectivity of cells in the cortex, however, is quite different from the directional selectivity of cells in the colliculus. First, changing the orientation of the stimulus and the direction of its movement from the optimum to 20 or 30 degrees away from optimum causes a profound decrease in the response of cortical cells but caused little or no decrease in the response of collicular cells. In fact, stimuli moving 90 degrees to the preferred direction often evoked quite a vigorous response from collicular cells, although such stimuli would be completely ineffective for cortical cells.

Hence collicular cells responded over a much wider range of directions of movement than cortical cells do. Second, for collicular cells the null direction, the direction that evokes the least response, was always diametrically opposite to the preferred direction, whereas for cortical cells the null direction is 90 degrees to the preferred direction and movement opposite to the preferred direction usually evokes some response [*see two upper illustrations on page 74*]. Third, there is no indication in the visual cortex that any one preferred direction is commoner than any other.

In the colliculus, however, the distribution of preferred directions was nonuniform in two respects. In the first place, for most directionally selective units the preferred direction was either parallel to the horizontal meridian of the visual field or made an angle of less than 45 degrees to it. In the second place, for more than three-quarters of the directionally selective units the horizontal component of the preferred direction was away from the center of gaze and toward the periphery of the visual field. Therefore most units recorded in the right colliculus had receptive fields in the left field of vision and responded best to movement going from right to left. This result has been confirmed and extended by the work of M. Straschill and K. P. Hoffman of the Max Planck Institute for Psychiatry in Munich, who found that cells with receptive fields in the upper portion of the visual field had preferred directions with upward vertical components, whereas cells with receptive fields in the lower portion of the visual field had preferred directions with downward vertical components.



CORTICAL INFLUENCE ON COLLICULUS was studied by removing most of the visual cortex of cats. Three main effects were observed. In animals with large cortical lesions most collicular cells respond to stationary stimuli, whereas in normal animals most cells are unresponsive (*a*). After emplacement of lesions collicular cells are no longer sensitive to direction visual stimuli are moving (*b*). In animals with cortical lesions most of the collicular cells respond almost exclusively to stimulation of the contralateral eye, whereas almost all collicular cells in normal animals can be driven by stimulation of either eye (*c*).

We also observed that cortical cells are much fussier about the size and shape of the stimulus than collicular cells. A typical complex cortical cell responds only to a slit, a bar or an edge. Cortical cells also have stringent requirements for the width and orientation of the stimulus. Hypercomplex cortical cells require that the stimulus also have a specific length.

In contrast, most collicular cells responded well to a wide range of stimulus sizes and shapes. For some 90 percent of the cells, however, the receptive field consisted of both an activating region and a suppressive region just outside the activating one. Stimuli confined to the activating region (even if they were much smaller than that region) evoked a vigorous response. If, however, the stimulus was made large enough to invade the suppressive region, the cell's firing rate began to decrease [*see top illustration on page 76*]. Thus cells in the superficial layers of the cat's superior colliculus tend to be more responsive to small moving objects than they are to large ones.

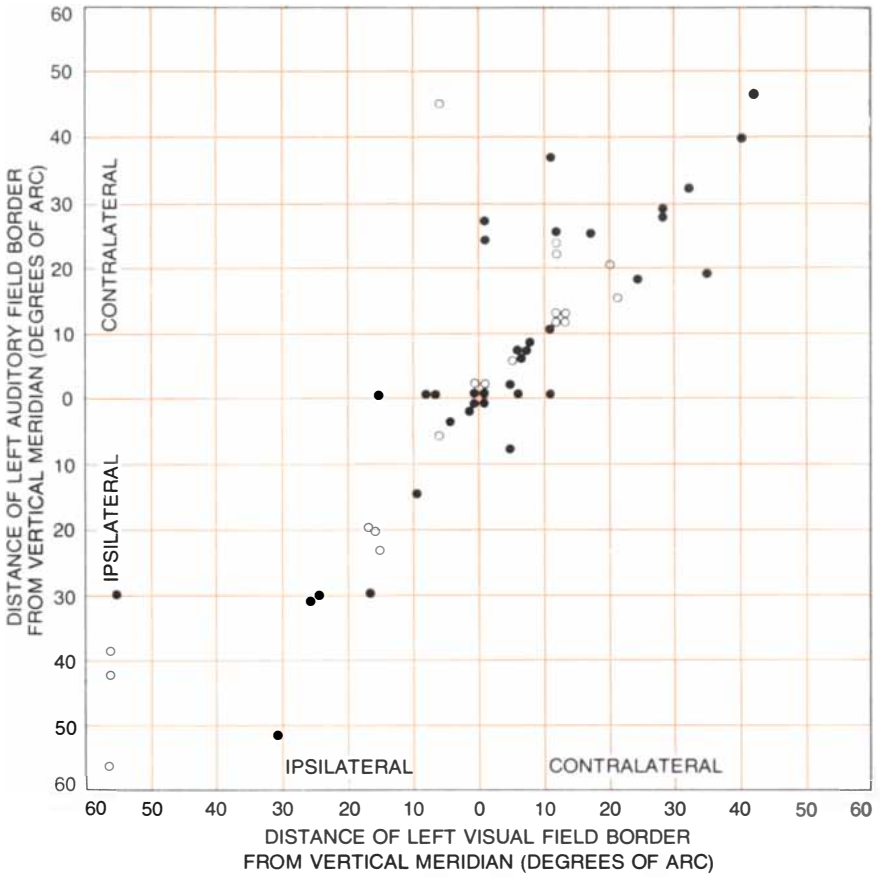
The relative insensitivity of collicular cells to the size, shape and orientation of stimuli suggests that the colliculus is not concerned with exactly what the stimulus is but is primarily concerned with its direction of movement. Superior colliculus cells are most likely to be activated if the stimulus is moving toward the periphery of the visual field. That is exactly the information an animal needs in order to control its head and eye movements and prevent a stimulus from leaving its visual field.

Sterling and I were puzzled about

why collicular cells should exhibit such loose requirements for the size and shape of stimuli, considering that they receive sensory input from visual-cortex cells that have precise stimulus requirements. In order to investigate the function of the cortical input to the colliculus we removed the visual cortex from several cats. Two weeks after removal of the visual cortex we found three changes in the properties of collicular receptive fields [*see illustration on opposite page*].

First, we found no cells that we could be certain were directionally selective. Second, nearly all the cells were now driven only by the contralateral eye. In the normal colliculus most of the cells can be driven by either eye. This result is what one would expect from the anatomy. Most cortical cells are binocularly driven and therefore the collicular cells with which they are connected by synapses are also binocularly driven. The retinal input to the colliculus, on the other hand, is primarily from the contralateral eye; relatively little input is from the ipsilateral eye. Third, somewhat more cells could be driven by stationary stimuli flashed on and off within the receptive field in the lesioned animals than in normal animals.

Although many of the precise features of cortical receptive fields are lost when the axons of many cortical cells converge on a single collicular cell, the essential properties of collicular receptive fields depend on the presence of the cortical projection to the colliculus. Thus the colliculus cannot perform its normal function without receiving the results of the cortical processing of visual information.



VISUAL AND AUDITORY RECEPTIVE FIELDS, when mapped for deep collicular cells, exhibit a high degree of congruence. The solid dots represent the location of the leading borders of the receptive fields for cells that responded to both visual and auditory stimuli. The open circles represent location of leading receptive-field borders for cells that respond only to auditory stimuli. The position of the visual receptive-field borders for such cells was assumed to be the field border of the nearest cell that responded to visual stimuli.

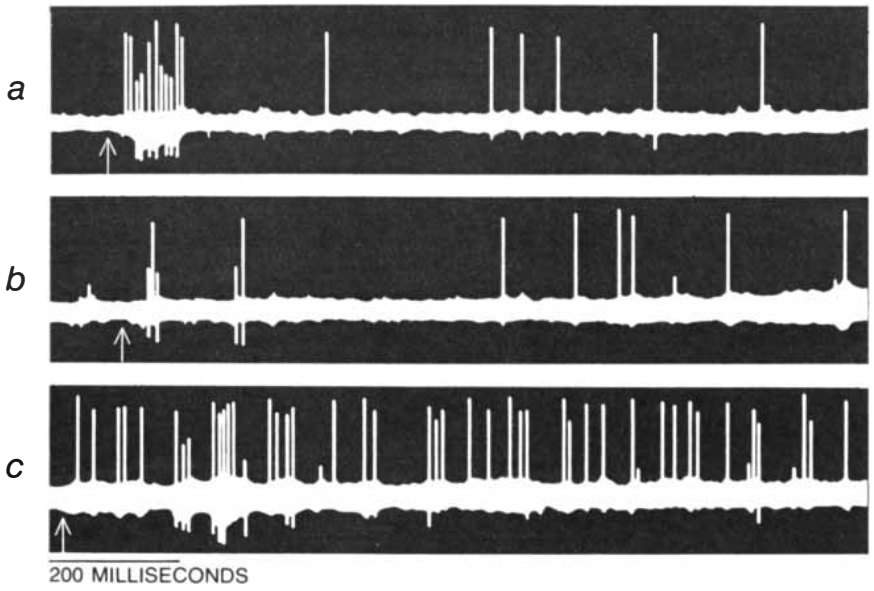
When I moved to the University of Oregon, I became increasingly interested in investigating the properties of cells in the deeper layers of the cat's superior colliculus. Sterling and I had not studied these cells at Harvard because we found that in animals anesthetized with barbiturates, which we had used in our experiments, the cells simply did not respond to sensory stimulation. At Oregon I developed a procedure, similar to one used in a number of other laboratories, in which collicular cells could be studied in an unanesthetized animal.

The animals involved in these experiments were prepared several weeks before the actual recording by implantation in their skulls of four sterile bolts and a well with a screw-on cap. During the experiments the animal's head was supported by the bolts and the electrode was lowered through the well. Thus the animals had no open wounds or pressure points and did not have to be anesthetized. I found that most of the cells in the deeper layers have visual receptive fields that are quite similar to the visual receptive fields of cells in the superficial layers. The fields, however, were extremely large, sometimes covering an entire quadrant or half of the visual field. Moreover, the deep cells responded to an even wider variety of stimulus sizes and shapes than the superficial cells.

The most striking change encountered when the electrode left the superficial layers and entered the deeper layers was the presence of cells that responded to auditory and somatic stimuli. Some cells responded only to auditory stimuli or somatic stimuli, but a large number responded to both visual and auditory stimuli and a few to both visual and somatic stimuli. Cells that responded to auditory stimuli responded most vigorously to complex sounds such as the hiss made by air moving through a partially constricted hose.

The most striking characteristic of cells responding to both auditory and visual stimuli was that many of their requirements for auditory stimuli were similar to their requirements for visual stimuli. The cells had auditory receptive fields just as they had visual receptive fields. That is, they did not respond to sounds placed anywhere with respect to the cat's ears just as they did not respond to visual stimuli placed anywhere with respect to the cat's eyes. In fact, there was a striking correlation, although far from an exact correspondence, between the position of the leading edge of the visual receptive field and the position of the leading edge of the auditory receptive field. (The leading edge of the receptive field is the edge where the stimulus first evokes a response from a collicular cell as it enters the receptive field in the preferred direction.) Thus the colliculus embodies not only a topographic map of visual space but also a topographic map of auditory space.

Most of the cells that respond to sound required a moving stimulus.



TOUCH SENSITIVITY is exhibited by cells in the colliculus of a cat. The particular cell represented here responded when something lightly touched any part of the dorsal and lateral surface of the animal's foreleg. The arrows under the traces show when the stimulus was applied. The cell responds with a short burst of impulses when touched with a camel's-hair brush (*a*). When the foreleg is pinched sharply, however, there is no evident change in the cell's random firing pattern (*b*). When the camel's-hair brush is moved lightly across the somatic receptive field (*c*), the cell responds with a sustained volley of impulses. The collicular cell also responds to visual stimuli in the lower portion of the right visual field.

Turning a stationary stimulus on and off within the receptive field was relatively ineffective. Many cells were directionally selective for both auditory and visual stimuli, and the horizontal component of the preferred direction was nearly always toward the periphery of the contralateral field for both kinds of stimulus [*see illustration on preceding page*].

Some of the cells responded to the tactile stimulation of a distinct area of the body, such as the contralateral foot or forepaw. The most effective stimulus for these cells was usually a camel's-hair brush, which ruffled the cat's hair as it was moved across the receptive field. Stationary stimuli were largely ineffective. The touch-sensitive cells were clearly not designed to detect painful stimuli because they responded no better to pressure or a pinch than to a light touch [*see illustration above*].

Although rather few of the cells responded to both visual and somatic stimuli, the position of a cell's somatic receptive field was related to the receptive-field positions of nearby cells that responded to visual stimuli. Thus the deep layers of the superior colliculus seem to embody superposed topographic maps of the visual, auditory and somatic fields. These maps are much less precise than the maps found in the nuclei of the primary sensory pathways and in the superficial collicular layers; moreover, the receptive fields of individual cells are much larger than the receptive fields of cells in the primary sensory pathways.

Cells in the deeper layers of the superior colliculus seem to be able to integrate information about the approximate location and direction of movement of the stimuli that impinge on both the auditory and visual systems. The activity of nearby cells encodes the approximate location of the somatic stimuli. It seems reasonable to conclude that the colliculus aids in visual orienting, searching and tracking, regardless of the type of stimulus that initiates the movements.

Most animals do not orient themselves repeatedly to repeated presentations of the same stimulus unless the animal is rewarded or punished for responding to it. This decline in response is termed habituation. One might therefore expect collicular cells to become habituated to repeated presentations of the same stimulus, and indeed that is what happens in the deep layers of the superior colliculus of heavily anesthetized cats. (Habituation also makes it frustratingly difficult for the experimenter to check his notions of the optimal stimulus for any given cell.) Wurtz and Goldberg have recently performed an ingenious experiment with monkeys demonstrating that the collicular cells become habituated only when the stimulus has no behavioral significance for the animal. The particular cells they examined were in the superficial layers of the colliculus.

The animals were trained to fixate on a small spot of light. They were then rewarded for shifting their fixation point to a second spot of light if the second spot was turned on and simultaneously the first spot was turned off. This can be called the eye-movement condition. If both lights remained on, the animals maintained fixation on the first spot (the no-movement condition). Wurtz and Goldberg recorded from single cells in the superior colliculus of the trained animals under both conditions.

First they presented the no-eye-movement condition: the animal fixated one spot and the cell responded (as expected) to a second spot of light turned on within the cell's receptive field. When the second spot was presented repeatedly, however, the response of the cell habituated. (Monkey collicular cells, unlike those in cats, are not directionally selective and do not require moving stimuli.) Wurtz and Goldberg then presented the eye-movement condition: the fixation stimulus was turned off at the instant the receptive-field stimulus was turned on. The monkey then made a saccade (a rapid eye movement) toward the receptive-field stimulus. (After the saccade, of course, the receptive-field stimulus was no longer within the receptive field of the cell they were recording from.) The response of the cell did not habituate during repeated presentations of the eye-movement condition. In fact, the initial response was sometimes enhanced, that is, the cell fired more often during the eye-movement condition than it did in response to the first presentation of this stimulus during the no-eye-movement condition. The enhancement was specific for movement elicited by stimuli within the cell's receptive field. There was no enhancement if the eye stimulus controlling eye movements was outside the cell's receptive field.

The enhancement also did not require actual eye movement, only that the stimulus have a behavioral significance for the animal. When the animal was returned to the no-movement condition, the enhanced response of the cell was maintained for several trials [*see illustration on opposite page*]. Thus the enhanced response seems to be related to the animal's "paying attention" to the stimulus. Perhaps the habituation of collicular cells in the deeply anesthetized cat results from the animal's in-

ability to move its eyes in response to sensory stimuli and its "inattention" to subsequent presentations of the same stimulus.

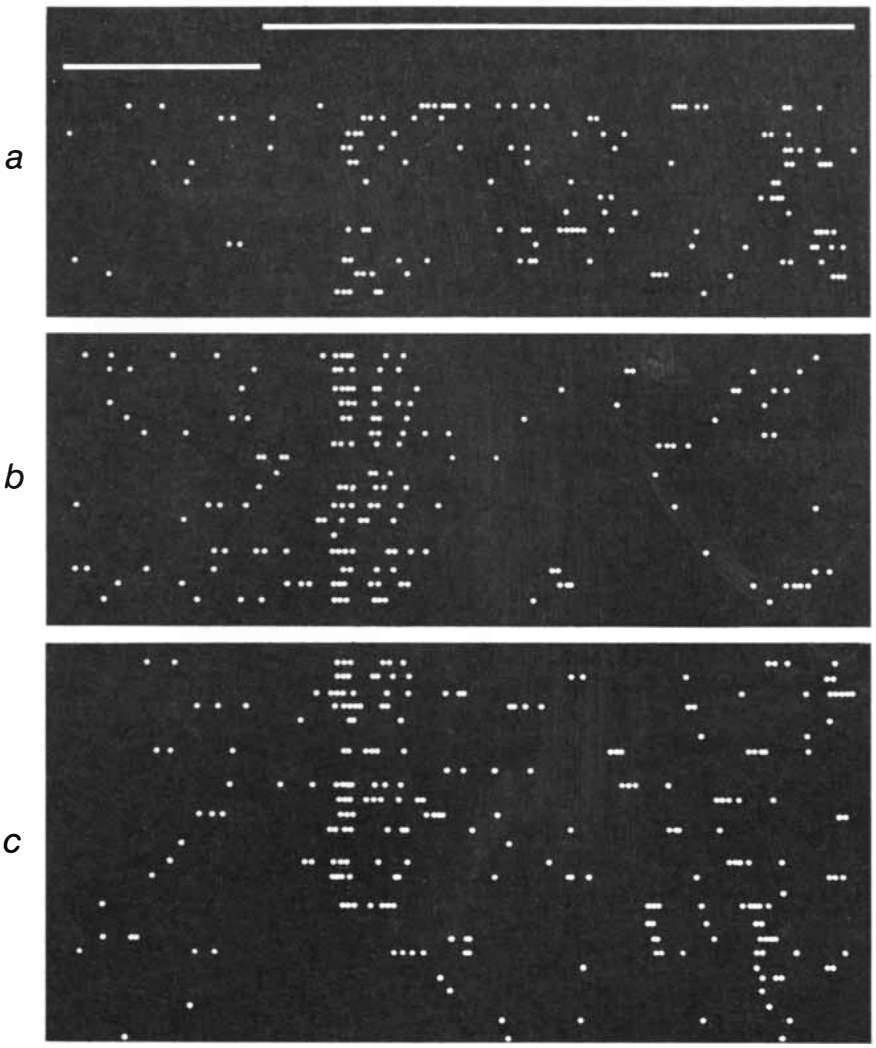
Perhaps the most direct demonstration that cells in the superior colliculus are intimately related to eye movement comes from experiments in which monkeys were trained to move their eyes in a specific way and the behavior of collicular cells was examined while the monkeys were making such movements. Experiments of this type have been done independently by Schiller at M.I.T. and by Wurtz and Goldberg. They found that cells in the superficial layers of the monkey superior colliculus had visual receptive fields but did not respond in relation to eye movements. The activity of many cells in the deep layer, however, was clearly related to eye movements.

In Wurtz and Goldberg's laboratory these cells were studied in experiments quite similar to those used to study the enhancement responses. The animals were trained to move their eyes when one fixation point was turned off and a second one turned on in a different part of the visual field. The cells that responded in relation to eye movements began to respond between 30 and 300 milliseconds before the beginning of the eye movement. The timing of the cells' response was more closely correlated with the onset of the eye movement than it was with the presentation of the visual stimulus eliciting the movement.

Each cell has what Wurtz and Goldberg call a movement field, that is, the cell responds only in conjunction with eye movements toward a particular area of the visual field. The notion of a movement field implies that the cells respond only in conjunction with eye movements of a particular extent. If an animal moves its eyes in the direction of the movement field but the movement stops short of the movement field or extends beyond the farthest border of the movement field, the cell does not fire. And of course if the eyes move in a direction other than toward the movement field, the cell also does not fire. Many of the cells that responded in relation to eye movement also had visual receptive fields. For any given cell the visual receptive field and the movement field were in the same portion of the visual field, but they were usually not precisely superposed.

The movement field of a single cell was independent of the initial position of the eyes in the head. This finding is just what one would expect from knowing that the size and direction of eye movements elicited by electrical stimulation of the colliculus are independent of the position of the eyes in the head. The cells of the superior colliculus do not code for a specific amount of tension on each of the muscles that move the eyes but may code specific changes in fixation. Wurtz and Goldberg point out that because the movement fields of collicular cells are rather large, sometimes as much as 10 or 20 degrees on a side, the active cells probably do no more than turn the animal's eyes to the general region of the visual field where the stimulus appears; they are unlikely to provide the fine control needed for precise visual fixation.

The general conception emerging from these studies of the superior colliculus and visual cortex of cats and monkeys is that the cortex processes sensory information in order to determine "what the stimulus is." The colliculus determines "where the stimulus is and where it is going" in order to bring the stimulus into the center of



EFFECT OF REWARDING EYE RESPONSE is shown in these three sets of recordings from the superior colliculus of a monkey. The break in the horizontal line at the top shows when a visual stimulus in the receptive field of the collicular unit is turned on. Each line of dots shows how a collicular cell responds to one presentation of the stimulus. The set of traces in *a* shows the response of the unit when the stimulus has acquired no behavioral significance for the animal, that is, a fixation light is not turned off when the receptive-field light is turned on. The stimulus is then presented as the second light in a two-light sequence; the fixation light is turned off when the receptive-field light is turned on. When the animal shifts its gaze quickly to the second light, it is rewarded. Such an eye shift is called a saccade. The traces in *b* show the enhanced firing of the collicular unit after such saccades have acquired behavioral significance. The traces in *c* show a sequence when the two lights are again presented as in *a* (the no-eye-movement condition). Collicular unit fires in enhanced fashion for a short while, then its firing decreases. Experiment was performed by Robert H. Wurtz and Michael E. Goldberg of the National Institute of Mental Health.

the visual field and keep it there. Different experimental methods have nonetheless provided somewhat different types of information.

Collicular lesions in cats cause deficits in orienting to visual, auditory and somatic stimuli and in learning visual tasks that require frequent changes in fixation. Collicular lesions also decrease the speed with which monkeys can change their fixation point. Electrical stimulation of the colliculus in monkeys causes eye movements; the size and direction of the movement depend on the portion of the colliculus that is stimulated. Studies of receptive fields show that single cells in the cat colliculus respond to visual and auditory stimuli moving away from the animal. Presumably the responses of these cells cause eye movements that keep the stimuli within the visual field, but this connection has not yet been demonstrated.

The response of cells in the monkey colliculus to visual stimuli rapidly becomes habituated if the stimulus has no behavioral significance for the animal. The response is maintained and even enhanced, however, if visual tracking is rewarded. Finally, the deep layers of the monkey colliculus contain cells that respond before eye movements of a specific size and direction. It seems reasonable to suppose that the output of these cells helps to trigger the eye movement. We know little about how the output is transmitted to the motor cells that control head or eye movements. We do know that there are no monosynaptic (that is, direct) connections from the colliculus to either the motor-nerve cells that move the eyes or the motor-nerve cells in the neck that turn the head.

Thus we are still in the dark about many aspects of the role of the superior colliculus in controlling the movement of the head and the eye. It is a puzzle how the output of the colliculus can specify an eye movement independently of the initial position of the eye in its socket. Nor do we know how the colliculus receives information that a particular eye movement has been made. Does it receive sensory information indicating that the attempted tracking has been successful or does it receive feedback directly from motor-nerve cells? We know nothing about how the motor-nerve cells innervating neck and eye muscles combine information from the colliculus with information from other portions of the brain in order to determine which muscles should contract and hence how the head and eyes should move.

"LASER LIGHT"

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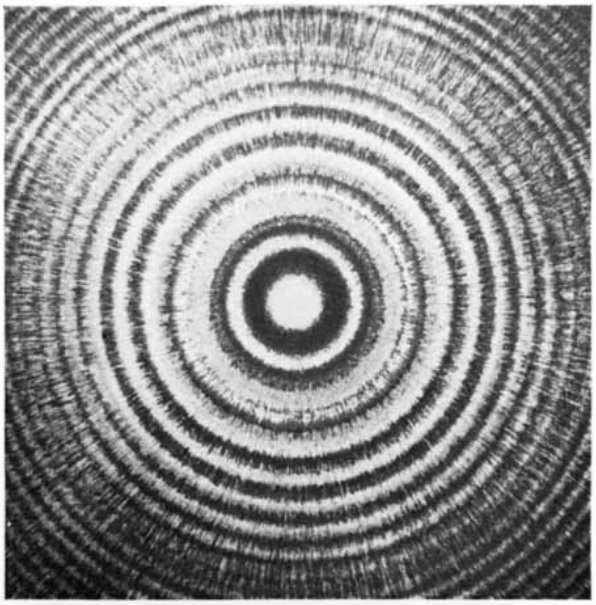

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Prematurity and Uniqueness in Scientific Discovery

A molecular geneticist reflects on two general historical questions: (1) What does it mean to say a discovery is "ahead of its time"? (2) Are scientific creations any less unique than artistic creations?

by Gunther S. Stent

The fantastically rapid progress of molecular genetics in the past 25 years now obliges merely middle-aged participants in its early development to look back on their early work from a depth of historical perspective that for scientific specialties flowering in earlier times came only after all the witnesses of the first blossoming were long dead. It is as if the late-18th-century colleagues of Joseph Priestley and Antoine Lavoisier had still been active in chemical research and teaching in the 1930's, after atomic structure and the nature of the chemical bond had been revealed. This somewhat depressing personal vantage provides a singular opportunity to assay the evolution of a scientific field. In reflecting on the history of molecular genetics from the viewpoint of my own experience I have found that two of its most famous incidents—Oswald Avery's identification of DNA as the active principle in bacterial transformation and hence as genetic material, and James Watson and Francis Crick's discovery of the DNA double helix—illuminate two general problems of cultural history. The case of Avery throws light on the question of whether it is meaningful or merely tautologous to say that a discovery is "ahead of its time," or premature. And the case of Watson and Crick can be used, and in fact has been used, to discuss the question of whether there is anything unique in a scientific discovery, in view of the likelihood that if Dr. *A* had not discovered Fact *X* today, Dr. *B* would have discovered it tomorrow.

Five years ago I published a brief retrospective essay on molecular genetics, with particular emphasis on its origins. In that historical account I mentioned neither Avery's name nor DNA-mediated bacterial transformation. My essay elicited a letter to the editor by a microbiologist, who complained: "It is a sad and surprising omission that... Stent makes no mention of the definitive proof of DNA as the basic hereditary substance by O. T. Avery, C. M. MacLeod and Maclyn McCarty. The growth of [molecular genetics] rests upon this experimental proof.... I am old enough to remember the excitement and enthusiasm induced by the publication of the paper by Avery, MacLeod and McCarty. Avery, an effective bacteriologist, was a quiet, self-effacing, non-disputatious gentleman. These characteristics of personality should not [cause] the general scientific public...to let his name go unrecognized."

I was taken aback by this letter and replied that I should indeed have mentioned Avery's 1944 proof that DNA is the hereditary substance. I went on to say, however, that in my opinion it is not true that the growth of molecular genetics rests on Avery's proof. For many years that proof actually had little impact on geneticists. The reason for the delay was not that Avery's work was unknown to or mistrusted by geneticists but that it was "premature."

My *prima facie* reason for saying Avery's discovery was premature is that it was not appreciated in its day. By lack of appreciation I do not mean that Avery's discovery went unnoticed, or even that it was not considered important. What I do mean is that geneticists did not seem to be able to do much with it or build on it. That is, in its day Avery's discovery had virtually no effect on the general discourse of genetics.

This statement can be readily supported by an examination of the scientific literature. For example, a convincing demonstration of the lack of appreciation of Avery's discovery is provided by the 1950 golden jubilee of genetics symposium "Genetics in the 20th Century." In the proceedings of that symposium some of the most eminent geneticists published essays that surveyed the progress of the first 50 years of genetics and assessed its status at that time. Only one of the 26 essayists saw fit to make more than a passing reference to Avery's discovery, then six years old. He was a colleague of Avery's at the Rockefeller Institute, and he expressed some doubt that the active transforming principle was really pure DNA. The then leading philosopher of the gene, H. J. Muller of Indiana University, contributed an essay on the nature of the gene that mentions neither Avery nor DNA.

So why was Avery's discovery not appreciated in its day? Because it was "premature." But is this really an explanation or is it merely an empty tautology? In other words, is there a way of providing a criterion of the prematurity of a discovery other than its failure to make an impact? Yes, there is such a criterion: A discovery is premature if its implications cannot be connected by a series of simple logical steps to canonical, or generally accepted, knowledge.

Why could Avery's discovery not be connected with canonical knowledge? Ever since DNA had been discovered in the cell nucleus by Friedrich Miescher in 1869 it had been suspected of exerting some function in hereditary processes. This suspicion became stronger

in the 1920's, when it was found that DNA is a major component of the chromosomes. The then current view of the molecular nature of DNA, however, made it well-nigh inconceivable that DNA could be the carrier of hereditary information. First, until well into the 1930's DNA was generally thought to be merely a tetranucleotide composed of one unit each of adenylic, guanylic, thymidylic and cytidylic acids. Second, even when it was finally realized by the early 1940's that the molecular weight of DNA is actually much higher than the tetranucleotide hypothesis required, it was still widely believed the tetranucleotide was the basic repeating unit of the large DNA polymer in which the four units mentioned recur in regular sequence. DNA was therefore viewed as a uniform macromolecule that, like other monotonous polymers such as starch or cellulose, is always the same, no matter what its biological source. The ubiquitous presence of DNA in the chromosomes was therefore generally explained in purely physiological or structural terms. It was usually to the chromosomal protein that the informational role of the genes had been assigned, since the great differences in the specificity of structure that exist between various proteins in the same or-

PICASSO'S "LES DESMOISELLES D'AVIGNON," painted in Paris in 1907, is often cited by art historians as the first major Cubist painting and a milestone in the development of modern art. It is reproduced here as an archetype of the proposition that works of artistic creation are unique (in the sense that if Picasso had not existed, it would never have been painted), whereas works of scientific creation are inevitable (in the sense that if Dr. *A* had not discovered Fact *X* today, Dr. *B* would discover it tomorrow). The validity of the proposition is disputed by the author. The painting is in the collection of the Museum of Modern Art in New York.

ganism, or between similar proteins in different organisms, had been appreciated since the beginning of the century. The conceptual difficulty of assigning the genetic role to DNA had not escaped Avery. In the conclusion of his paper he stated: "If the results of the present study of the transforming principle are confirmed, then nucleic acids must be regarded as possessing biological specificity the chemical basis of which is as yet undetermined."

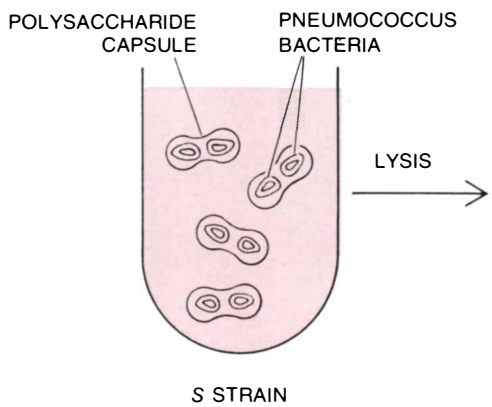
By 1950, however, the tetranucleotide hypothesis had been overthrown, thanks largely to the work of Erwin Chargaff of the Columbia University College of Physicians and Surgeons. He showed that, contrary to the demands of that hypothesis, the four nucleotides are not necessarily present in DNA in equal proportions. He found, furthermore, that the exact nucleotide composition of DNA differs according to its biological source, suggesting that DNA might not be a monotonous polymer after all. And so when two years later, in 1952, Alfred Hershey and Martha Chase of the Carnegie Institution's laboratory in Cold Spring Harbor, N.Y., showed that on infection of the host bacterium by a bacterial virus at least 80 percent of the viral DNA enters the cell and at least 80 percent of the viral protein remains outside, it was possible to connect their conclusion that DNA is the genetic material with canonical knowledge. Avery's "as yet undetermined chemical basis of the biological specificity of nucleic acids" could now be seen as the precise sequence of the four nucleotides along the polynucleotide chain. The general impact of the Hershey-Chase experiment was immediate and dramatic. DNA was suddenly in and protein was out, as far as thinking about the nature of the gene was concerned. Within a few months there arose the first speculations about the genetic code, and Watson and Crick were inspired to set out to discover the structure of DNA.

Of course, Avery's discovery is only one of many premature discoveries in the history of science. I have presented it here for consideration mainly because of my own failure to appreciate it when I joined Max Delbrück's bacterial virus group at the California Institute of Technology in 1948. Since then I have often wondered what my later career would have been like if I had only been astute enough to appreciate Avery's discovery and infer from it four years before Hershey and Chase that DNA must also be the genetic material of our own experimental organism.

Probably the most famous case of prematurity in the history of biology is associated with the name of Gregor Mendel, whose discovery of the gene in 1865 had to wait 35 years before it was "rediscovered" at the turn of the century. Mendel's discovery made no immediate impact, it can be argued, because the concept of discrete hereditary units could not be connected with canonical knowledge of anatomy and physiology in the middle of the 19th century. Furthermore, the statistical methodology by means of which Mendel interpreted the results of his pea-breeding experiments was entirely foreign to the way of thinking of contemporary biologists. By the end of the 19th century, however, chromosomes and the chromosome-dividing processes of mitosis and meiosis had been discovered and Mendel's results could now be accounted for in terms of structures visible in the microscope. Moreover, by then the application of statistics to biology had become commonplace. Nonetheless, in some respects Avery's discovery is a more dramatic example of prematurity than Mendel's. Whereas Mendel's discovery seems hardly to have been mentioned by anyone until its rediscovery, Avery's discovery was widely discussed and yet it could not be appreciated for eight years.

Cases of delayed appreciation of a discovery exist also in the physical sciences. One example (as well as an explanation of its circumstances in terms of the concept to which I refer here as prematurity) has been provided by Michael Polanyi on the basis of his own experience. In the years 1914–1916 Polanyi published a theory of the adsorption of gases on solids which assumed that the force attracting a gas molecule to a solid surface depends only on the position of the molecule, and not on the presence of other molecules, in the force field. In spite of the fact that Polanyi was able to provide strong experimental evidence in favor of his theory, it was generally rejected. Not only was the theory rejected, it was also considered so ridiculous by the leading authorities of the time that Polanyi believes continued defense of his theory would have ended his professional career if he had not managed to publish work on more palatable ideas. The reason for the general rejection of Polanyi's adsorption theory was that at the very time he put it forward the role of electrical forces in the architecture of matter had just been discovered. Hence there seemed to be no doubt that the adsorption of gases must also involve an electrical attraction between the gas molecules and the solid surface. That point of view, however, was irreconcilable with Polanyi's basic assumption of the mutual independence of individual gas molecules in the adsorption process. It was only in the 1930's, after a new theory of cohesive molecular forces based on quantum-mechanical resonance rather than on electrostatic attraction had been developed, that it became conceivable gas molecules could behave in the way Polanyi's experiments indicated they were actually behaving. Meanwhile Polanyi's theory had been consigned so authoritatively to the ashcan of crackpot ideas that it was rediscovered only in the 1950's.

Still, can the notion of prematurity be said to be a useful historical concept? First of all, is prematurity the only possible explanation for the lack of contemporary appreciation of a discovery? Evidently not. For example, my microbiologist critic suggested that it was the "quiet, self-effacing, non-disputatious" personality of Avery that was the cause of the failure of his contribution to be recognized. Furthermore, in an essay on the history of DNA research Chargaff supports the idea that personal modesty and aversion to self-advertisement account for the lack of contemporary scientific appreciation. He attributes the 75-year lag between Miescher's discovery of DNA and the general appreciation of its importance to Miescher's being "one of the quiet in the land," who lived when "the giant publicity machines, which today accompany even the smallest move on the chess-board of nature with enormous fanfares, were not yet in place." Indeed, the 35-year hiatus



EXPERIMENT OF 1944 with which Oswald Avery correctly identified the chemical nature of the genetic material is regarded by the author as a classic example of a premature scientific discovery. The virulent normal, or S-type, pneumococcus, a bacteri-

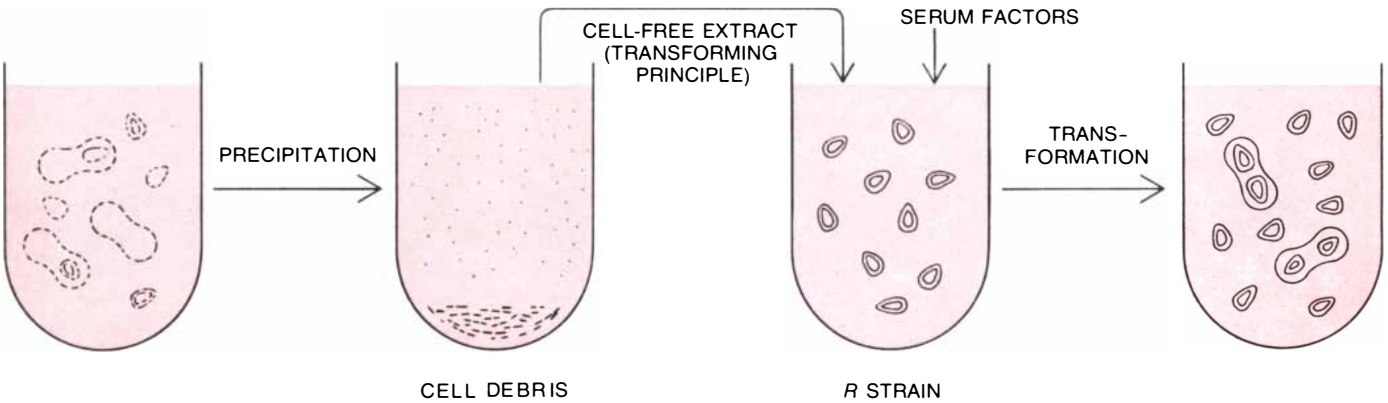
in the appreciation of Mendel's discovery is often attributed to Mendel's having been a modest monk living in an out-of-the-way Moravian monastery. Hence the notion of prematurity provides an alternative to the invocation—in my opinion an inappropriate one for the instances mentioned here—of the lack of publicity as an explanation for delayed appreciation.

More important, does the prematurity concept pertain only to retrospective judgments made with the wisdom of hindsight? No, I think it can be used also to judge the present. Some recent discoveries are still premature at this very time. One example of here-and-now prematurity is the alleged finding that experiential information received by an animal can be stored in nucleic acids or other macromolecules.

Some 10 years ago there began to appear reports by experimental psychologists purporting to have shown that the engram, or memory trace, of a task learned by a trained animal can be transferred to a naïve animal by injecting or feeding the recipient with an extract made from the tissues of the donor. At that time the central lesson of molecular genetics—that nucleic acids and proteins are informational macromolecules—had just gained wide currency, and the facile equation of nervous information with genetic information soon led to the proposal that macromolecules—DNA, RNA or protein—store memory. As it happens, the experiments on which the macromolecular theory of memory is based have been difficult to repeat, and the results claimed for them may indeed not be true at all. It is nonetheless significant that few neurophysiologists have even bothered to check these experiments, even though it is common knowledge that the possibility of chemical memory transfer would constitute a fact of capital importance. The lack of interest of neurophysiologists in the macromolecular theory of memory can be accounted for by recognizing that the theory, whether true or false, is clearly premature. There is no chain of reasonable inferences by means of which our present, albeit highly imperfect, view of the functional organization of the brain can be reconciled with the possibility of its acquiring, storing and retrieving nervous information by encoding such information in molecules of nucleic acid or protein. Accordingly for the community of neurophysiologists there is no point in devoting time to checking on experiments whose results, even if they were true as alleged, could not be connected with canonical knowledge.

The concept of here-and-now prematurity can be applied also to the troublesome subject of ESP, or extrasensory perception. In the summer of 1948 I happened to hear a heated argument at Cold Spring Harbor between two future mandarins of molecular biology, Salvador Luria of Indiana University and R. E. Roberts of the Carnegie Institution's laboratory in Washington. Roberts was then interested in ESP, and he felt it had not been given fair consideration by the scientific community. As I recall, he thought that one might be able to set up experiments with molecular beams that could provide more definitive data on the possibility of mind-induced departures from random distributions than J. B. Rhine's then much discussed card-guessing procedures. Luria declared that not only was he not interested in Roberts' proposed experiments but also in his opinion it was unworthy of anyone claiming to be a scientist even to discuss such rubbish. How could an intelligent fellow such as Roberts entertain the possibility of phenomena totally irreconcilable with the most elementary physical laws? Moreover, a phenomenon that is manifest only to specially endowed subjects, as claimed by "parapsychologists" to be the case for ESP, is outside the proper realm of science, which must deal with phenomena accessible to every observer. Roberts replied that far from him being unscientific, it was Luria whose bigoted attitude toward the unknown was unworthy of a true scientist. The fact that not everyone has ESP only means that it is an elusive phenomenon, similar to musical genius. And just because a phenomenon cannot be reconciled with what we now know, we need not shut our eyes to it. On the contrary, it is the duty of the scientist to try to devise experiments designed to probe its truth or falsity.

It seemed to me then that both Luria and Roberts were right, and in the intervening years I often thought about this puzzling disagreement, unable to resolve it in my own mind. Finally six years ago I read a review of a book on ESP by my Berkeley colleague C. West Churchman, and I began to see my way toward a resolution. Churchman stated that there are three different possible scientific approaches to ESP. The first of these is that the truth or falsity of ESP, like the truth or falsity of the existence of God or of the immortality of the soul, is totally independent of either the methods or the findings of empirical science. Thus the problem of ESP is de-



um that causes pneumonia in mammals, is enclosed in a smooth (hence *S*) polysaccharide capsule that protects the bacterium from the ordinary defense mechanisms of the infected animal. The avirulent mutant, or *R*-type (*R* for rough), strain has lost the genetic capacity to form this protective capsule and hence is comparatively harmless. When a "transforming principle" extracted from normal *S* donor bacteria was added to mutant *R* recipient bacteria, some of the mutants were found to regain the genetic capacity to form the capsule and thus were transformed back into the normal, virulent *S* type. Avery purified the transforming principle and succeeded in showing that it is DNA. The significance of Avery's discovery was not appreciated by molecular geneticists until 1952.

fined out of existence. I imagine that this was more or less Luria's position.

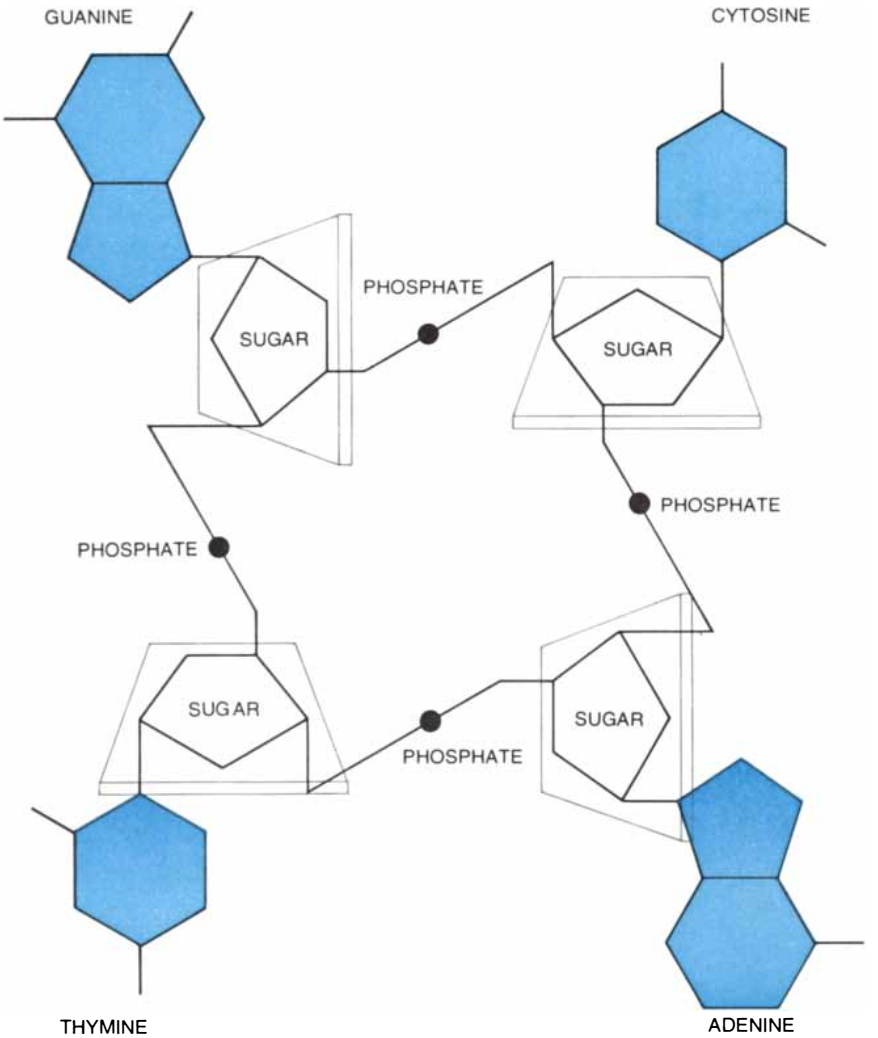
Churchman's second approach is to reformulate the ESP phenomenon in terms of currently acceptable scientific notions, such as unconscious perception or conscious fraud. Hence, rather than defining ESP out of existence, it is trivialized. The second approach probably would have been acceptable to Luria too, but not to Roberts.

The third approach is to take the proposition of ESP literally and to attempt to examine in all seriousness the evidence for its validity. That was more or less Roberts' position. As Churchman points out, however, this approach is not likely to lead to satisfactory results. Parapsychologists can maintain with some justice that the existence of ESP has already been proved to the hilt, since no other set of hypotheses in psychology has received the degree of critical scrutiny that has been given to ESP experiments. Moreover, many other phenomena have been accepted on much less statistical evidence than what is offered for ESP. The reason Churchman advances for the futility of a strictly evidential approach to ESP is that in the absence of a hypothesis of how ESP could work it is not possible to decide whether any set of relevant observations can be accounted for only by ESP to the exclusion of alternative explanations.

After reading Churchman's review I realized that Roberts would have been ill-advised to proceed with his ESP experiments, not because, as Luria had claimed, they would not be "science" but because any positive evidence he might have found in favor of ESP would have been, and would still be, premature. That is, until it is possible to connect ESP with canonical knowledge of, say, electromagnetic radiation and neurophysiology no demonstration of its occurrence could be appreciated.

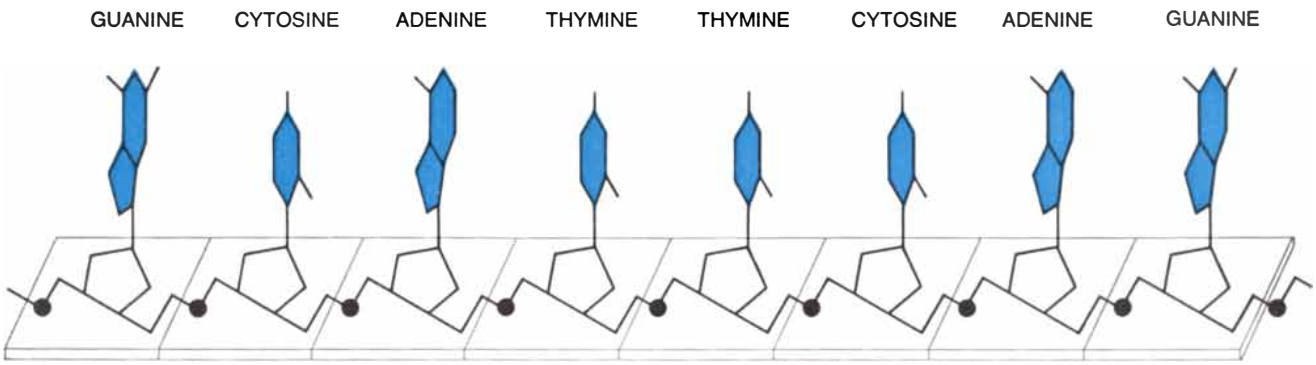
Is the lack of appreciation of premature discoveries merely attributable to the intellectual shortcoming or innate conservatism of scientists who, if they were only more perceptive or more open-minded, would give immediate recognition to any well-documented scientific proposition? Polanyi is not of that opinion. Reflecting on the cruel fate of his theory half a century after first advancing it, he declared: "This miscarriage of the scientific method could not have been avoided.... There must be at all times a predominantly accepted scientific view of the nature of things, in the light of which research is jointly conducted by members of the community of scientists. A strong presumption that any evidence which contradicts this view is invalid must prevail. Such evidence has to be disregarded, even if it cannot be accounted for, in the hope that it will eventually turn out to be false or irrelevant."

That is a view of the operation of science rather different from the one commonly held, under which acceptance of authority is seen as something to be avoided at all costs. The good scientist is seen as an unprejudiced man with an open mind who is ready to embrace any new idea supported by the facts. The history of science shows, however, that its practitioners do not appear to act according to that popular view.



OLD VIEW of the chemical structure of DNA, widely held until well into the 1930's, saw the molecule as being merely a tetranucleotide composed of one unit each of adenylic, guanylic, thymidylic and cytidylic acids. This hypothesis demanded that the molecular weight of DNA be little more than 1,000 and that the four nucleotide bases (adenine, guanine, thymine and cytosine) occur in exactly equal proportions. Even when it was finally realized in the 1940's that the molecular weight of DNA is much higher (in the millions or billions), it was still widely believed that the tetranucleotide was the basic repeating unit of the large DNA polymer. The mistaken belief in this uniform macromolecular structure proved to be an obstacle to the eventual acceptance of the idea that DNA is the genetic material.

Five years ago Chargaff wrote one of the many reviews of *The Double Helix*, Watson's autobiographical account of his and Crick's discovery of the structure of DNA. In his review Chargaff observes that scientific autobiography is "a most awkward literary genre." Most such works, he says, "give the impression of having been written for the remainder tables of bookstores, reaching them almost before they are published." The reasons for this, according to Chargaff, are not far to seek: scientists "lead monotonous and uneventful lives and... besides often do not know how to write." Moreover, "there may also be profounder reasons for the general triteness of scientific autobiographies. *Timon of Athens* could not have been written, 'Les Desmoiselles d'Avignon' not have



PRESENT VIEW of the chemical structure of DNA sees the molecule as a long chain in which the four nucleotide bases can be arranged in any arbitrary order. Although the proportion of adenine is always equal to that of thymine and the proportion of guanine is always equal to that of cytosine, the ratio of adenine-thymine to guanine-cytosine can vary over a large range, depending on the biological source of the DNA. With the elaboration of this single-strand structure it became possible to envision that genetic information is encoded in the DNA molecule as a specific sequence of the four nucleotide bases (*see illustration on next page*).

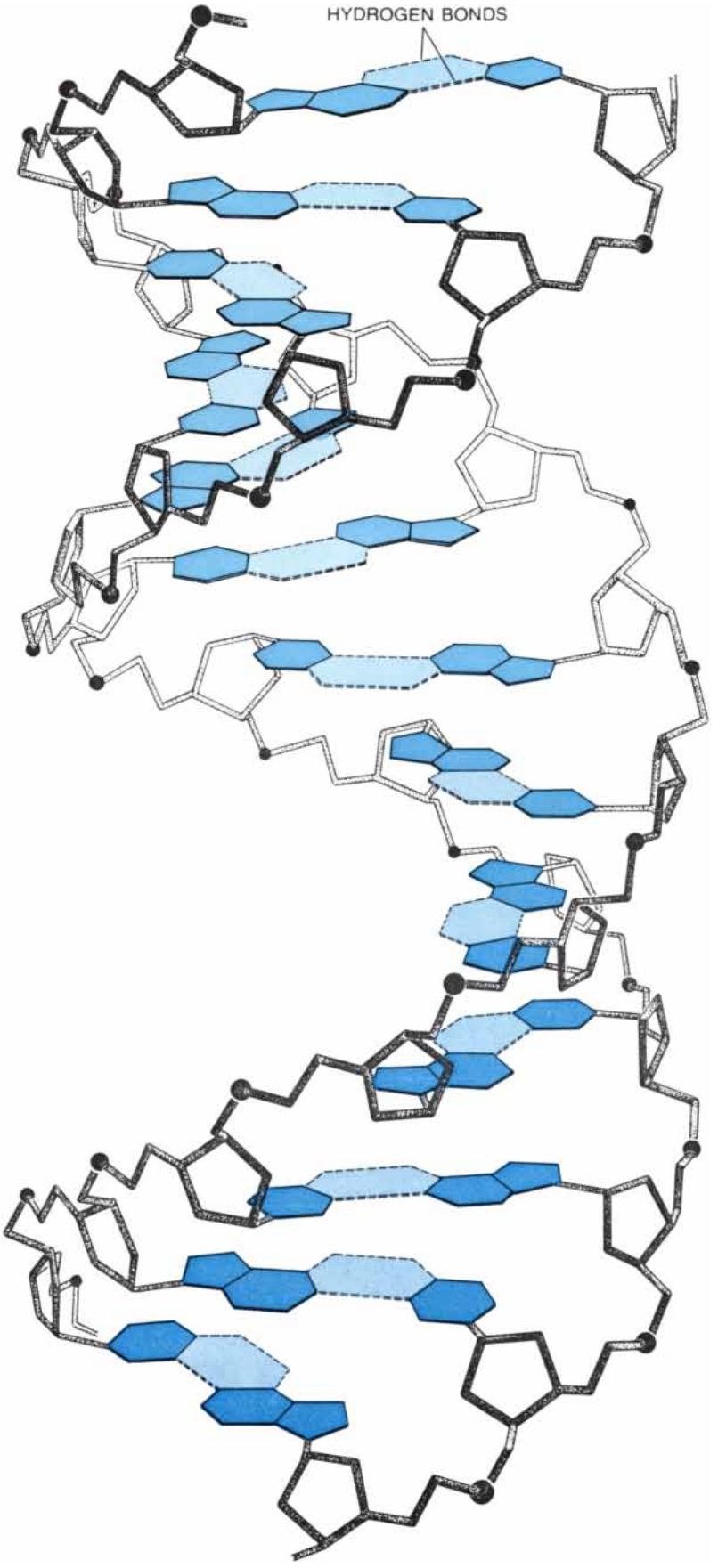
been painted, had Shakespeare and Picasso not existed. But of how many scientific achievements can this be claimed? One could almost say that, with very few exceptions, it is not the men that make science, it is science that makes the men. What *A* does today, *B* or *C* or *D* could surely do tomorrow."

On reading this passage, I found myself in full agreement on the general lack of literary skills among men of science. I was surprised, however, to find an eminent scientist embracing historicism (the theory championed by Hegel and Marx holding that history is determined by immutable forces rather than by human agency) as an explanation for the evolution of science while at the same time professing belief in the libertarian "great man" view of history for the evolution of art. Since it had not occurred to me that anyone could hold such contradictory, and to me obviously false, views concerning these two most important domains of human creation, I began to ask scientific friends and colleagues whether they too, by any chance, thought there was an important qualitative difference between the achievements of art and of science, namely that the former are unique and the latter inevitable. To my even greater surprise, I found that most of them seemed to agree with Chargaff. Yes, they said, it is quite true that we would not have had *Timon of Athens* or "Les Desmoiselles d'Avignon" if Shakespeare and Picasso had not existed, but if Watson and Crick had not existed, we would have had the DNA double helix anyway. Therefore, contrary to my first impression, it does not seem to be all that obvious that this proposition has little philosophical or historical merit. Hence I shall now attempt to show that there is no such profound difference between the arts and sciences in regard to the uniqueness of their creations.

Before discussing the proposition of differential uniqueness of creation it is necessary to make an explicit statement of the meaning of "art" and of "science." My understanding of these terms is based on the view that both the arts and the sciences are activities that endeavor to discover and communicate truths about the world. The domain to which the artist addresses himself is the inner, subjective world of the emotions. Artistic statements therefore pertain mainly to relations between private events of affective significance. The domain of the scientist, in contrast, is the outer, objective world of physical phenomena. Scientific statements therefore pertain mainly to relations between or among public events. Thus the transmission of information and the perception of meaning in that information constitute the central content of both the arts and the sciences. A creative act on the part of either an artist or a scientist would mean his formulation of a new meaningful statement about the world, an addition to the accumulated capital of what is sometimes called "our cultural heritage." Let us therefore examine the proposition that only Shakespeare could have formulated the semantic structures represented by *Timon,* whereas people other than Watson and Crick might have made the communication represented by their paper, "A Structure for Deoxyribonucleic Acid," published in *Nature* in the spring of 1953.

First, it is evident that the exact word sequence that Watson and Crick published in *Nature* would not have been written if the authors had not existed, any more than the exact word sequence of *Timon* would have been written without Shakespeare, at least not until the fabulous monkey typists complete their random work at the British Museum. And so both creations are from that point of view unique. We are not really concerned, however, with the exact word sequence. We are concerned with the content. Thus we admit that people other than Watson and Crick would eventually have described a satisfactory molecular structure for DNA. But then the character of *Timon* and the story of his trials and tribulations not only might have been written without Shakespeare but also were written without him. Shakespeare merely reworked the story of *Timon* he had read in William Painter's collection of classic tales, *The Palace of Pleasure,* published 40 years earlier, and Painter in turn had used as his sources Plutarch and Lucian. But then we do not really care about Timon's story; what counts are the deep insights into human emotions that Shakespeare provides in his play. He shows us here how a man may make his response to the injuries of life, how he may turn from lighthearted benevolence to passionate hatred toward his fellow men. Can one be sure, however, that *Timon* is unique from this bare-bones standpoint of the work's artistic essence? No, because who is to say that if Shakespeare had not existed no other dramatist would have provided for us the same insights? Another dramatist would surely have used an entirely different story (as Shakespeare himself did in his much more successful *King Lear*) to treat the same theme and he might have succeeded in pulling it off. The reason no one seems to have done it since is that Shakespeare had already done it in 1607, just as no one discovered the structure of DNA after Watson and Crick had already discovered it in 1953.

Hence we are finally reduced to as-



WATSON-CRICK MODEL of the structure of DNA, the discovery of which was announced in 1953, can now be described adequately as a double-strand self-complementary helix.

serting that *Timon* is uniquely Shakespeare's, because no other dramatist, although he might have brought us more or less the same insights, would have done it in quite the same exquisite way as Shakespeare. But here we must not shortchange Watson and Crick and take for granted that those other people who eventually would have found the structure of DNA would have found it in just the same way and produced the same revolutionary effect on contemporary biology. On the basis of my acquaintance with the personalities then engaged in trying to uncover the structure of DNA, I believe that if Watson and Crick had not existed, the insights they provided in one single package would have come out much more gradually over a period of many months or years. Dr. *B* might have seen that DNA is a double-strand helix, and Dr. *C* might later have recognized the hydrogen bonding between the strands. Dr. *D* later yet might have proposed a complementary purine-pyrimidine bonding, with Dr. *E* in a subsequent paper proposing the specific adenine-thymine and guanine-cytosine nucleotide pairs. Finally, we might have had to wait for Dr. *G* to propose the replication mechanism of DNA based on the complementary nature of the two strands. All the while Drs. *H, I, J, K* and *L* would have been confusing the issue by publishing incorrect structures and proposals. Thus I fully agree with the judgment offered by Sir Peter Medawar in his review of *The Double Helix:* "The great thing about [Watson and Crick's] discovery was its completeness, its air of finality. If Watson and Crick had been seen groping toward an answer, if they had published a partly right solution and had been obliged to follow it up with corrections and glosses, some of them made by other people; if the solution had come out piecemeal instead of in a blaze of understanding; then it would still have been a great episode in biological history; but something more in the common run of things; something splendidly well done, but not in the grand romantic manner."

Why is it that so many scientists apparently fail to see that it can be said of both art and science that whereas "what *A* does today, *B* or *C* or *D* could surely do tomorrow," *B* or *C* or *D* might nevertheless not do it as well as *A*, in the same "grand romantic manner." I think a variety of reasons can be put forward to account for this strange myopia. The first of them is simply that most scientists are not familiar with the working methods of artists. They tend

to picture the artist's act of creation in the terms of Hollywood: Cornel Wilde in the role of the one and only Frédéric Chopin gazing fondly at Merle Oberon as his muse and mistress George Sand and then sitting down at the Pleyel pianoforte to compose his "Preludes." As scientists know full well, science is done quite differently: Dozens of stereotyped and ambitious researchers are slaving away in as many identical laboratories, all trying to make similar discoveries, all using more or less the same knowledge and techniques, some of them succeeding and some not. Artists, on the other hand, tend to conceive of the scientific act of creation in equally unrealistic terms: Paul Muni in the role of the one and only Louis Pasteur, who while burning the midnight oil in his laboratory has the inspiration to take some bottles from the shelf, mix their contents and thus discover the vaccine for rabies. Artists, in turn, know that art is done quite differently: Dozens of stereotyped and ambitious writers, painters and composers are slaving away in as many identical garrets, all trying to produce similar works, all using more or less the same knowledge and techniques, some succeeding and some not.

A second reason is that the belief in the inevitability of scientific discoveries appears to derive support from the often-told tales of famous cases in the history of science where the same discovery was made independently two or more times by different people. For instance, the independent invention of the calculus by Leibniz and Newton or the independent recognition of the role of natural selection in evolution by Wallace and Darwin. As the study of such "multiple discoveries" by Robert Merton of Columbia University has shown, however, on detailed examination they are rarely, if ever, identical. The reason they are said to be multiple is simply that in spite of their differences one can recognize a semantic overlap between them that is transformable into a congruent set of ideas.

The third, and somewhat more profound, reason is that whereas the cumulative character of scientific creation is at once apparent to every scientist, the similarly cumulative character of artistic creation is not. For instance, it is obvious that no present-day working geneticist has any need to read the original papers of Mendel, because they have been completely superseded by the work of the past century. Mendel's papers contain no useful information that cannot be better obtained from any modern textbook or the current genetical literature. In contrast, the modern writer, composer or painter still needs to read, listen or look at the original works of Shakespeare, Bach or Leonardo, which, so it is thought, have not been superseded at all. In spite of the seeming truth of this proposition, it must be said that art is no less cumulative than science, in that artists no more work in a traditionless vacuum than scientists do. Artists also build on the work of their predecessors; they start with and later improve on the styles and insights that have been handed down to them from their teachers, just as scientists do. To stay with our main example, Shakespeare's *Timon* has its roots in the works of Aeschylus, Sophocles and Euripides. It was those authors of Greek antiquity who discovered tragedy as a vehicle for communicating deep insights into affects, and Shakespeare, drawing on many earlier sources, finally developed that Greek discovery to its ultimate height. To some limited extent, therefore, the plays of the Greek dramatists have been superseded by Shakespeare's. Why, then, have Shakespeare's plays not been superseded by the work of later, lesser dramatists?

Here we finally do encounter an important difference between the creations of art and of science, namely the feasibility of paraphrase. The semantic content of an artistic work—a play, a cantata or a painting—is critically dependent on the exact manner of its realization; that is, the greater an artistic work is, the more likely it is that any omissions or changes from the original detract from its content. In other words, to paraphrase a great work of art—for instance to rewrite *Timon*—without loss of artistic quality requires a genius equal to the genius of the original creator. Such a successful paraphrase would, in fact, constitute a great work of art in its own right. The semantic content of a great scientific paper, on the other hand, although its impact at the time of publication may also be critically dependent on the exact manner in which it is presented, can later be paraphrased without serious loss of semantic content by lesser scientists. Thus the simple statement "DNA is a double-strand, self-complementary helix" now suffices to communicate the essence of Watson and Crick's great discovery, whereas "A man responds to the injuries of life by turning from lighthearted benevolence to passionate hatred toward his fellow men" is merely a platitude and not a paraphrase of *Timon*. It took the writing of *King Lear* to paraphrase (and improve on) *Timon*, and indeed the for-

mer has superseded the latter in the Shakespearean dramatic repertoire.

The fourth, and probably deepest, reason for the apparent prevalence among scientists of the proposition that artistic creations are unique and scientific creations are not can be attributed to a contradictory epistemological attitude toward the events in the outer and the inner world. The outer world, which science tries to fathom, is often viewed from the standpoint of materialism, according to which events and the relations between them have an existence independent of the human mind. Hence the outer world and its scientific laws are simply there, and it is the job of the scientist to find them. Thus going after scientific discoveries is like picking wild strawberries in a public park: the berries *A* does not find today *B* or *C* or *D* will surely find tomorrow. At the same time, many scientists view the inner world, which art tries to fathom, from the standpoint of idealism, according to which events and relations between them have no reality other than their reflection in human thought. Hence there is nothing to be found in the inner world, and artistic creations are cut simply from whole cloth. Here *B* or *C* or *D* could not possibly find tomorrow what *A* found today, because what *A* found had never been there. It is not altogether surprising, of course, to find this split epistemological attitude toward the two worlds, since of these two antithetical traditions in Western philosophical thought, materialism is obviously an unsatisfactory approach to art and idealism an unsatisfactory approach to science.

It is only in the past 20 years or so, more or less contemporaneously with the growth of molecular biology, that a resolution of the age-old epistemological conflict of materialism v. idealism was found in the form of what has come to be known as structuralism. Structuralism emerged simultaneously, independently and in different guises in several diverse fields of study, for example in psychology, linguistics, anthropology and biology.

Both materialism and idealism take it for granted that all the information gathered by our senses actually reaches our mind; materialism envisions that thanks to this information reality is mirrored in the mind, whereas idealism envisions that thanks to this information reality is constructed by the mind. Structuralism, on the other hand, has provided the insight that knowledge about the world enters the mind not as raw data but in already highly abstracted form, namely as structures. In the preconscious process of converting the primary data of our experience step by step into structures, information is necessarily lost, because the creation of structures, or the recognition of patterns, is nothing else than the selective destruction of information. Thus since the mind does not gain access to the full set of data about the world, it can neither mirror nor construct reality. Instead for the mind reality is a set of structural transforms of

SCIENTISTS' MISCONCEPTION of the working methods of artists is idealized in this scene from the 1945 Columbia Pictures production *A Song to Remember*. Frédéric Chopin (played by Cornel Wilde), after gazing fondly at his muse George Sand (Merle Oberon), sits down at the Pleyel pianoforte and composes his "Preludes." Science, as any scientist knows, is done quite differently.

primary data taken from the world. This transformation process is hierarchical, in that "stronger" structures are formed from "weaker" structures through selective destruction of information. Any set of primary data becomes meaningful only after a series of such operations has so transformed it that it has become congruent with a stronger structure preexisting in the mind. Neurophysiological studies carried out in recent years on the process of visual perception in higher mammals have not only shown directly that the brain actually operates according to the tenets of structuralism but also offer an easily understood illustration of those tenets.

Finally, we may consider the relevance of structuralist philosophy for the two problems in the history of science under discussion here. As far as prematurity of discovery is concerned, structuralism provides us with an understanding of why a discovery cannot be appreciated until it can be connected logically to contemporary canonical knowledge. In the parlance of structuralism, canonical knowledge is simply the set of preexisting "strong" structures with which primary scientific data are made congruent in the mental-abstraction process. Hence data that cannot be transformed into a structure congruent with canonical knowledge are a dead end; in the last analysis they remain meaningless. That is, they remain meaningless until a way has been shown to transform them into a structure that is congruent with the canon.

As far as uniqueness of discovery is concerned, structuralism leads to the recognition that every creative act in the arts and sciences is both commonplace and unique. On the one hand, it is commonplace in the sense that there is an innate, or genetically determined, correspondence in the transformational operations that different individuals perform on the same primary data. With reference to science, cognitive psychology has taught that different individuals recognize the same "chairness" of a chair because they all make a given set of sense impressions from the outer world congruent with the same *Gestalt,* or mental structure. With reference to art, analytic psychology has taught that there is a sameness in the subconscious life of different individuals because an innate human archetype causes them to make the same structural transformations of the events of the inner world. And with reference to both art and science structural linguistics has taught that communication between different individuals is possible only because an innate human grammar causes them to transform a given set of semantic symbols into the same syntactic structure. On the other hand, every creative act is unique in the sense that no two individuals are quite the same and hence never perform exactly the same transformational operations on a given set of primary data. Although all creative acts in both art and science are therefore both commonplace and unique, some may nonetheless be more unique than others.

ARTISTS' MISCONCEPTION of the scientific act of creation is equally unrealistic. In this scene from the 1935 Warner Brothers film *The Story of Louis Pasteur* the great scientist (played by Paul Muni) has the sudden inspiration to discover the vaccine for rabies. Art, as any artist knows, is done quite differently. Both photographs are from the Museum of Modern Art Film Stills Archive.

THE MESOZOA

Animals that consist of perhaps only 20 cells live in a remarkably restricted habitat: the urine of the octopus and other cephalopods. They may provide clues to the development of many-celled organisms

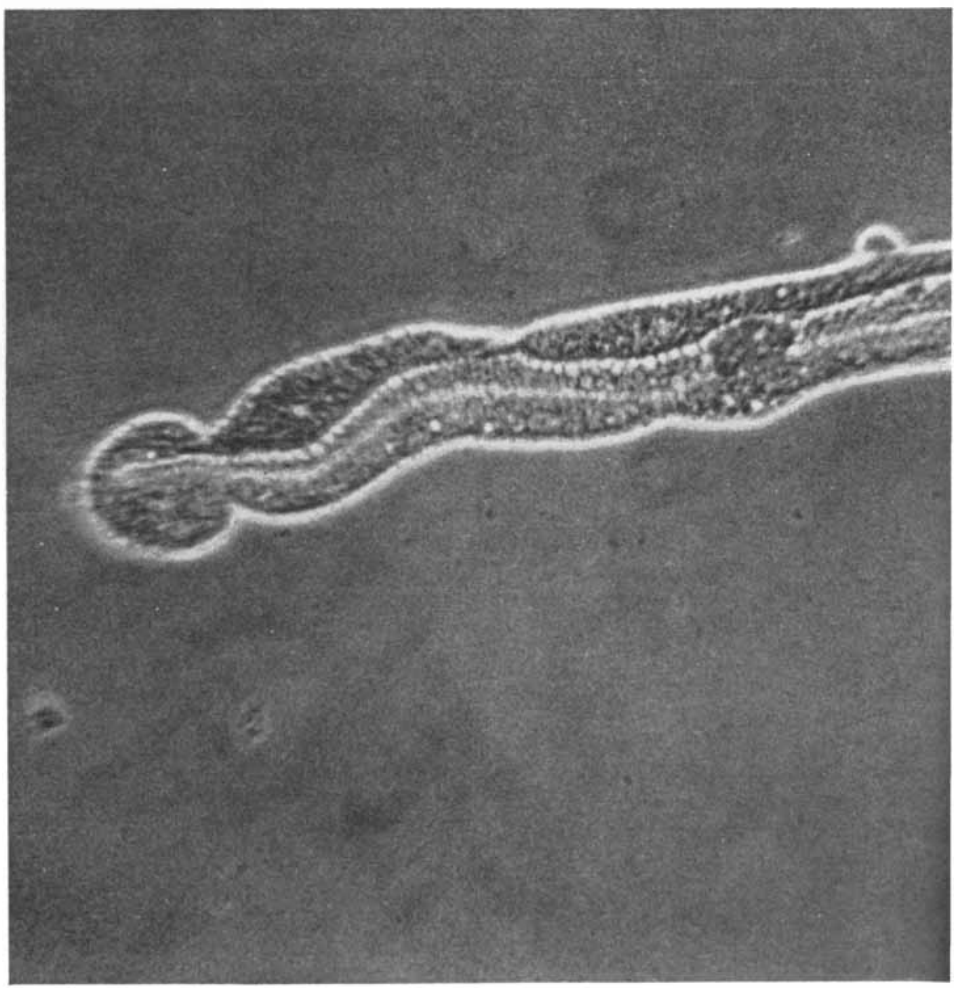
by Elliot A. Lapan and Harold Morowitz

In various niches and crannies of the biosphere there are organisms that are quite different from the species biologists are accustomed to working with in the laboratory. The peculiar features of these organisms sometimes provide clues to basic problems of biology. In the animal kingdom most organisms are either highly multicellular, consisting of anywhere from thousands to trillions of cells, or unicellular, consisting of one cell. Only one minor group, which may actually represent a subkingdom of the Animalia, has organisms with an intermediate number of cells. The tiny marine animals of this group, called the Mesozoa, mostly consist of between 20 and 30 cells.

The Mesozoa have been virtually unknown to experimental biologists because of their remote habitat: the kidney of benthic cephalopods (bottom-dwelling octopuses, cuttlefishes and their relatives). Our incentive for descending into the benthos to seek these obscure creatures is the intriguing possibility of studying the differentiation of cells and the development of the embryo with an organism that represents the simplest known level of multicellular organization.

Late in the 18th century small worm-like organisms were found in octopuses by Filippo Calvolini of Italy. In 1839 they were described by A. Krohn of Germany, who named them dicyemids. In 1876 the Belgian biologist Éduard van Beneden subjected the dicyemids to careful examination. He concluded that they fit into the evolutionary gap between the unicellular Protozoa and the multicellular Metazoa, and he invented the term Mesozoa to describe them. The term was soon applied to a variety of animals of doubtful ancestry. As most of these animals found homes in other divisions of the animal kingdom, the realm of the Mesozoa was reduced to the Dicyemida and one other group, the Orthonectida. Recent work by Eugene N. Kozloff of the University of Washington has indicated, however, that the orthonectids are structurally more complex than was originally believed. Hence after nearly 100 years the Mesozoa may once again include only the dicyemids.

Of the small number of biologists who have studied the Mesozoa since van Beneden made his detailed observa-

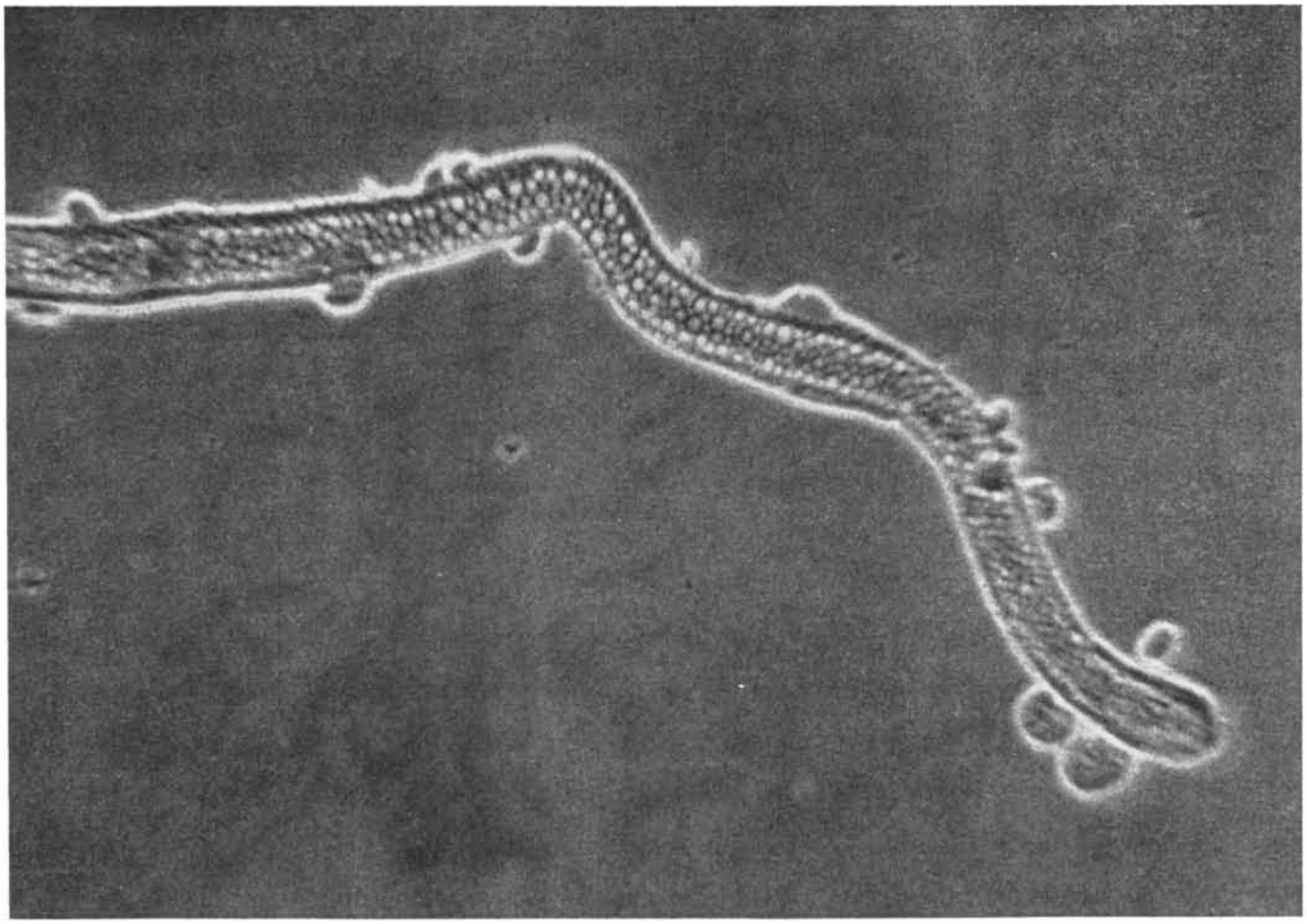


MESOZOAN is magnified 160 times in this composite micrograph. It is an adult dicyemid, a parasite that infests the kidneys of octopuses, cuttlefishes and other cephalopods. Known

tions, an even smaller number have supported his view that the Mesozoa represent intermediates in the course of multicellular evolution. The majority opinion has been that the Mesozoa have undergone secondary simplification, or have "degenerated," from a flatworm ancestor. This latter view, however, was based mainly on the belief that the Mesozoa had a more complex life cycle than is actually the case and on somewhat imaginative perception of resemblances between mesozoan and flatworm larvae. Recent studies in our laboratory at Yale University, some of them at the molecular level, indicate that van Beneden's position deserves another chance. His Mesozoa may yet provide us with valuable evidence on the evolution of multicellularity and on the mechanisms of differentiation and development.

The adult mesozoan, whose natural habitat is the urine of cephalopods, is a long, slender organism varying in length from less than .5 millimeter to more than seven millimeters, depending on the species. It essentially consists of a long cylindrical cell (the axial cell) enveloped by between 20 and 30 jacket cells. The exact number of jacket cells varies according to the species, but it is constant for each one. Within the axial cell are a number of small cells whose function is restricted to reproduction. These cells, called axoblasts and present in numbers between one and more than 100, can give rise directly to an adult form or indirectly to a larval form. Only two divisions of an axoblast are needed to establish the different cell lines of the adult, which is known as the vermiform (wormlike form). The first division sets off the original somatic jacket cell, which gives rise to the rest of the jacket cells; a second division separates the progenitor of the next generation of axoblasts from the axial cell. Up to this point development is entirely within the confines of the axial cell of the parent. After some elongation of the embryo and modification of the forward jacket cells the immature organism is released from the parental axial cell into the urine of the host. Growth proceeds by an increase in cell size, and the developing organism eventually attaches itself to the spongy tissue of the cephalopod kidney, adding to the population of the wormlike forms inhabiting the organ.

Another type of development occurs when the population of vermiforms in the host kidney becomes dense. Some of the axoblasts, instead of developing into vermiform embryos, develop into a structure that remains within the axial cell of the adult vermiform and may be thought of as a hermaphroditic gonad. The term infusorigen has been applied to this structure, which in a sense is the only organ the Mesozoa possess. Eggs produced by the organ are fertilized by sperm, frequently from the same organ, and develop into an organism, known as an infusoriform dispersal larva, that bears little resemblance to the vermi-



as vermiforms because of their wormlike appearance, adult dicyemids may exceed seven millimeters in length. Dimly visible inside the long axial cell of this specimen are several other cells. They are reproductive "axoblasts" that give rise to two kinds of young.

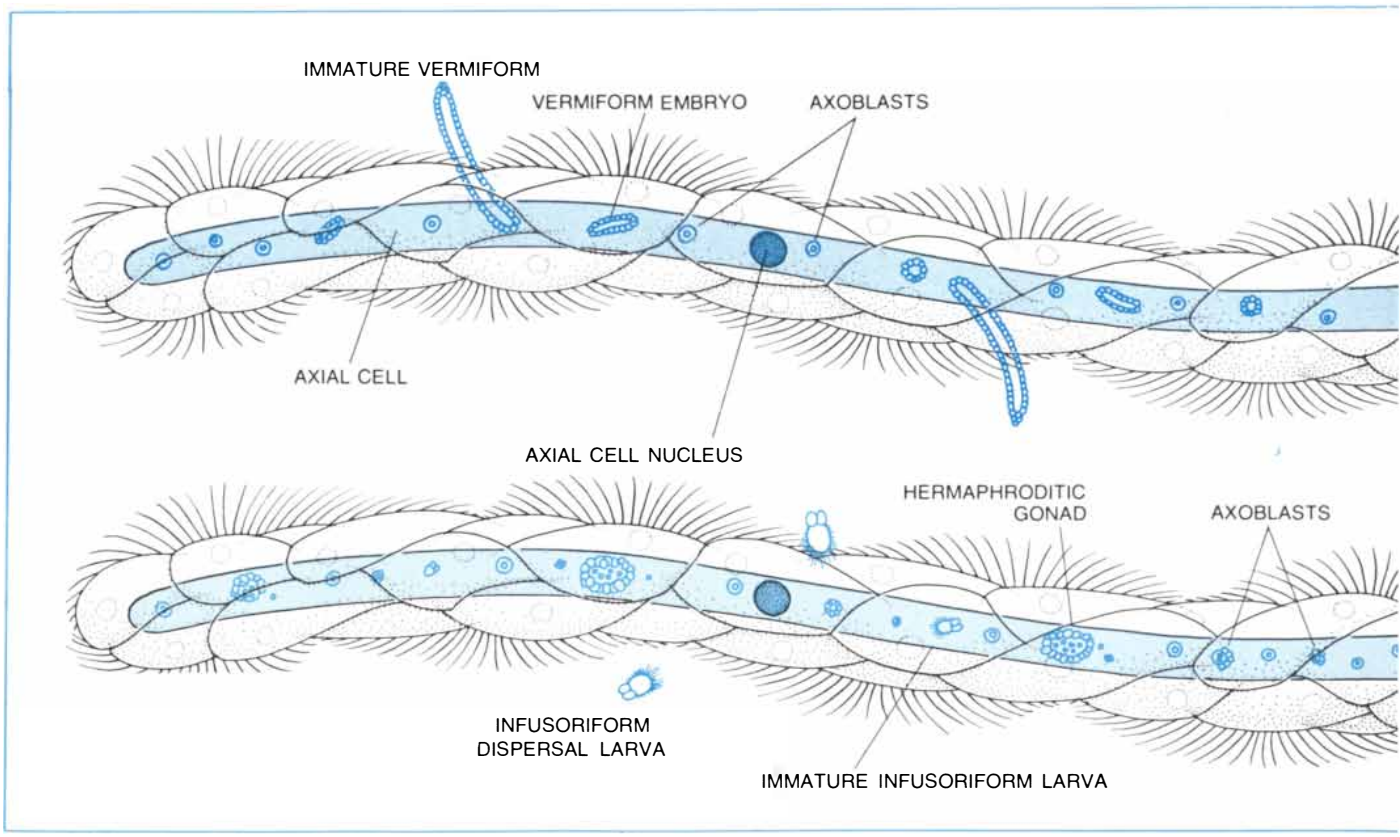
form. This larva is rarely more than .04 millimeter in any dimension; its shape varies from spherical to top-shaped, depending on the species, and it has two peculiar cells at the forward end. These cells, called apical cells, are nearly filled with a substance of remarkably high density. Four encapsulated cells in the middle of the lower surface of the infusoriform each contain another cell. The contained cells are believed to serve as germinal cells in the transmission of the mesozoan infection to other cephalopods. When development of the infusoriform dispersal larva is complete, the 28-cell organism escapes from the axial cell of the parent vermiform into the cephalopod urine and is shed into the sea. For some time it was believed the dispersal larvae infected an intermediate host, but evidence recently acquired indicates that no intermediate is necessary for the transmission of the infection.

A form resembling the adult mesozoan is seen in the early stages of the infection of a cephalopod. Known as a stem vermiform, it differs from the adult organism in several aspects: it has three axial cells arranged in a linear sequence, it is shorter and broader than the adult vermiform and it gives rise to vermiforms exclusively. The stem vermiform must derive directly or indirectly from some of the cells of the infusoriform.

The life cycle of the dicyemid Mesozoa can be summarized from the preceding descriptions: The infusoriform (or some part of it), which is weighted to the sea bottom by the dense apical cells, is picked up by a bottom-crawling cephalopod. After taking an uncertain route through the cephalopod (recent evidence in our laboratory indicates that the route may be through the circulatory system) cells from the infusoriform enter the cephalopod kidney and develop into stem vermiforms. The stem vermiforms give rise to vermiforms in the same way that vermiforms normally give rise to more of themselves. Vermiforms then take over the role of producing vermiforms and continue to do so until the population in the kidney of the host becomes dense. The sight under a microscope of a kidney with hundreds of thousands of wormlike forms attached to its surface is startling. At this point many of the vermiforms become involved in the production of infusoriform dispersal larvae, a logical step when the immediate environment becomes crowded. The larvae leave the cephalopod with the effluent urine and the cycle is complete.

The uncertain evolutionary position of the Mesozoa cannot be resolved on the basis of appearance alone. A unique mode of multicellular organization, a strange intracellular development of embryos, an abundance of cilia in all forms, the development of a protozoan-like macronucleus in the axial cell of adult forms and the relatively simple life cycle of the Mesozoa—all controvert the hypothesis that the mesozoans are secondarily simplified parasitic flatworms. The importance of these characteristics cannot, however, be quantitatively assessed. Biochemistry may provide the only means by which the evolutionary position of the Mesozoa can be determined.

Biochemical taxonomy has for some time been gaining acceptance as a means of evaluating relationships between organisms. Group-specific variations in the composition of certain common proteins and in the sequence of their constituent amino acids are indicative of group affinities. The nucleic acids, which encode the information

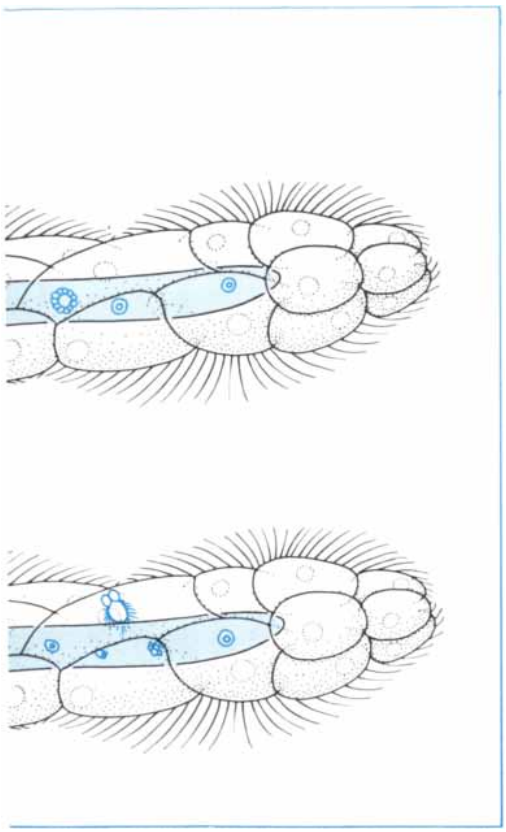


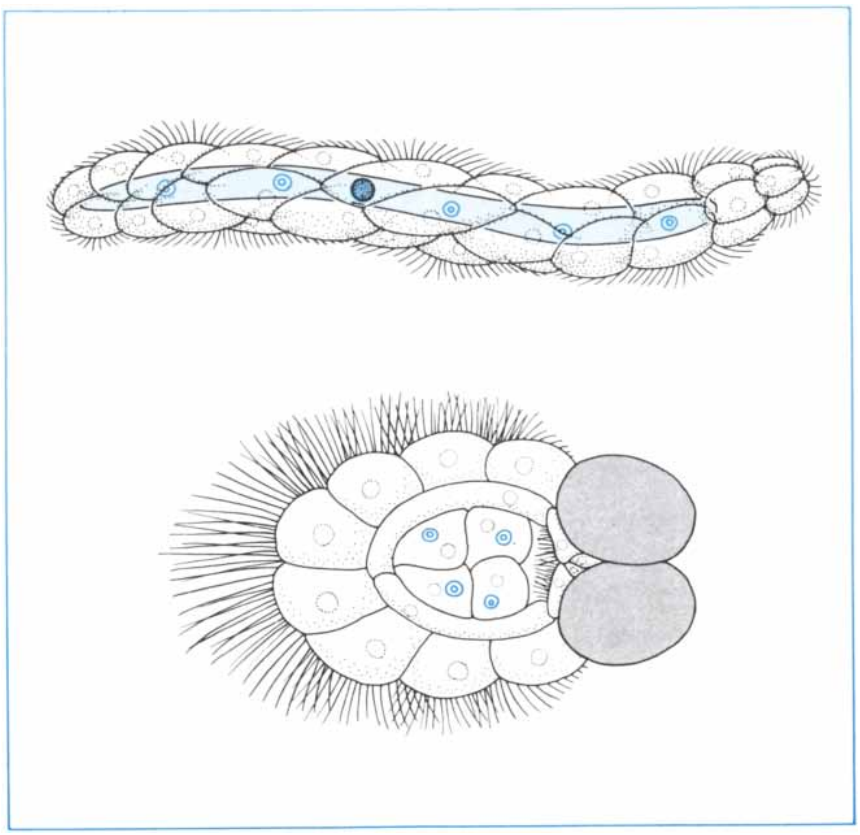
DUAL MODE OF REPRODUCTION in dicyemids is illustrated by these morphologically similar vermiforms. One (*top*) produces offspring like itself; the other (*bottom*) produces quite different offspring. Axoblasts inside the long axial cell of the top dicyemid grow into wormlike replicas of the parent before they are released. Axoblasts in the bottom dicyemid instead develop into gonads that

that determines the sequence of the amino acids and the composition of proteins, have also been found to display group specificities. Some of the nucleic acid specificities are reflected in a rather simple and basic characteristic: The relative amounts of the four common bases (adenine, thymine, guanine and cytosine) in DNA are constant for a given organism and can be expressed in terms of the percent of guanine plus cytosine (G + C). Among closely related groups of organisms (species and genera) the G + C content of the bulk of the DNA contained by organisms in these groups usually differs imperceptibly. The principal exceptions are among rapidly reproducing ancient organisms, which have had more time to diverge from one another than members of the more recently evolved groups have. Similarities or differences in G + C content among major groups of organisms, when such values fall into distinct ranges, may provide an indication of group affinities.

We have found that DNA from *Dicyemennea,* one of the two common genera of the dicyemid Mesozoa, has the very low G + C content of 23 percent. Values this low have been reported for only a few other organisms, all of them unicellular. Different species and strains of *Tetrahymena,* a ciliate protozoan widely used for cellular and biochemical studies, have G + C values in the range of 23 to 30 percent. Species of *Paramecium,* another ciliate protozoan, also have a G + C content as low as 23 percent. *Dictyostelium discoideum,* an aggregating amoeba-like organism of interest to developmental biologists studying the control mechanisms of multicellular organization, has a 22 percent G + C content. Most significant, the reported G + C values for the ciliate Protozoa are clustered in the range of 22 to 35 percent, whereas the G + C values for the flagellate Protozoa are clustered in the range of 45 to 60 percent. Unfortunately little G + C data is available for the platyhelminths, the group (commonly known as flatworms) from which the Mesozoa were supposed to have originated. Of the few flatworm G + C values that we have determined or have been informed of, all are clustered in the range of 35 to 50 percent.

A more stringent index of the relationships between distantly related groups can be obtained by comparison of the G + C contents of ribosomal RNA from different organisms. Ribosomal RNA is a particular type of RNA that is integrated into the ribosome, the cellular structure that is intimately involved in the process of protein synthesis. The sequences, as well as the relative percents, of the constituent bases in the ribosomal RNA chain are known to vary little between distantly related organisms. At present information of this type is far scantier than DNA G + C data. Preliminary experiments in our laboratory have indicated that mesozoan ribosomal RNA has a G + C content of about 40 percent. This value is as unusually low for ribosomal RNA as the 23 percent value for bulk DNA's. *Tetrahymena* and *Dictyostelium* have been reported to have similar ribosomal RNA G + C contents. The prospects of clarifying many of the evolutionary relationships that are now in question, however, have been most advanced by the development of new techniques for comparing the sequences of the ribosomal RNA of different organisms. Application of these techniques to the lower invertebrate animals may eventually reveal the evolutionary significance not only of the Mesozoa but also





contain both sperm and eggs. When the eggs are fertilized, the embryos that develop are unwormlike top-shaped "infusoriforms."

TWO KINDS OF OFFSPRING, a vermiform (*top*) and an infusoriform (*bottom*), are shown enlarged. After being released from the parent young vermiforms remain as parasites in the kidney of the host. Infusoriforms, however, are excreted with the host's urine.

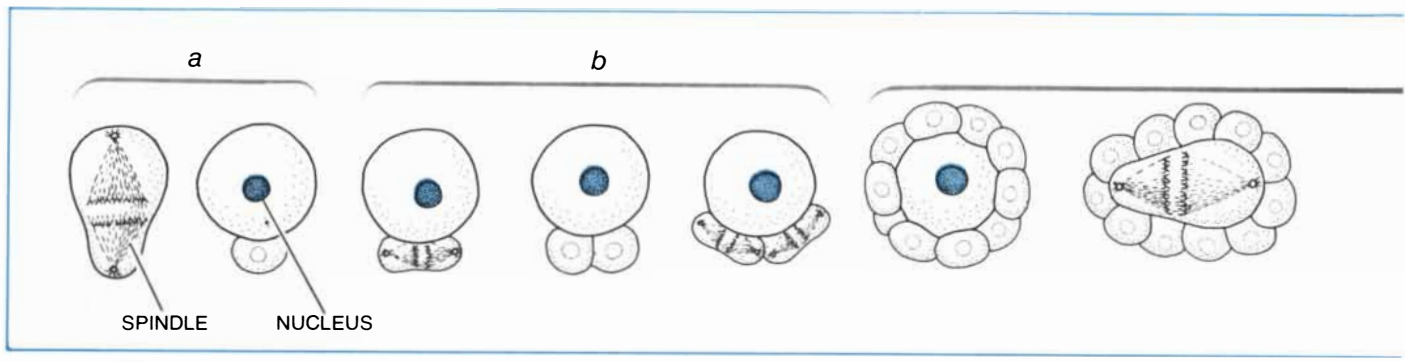
of the ciliate and flagellate Protozoa and of the other primitive groups of organisms.

Major obstacles to an understanding of the history and life of the dicyemid Mesozoa are presented by the remarkably restricted environment and nutritive conditions of these organisms. More barriers appear with the supposition that an unknown intermediate host and stage in the life cycle remain to be discovered. The study of the development and biochemistry of an organism that cannot be readily maintained in the laboratory is fraught with difficulties. Only recently has it even been possible to raise cephalopods in captivity. Much of our own effort has therefore been directed toward the maintenance and culture of Mesozoa.

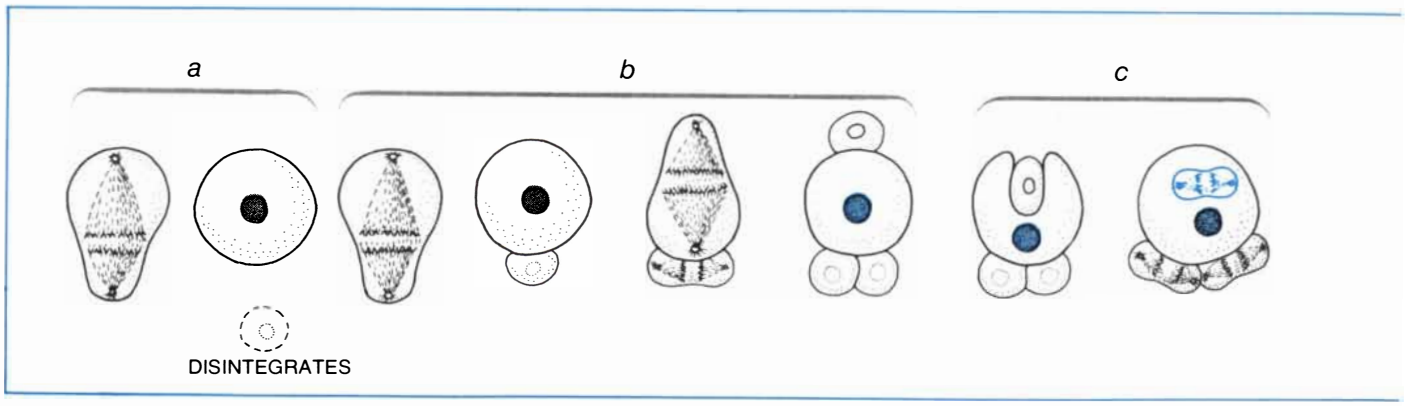
Our initial plan was to simulate the cephalopod urine from which the Mesozoa get their nutrients. This failed, probably because we inadvertently omitted nutrient factors and trace elements that had gone undetected in the only partially characterized urine. We solved the problem by maintaining part of an octopus kidney in organ culture, thereby providing conditions approximating the natural environment of the Mesozoa. We could get the tiny organisms out of the octopus tissue and into a glass container for observation. It finally turned out that the Mesozoa did not need to be in physical contact with the kidney in order to reproduce. An apparatus was designed that separated the Mesozoa from the kidney by a physical barrier: a dialysis membrane that allowed essential elements and molecules to diffuse between the organ and the organisms.

Although we had originally set out to establish the Mesozoa as laboratory animals in order to take advantage of their relative simplicity to study some of the problems of the development of multicelled organisms, we found that the culture of these organisms was also providing clues to their mysterious life cycle. Two different wormlike stages of the Mesozoa have been described: "nematogens" were reported to produce nematogens and "rhombogens," whereas rhombogens were reported to produce infusoriform dispersal larvae and occasionally to both produce larvae and revert to the nematogen stage. Observations on laboratory populations of Mesozoa make this distinction untenable. Under conditions of low population density the vermiforms produce more vermiforms, and when conditions of high population density are created, most of the vermiforms produce infusoriforms. A simple experiment has shown that the stimulus responsible for shifting the reproductive activity of the organisms must be related to the accumulation of a chemical factor in the milieu of the Mesozoa. When liquid medium in which a dense population of Mesozoa has been incubated is cleared of all organisms and then added to a low-density population of Mesozoa, most of the vermiforms in the low-density population begin producing infusoriform dispersal larvae within 24 hours.

Small, axoblast-like cells have been found in certain regions of the octopus circulatory system outside the kidney. DNA extracted from cultures of these



DEVELOPING VERMIFORM goes through the stages illustrated here, beginning with an unequal division of the axoblast (*a*) into two cells. The smaller cell continues to divide (*b*) and the larger cell is soon enveloped in a jacket of small cells. When this stage is

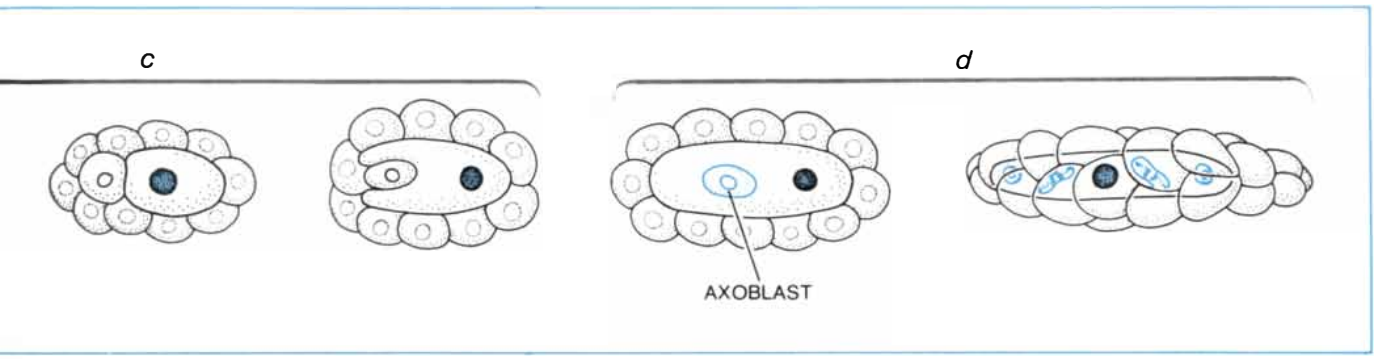


DEVELOPING INFUSORIFORM goes through a quite different series of stages, leading to sexual reproduction. Only the larger cell produced by the first unequal division of the axoblast (*a*) is involved. It divides unequally (*b*) and both cells produced by the division go on to divide again; the larger does so unequally and the smaller equally. The equal cells continue to divide until they

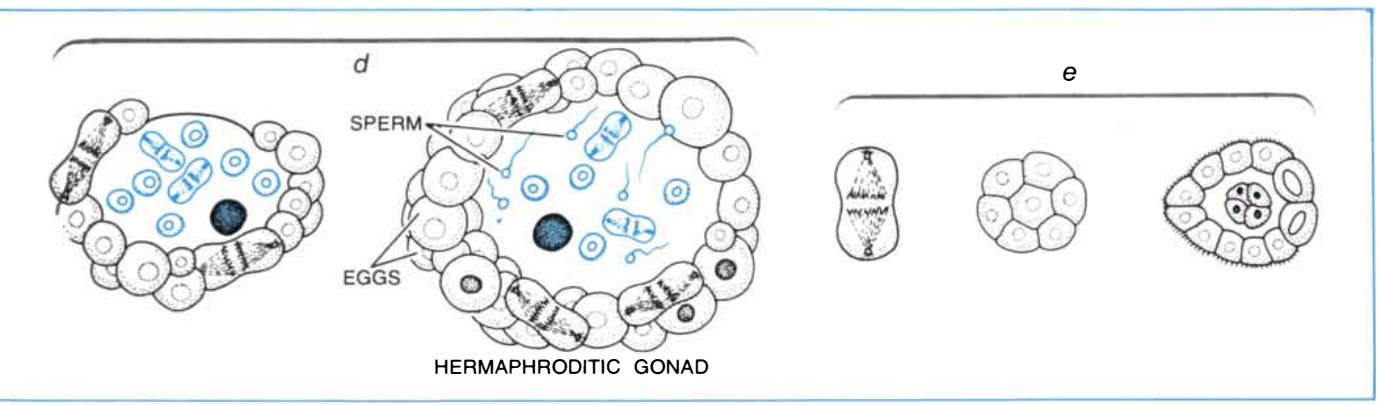
cells has the same characteristic G + C content as DNA from Mesozoa, and the morphology of the nuclei of these cells is typical of mesozoan nuclei. It will be interesting to see if these cells can be triggered to develop into a recognizable form of mesozoan. In several cultures of kidney tissue in which the axoblast-like cells and both the vermiform and infusoriform stages of the Mesozoa were present stem nematogens were observed. Because stem nematogens, which are variant vermiforms, are seen only in the early stages of the infection of a cephalopod and because only axoblast-like cells, vermiforms and infusoriforms were present in the cultures it is likely that the hypothetical stage that was supposed to give rise to the stem nematogen is nonexistent.

Observations on cephalopods raised in captivity have enabled us to rule out the necessity for an intermediate host in the mesozoan life cycle. Working at the Scripps Institution of Oceanography two summers ago, in collaboration with Erich Hochberg and Dennis Todd, we found mesozoan infections in young octopuses that had been hatched in aquariums. An examination of the aquariums in which the octopuses had been kept revealed no candidates for the supposed intermediate host. Two principal uncertainties remained: the intermediate hosts could have been eaten by the young cephalopods or could have otherwise disappeared from the aquariums and the infection could have been somehow transmitted in the cephalopod eggs or egg jelly. The latter possibility seemed unlikely, because Bayard H. McConnaughey of the University of Oregon had carefully sectioned eggs from infected cephalopods and found no trace of Mesozoa. Both possibilities were ruled out by the observations of Alain Richard of the Institute of Maritime Biology at Wimereux in France, who has raised *Sepia* (the cephalopods commonly known as cuttlefish) in isolated aquariums. Richard has informed us that when cuttlefish are hatched and raised to maturity in isolation from cephalopods other than siblings from the same batch of eggs, they are never found to be infected by Mesozoa until they are placed in an aquarium with infected cuttlefish.

The simplification of the interpretation of the mesozoan life cycle weakens one of the primary arguments used to associate the Mesozoa with the parasitic flatworms, which have complex life cycles and one intermediate host or more. The possibility for both asexual and sexual modes of reproduction is not, as some biologists have implied in arguing the origin of the Mesozoa, restricted to parasitic flatworms. Most protozoans and also bacteria can reproduce either by simple cell division or by recombination of their genetic material. The life cycle of the dicyemid Mesozoa cannot be accurately said to be one of alternation of generations in any case: vermiforms do not need to produce infusoriforms in order to produce more vermiforms. In true cases of alternation of generations each form derives exclusively from the alternate form. The Mesozoa may once have been free-living organisms, possibly existing only as



reached, the larger cell undergoes an unequal division (*c*); following the division the larger of the two cells engulfs the smaller. The engulfed cell becomes the immature vermiform's first axoblast; as it divides further (*d*) additional axoblasts appear in the axial cell.



envelop the unequal pair. At the same time the larger cell of the unequal pair engulfs the smaller one (*c*), whereupon the engulfed cell begins dividing. The axoblast has now become a hermaphroditic gonad (*d*); enveloping cells produce eggs and engulfed cells produce sperm. If fertilized by sperm from the same gonad or a nearby one, the eggs develop into infusoriform larvae (*e*).

vermiforms, in the ancient oceans. As the conditions in those oceans changed, the Mesozoa may have found a habitat in the urine of cephalopods. There they thrive with no apparent injury to their host. The urine of cephalopods differs from the seawater of the current epoch principally in containing far higher concentrations of nitrogen compounds and phosphate. The evolution of a larval form, produced in abundance and suited for survival in the changing oceans, would have allowed the dispersal of the mesozoan species into their now isolated niches. We have shown that vermiforms reproduce simply and directly until they become crowded in their habitat. The production of dispersal larvae is the mesozoan's way of coping with a population explosion and at the same time ensuring that its species will survive beyond the eventual death of its environment: the cephalopod host.

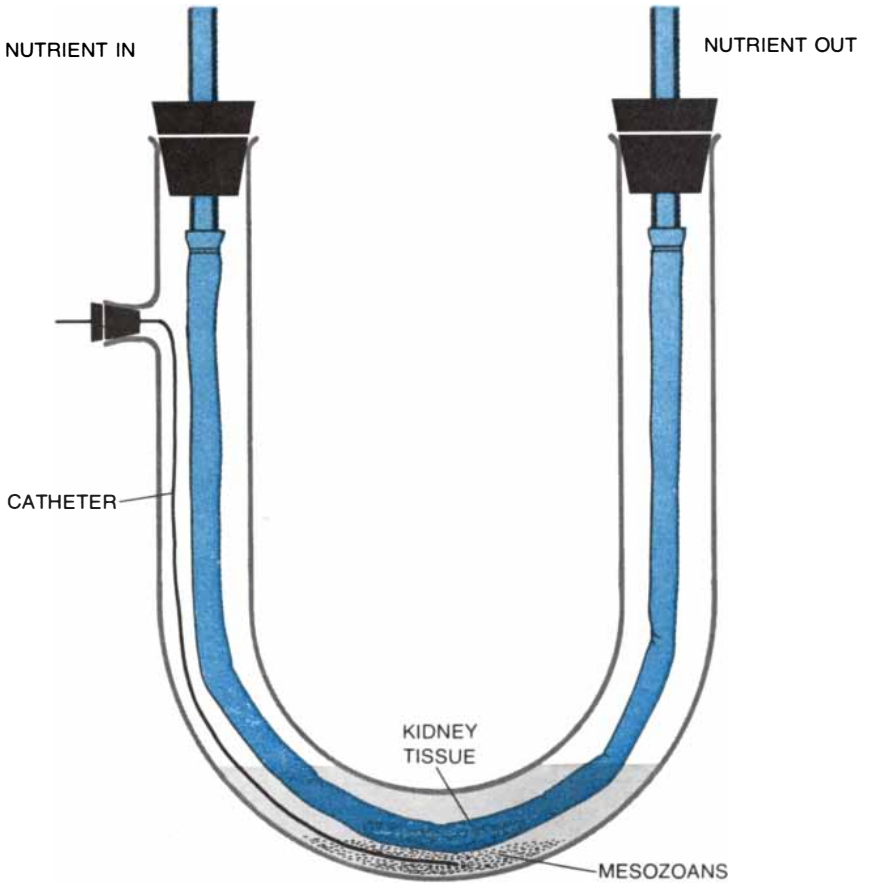
What can we hope to learn from the study of the dicyemid Mesozoa? All multicellular organisms, from mesozoans to men, develop from a single cell with a single set of chromosomes. The chromosomes contain DNA, which in turn contains most of the information necessary for the synthesis of cellular materials and the control of cellular functions for all the different cells of the organism. The entirety of this information appears to be transmitted during embryological development to most, if not all, of the cells of a multicelled organism. Why and how, then, can two cell lines with identical "banks" of genetic information, such as liver cells and muscle cells or rapidly dividing nerve-tumor cells and the nondividing normal nerve cells from which they arise, differ physiologically and morphologically from each other?

The Mesozoa provide a simple system to which this question can be addressed. Under one set of conditions the axoblast cells of a vermiform will develop directly into embryonic vermiforms; under another set of conditions (those of high population densities) some of the axoblasts will develop into the sperm- and egg-producing infusorigen structures. Such differentiation, or specialization, of cells occurs naturally in all multicellular organisms. The simplicity of the Mesozoa makes these organisms ideal subjects for an investigation of the conditions that lead to differentiation.

An outstanding experimental opportunity is presented by the mesozoan response to high population densities. We have shown that at high population densities a soluble chemical factor accumulates in the milieu of the mesozoans and induces the differentiation of axoblasts into infusorigen structures. A sequence of events, revealed at the determinative first division of an axoblast and continued through the production of infusoriform dispersal larvae, is triggered by this dense-population factor. Because we can readily create the conditions that lead to the accumulation of this factor, and because we can conduct these experiments in defined mediums in which the chemical constituents can be carefully controlled, we are optimistic about the prospects of isolating and identifying the factor.

The sequence of events initiated by the dense-population factor is a developmental pathway. The terminal end of the pathway is dominated by another substance: the dense material that begins to accumulate in the apical cells of the infusoriform within 24 hours after the induction of the pathway, and that ultimately accounts for more than a third of the weight of each larva. We have isolated this substance and are in the process of identifying it.

Additional experimental opportunities are gained both from the rapidity of the developmental events and from the quantity in which the apical-cell substance is produced. The synthesis and accumulation of a substance that accounts for more than a third of the weight of an organism must be accompanied by the presence of substantial amounts of specific nucleic acid messengers, enzymes and whatever other specific control factors direct those processes. The Mesozoa thus present an experimental system where the initial trigger and final product of a developmental pathway are at hand and in which the possibilities for the investigation of the intermediate steps and control mechanisms of a developmental pathway are considerable. The introduction of isolated intermediate metabolites and control factors into organisms that were in the process of moving along the pathway could reveal the pathway's dynamics. The eventual investigation of the pathway in a cell-free system, one in which a biological process is reproduced with isolated cellular



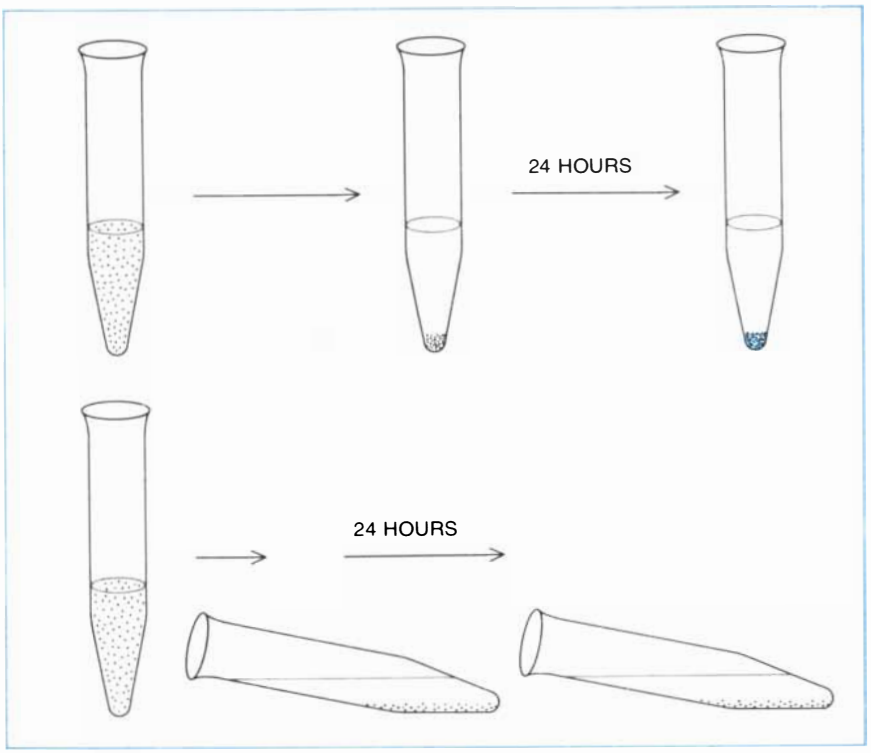
***U*-SHAPED TUBE can provide a laboratory environment for mesozoans. Octopus kidney tissue is kept alive in a narrow tube composed of dialysis membrane by a flow of nutrient liquid (*color*). The tissue in turn secretes a variety of nutrients that diffuse through the membrane into the bend of the larger tube, where the mesozoans are housed. A catheter enables the experimenter to withdraw mesozoans at will and thus regulate their number.**

substances, may reveal some of the physical and chemical mechanisms involved in cell differentiation.

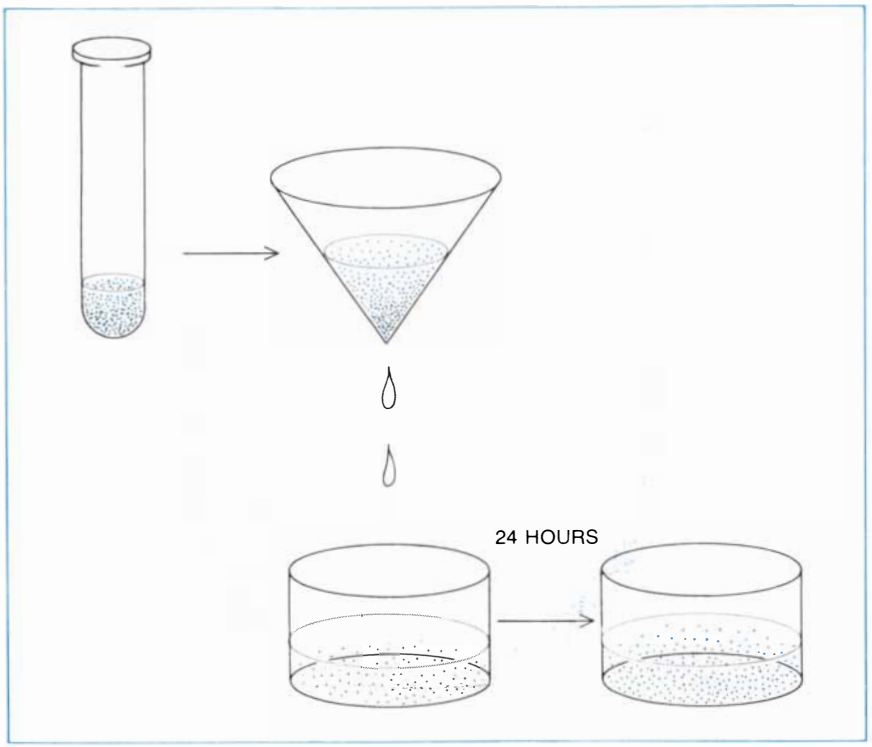
Multicellular organisms may have evolved in at least three different ways: the division of a unicellular organism into compartments, the development of colonial protozoans or the replication and specialization of the cells within an aggregate derived from a single-celled organism. No organism has been found that would exemplify the first mode of evolution. A few organisms, including the sponges and the aggregating amoeboid slime molds, embody suggestions of colonial organization. All other known multicellular organisms, including the tiny group of the Mesozoa and the huge group of the Metazoa, are most suggestive of the third possibility.

It is beginning to appear that the Mesozoa are not secondarily simplified flatworms and that they are possibly related to the ciliate Protozoa. Since the flagellate Protozoa have been suspected of being the most immediate ancestors of the Metazoa, the Mesozoa and the Metazoa may represent groups of organisms that have developed multicellularity independently but by the same process. If so, can we expect to find something basic in the molecular architecture of cells that reflects a particular type of multicellular development? Could the Mesozoa provide us with clues to the origin and organization of the Metazoa?

Biological research has always tended to demonstrate a fundamental unity in biological organization. This concept has been most recently and most strikingly supported by the discovery of the universality of the genetic code. Moreover, close similarities are seen among the enzymes that catalyze similar energetic and synthetic processes in the most diverse organisms. Hence there is much reason to hope and believe that the discovery of the principles of developmental control in simple organisms will lead readily to an understanding of the processes of cell differentiation and development in higher organisms. In the Mesozoa the beginning and the end of a developmental pathway can be identified and manipulated, thus providing a convenient system for the investigation of the control mechanisms of cell differentiation. More of the special and simple features of the Mesozoa can be expected to become useful for the study of general principles of multicellular organization as our familiarity with these odd organisms increases.



TUBES WITH A NARROW BOTTOM were used to test the effect of crowding on mesozoans. A suspension of dicyemids that were giving rise to vermiforms was divided between two tubes; one tube was kept upright so that the dicyemids became concentrated in the tip of the tube. The other tube was tilted almost horizontally, preventing a concentration of the animals. In 24 hours the close-packed dicyemids had begun to produce infusoriforms. In effect they had been transformed from vermiform-producers into infusoriform-producers.



SECOND EXPERIMENT proved that the dicyemids' shift from the asexual to the sexual mode of reproduction was caused by the accumulation of a "dense-population factor" in the crowded milieu. A dense concentration of dicyemids was incubated for 48 hours; at the end of the incubation period the animals were producing many infusoriforms. The animals were then removed and the liquid alone was added to a dish containing an uncrowded dicyemid population. Within 24 hours the uncrowded animals were producing infusoriforms.

MATHEMATICAL GAMES

Knotty problems with a two-hole torus, and solutions for last month's ciphers

by Martin Gardner

As you ramble on through life, brother,
Whatever be your goal,
Keep your eye upon the doughnut
And not upon the hole!

—ANON.

A torus is a doughnut-shaped surface generated by rotating a circle around an axis that lies on the plane of the circle but does not intersect the circle. Small circles can be drawn around the torus with radii equal to that of the generating circle, and they are called meridians. Circles of varying radii that go around the hole or center of the torus on parallel planes are called parallels [*see illustration below*]. Both meridians and parallels on a torus are infinite in number. There are two other less obvious infinite sets of "oblique" circles with radii equal to the distance from the center of the generating circle to the center of the torus's hole. Can you find them? Members of one set do not intersect one another, whereas any member of one set twice intersects any member of the other.

To a topologist, concerned only with properties that do not alter when a figure is elastically deformed, a torus is topologically equivalent to the surface of such objects as a ring, a bagel, a life preserver, a button with one hole, a coffee cup, a soda straw, a rubber band, a sphere with one handle, a cube with one hole through it, and so on. Think of these surfaces as a thin membrane that can be stretched or compressed as much as one wishes. Each can be deformed until it becomes a perfect toroidal surface. In what follows, "torus" will mean any surface topologically equivalent to a torus.

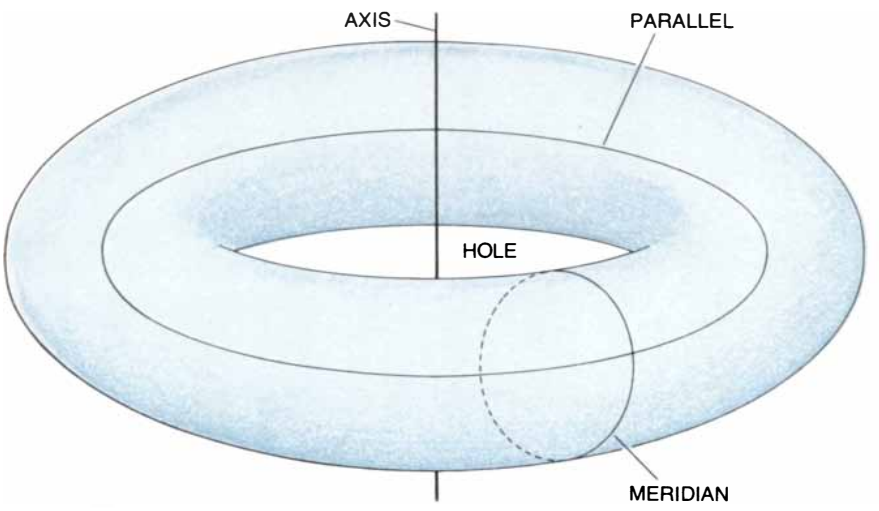
A common misunderstanding about topology is the belief that a rubber model of a surface can always be deformed in three-dimensional space to make any topologically equivalent model. This often is not the case. A Möbius strip, for example, has a handedness in 3-space that cannot be altered by twisting and stretching. Handedness is an extrinsic property it acquires only when embedded in 3-space. Intrinsically it has no handedness. A 4-space creature could pick up a left-handed strip, turn it over in 4-space and drop it back in our space as a right-handed model.

A similar dichotomy applies to knots in closed curves. Tie a single overhand (or trefoil) knot in a piece of rope and join the ends. The surface of the rope is equivalent to a knotted torus. It has a handedness, and no amount of fiddling with the rope can change the parity. Intrinsically the rope is not even knotted. A 4-space creature could take from us an unknotted closed piece of rope and, without cutting it, return it to us as knotted in either left or right form. All the properties of knots are extrinsic properties of toruses (or, if you prefer, one-dimensional curves that may be thought of as toruses whose meridians have shrunk to points) that are embedded in 3-space.

It is not always easy to decide intuitively if a given surface in 3-space can be elastically deformed to a different but topologically equivalent surface. A striking instance, discussed more than 20 years ago in this magazine [see "Topology," by Albert W. Tucker and Herbert S. Bailey, Jr.; SCIENTIFIC AMERICAN, January, 1950], concerns a rubber torus with a hole in its surface. Can it be turned inside out to make a torus of identical shape? The answer is yes. It is hard to do with a rubber model (such as an inner tube), but a model made of wool reverses readily. Stephen Barr, in his *Second Miscellany of Puzzles* (Macmillan, 1969), recommends making it from a square piece of cloth. Fold the cloth in half and sew together opposite edges to make a tube. Now sew the ends of the tube together to make a torus that is square-shaped when flattened. For ease in reversing, the surface hole is a slot cut in the outer layer of cloth [*shown by the broken line in the illustration on page 104*].

After the cloth torus is turned inside out it is exactly the same shape as before except that what were formerly meridians have become parallels and vice versa. To make the switch visible, sew or ink on the model a meridian of one color and a parallel of another, so that both colors are visible from either side of the cloth. In 1958 Mrs. Eunice Hakala sent me a model she had made by cutting off the ribbed top of a sock, then joining the tube's ends. The ribbing provides a neat set of parallels that turn into meridians after the torus is reversed.

Let us complicate matters by considering a torus tied in a trefoil knot. Leaving handedness aside, there are only two such toruses: one with an external knot



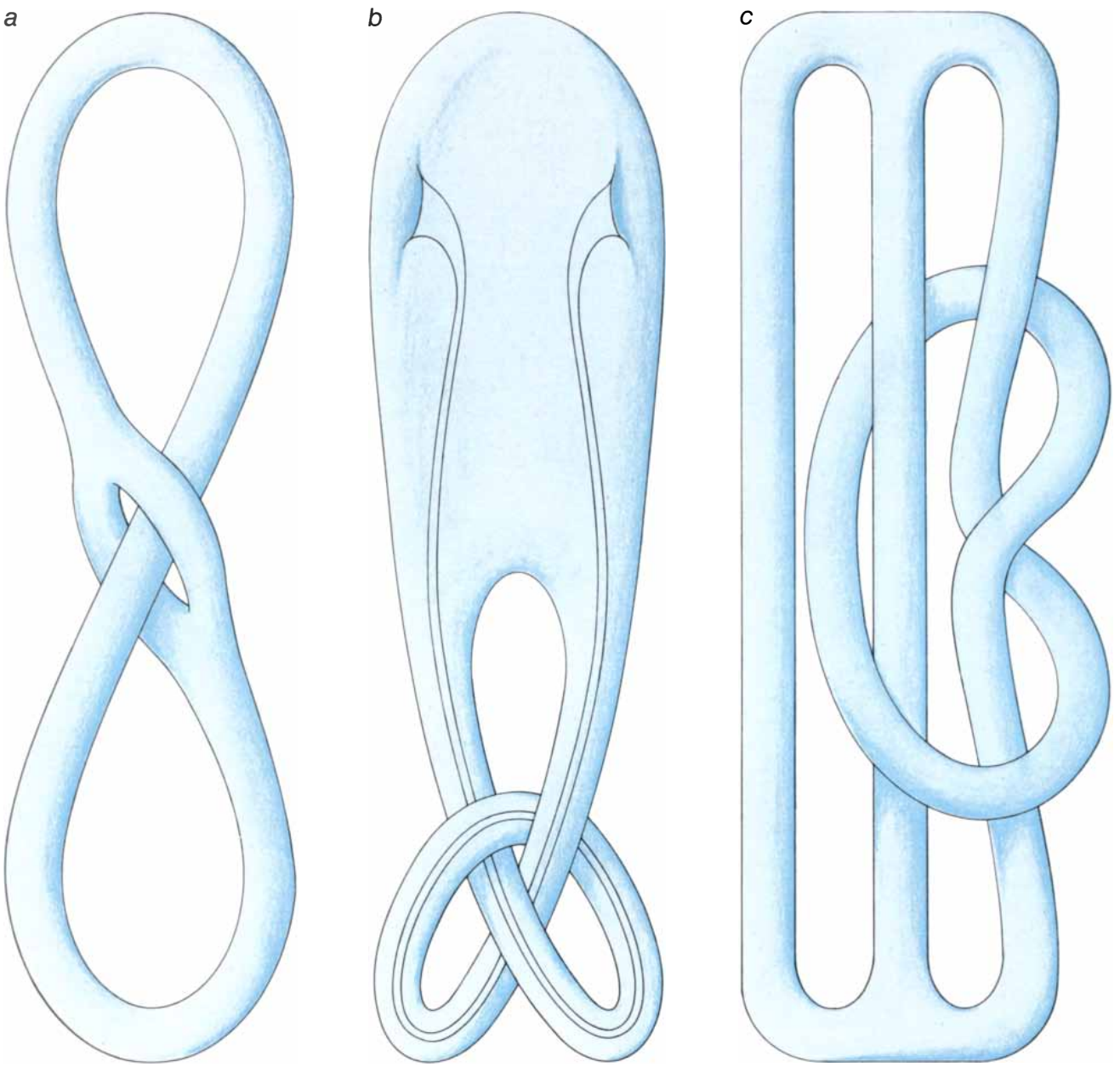
The torus

and one with an internal knot [*see "a" and "b" in top illustration on page 105*]. A way to visualize the internally knotted torus is to imagine that the externally knotted torus on the left is sliced open along a meridian outside the knot. One end is turned back, as though reversing a sock, then the tube is expanded and drawn over the entire knot and its ends are joined once more. Or imagine a solid wood cube with a hole bored through it, but instead of going straight the hole ties a knot before it emerges on the opposite side. The surface of such a cube is topologically equivalent to an internally knotted torus.

You might suppose that a torus could be simultaneously knotted externally and internally, but it cannot be done. One kind of torus seems to have both an outside and an inside knot [*see "c" in top illustration on page 105*]. Actually both knots are humbugs. Untying the outer knot simultaneously unties the inner one, proving that the model is topologically the same as an unknotted torus, its hole elongated like the hole of a garden hose.

Although an outside knotted torus is intrinsically identical with an inside knotted one, when it is embedded in 3-space it is not possible to deform one to the other. If there is a hole in the side of an outside knotted torus, can the torus be reversed in 3-space to put the knot inside? Next month I shall show how R. H. Bing, a topologist at the University of Wisconsin, answers this question with a simple sketch.

A similar but harder problem is solved by Bing in his paper "Mapping a 3-sphere onto a Homotopy 3-sphere," in *Topology Seminar, Wisconsin, 1965*, edited by Bing and R. J. Bean (Princeton University Press, 1966). Imagine a cube with two straight holes [*see "a" in bottom illustration on page 105*]. Its surface is topologically the same as a two-hole doughnut. We can also have a cube with two holes, one straight, one knotted [*"b" in illustration*]. It is not possible in 3-space to deform the second cube so that the knot dissolves and the model looks like the first one. A third



Two-hole toruses

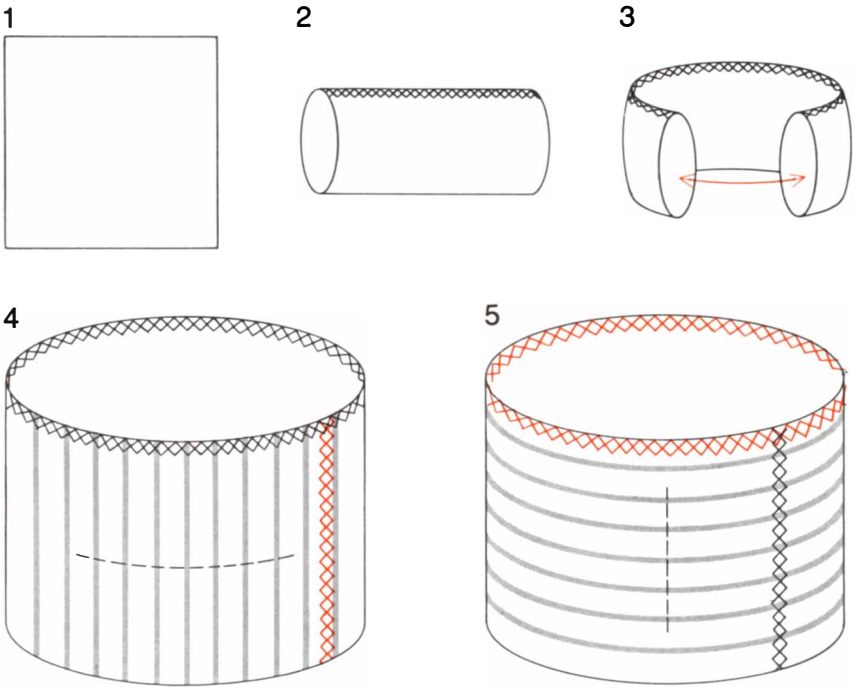
cube has one straight hole and one knotted hole with the knot around the straight hole [*"c" in illustration*]. Can this cube be elastically deformed until it becomes the first model? It is hard to believe, but the answer is yes. Bing's proof is so elegant and simple that the diagrams for it are almost self-explanatory [*see top illustration on page 106*]. In elastic deformation a hole can be moved any distance over a surface without altering the surface's topology. As the hole moves, the surface merely stretches in back and shrinks in front. In Bing's proof the knotted tube is drawn as a single line to make the proof easier to follow. Hole *B*, at the base of this tube, is moved over the cube's surface as indicated by the arrows, dragging the tube along with it. It goes left to the base of the other tube, climbs that tube's side, moves to the right across the top of the cube, circles hole *A* counterclockwise, continues left around the other hole, over the cube's front edge, down the front face, around the lower edge to the cube's bottom face, then across that face to the position it formerly occupied. It is easy to see that the tube attached to this hole has been untied. Naturally the procedure is reversible. If you had a sufficiently pliable doughnut surface with two holes, you could manipulate it until one hole became a knot tied around the other.

Topologists worried for decades about whether two separate knots, side by side on a closed rope, could cancel each other; that is, could the rope be manipulated until both knots dissolved? No pair of canceling knots had been found, but proving the impossibility of such a pair was another matter. It was not even possible to show that two trefoil knots of opposite handedness could not cancel. Proofs of the general case were not found until the early 1950's. One way of proving it is explained by Ralph H. Fox in "A Quick Trip Through Knot Theory," in *Topology of 3-Manifolds and Related Topics,* edited by M. K. Fort, Jr. (Prentice-Hall, 1962). It is a *reductio ad absurdum* proof that unfortunately involves the sophisticated concept of an infinity of knots on a closed curve and certain assumptions about infinite sets that must be carefully specified to make the proof rigorous.

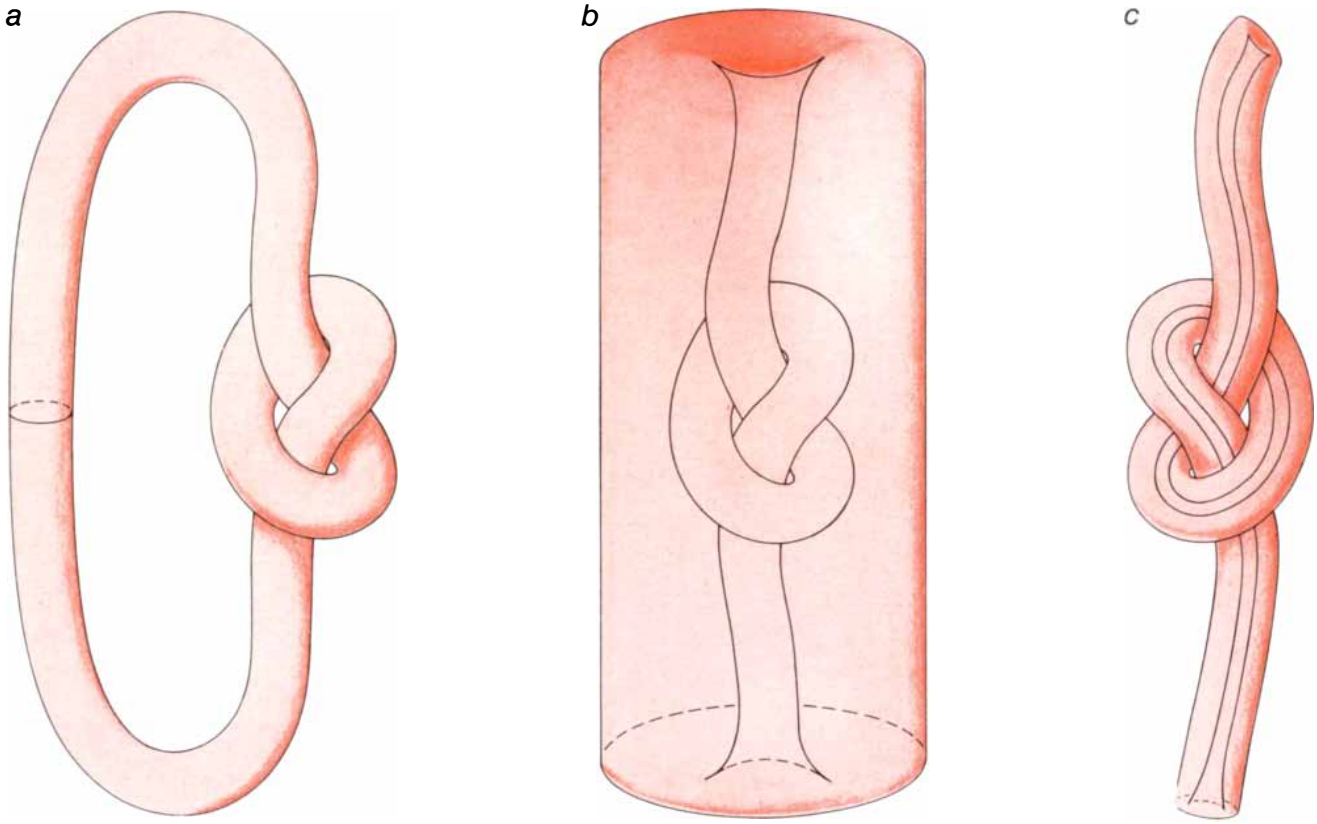
When John Horton Conway, the University of Cambridge mathematician, was in high school he hit on a simpler proof that completely avoids infinite sets of knots. Later he learned that essentially the same proof had been formulated earlier, but I have not been able to determine by whom. Here is Conway's version as he explained it years ago in a letter. It is a marvelous example of how a knotted torus can play an unexpected role in proving a fundamental theorem of modern knot theory.

Conway's proof, like the one for the infinite knots, is a *reductio ad absurdum*. We begin by imagining that a closed string passes through the opposite walls of a room [*see bottom illustration on page 106*]. Since we shall be concerned only with what happens inside the room, we can forget about the string outside and regard it as being attached to the side walls. On the string are knots *A* and *B*. Each is assumed to be genuine in the sense that it cannot be removed by manipulating the string if it is the only knot on the string. It also is assumed that the two knots will cancel each other when both are on the same closed curve. The proof applies to pairs of knots of any kind whatever, but here we show the knots as simple trefoils of opposite parity. If the knots can cancel, it means that the string can be manipulated until it stretches straight from wall to wall. Think of the string as being elastic to provide all the needed slack for such an operation. In the center figure we introduce an elastic torus around the string. Note that the tube "swallows" knot *A* but "circumnavigates" knot *B* (Conway's terminology). Any parallel drawn on this tube, on the section between the walls, obviously must be knotted in the same way as knot *B*. Indeed, it can be shown that any line on the tube's surface, stretching from wall to wall and never crossing itself at any spot on the tube's surface, will be knotted like knot *B*.

"Now," writes Conway, "comes the crunch." Perform on the string the operation that we assumed would dissolve both knots. This can be done without breaking the tube. Because the string is never allowed to pass through itself during the deformation, we can always push the tube's wall aside if it gets in the way. The third drawing in the bottom illustration on page 106 shows the final result. The string is unknotted. The tube may have reached a horribly complicated shape, impossible to draw. Consider a vertical plane passing through the straight string and cutting the twisted tube. We can suppose that the tube's cross section will look something like what is shown in color, with the possibility of various "islands," but there will necessarily be two lines, *XY* and *MN*, from wall to wall that do not cross themselves at any point on the vertical plane. Each line will be unknotted. Moreover, each line also is a curve that does not cross itself on the tube's surface. As we have seen, all such lines were (before the deformation) knotted like knot *B*. The deformation has therefore removed a knot equivalent to knot *B* from each of these two lines. Therefore knot *B*, alone on a line, can be removed by



Reversible cloth torus



Torus with outside knot (a), *inside knot* (b) *and pseudoknots* (c)

manipulating that line. But knot *B*, by definition, is a genuine knot that cannot be so removed. We have contradicted an assumption. If two knots on a string can cancel, neither knot (since the same proof can be applied to knot *A*) can be genuine. Both must really have been pseudoknots.

Although a one-hole torus can be embedded in 3-space in only three ways (outside knot, inside knot, no knot), a two-hole torus has so many bizarre forms that the number is, I believe, not yet known. In some cases it can be reduced to a simpler form by deformation. For example, a tube-through-hole is equivalent to an ordinary two-hole doughnut [*see "a" in illustration on page 103*], but what about the other two figures [*"b" and "c"*]? They are among several dozen monstrosities sketched by Piet Hein in a moment of meditation on two-hole toruses. In *b* an inside knot goes through an outside one, and in *c* an outside knot goes through a hole. Is it possible, by deformation, to dissolve the inside knot of *b* and the outside knot of *c*? I shall give Piet Hein's answers next month.

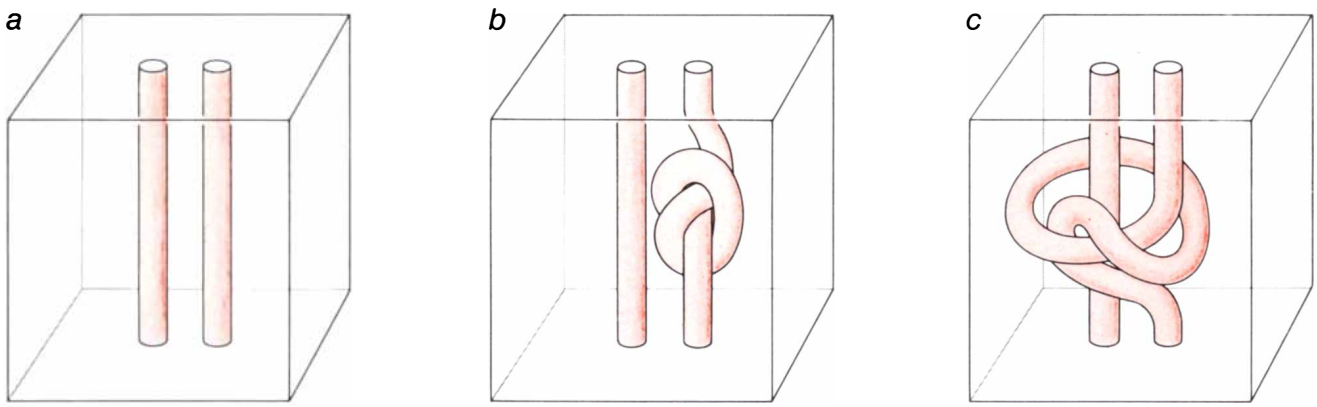
With more complicated pairs of two-holers embedded in 3-space, proofs that one can be deformed to the other are not so easy. As one of Piet Hein's "grooks" puts it:

There are doughnuts and doughnuts
with knots and with no knots
and many a doughnut
so nuts that we know not.

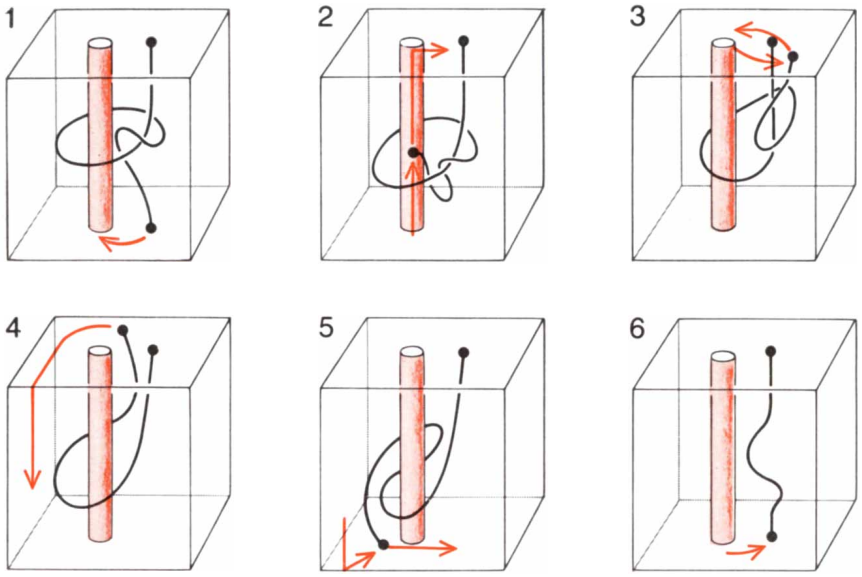
Here are three more toroidally knotty questions that will be answered next month:

1. How many closed curves can be drawn on a torus, each a trefoil knot of the same handedness, so that no two curves cross each other at any point?

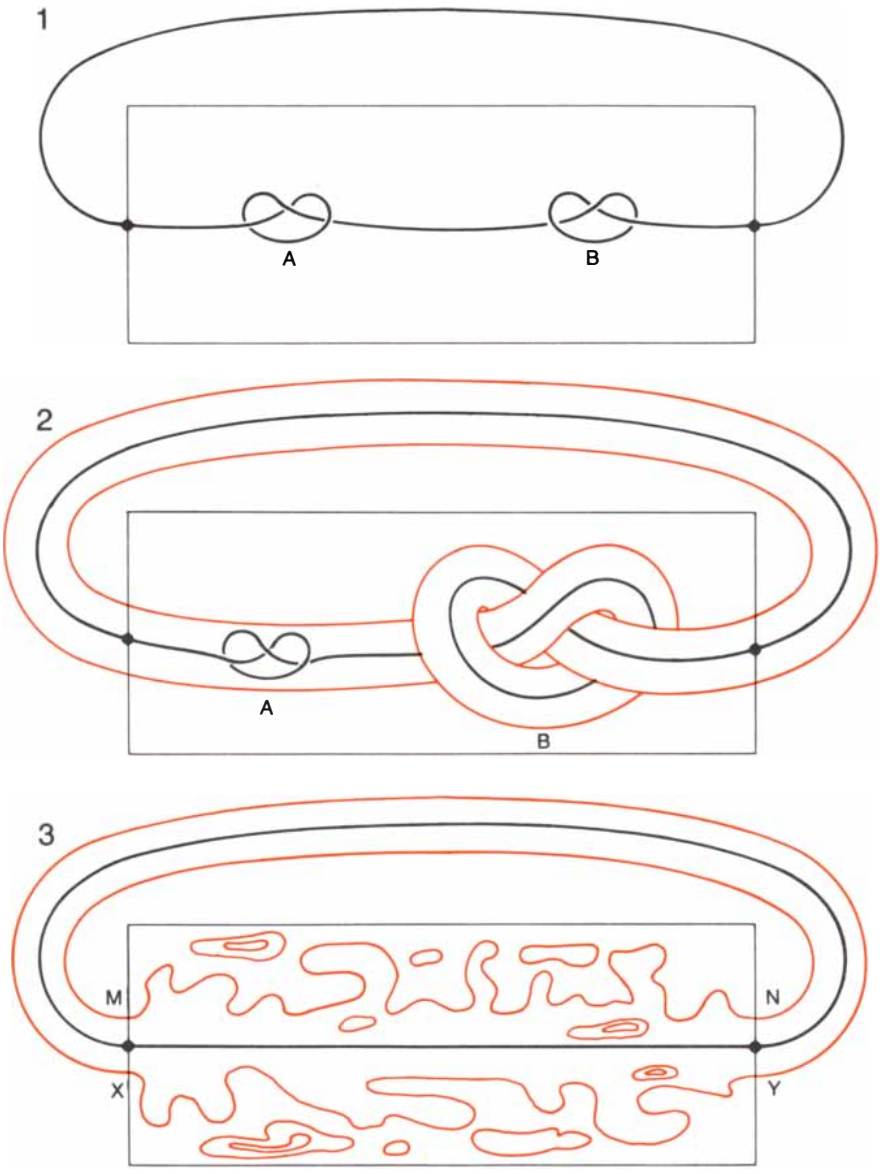
2. If two closed curves are drawn on



Three varieties of a two-hole torus



R. H. Bing's proof



John Horton Conway's proof

a torus so that each forms a trefoil knot but the knots are of opposite parity, what is the minimum number of points at which the two curves will intersect each other?

3. Show how to cut a solid two-hole doughnut with one slice of a knife so that the result is a solid outside-knotted torus. The "slice" is not, of course, planar. More technically, show how to remove from a two-hole doughnut a section topologically equivalent to a disk so that what remains is a solid knotted torus. (This amusing result was discovered by John Stallings in 1957 and was communicated to me recently by James Stasheff.)

Two unsolved problems in September's column on polycubes are now settled. There are (appropriately) 13 ways to construct the Diabolical cube, and there are indeed ways of arranging the pentominoes to create 13 nontouching interior unit holes. Because letters on both problems are still arriving, I am postponing a report until next month. For readers interested in polycube dissections of the three-by-three-by-three cube, there is now on the market a set of six such dissections under the name Impuzzable. Each plastic cube is a five-, six- or seven-piece dissection, and each is a different color. The colors are assigned an order of difficulty from the easiest (yellow) to the hardest (blue). The puzzles were designed by Gerard D'Arcey, a California game inventor.

Astonishing new discoveries in Conway's cellular-automaton game "life" continue to come so thick and fast that it is impossible to report them here. Fortunately they are disclosed four times a year in *Lifeline*, a lively quarterly about "life," obtainable at $2 a year from Robert T. Wainwright, 1280 Edcris Road, Yorktown Heights, N.Y. 10598. Conway is currently offering $50 each for first solutions of the "grandfather problem" and the "irresistible-force problem," as detailed in the November issue of *Lifeline*.

The three translations of last month's Baconian cipher are Fermat, Galois, Newton. The three biliteral keys respectively are:

1. Any letter in WILLIAM SHAKESPEARE is *a*, all others are *b*.

2. Any letter with one or more legs when printed as a capital is *a* (A, F, H, I, K, M, N, P, Q, R, T, X, Y). No-leg letters are *b*.

3. Any letter that, in simplest capital form, is topologically equivalent to a line segment is *a* (C, I, L, M, N, S, U, V, W, Z). All others are *b*.

"REVOLUTIONARY" "SENSATIONAL" "A BREAKTHROUGH" "STARTLING"
"EXTRAORDINARY" "MONUMENTAL" "MARVELOUS" "A MILESTONE"

THE ROOTS OF CIVILIZATION

By Alexander Marshack, *Peabody Museum, Harvard*

Profusely illustrated, "The Roots" has become the source book on the range of man's first art and symbol. But it is no art book. It introduces a new method to archaeology. It has helped found a subdiscipline in the study of man, "cognitive archaeology." It is a basic work in the new subdiscipline, "astro-archaeology." It provides new data on the evolution of man, his intelligence, language, art, symbol; it analyzes man's first images of "sex" and "killing." It offers new insight into the eventual rise of civilization. It is the new story of man.

Reviews In The Science Journals Or By Scientists

Scientific American (lead review): ". . . a pioneer, a beauty, a new door ajar . . ."

Natural History, journal of the American Museum of Natural History (lead review): ". . . shows that the days of discovery are not yet over . . . a real and important discovery."

Smithsonian, journal of the Smithsonian Institution (lead review): ". . . a marvelous breakthrough in our knowledge of prehistory."

The Sciences, journal of the N. Y. Academy of Sciences (cover story): ". . . some of the most extraordinary strides in the study of prehistory."

Washington Post: "Breakthroughs in the study of Paleolithic man are relatively rare . . . Marshack's fascinating analyses . . . marks one of these milestones . . . drama of a good detective story . . . has shown that great contributions can be made by introducing a new way of thinking. . . ." Wm. Fitzhugh, Smithsonian Institution.

Columbus Dispatch: ". . . a genuine milestone . . . should provide anthropologists, archaeologists and other interested scientists with material for reference and study for at least another decade." R. S. Baby, Ohio State University.

Research papers in print, 1972:
Alexander Marshack, "Upper Paleolithic Notation and Symbol," *Science,* Nov.
— — —, "Cognitive Aspects of Upper Paleolithic Engraving," *Current Anthropology,* June-October.

The Media

". . . fascinating . . . a new way of looking at prehistoric man and hence at ourselves . . . the human past that emerges is awesome." *The New Yorker*

". . . a careful, documented account . . . The implications for science, art, psychology and anthropology are tremendous." *Los Angeles Times*

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THE AMATEUR SCIENTIST

The joys of culturing spiders and investigating their webs

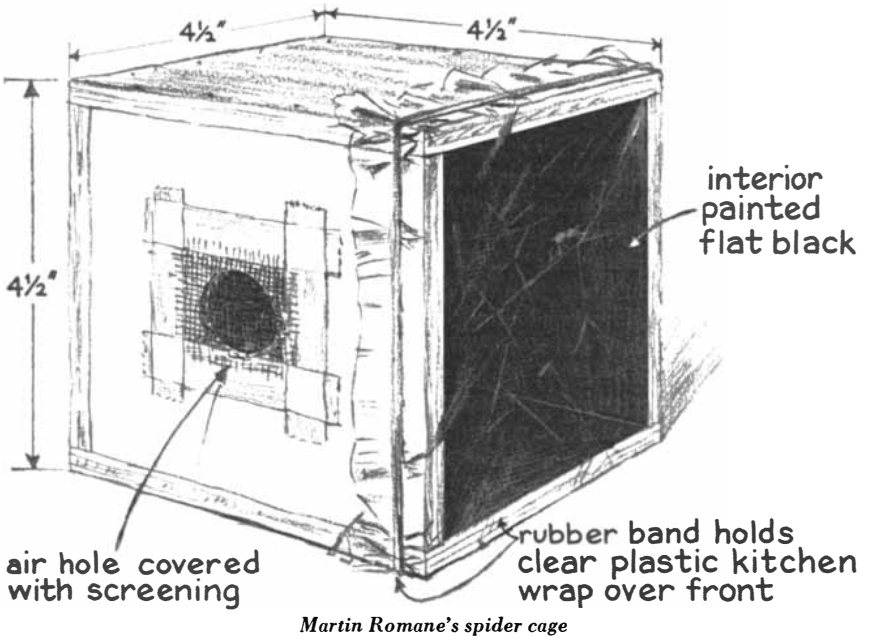
Conducted by C. L. Stong

Spiders are among the most ubiquitous of living organisms. They live wherever man does, including the heart of big cities. Accordingly they are a good subject for the city person who seeks to study a living member of his natural environment. One such student is Martin Romane, who attends high school in New York City. Last year he won a number of awards in the Annual Science Talent Search with his experiments on spiders of the kind that make webs. Romane writes about his investigations as follows:

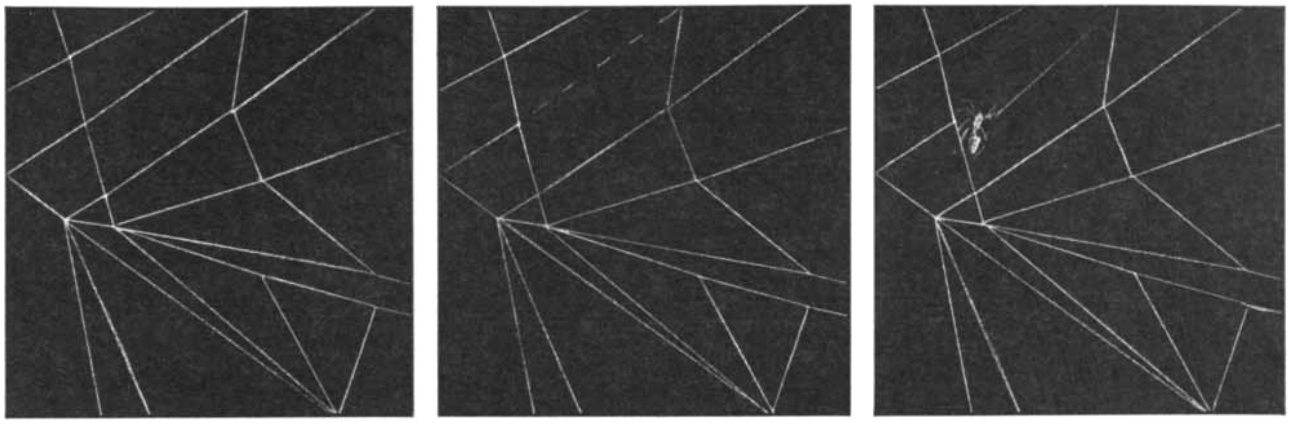
"I have always enjoyed wild animals, even though New York does not rank high as a natural preserve. Staten Island, where I live, has squirrels, rabbits, muskrats, raccoons and even an occasional deer. The larger animals are not plentiful, nor are they convenient to capture for study at home. For this reason I did not take an active interest in animal behavior until three years ago, when I happened to see a spider spinning its web in our backyard. It was a drab gray and about a quarter of an inch long. What impressed me was the speed of the operation. The spider paid out silk at a dead run. It would attach a strand to a blade of grass, race across the ground to a bush and climb to a branch, paying out the silk en route. Without appearing to stop, it would then pull in the slack, anchor the end and sprint down the taut line to begin another attachment. The web was rather a slapdash affair. Strands ran in every direction, were of various lengths and appeared to be anchored at random. It occurred to me that the spider might not be following a specific plan and in its haste would not detect a missing strand if I were to break one. To test this idea I heated a sewing needle with a match and with it cut out one short strand near a corner of the web. The spider soon rushed to the spot, inspected the damage and promptly replaced the missing silk. That did it! A dozen other questions came to my mind. Would the spider spin a second web exactly like the first? Would all spiders of the species make identical webs? What would happen if one member of the species were transferred to the web of another member, and so on?

"Our school library has a number of excellent books about spiders. From them I learned that we are rarely more than a few feet from a spider, even when we travel by air. Spider webs can be found under the seats and in the crannies of baggage compartments in aircraft. In even the cleanest of houses spiders live behind bookshelves, on the backs of framed pictures and in overstuffed furniture. Outdoors, particularly in grassy areas of the city, I have counted more than 120 spiders per square yard, a population density of more than a million individuals per acre. The variety of spiders is almost as impressive as their number. I have found more than 100 kinds on Staten Island, perhaps a tenth of the local species. According to the books, about 2,500 species are found in the U.S. Each species is characterized by its own pattern of behavior. Some trap their prey in webs. Others make no webs; they run down their prey as wolves do. Others crouch in a selected spot until the prey wanders within range and then jump to make the kill. Some species live only a year or two. Others, such as the tarantula, can survive for 25 years.

"Summer is the best time to collect specimens. They are in the open and are actively reproducing. The majority of the kinds that trap their prey build webs in shrubs, low bushes, grasses, under stones and on or in man-made structures. Collected specimens can be preserved in alcohol or maintained in captivity. I am interested primarily in the behavior of the web spinners and therefore maintain live specimens in cages. Confinement undoubtedly alters the behavior of the specimens in some respects. For example, some reference texts state that the female spider always kills and eats the male immediately after mating. This is disputed by Roman Vishniac, the well-known microscopist and naturalist. He believes that canni-



Martin Romane's spider cage



When a strand of silk is broken (broken line), *spider repairs web*

balism is the rule when mating spiders are caged but not when they are free in natural surroundings that allow the male to escape. Caging does not appear to influence other aspects of the spider's behavior. A live collection has the great advantage of enabling the observer to examine the insects at any hour of the day and in winter, when specimens are hard to find outdoors.

"A cage can be almost any box or jar of ample size. In the case of the web spinners the container should be large enough to accommodate webs of the size found in nature. This limits the collector somewhat. For example, I have not attempted to collect *Aranea*, the species that spins orb webs (webs that have a bull's-eye pattern) up to eight feet in diameter. My cages are cubic boxes made of quarter-inch plywood. I cut an air hole about half an inch in diameter in one side and cover it on the outside with a screen cut from a discarded nylon stocking. Usually I fasten the screen in place with pressure-sensitive tape. The transparent lid of the box can be a sheet of plastic kitchen wrap held in place with a rubber band. As an alternative I have used window glass for lids. Metal slides that accept sheet glass can be attached to the rim of the box. The slides are available from hardware dealers. Glass is convenient for covering cages that must be opened frequently for making experiments. The interior of the cages is sprayed with flat black paint to provide a background of maximum contrast for viewing the webs. The cages should not be used for a week after they have been painted: the evaporating fumes might poison the spiders.

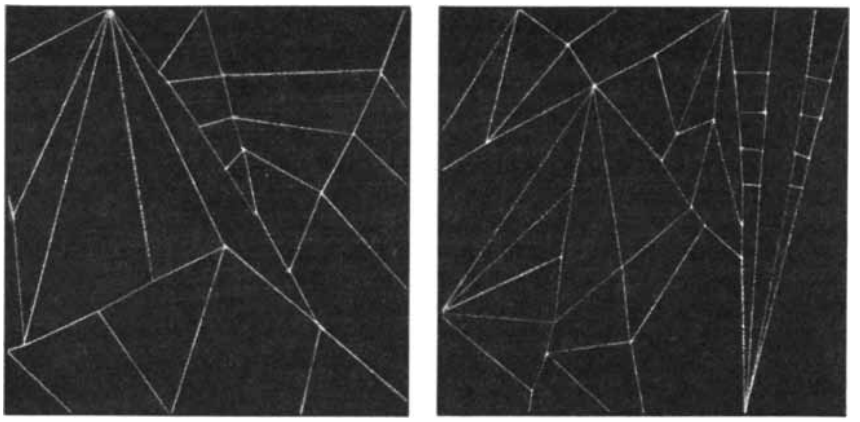
"When I am collecting, I take along several glass jars with a wide mouth and a screw cap, a hand lens for identification, a notebook and a small net. The net is used mostly for capturing spiders of the wolf type and the jumpers. I simply scoop material from the ground and sift or otherwise separate the contents until the specimens become visible. The general location of the web spinners is easy to spot. Look for the webs. Not all web spinners are found on the webs, however. Some attach a strand of silk that functions as a telegraph line between the center of the web and a remote location where they wait for prey. They keep their forelegs on the signal line and sense disturbances of the web by feel. When an insect launches a signal by agitating the web, the spider rushes from its lair by means of the line.

"Spiders feed exclusively on live prey. With few exceptions they will not eat anything they do not kill themselves. They must also have water. Those that make webs will stop spinning unless they are fed about once a week. According to the scientific literature, spiders have survived without food for as long as 18 months, but without water they die within 90 days. Feeding is simple. Just drop three or four insects into the cage once a week. The weight of each insect should approximate the weight of the spider. Water also need be supplied only once a week. With a pair of forceps grasp a tuft of cotton some four times larger than the body of the spider, saturate it with water and put it in the cage. The spider will suck water from the cotton just as it draws body fluids from the insects on which it feeds. Do not place bulk water in the cage, not even a single drop. A small spider may be drawn into the liquid by surface tension and drown.

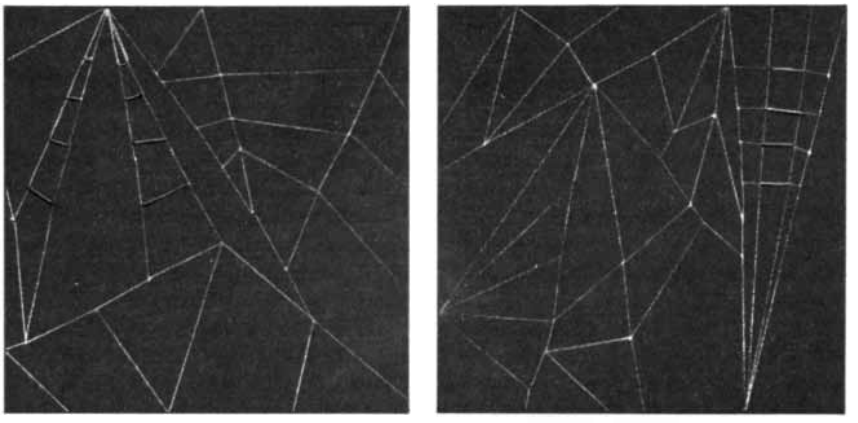
"A diet of houseflies will keep the spiders active through the winter months. The flies are easy to raise. With a net or trap catch two dozen or so in the fall and transfer them to a wide-mouthed container with a capacity of about a gallon. That number should ensure that the captives include at least one male and one female. Close the container with plastic fly screening. The flies can be fed a mixture of dried milk and sugar in equal proportions, to which sufficient water is added to make a stiff paste. Place a dab of the mixture in the cage and with a medicine dropper add sufficient water from time to time to keep the food moist. Water the flies, like the spiders, with moist cotton. Within a few days the flies will be ready to lay eggs. Make an incubator of a second container, preferably of clear plastic. The incubator can be smaller, perhaps a pint jar. It must be connected to the cage so that the flies can find their way between the containers. I simply cut a hole in the bottom of the cage and set it on the open top of the incubator.

"A good medium on which houseflies will lay eggs can be made by soaking a tablespoon of dry dog food in warm water for a few minutes, draining off the excess water and mixing into the dog food about a quarter of a cake of dry yeast. Transfer the medium loosely to the bottom of the incubator and place the apparatus in the warmest part of the house. The yeast grows on the dog food and the fly larvae will feed on the yeast. Moisten the medium from time to time. Within a day or so the flies should have laid eggs in the medium. The maggots will appear a few days later and young flies shortly thereafter. Adults can be harvested by folding back a corner of the plastic screening and inverting a wide-mouthed bottle over the opening. Flies that climb up into the bottle can be trapped for transfer to the spiders by slipping a small sheet of cardboard between the mouth of the bottle and the screening. Experimenters who are mechanically inclined can undoubtedly improvise a more elegant apparatus, but this simple arrangement works.

"The notebook is an important accessory. When I am collecting, I keep a rec-



Two spiders of the same species each spin a web



When the spiders are switched, each slightly modifies the other's web

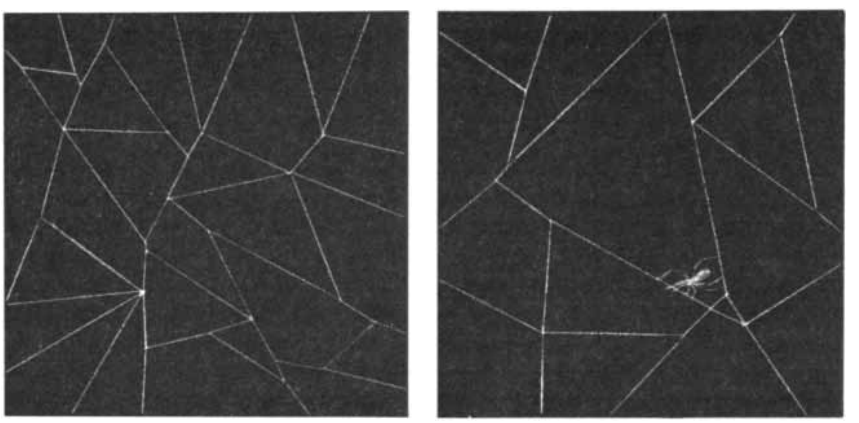
ord of the location and date on which each specimen is taken. The information comes in handy when additional specimens of the same species are desired. By using a hand lens and referring to a handbook I try to identify and record the species of each specimen as I collect it. A few of the handbooks I have used are listed in the bibliography of this issue of *Scientific American* [*page 128*]. Thereafter I keep a running account of the behavior of all specimens: the nature of the web, the frequency with which webs are spun and the length of time the spider takes to spin its web. This information is useful during subsequent experiments. By knowing how a spider should behave under given conditions it is easy to spot departures from that behavior when the conditions are modified.

"I have been particularly interested in recording the pattern of webs. Some webs are so intricate that they are difficult to draw. Webs can be photographed, however, even though some of the filaments are almost invisibly thin, by dusting the silk with a white powder that makes every strand appear in sharp contrast to the black background of the cages. To dust a web, place a few drops of household ammonia in a small glass container and an equal amount of hydrochloric acid in a second container. I use whiskey glasses for containers. Remove the spider and set the containers side by side under the web. The rising vapors react chemically to form a white cloud composed of ammonium chloride in the form of microscopic crystals. Many crystals collect on the silk. Within less than 30 minutes the web will be coated with a white layer that can be photographed nicely when it is lighted from the side. The crystals do not seem to annoy the spider after it is returned to the cage, nor do they damage the web. The acid is corrosive and should be handled accordingly. The crystals are only mildly toxic but should not be inhaled.

"Specimens can be photographed by conventional techniques and can also be preserved in alcohol. To preserve a specimen drop the spider into a jar and add undiluted rubbing alcohol. If the insect is larger than a grain of rice, change the alcohol after a week to compensate for the dilution of the alcohol by the spider's body fluids. The cap of the jar should have a rubber ring to prevent evaporation.

"The number of experiments that can be made with spiders appears to be limited only by the number of questions that come to mind as you observe their ways. As I have mentioned, the first experiment I conducted involved destroying one strand in a web to see if the spider would replace it.

"Will a spider accept the web made by another spider of the same species? Experiments that I conducted with the two species *Aranea tepidariorum* and *Steatoda triangulosa* suggest that at least some spiders will. A pair of spiders of each species, one spider per cage, were allowed to spin their webs. The individuals were then switched: spider *A* of one species was transferred to the web of spider *B* of the same species, and vice versa. In each experiment both spiders spent some time exploring the strange webs, after which each made certain additions. When the additions were finished, each spider appeared to be content and settled down to await the arrival of its prey. The webs of these species appear to be haphazard affairs with strands of various lengths running in every direction. Yet the experiments suggest that the web patterns cannot be



Web of normal spider (left) *compared with web of drugged spider* (right)

fully random. Spiders of these species appear to recognize instinctively that the similar web of another individual departs from its own ideal pattern. They modify the structure in some trivial way. Other experiments suggest that not all species are so fussy.

"Comparable experiments can be done to learn how a spider will react to a synthetic web made of nylon filaments and how heat, noise and light influence web-building. As I have mentioned, most web spinners sense the presence of their trapped prey by feel. Those that make orb webs wait for a struggling insect to send a signal down the telegraph line in spite of the fact that bits of wind-blown debris agitate the line almost continuously. When a fly lands on the web, the spider immediately rushes to the scene. How does it recognize the prey? An amateur in England explained the mystery by touching the web with a tuning fork that vibrated at roughly the same rate at which a fly beats its wings. The critical frequency of vibration caused the spider to pounce at once!

"Although not all spiders spin webs, substantially all make silk, particularly when they are young. The silk functions as a primitive but effective form of aircraft for dispersing spiders much as the downy seeds of some plants are carried aloft and scattered by the wind. The young spiders rarely set sail in a breeze, however. They prefer to wait for a warm day of flat calm when thermal currents sweep upward. Then, when conditions are just right, they project a jet of silk into the rising air. The silk appears to solidify instantly and then the flight is under way.

"The eggs from which the spiders hatch are laid in a cocoon of silk. The shape and size of the cocoon vary with the species, as does the number of eggs, which ranges from less than a dozen to several hundred. I transfer the cocoon from the cage to a glass jar with a wide mouth and cover the opening with fine screening, usually a scrap of nylon stocking. Fine screening must be used because the young of some species may be no larger than the head of a pin. Eggs laid in the fall may hatch the following spring. The newly hatched spiders may remain inactive for some time. Eventually they crawl up the wall of the jar. On a day that seems promising I take the jar outside, place it on the grassy lawn, remove the cover and watch. According to the scientific literature, the young spiders may land hundreds of miles from their starting point. Spiders are found in Death Valley far below sea level and on Mount Everest at elevations above 20,000 feet. On dewy mornings in spring I occasionally spot strands of discarded silk in the grass of our local parks, remains that mark the landing sites of young that had migrated perhaps only a few yards.

"A group of investigators in Germany has demonstrated that the administration of certain drugs causes the *Zilla x-notata*, a spider that spins an orb web, to make errors that are characteristic of each compound. For example, when given marihuana, the spider leaves a telltale space between the frame of the web and the spiral strands. Benzedrine causes *Zilla x-notata* to weave an erratic spiral, and so on. This suggests that the spider can be used to help identify unknown compounds [see "Spider Webs and Drugs," by Peter Witt; SCIENTIFIC AMERICAN, December, 1954].

"I made the experiment by administering Librium to *Aranea tepidariorum*. Librium is a depressant that can be obtained by prescription at drugstores. The spider was allowed to spin its normal web in a cage. I then mixed one capsule of Librium in 10 drops of water. With a pair of forceps I gently removed the spider from the cage and held it still as I applied a drop of the solution to the area of its head with a medicine dropper. I removed the excess fluid after about a minute by touching the drop with the corner of a sheet of blotting paper and repeated the treatment at five-minute intervals. I applied an equal amount of tap water to the head of a second spider that served as a control. Both spiders were then placed in separate cages. The spider that was drugged spun a skimpy web; the control spun a normal web. Two days later the drugged spider was transferred to a third cage. It subsequently spun a normal web, indicating that the effect of the drug had worn off.

"Friends occasionally ask me about the possible hazard of experimenting with spiders. Everyone has heard about spider bites. I have never been bitten by a spider, nor has anyone I know. The risk must be small because we are all exposed to them constantly at home. I suppose the hazard varies with the locality. As far as I know the more venomous species are not usually found in the northeastern region of the U.S. According to the scientific literature, the venom of some tarantulas that are native to the Southern states can kill small animals. All entomologists agree that no chances should be taken with the black widow spider. This native of the Tropics is occasionally shipped north with bananas or other fruit. It is also found in Florida. The black widow has been known to put a horse out of action with a single bite. Although the risk of a spider bite is not great, if I ever get one, I'll have it examined by a physician."

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BOOKS

Books about science for the younger reader: an annual Christmas survey

by Philip and Phylis Morrison

This year we perceive a dearth of books in the physical sciences, although there was no decline in the quality of the ones we did see. Once again we recommend to young readers many books not at all intended for them, and we call to the attention of general readers the advantages of beginning a subject with a good book written for youngsters.

The impression we gain from the book list is that the female of the species is not expected to read about science. We have nonetheless found a few books that clearly overcome this defect, and their quality is remarkably high. We hope for more.

Forms of Life

WHARF RAT, by Miska Miles. Illustrated by John Schoenherr. Little, Brown and Company ($5.25). OF MAN AND MOUSE: HOW HOUSE MICE BECAME LABORATORY MICE, by Patricia Lauber. Illustrated with drawings by Hal Siegel and photographs. The Viking Press ($4.75). MOUSE AND COMPANY, story and photographs by Lilo Hess. Charles Scribner's Sons ($4.95). A MOUSE NAMED MUS, written and illustrated by Irene Brady. Houghton Mifflin Company ($4.95). The house mouse, *Mus Musculus,* is a grain-eating species from western Asia. Once mankind began to store grain, this clever rodent became a sharer at the human table. House mice are now as widespread as men. The gray rat, a larger, stronger cousin, has taken up a similar role, beating out other rat species and spreading worldwide since the rise of ocean shipping. The four books listed here all treat in one way or another the relations between mice and men. All are suited for readers from the second grade through the fifth or sixth. The first two books will be best for the older readers, the last two for the younger ones.

Wharf Rat is a brief look at an enemy: man. The rat lives under the pier, and on a good day it can find and eat a bird's egg. ("He broke the rest of them, every one, and he washed his pointed face.") The rat can live off warehouse and garbage; it bares its teeth at a dog. Then it is fouled with oil from a spill in the harbor. People are everywhere. The rat falls from a rope and crawls along half-blind. The people are saving the oiled birds, but they stone the oily rat. It bares its teeth again, and a way is opened. Finally the rat sleeps and feeds safely in a freighter's galley. Free of pity and sentiment, the tale is a parable of adaptation and courage. The drawings show our world in grays and blacks at rat scale. This small book will probably become a classic of the dark side.

Of Man and Mouse begins with a history of the rise of the relationship between our two species. There were pottery mousetraps in Mohenjo-Daro, and white mice were bred as sacred animals in old Crete. North America has two distinct strains, one entering from southern Europe and the other from northern Europe. The mouse is a superb laboratory animal because it shares so much with man, but it is easy to maintain in large sample populations. Laboratory mice are descended from the "fancies" that were bred as a hobby in 17th-century Japan and were eventually introduced into Britain. The second part of the book deals mainly with the mutants reared and studied at the Jackson Laboratory (two million mice per year, all with careful pedigrees) and their meaning for medicine. There are hairless mice and waltzing mice, dystrophic mice, diabetic, epileptic and maybe even alcoholic mice. It is an excellent account, particularly for young readers with a medical bent.

Mouse and Company is a warm little work with superb intimate photographs of a deer-mouse family in the wild and of many cousin mice. There are a fine tall, scruffy gerbil, a couple of fat dormice, a waltzing mouse walking backward with its young ones dragging along, and more in the same vein. Anyone with a pet rodent will be charmed by these admirable pictures.

A Mouse Named Mus is a sharply seen fictional account of a pet house mouse that flees its home and small-boy master by mischance and becomes a wild mouse for a while, bearing a litter and learning to escape from owl and coyote, bear and weasel and finally the house cat, in a "forest full of creatures." Set in what must be a small Western town, it is a good story, full of events, ending well and illustrated with loving detail around a mouse family in the woods.

ME AND MY BONES, by Roy A. Gallant. Doubleday & Company, Inc. ($4.50). If the skull under the skin is not too fearful to examine for its beauty and meaning, this cleverly made book of brief text and many photographs charts a high road to comparative anatomy and evolution. Engaging Cirsten Carle acts as the living counterpart of a child's skeleton in many close-ups and set positions. Other bones come on the scene, from cat and chimpanzee, horse and elephant. The skeleton walks, runs, jumps. The main bones are given their Latin names and diagrammed on the bony specimen, while Cirsten poses obligingly across the page to flesh out our own mineralized frame. Gallant goes pretty far toward cuteness in maintaining the lightheartedness such a *memento mori* seems to need. Apart from a few excesses—"Grownups have up to 32 teeth (for snapping at children with)"—he has made a book of value and delight for fifth-graders and up.

KINGDOM OF THE SEASHELL, by R. Tucker Abbott. Crown Publishers, Inc. ($14.95). Beautifully designed and luminously illustrated (the volume was printed in Verona), this is a crisp but full encyclopedia of the mollusk. The first half of the book examines mollusks in life, how and where they live, how they evolved and their look in many examples from all over the world. There

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is a tenfold enlarged view of the mantle lips of the common bay scallop, looking right at camera with its 17 beady baby-blue eyes, all matching in color but differing in size. The last half of the book is about humans and mollusks: the collecting of shells (with how and why), the economic aspects of shellfish, the use of shells through history and the connoisseur today. It is all a work of such learning, devotion and beauty as to excite envy in anyone who examines it. There have been several superb recent books about shells; this is perhaps the most generally accessible for dipping into or for reading at length. It is organized in brief sections, and there is something for cooks and cameo-cutters, for dyers, jewelers, poets, heralds and ecologists, with many another interest served. Altogether a rich clambake, it is a fine book for fans, libraries and the indulgent.

THE WHALE: MIGHTY MONARCH OF THE SEA, by Jacques-Yves Cousteau and Philippe Diolé. Translated from the French by J. F. Bernard. Doubleday & Company, Inc. ($9.95). The unity of experience that has marked Captain Cousteau's other books is not to be found here. Here the unity is the whale, whether it is found off the Horn of Africa, in the lagoons of Lower California, near Bermuda or in the strait of Juan de Fuca. The journals and the logbooks and the marvelous photographs of undersea intimacy combine in the usual way to make a story almost as matchless as the images Cousteau's *Calypso* gathers. Hunters come to know the ways of their game well, but whalers, who know whales best of all men, see them so much in extremes of fear and rage (on both sides) that their accounts are somewhat awry. Scientists have done better, but until the *Calypso* began to ply the seas few have had the ships, the time and the big equipment that whale-watching really requires. Cousteau and his men have not by any means finished the job, but they have started. Here is the clever technique: A hot-air balloon takes a man silently aloft to look deep into the water, a hydrogen-filled kite-balloon marks the whale for radar as it swims off. (A half-mile of line may not be enough for a sperm whale; it may dive 4,000 feet.) The book presents the case for the keen intelligence of the killer whale, which feeds on mammals—even other whales—but has never hurt men. An attractive and helpful apparatus of zoology and whaling history fills out the brief text. It is winter reading for the entire family, and a fine entry to *Moby Dick*. Perhaps we humans shall not bring an end to the great whales after all, even for soap and margarine.

GRASSHOPPERS AND THEIR KIN, by Ross E. Hutchins. Dodd, Mead & Company ($4.50). The order Orthoptera includes all those leggy insects—the grasshoppers, the crickets, the mantids, the walkingsticks and the katydids—and, as a surprise for the uninformed reader, the lumpy roaches. Indeed, it is they who cling to the old ancestral form, dating back to the time when the coal beds were deposited. Once again this expert author illuminates the intricacies of the insect world with his sharp lens, knowing observations and wide lore. Here you will see the instrument of the katydid's cheerful voice: the little musician has a sharp tooth at the base of its right wing and a neat file with some 50 ridges on its left. Scrape them together and the thin membranes on each wing sound the song. The chapter on the sounds of a summer night is fascinating, if a bit oversimplified. The reader will enjoy the temperature table too; the chirp rate indicates the temperature in two species of cricket.

There is a glacier in the Beartooths of Montana that holds a deep-frozen sample of past life. In Siberia they have frozen mammoths; our strange trove is frozen swarms of the Rocky Mountain grasshopper, sampled by the winds from ancient massed flights, carbon-14-dated at 600 years ago and still conspicuous enough to band the glacier face with layer on layer of grasshoppers, "so well preserved that fish and birds have been seen feeding on them." Once again we gain a book of surprises about the familiar, for readers from 10 up.

TOAD, by Anne and Harlow Rockwell. Doubleday & Company, Inc. ($4.95). "Toad lives under the day lily." That is the full text of page 1, and above it we see Toad, round, warty and somewhat supercilious, under blades of the lily that are colored green, pink and white. One bee flies beyond the neat frame of the picture, a drawing in line and wash, spare and full of character. So the book goes. Toad finds himself made a boxed pet. He grows, splitting his too tight skin, which has somehow vanished. Where? "Toad has eaten it, a swallow after each yawn." This well-observed story, lying between poetry and prose, is ornamented with pictures of such quality as to make the work an elegant whole. One ends it with a sigh, as "copying the moon, and bubble-round, Toad blows out his throat and trills his sweet song." This is a small book for reading aloud, maybe even to (and by) people who can read very well indeed.

WORMS, written and illustrated by Lois and Louis Darling. William Morrow and Company ($3.75). The rather didactic tone of this small book for young readers is leavened by wit and by the many detailed stippled drawings of objects familiar and strange. The frontispiece is an endearing tin can full of worms, and one of the last pictures shows a broad pasture with the remark that "all the worms underneath a meadow may weigh far more than all the cows on top of it." You can learn how to catch earthworms ("exciting") and how to keep them for a long time ("hard"). The worms are lifelike in every picture, although the Australian one "from four to twelve feet long" luckily does not come off quite as fearsome as it sounds.

Language and Mathematics

MAKE A BIGGER PUDDLE, MAKE A SMALLER WORM, devised and illustrated by Marion Walter. M. Evans and Company, Inc. ($3.95). Transformations have taken a major place in the world of mathematics since the days of Felix Klein. Here is a most original realization of the concept in a colorful, whimsical, protean little book by a well-known innovative teacher of mathematics teachers. The book presents a set of childlike paintings (done with flair by the author herself) and a sentence or two for each. The optical transformation is produced by placing the edge of a safe metal hand mirror supplied with each copy against the page somewhere. You can make the half-moon turn whole, mend the broken plate, put more fish in the tank or make the worm disappear. Even dots in their ranks are no longer invariant in number. There is a ghost, less scary than friendly; you can easily make it fatter or thinner or cause it to disappear with a pass of the mirror. Prereaders will like the action just fine; small sophisticates in the early grades will find the challenge interesting, particularly if they add their own constraints and try prediction. The foundations of optics, of geometry, of hand-eye control and of imagination itself are not too weighty to see in this deft and deceptively simple little book.

MARTIN GARDNER'S SIXTH BOOK OF MATHEMATICAL GAMES FROM SCIENTIFIC AMERICAN, by Martin Gardner,

naturally, with some help from his friends. W. H. Freeman and Company ($9.95). On display each month, these delights and intricacies need no review, but they richly merit one. The book presents mathematical and linguistic pleasures, 25 chapters of them, each based on one of the familiar monthly columns published in this magazine. They have not been published in book form before. Squdgy fez, blank jimp crwth vox, but never obscure Gardner!

COUNT AND SEE, by Tana Hoban. The Macmillan Company ($4.95). White numerals three inches high on ink black ground, the names of the numerals and a set of dots belonging to the digit make up half the pages of this nearly wordless book. The other pages are crisp full-page black-and-white photographs, in which the real world yields striking discrete sets that also match the number. Here, for example, are two small close friends, one black and one white, seven chubby fingers, nine fire helmets (of Engine Company No. 9), 20 watermelon seeds in their luscious matrix and 10 pods of 10 peas each. The early reader will count and see and enjoy.

Field Guides

CITY LEAVES, CITY TREES, by Edward Gallob. Photographs and photograms by the author. Charles Scribner's Sons ($6.50). "For the most part, the trees of the forest are native American trees, but the trees of the city are—like its people—from many different parts of the world." The large pages of the book show a photograph of each kind of tree and facing it a photogram of leaves and fruit full size. A photogram is made without a camera by exposing photographic paper to a point light source, the leaf or the fruit being placed directly on the paper. The result is not only a clear and effective guide to some 40 species of city trees and leaves of the northern U.S. but also a work of art in any part of the world and an invitation to participate.

TRACK WATCHING, by David Webster. Franklin Watts, Inc. ($4.95). Reliably provocative, David Webster presents his observations and deductions as a guide and a challenge to the reader. The book is not just a catalogue of the tracks of game animals, like many others in the past. It is a graphic guide to inference, based on tracks in snow, sand, mud and even flour. Tracks are made by cars and bulldozers, people on skis or bringing the mail, gulls and terns, owls and dinosaurs. They can be read one by one and put together to make an entire little drama. You can be a tracker in the backyard or on the city street as much as in the deep pine forest. You learn how to make casts of tracks and how to cause tracks (a circle of some powder in the backyard around the bait) if you want to survey the wildlife of a suburban neighborhood. For grades four and up, it is an entertaining book for sharpening the eye and the mind.

TERRARIUMS, by John Hoke. Franklin Watts, Inc. ($3.75). Admirable in clarity, good sense and technical ingenuity, this little how-and-why-to-do-it book outweighs a good many more elevated works on ecology for young people. Here the world is yours in a small container, and it is up to you to see that it works. A terrarium is "a place of earth," and every good terrarium is a functioning ecosystem. The scale must be chosen to fit the life within; a terrarium the size of a tabletop is as big "as the average home or school can manage—and finance." Four terrariums are worked out in some detail as guides: a big brandy snifter, a lazy Susan covered with a plastic dome, a cylinder made of sheet plastic with a circular fluorescent lamp (a "sun bowl") as a top and a shop-built glazed "twentieth-century Wardian case." Plant and animal selection is made explicit and understandable. The tricky job of blowing your own plastic dome is fully described. You use "blister pack" butyrate, an aquarium air pump and an oven made of cardboard and aluminum foil with a single screw-in heating element. It all seems remarkably neat and workable. A little shopwork is needed, for example to cut big circular holes in plywood. The children in the photographs look real enough, and the projects should reward fifth-graders undertaking the easier projects and junior high school shop groups working on the harder ones.

A list of living items, materials and equipment is given, with the addresses of suppliers. The ideas worked out here, the arguments made in support of them, the clever use of modern products and the air of enjoyment surrounding it all make this a gem of a workbook in a field of deep importance.

SMALL WORLDS: A FIELD TRIP GUIDE, by Helen Ross Russell. Photographs by Arline Strong. Little, Brown and Company ($3.75). "Small worlds are everywhere." The small worlds described and pictured here are unusual but not very hard to reach. There are the galls of plants; leaves, either mined from within or rolled up; worms in an apple. Each of these is the small world of some insect. You need only find one apple tree. In late summer a single milkweed plant is such a world; beetles, caterpillars, flies know this. A dead log is a complex world with many climates. Pavement cracks and sidewalk spaces for trees are microhabitats as well. Make your own on a windowsill or in a yard corner. The book is a gentle lead into a way of seeing that children up to 10 or so can share.

EXPLORING AS YOU WALK IN THE CITY, by Phillis S. Busch. Photographs by Mary M. Thacher. J. B. Lippincott Company ($3.95). Cities are dominated by people, but insects are found underfoot and on the trees, birds are many, dogs and cats and horses and sometimes a squirrel can be seen, and the street trees shed many seeds in hope. How many? "Any break in the pavement encourages some green to grow again." ("Again" because every city was once field or forest.) A sharp eye can even pick out ancient life: here is a section of a strange round sea beast in a polished limestone block decorating a big building. The book is full of suggestions for readers in early grades; a Leader's Guide leaflet gives some hints of value. The tones of the rough brick wall behind the foxtail grass growing out of a chink in a sidewalk are somehow marvelously evocative of big-city sights.

Voyages

THEMSELVES ALONE, by Richard Armstrong. Houghton Mifflin Company ($4.95). Although the book begins "Man is a gregarious animal," it deals with loners. They are "the sons of Martha," travelers who have sought to loose their ties, once to go in search of God but in this volume more to wander in deserts, over high mountain peaks, on the polar ice or on the wild oceans. Airmen are mostly excluded; they are not true loners because their loneliness is brief.

The desert travelers are many. The bare Australian deserts were crossed by European wanderers on horseback or with camels. The Sahara and the Arabian desert know the almost mystical journeys of Harry St. John Philby and T. E. Lawrence, men who admired the Bedouin and sought to emulate his virtues. After Philby's journey across the unmarked gravel plain of Abu Bahr he wrote: "Our great march... was a stupendous performance, just such a feat as they sing of in their ballads... the

crowning glory of our whole adventure, though a crown of thorns very painful in the making." The first known solo rower across the Atlantic, a man named Johnson, took his dory in 46 days westward from Europe to mark the centenary of the Declaration of Independence. Captain Romer, "the craziest of them all," paddled a 19-foot canvas kayak from the Canaries to the West Indies. He made it in 88 days of suffering, but he set out again for New York from St. Thomas and never arrived. The mountaineers treated are the Everest climbers before Hillary and Tensing Norkay, those who failed in glory. Then there are the yachtsmen, alone or with a wife, who plan long voyages in small craft, particularly around the Horn. Vito Dumas, an Argentinian, sailed alone around the world in 1942. He stayed south of all three capes like an albatross, all the way in the roaring forties. The 1968–1969 race for lone voyagers around the world is described, a doubtful event for folk heroes. Indeed, one unhappy sailor never left the Atlantic but killed time off the River Plate until he could plausibly head for home. He managed to escape this moral trap by going over the side. His craft was found abandoned 1,800 miles from England.

There is more here than meets the eye. The book is an open gate to a wonderful body of literature, and it is a dreamer's textbook with some small peril of its own. Parents may like to know that "radio and radar have gone a long way" toward disarming the Horn, where ships of the Chilean navy now efficiently patrol. The volume is written plainly and excitingly enough for readers from 12 up.

SKYLAB, by Charles Coombs. Morrow Junior Books ($3.95). Apollo is over, but its spare hardware will furnish the long-lived manned orbital excursions called Skylab, scheduled for 1973. This book for space buffs in the grades is a clear, detailed projection of the mission, complete with airbrush drawings looking like pictures from *2001*. The historical present tense is used throughout ("From Skylab as it circles 270 statute miles above the earth..."). The station is planned for a lifetime of eight months until its consumables are gone. It will play host, its planners hope, to three three-man crews, the first spending four weeks aloft, the second, rocketing up on the thrust of a spare Saturn IB booster a couple of months later, as much as eight weeks, and the third, after another month of preparation, a final eight weeks. Mishap or chronic medical problems not now foreseen may of course set earlier limits.

The Skylab cluster has five components. The major space, amounting to a small two-story house, is a converted second stage of a spare Saturn rocket, an orbital workshop built in what was planned as a liquid-hydrogen tank. Living quarters, water stores and all wastes are in this unit. (Sponge baths are *de rigueur*.) There is no laundry but plenty of clean clothes. The men eat standing, using forks, pressure guns for metering liquids but no spoons! The men drift and crawl about, grasping a network of railings and bars painted blue to identify them as handholds. Special cleated shoes lock with a single twist of the foot onto grids that serve as floors and also cover some wall surfaces. Toothbrushes, sponges, water guns, food—all are color-coded to give each man a sense of privacy and to make it possible to keep individual records. The men enter and leave orbit aboard Apollo command modules.

There is no doubt about the interest of this remarkable voyage. It is described in rather too bland a manner, as usual, and the entire future of manned space flight is viewed very rosily, but young (and older) readers of the right bent will find the details irresistible. The view from that wardroom window, an 18-inch circle, will certainly be an experience worth sharing.

THE VOYAGE OF THE CHALLENGER, by Eric Linklater. Doubleday & Company, Inc. ($15). This is an anniversary year for two sciences. Tycho Brahe saw his supernova in 1572, and in December of 1872 the steam corvette H.M.S. *Challenger* put to sea under the white ensign of the Royal Navy. The supernova lighted the way to Newton, and the *Challenger*'s voyage "made oceanography a science in its own right." This very handsome centennial volume, crammed with period photographs, engravings and paintings (with modern ones as required) is a fit commemorative. The author is no scientist but is an experienced writer and a naval enthusiast. His book is a narrative chronicle of the voyage itself, based soundly on the *Challenger* reports and on various journals and notes compiled by members of the expedition. The scientific results are given short shrift: there is not even a list of the 50 volumes of the reports and their contributors. Ernst Haeckel gets a sentence or so, although one splendid lithograph from his volume of the reports is reproduced. The deep soundings reached a record 4,475 fathoms off the Marianas on March 23, 1875. The line was a one-inch hemp rope weighed down with a sinker of four hundredweight; the sounding required several tedious hours with the steam winch. Japan was a marvel then as now. The young Mikado himself is shown here silent and impassive in gold braid in a private photograph by one of the ship's naturalists, later an Oxford anatomy professor. (Each member of the party of visitors bowed seven or eight times as he entered the imperial presence and seven or eight times more as he retired from it.) There is a photograph from a volume of the reports showing a Tahitian girl dressed in "a shapeless nightgown." Mr. Moseley, who photographed the Mikado, found a Tahitian model more traditionally dressed only in a waist-high wrap. The harbor at Bahía is shown in a wide view; some 60 tall ships are anchored there, the *Challenger* lost among them. This is a kind of factual Jules Verne trip, a Victorian wonder, written so as to celebrate the adventure and to recall the manners and morals of another time.

TREASURE ISLAND, by Robert Louis Stevenson. Illustrated by Eleanore Schmidt. New York Graphic Society, Ltd. ($7.95). This is the full text of the classic pirate romance of 1882, with a splendid apparatus of detailed pictorial annotation. Flint's map is rendered large (if not quite as clearly as it might be); the rigging and tackle, bosun's pipe and lanyards are clearly depicted, and the meaning of sailing close-hauled, wearing ship and other maneuvers are made plain not by mere dictionary entries but by drawings. So it is with flintlocks and flags, coracles and macaws, coins of the period (a piece of eight seems to be an eight-escudo coin with Philip's head on it) and much more. The book ends with a gatefold (there are half a dozen of them) presenting a map and brief account of some 20 wrecks and pirate hoards in the Caribbean. There is a series of children's fiction classics given the same embellishment; *Treasure Island* is the most technological.

THE TRAVELS OF CAPTAIN COOK, by Ronald Syme. Photographs by Werner Forman. McGraw-Hill Book Company ($12.95). This thorough and well-written narrative of Captain Cook from his birth ("James, Ye Son of a Day Labourer, James Cook, and of his wife, Grace") to his death in a melee around the house of

King Kalaniopu in Kealakekua Bay is based squarely on the documents. It is illustrated with large facsimiles of old prints and drawings (particularly handsome are details from the plans of the *Resolution* and the *Endeavour*) and with photographs (both in color and in black and white) showing the places, the peoples and the artifacts Cook saw in his lifetime's exploration of the vast Pacific. It is a big volume, and the photographs often spread across the page in a luxurious way. Cook's own words are used as captions for most of the plates. ("These images are made of wood and covered with small feathers" is nonetheless a drab description of the Hawaiian god of war with fierce dogs' teeth, mother-of-pearl eyes and a feather crest of scrolled magnificence.) There is a twilight view of the Royal Greenwich Observatory, where one of Cook's chronometers still accurately ticks, "Mr. Kendalls Watch." Cook is the most attractive of the great naval voyagers, a man of justice and compassion in an age not given to much of either. The account of his death, when he quite unreasonably sought to take an old king hostage for a stolen cutter, is a plain tragedy, a prelude to the wider tragedy of the Polynesians he, but not his successors, dealt with as fellow men and women. This book may well entice readers of adventure to the richness of the documents themselves. Its visual beauty is a halfway step to the more abstract delights of scholarship. High school libraries and Pacific-facing schools should have this fine volume.

Perception

LOOK AGAIN!, by Tana Hoban. The Macmillan Company ($4.95). IS THIS A BABY DINOSAUR? AND OTHER SCIENCE PICTURE-PUZZLES, by Millicent E. Selsam. Harper & Row, Publishers ($3.95). Photographs are evidence, but they gain meaning only from the viewer. Such is the epistemological content of these two brief, simple picture books, each by a gifted author of works for the pre- or early reader. Tana Hoban is herself a photographer. She gives us a book quite free of words, 18 handsome black-and-white photographs, showing children, dandelion puffs, peacock feathers, a turtle, a zebra and other beautiful and more or less familiar forms. Between each pair of pictures, working against either one of them, is a blank white page with a small square window cut into it. You see every photograph first through that insufficient opening into the visual world. Texture replaces form, and the inward beauty of a pear core, a turtle shell, a zebra stripe and starfish spines are revealed in an enjoyable short-lived mystery.

The Selsam book is a little wider in scope but less pure in concept. Again we see photograph after photograph, the scale uncertain, the pictures cropped to present a handsome and enigmatic part of a more familiar whole. There are magnifications of five and 10, and we see bighorn sheep and windowpane frost feathers in addition to the plants and animals of the home, the beach or the zoo. The establishing shots follow to make the puzzles come clear; you can be sure it is not a baby dinosaur when you see the fledglings in their nest. The pictures are chiefly those made by the photographers of the National Audubon Society. Questions and answers only about as long as the title accompany the photographs, so that the book repays the effort of early readers.

CRASH! BANG! BOOM! by Peter Spier. Doubleday & Company, Inc. ($4.95). Last year this author-artist discovered a vein of rich ore, producing a book delightful for the prereading set and yet rewarding at almost any age. There is plenty of pay dirt left, although the mining lacks the excitement of the first discovery. Here each big colorful page is spread with detailed but cheerful vignettes from everyday experience, one page for the kitchen, one for the highway, one for the construction site, and many more. With each scene the careful observer has found just the words to mimic the sound each action would make. The words span a range too wide for the human voice; volcanoes and breaking eggs are more different than the oxpecker and the elephant, two of the animals that appeared in last year's zoological version. The sounds of the inanimate world are less unified and less imitable than those of our kin, the animals. Still, the style is the same, and the book is a pleasure. Blubba-lubba-lubba, the potatoes boil; afew, afew, afew, the file strokes say; thumpa-thump-thump-thump, the tall basketball player dribbles down the floor. Nonetheless, an orchestra is too complex and a volcano too grand for even the long strings of varying letters Spier so tellingly uses.

FRONTIERS OF PHOTOGRAPHY, by the editors of Time-Life Books. Time-Life Books ($9.95). It is all too easy to examine a photograph on a page with a naïve expectation of its history. Some lens was aimed artfully at a scene, we think, and the rest follows. This remarkably illustrated book, one of a monographic series on all facets of the art and technology of photography, serves to correct that naïveté. What we see is never input but is output; step by step back to the beginning we can trace a path very different from the aim-shoot-print sequence. Both as widened visual experience and as a guide to the dreams and the actuality of today's experimental photography, these pages mix virtuosity and playfulness in a menu highly suited to any young person past the grades who is caught up in making images, whether with brush or with hypo tray. The abstract painter Robert Rauschenberg produces a dazzling two-page lithographic spread, a composite of full-length X-ray pictures of his own skeleton with photographs, rubbings and a celestial chart. Darkroom transformations abound; every rule is broken for some set purpose. Three-dimensions enter by way of holograms (although neither a real hologram nor any other three-dimensional picture is included) shown in a number of photographs, with discussion of other approaches to depth. One sees a Swedish model by deep infrared in an image tube, or by the stresses her weight induces in a photoelastic device, or by contour-mapping, or by the sonogram of her voice, or—the extreme in tight close-ups—by the scanning electron microscope. The entire range of mixed media (prints on cloth or on engraved plates, modified opaque paint patches), multiple images and printing appears here in successful exemplars going back to Man Ray and on to this year's surprises.

Such freedom is tempered by a sound basis of technical necessity. Plenty of taking-off places are described in caption after caption, and a few offbeat darkroom processes are described with step-by-step pictorial detail. Curiously, among the finest photographs are two "abstract" images that are literal color photography, one of peeling paint on a wall and the other of an ice cave on Mount Rainier. Here are some 125 images for the imaginative.

Technology

BIKES: A HOW-TO-DO-IT GUIDE TO SELECTION, CARE, REPAIR, MAINTENANCE, DECORATION, SAFETY, AND FUN ON YOUR BICYCLE, by Stephen C. Henkel. The Chatham Press, Inc. ($4.95). MOTORCYCLES, CLASSICS AND THOROUGHBREDS, with an introduction by

Roberto Patrignani and Mario Colombo. Golden Press ($2.95). The explicit title of the bicycle book is virtually a review in itself. Still, some observations are in order. The author's line drawings are in a careful but not impersonal style, agreeable to the eye and yet clear and detailed enough to be a real help. The work is practical as well as fun: an exploded view of the 127 parts of a single-speed bicycle is the beginning of an account that can lead a novice through routine care to proper disassembly, first-echelon repair and thorough lubrication. The tools are drawn completely. The set suggested does not extend beyond a clutch of Allen wrenches and a rivet-setting fitting. The specialized tools of the professional repairman are shown but are not recommended for the cyclist; "the really tough jobs" ought to go to the bicycle shop. Don't take the derailleur (pronounce it day-rye-err or de-rail-er) apart "unless you are really mechanically inclined." There is history too: the first high-rise models were built a decade ago by southern California teenagers who assembled them out of disparate commercial parts, and in 1928 the heroic Leon Vanderstuft covered 76.3 miles in one hour around a French track for his long-lived record.

There are only a few brand names of parts, but a good comparison of gear styles, accessories and frame heights is given, with typical prices of parts and of many kinds of bicycles as of early 1972. Observe that a unicycle costs only a little less than a medium-quality three-speed tourer, which sells for a seventh the cost of a professional quality 10-speed lightweight, capable of offering daily transportation to a distant school or office. Theft is the cyclist's bane, and there is no easy answer. Altogether this is a fine up-to-date book for the reading cyclist, whether beginning or further along, and a valuable resource for libraries and clubs. The pages will not withstand grease stains.

Motorcycles is one of an excellent series (a companion volume is about roses!) translated from the Italian and printed in Italy. It is a book of dreams rather than a practical handbook, displaying at a real bargain price in lustrous colors some 50 machines, the latest models of manufacturers in Italy, Britain, Germany, Japan and the U.S. The Italian machines are presented most completely, but all the larger examples are treated with loving close-ups as well as overall views, and with succinct textual comments and specifications. Motorcycles are dual in their appeal: the smaller ones are cheap independent transportation, particularly for the young, and the large machines are the idols of an elitist cult. How elegant are the chromium-plated coil springs, the finny cylinders, the smoothly curved steel tubes profusely shown here! The introduction is knowing and devoted, giving a brief historic and technical background (discussing, for example, the gyroscopic forces that favor the transverse engine with its "archaic" chain drive over the modern automobile-like longitudinal spin axis and shaft). Unfortunately the book does not take up materials. The monstrous quality of motorcycles is faced; the editors begin by admitting that the "motorcycle has always been one of the most controversial forms of motor transport." This paper surrogate, however, is quietly beyond the controversy.

SHIPS-IN-BOTTLES: A STEP-BY-STEP GUIDE TO A VENERABLE NAUTICAL CRAFT, written and illustrated by Commander Donald Hubbard, U.S.N. (Ret.). McGraw-Hill Book Company ($7.95). A three-inch schooner under way across a putty sea, all caught in a bottle with a narrow corked neck, can hardly fail to earn attention and a place of proud display anywhere seafaring is prized. The art is a sailor's folk art, from forecastle days off watch on the long voyages before steam; the museums hold examples in New York, Greenwich, Saint-Malo and Barcelona. Nowadays the work is not to be bought; if you covet a ship in a bottle, make one!

This book is an invitation of remarkable attractiveness. The scale is so small that the materials and tools are cheap and easy to get. The best sails are made of bond paper (aged for half an hour in warm coffee); spars can be rounded from cocktail skewers with an electric drill; deckhouses and hatch covers can be carved out of Popsicle sticks. The hull and the boats are made of a wood such as fir (balsa is too soft and oak too hard). The modeler needs care and taste rather than sheer manual dexterity; he must work slowly, often under a magnifier. The book is more than a set of directions: the one-man author, draftsman and photographer adds context. Every part of the rigging is functional ("nothing . . . is there by accident"); the sea for coastal vessels should be tinged green for the plankton found in such waters but not in the blue-water deeps; there is a glossary of the sea jargon, and you cannot remain ignorant of the position of the mizzen-topgallant staysail.

Many a young person who has time and patience can undertake this form of modeling, so much more challenging than the plastic kits of the hobby shop. The central secret that enables the tall ship to sail although locked behind the bottleneck is fully disclosed but will remain outside this review. There is one tool made of a small piece of razor blade held on a long, thin stick, but its use is brief and specialized.

MODEL ROCKETRY, HOBBY OF TOMORROW, by Peter Lowry and Field Griffith. Drawings by Ritchie Lowry. Doubleday & Company, Inc. ($4.50). "We first thought of writing this book the summer we were thirteen. . . . Now we are seventeen and here it is." This is a book from the inside.

Model rocketeers fly light reflyable rockets they make themselves or from kits, using commercial model rocket engines. Their hobby is exciting, reasoned and safe; the rockets carry a one-ounce payload half a mile or more into the air. These enthusiasts never work with their own propellant or explosive mixtures; such work (even with matchheads) is unsafe for the untrained, whether they are youths or adults. The estimate is that working with explosive mixtures carries a risk of about one in seven per year of serious injury or death. Such "basement bombing" is not model rocketry. Four or five American companies make model rocket engines in a wide variety of sizes. Most of these engines use ceramic nozzles and solid-propellant grains loaded into paper casings. They are ignited with an electrical glow wire. One type uses a volatile liquid refrigerant in a light aluminum tank; when the pressure is released, the vapor forms the driving jet.

The book is practical, but it does not omit the essential data and simple theory. Engines generate a few pound-seconds of thrust for up to a second or so; rockets must be stable in the strong aerodynamic forces; it is no cinch to measure the height you attain. The tables and formulas are given; a long reprint of computer output sets up a model of performance for a wide variety of designs. One task would be checking how realistic these computations are. Payloads vary from hornets to raw eggs for trials, and extend to still cameras and radio telemetry. Many a model rocketeer can show his own aerial photograph of the launch site from 1,000 feet up. The rocket returns either on its own, fluttering down easily once the nose cone is blown off, or aided by

streamers, a parachute or a glider. It goes up at 600 miles per hour; the down trip is always gentle. The authors include plenty of suggestions for payloads, additional reading, club activities, clusters and staging, commercial suppliers and more. One misses a few pages of guidance about where to launch; the photographs show large, stubbly suburban fields or parkland.

The Physical Sciences

8,000 STONES: A CHINESE FOLKTALE, told by Diane Wolkstein. Illustrated by Ed Young. Doubleday & Company, Inc. ($4.95). Eighteen hundred years ago Ts'ao Ts'ao ruled over the royal city of Loyang from his palace amidst gardens, woods and lakes. One year the Satrap of India sent him a royal gift, a beast unique in the kingdom. Peasants ran out of their fields and courtiers from the palace to see the marvelous creature, called elephant. It stood full 10 feet tall. When Ts'ao Ts'ao asked how much the sturdy elephant weighed, the Indian envoys admitted that they did not know. There were no scales in India large enough to weigh an elephant.

The ruler of Loyang, commander of 10,000 soldiers, felt a challenge. He asked his advisers to find a means of weighing the elephant before the Indian mission returned home at the end of the month. The time passed, and the advisers had no answer. Then little P'ei, the ruler's son, told them how. He worked it out with a toy boat and a carved ivory elephant. The real elephant weighed just 8,000 stones, and clever P'ei grew up to become emperor of all China.

The book is a small treatise on ingenuity, reproducibility, calibration and the methods of physics, disguised as a charming and lovely book for readers up to about eight years old and for those who listen to good stories. The watercolors have the color of Loyang's gardens and lakes; they are simply done on a white ground, with a hint of the Chinese painters. The book as a whole is a rare pleasure to see and to muse on.

SCIENCE EXPERIMENTS YOU CAN EAT, by Vicki Cobb. Illustrated by Peter Lippman. J. B. Lippincott Company ($4.82). The kitchen is the best-equipped laboratory in the ordinary household; it has water, heat, many containers and their washing facilities, thermometers, volumetric measures and the rest. Cooking is a most ancient branch of applied biochemistry. This cheerily casual and inviting book takes full advantage of the kitchen; the experiments are neither wasteful, unpleasant nor dangerous. You can eat them!

What experiments are here? Freezing and dissolving crystals of sugar and of ice span the domain of the Popsicle. Mayonnaise and strawberry bombe illustrate emulsions, complete with the Tyndall effect. Popcorn and yeasts take on meaning; kitchen litmus, an indicator made of the juice of red cabbage, allows following the acid-base changes in a variety of reactions. The most advanced experiment is one that tests the action of the enzyme of a meat tenderizer. Here the effect is titrated by counting the chews before each treated piece of meat was swallowed. (The equipment includes "a hungry friend.") With such a measure careful controls are needed, and randomization of the order of chewing is part of the experiment. (The author stops short of using nonparametric tests of significance.) The book is a first-rate introduction to the sciences of matter for boys and girls old enough to work by themselves, probably around junior high school age.

THE STARS BY CLOCK AND FIST, by Henry M. Neely. Revised edition, with planet schedules for 1972–1985 compiled by Phillip D. Stern and George Lovi. The Viking Press ($5.95). STARS FOR THE SPACE AGE, by Joseph B. Breed III. The World Publishing Company ($5.95). These two books deal quite individually with much the same topic: how to find and recognize the stars in the sky. Each is a pedagogical *tour de force,* the first aimed at young stargazers, the second at older ones with a navigational bent. *The Stars by Clock and Fist* is already well known; it was first published some 15 years ago, and this is an updated edition. The root idea is simple: one can fix a direction by assigning an azimuth and an altitude. The azimuth is here coded by the familiar imaginary clock face, with the observer standing in the middle and 12 oriented due north. The altitude is given by the number of fist widths measured up from the horizon by the fist held out at arm's length. These crude and handy measures are ample for picking out stars by eye. Twenty-four lists are provided, and on each list we read the names of some 30 conspicuous stars and the visible zodiacal constellations. Each listing bears a pair of coordinates such as "Face 11, 6 fists." The proper list is chosen (the entries represent the hours of sidereal time) from a graph that allows for every day of the year and hour of the night. (Only the latitudes of the U.S. and Canada are catered to in detail; the maps, but not the lists, extend farther south.) Star maps in some detail are keyed to the lists; about 150 stars are included. The planets are tabulated as to zodiacal constellation over the decade ahead, so that the lists can indicate which planets are visible at any time. The work is clear but bulky. The scheme seems good enough to enable a lone beginner to find his sky way expertly from the printed word alone.

Stars for the Space Age is of the same class, but it is aimed at more mature readers with arithmetical abilities and a hope of high accuracy. Here the sky is presented on a Mercator projection and neatly compared to the earth. Star position is related to terrestrial longitude and latitude in a very clear and explicit account, fixed seaports are compared to fixed stars. Sky grid and earth grid are geared together by the changing hour angle of the First Point of Aries, which the author does not tabulate except in one example, relying on the tables published in the *Air Almanac* or the *Nautical Almanac.* The text alone is thus a guide to theory—an excellent one, if a bit polemical—but not a working pointer to the bright stars. It includes a neat endpaper slide rule, giving the longitude of every navigational star, once the First Point is set, to an accuracy of half a degree.

Other Times, Other Peoples

PITSEOLAK: PICTURES OUT OF MY LIFE, by Pitseolak, from recorded interviews by Dorothy Eber. Illustrations by Pitseolak. University of Washington Press ($9.95). "My name is Pitseolak, the Eskimo word for the sea pigeon. When I see pitseolaks over the sea, I say 'There go those lovely birds—that's me flying!' I have lost the time when I was born but I am old now—my sons say maybe I am 70." So begins this extraordinary book. It is the translation of conversations in the summer of 1970 between a Montreal journalist and a distinguished artist of the Cape Dorset Eskimos, of Baffin Island north of Hudson Bay, beautifully presented with many drawings by the artist herself, some in felt-pen colors. Its distinctions are manifold: it is the pithy autobiography of an old and wise woman, the story of an articulate artist, the account of one who has spanned a gulf in culture change, an ethnographic narrative of an unusual people and an album of graphic works

of acclaimed excellence. "I know I have had an unusual life, being born in a skin tent and living to hear on the radio that two men have landed on the moon." "There were good shamans and bad shamans but most people feared them—in the old days there were many things to fear." "I don't know if it is easier to have babies in a hospital. Ahalona! At any time it is hard. There is a saying, 'It is hard but it is well.' I had 17 children—every year I had a baby—and many of them died as little children." "To make prints is not easy. You must think first and this is hard to do. But I am happy doing the prints.... I am going to keep on doing them until they tell me to stop. If no one tells me to stop, I shall make them as long as I am well. If I can, I'll make them even after I am dead."

Animals, insects and birds from life and from the free fancy, spirits and monsters of legend, scenes from everyday life and lively remembrances of yesterday (like "the old life was a hard life but it was good. It was happy") are the subjects of Pitseolak's strong line and bold color. As if these were not enough, the entire text is carried along bilingually, with adjoining columns bearing the English version and the Eskimo. The latter is presented in the handsome geometrical alphabet invented by the missionaries a century ago and used all across Canada. This is a book for all literate ages and conditions, but young women should value it in particular. Those who delight in the hand and the eye will find it a work to live with year after year.

ANANSI THE SPIDER: A TALE FROM THE ASHANTI, adapted and illustrated by Gerald McDermott. Holt, Rinehart and Winston ($5.95). In glowing offset colors, the white paper almost entirely lost, this small book for small readers or the read-to tells one of the myths of this tradition. The illustrations are bold, hard-edged and largely geometrical, a kind of op-art adaptation of the strong conventions of Ashanti graphics. The speech too suggests West African meter. The book derives from the successful animated cartoon that was the film-making author's first telling of the tale. The result is striking. Cartoon-watchers can make the transition to the self-paced style of the printed word with this book.

The tale tells of the great spider and his six skillful, strong spider-sons. They all helped him in a time of trouble. For example, River Drinker took a big drink, and Game Skinner opened the awful fish to release Father Anansi. When Anansi encountered the great globe of light in the forest, he wanted to make it a gift to one son. Which one? Finally the God of All Things took it into the sky, where He keeps it still for all to see by night.

WHEN CLAY SINGS, by Byrd Baylor. Illustrated by Tom Bahti. Charles Scribner's Sons ($4.95). Across the earth-toned pages the poetic and evocative brief text runs, along with a hundred drawings in bold outline, the designs all derived from prehistoric pottery of the American Southwest, from the Anasazi, Mogollon, Hohokam and Mimbres cultures. Leaping fish, strong bowmen, whirlwinds, jumpy bugs, rabbits and flute players—all are presented as the artful women drew them long ago, the women who "must have spoken to the earth as they took its clay." "Sometimes children may have said (but in that other language): 'Mama, make a bowl with pictures of big animals for me.'" "Indians who find this pottery today say that everything has its own spirit—even a broken pot. They say the clay remembers the hands that made it. Does it remember the cornfields too? And the summer rains?" This is a beautiful book, like its superb predecessor reviewed here last year. Its pages will recall to many young readers over many years to come their gifted artist, whose untimely death this year we note here in sadness.

EXPLORING THE UNKNOWN: MYSTERIES IN AMERICAN ARCHAEOLOGY, by Sharon S. McKern. Praeger Publishers ($5.95). Ever since the Mound Builders were held to be the Lost Tribes of Israel, American archaeology has been host to a proliferation of fanciful theories, generally rationalizing the notion that the local people, vanquished and forlorn, could not have made the monuments of the land without exotic aid. This lively book recounts the most credible of the riddles of the past of the Americas, offering no answers and being entirely reasonable about the enigmas still unsolved. Although the orthodox might well regard some of these "riddles" as contrived, it is well to treat them with respect. What we do not know is plainly large and important in this domain of knowledge.

Here is Machu Picchu, "lost city in the clouds." Surely Inca, its splendid granite citadel, with its piped water, its masterfully fitted ton-size masonry and its central sundial, is unique. Its purpose is unknown, and the guesses are many. The trepanned skulls of ancient Peru seem less remarkable; in East Af-

rica such operations have been carried out in recent times with stone-age implements and technique. The hundreds of remarkable figures of the Nazca Valley, made by removing the darkened surface pebbles to mark out networks over as much as tens of miles of desert, some of them geometric, some perhaps astronomical alignments, some in animal shapes, are amazing. Were they dedicated to the "ever watchful" gods who looked down on the earth from the sky? They are too large to be made out fully except in an aerial view. Nor do we yet know what causes brought the classic Maya civilization to its long immersion in the jungle green. With a few other chapters, these stories are well told. The book is a welcome one; it acts as an introduction to real puzzles of the American past, without all the romancing of the zealots who have carpentered their theories to fit each of the mysteries. From the higher grades and up, readers who admire the witness of the spade will enjoy this unusual book.

LOOK TO THE MOUNTAIN TOP, edited by Robert L. Iacopi, Bernard L. Fontana and Charles Jones. Gousha Publications, San Jose, Calif. ($3.95). In large magazine format, with many color photographs and drawings, this collection of essays breathes the contemporary pride and spirit of the American Indian, determined to reclaim a heritage long denied. The pieces range from politics to religion, from an estimate of the role of women in Indian life to a review of Indian art. Most of these are vivid with the tones of advocacy: the strong voices of Indian writers, with a number of others. There is a second part with maps, a chronology, citations from Indian orators of the past (whose eloquence and reason seldom won their case) and guides to cookery and the purchase of Indian arts and crafts. One old Shawnee singer a decade ago told his questioner a story like that of Our Lady of Guadalupe to validate not the Church of Rome but the Ketoowa Society of the Cherokee. So does the past entwine us all. Readers of any age beyond the early grades will learn and gain from this strong statement.

THE GREAT SHIP VASA, written and designed by Greta Franzen. Hastings House ($5.95). During the Thirty Years' War, when the Swedes were a truculent great power, the King caused to be built a grand three-decker, intended to crown the fleet serving in support of the Prussian campaign. The *Vasa* was made of

the best black oak timbers; she was sumptuously carved and fitted and carried 48 heavy bronze cannon and 16 lighter guns. Her proud maiden voyage began on the afternoon of August 10, 1628, and ended in ignominy an hour or so later. The pride of the King's navy had sunk at a depth of 110 feet, with some 50 drowned, in Stockholm's muddy harbor. She was a crank ship; narrow and top-heavy, guns too big and misplaced, gunports too near the waterline.

This small, attractive, informed and personal book tells the story of how the *Vasa* was found, was salvaged and is now being preserved in a special museum in sight of her resting place, her cargo and frame a kind of random sample of life caught as though by a time machine and brought to us out of the baroque period. The salvage has two heroes. The first was Lieutenant Colonel Hans von Treileben of the Swedish Army in the 1660's, whose crude diving bell, manned in the dark cold sea by workmen of magnificent courage and stamina, recovered most of the valuable bronze cannon with ropes and boathooks. That task done, the *Vasa* was abandoned and forgotten, to be covered over by the silt of the centuries, until a young engineer, Anders Franzén (no relation to the author), fulfilled his boyhood dreams by locating the *Vasa* in 1956, after decades of ingenious searching both in the old archives and on the harbor bottom. He knew she would be in salvageable condition; he reasoned that the shipworm, which holes old wet timbers into a spongy mass, could not live in the low-salinity Baltic. No other sea has had such large ships and such good conditions for the preservation of wooden wrecks.

The *Vasa* was raised, and she now lies in a temporary museum. Her entire frame is given a shower bath all night long and for every other 20 minutes during the day. For some 10 years she has been bathed and sprayed to replace the water in her timbers with a "stiffer" substance: an antifreeze polymer. Once the process is complete (it will take a few years more), the wood will neither rot nor shrink and crack. Twenty-four thousand objects found aboard are listed; they are parts of the ship and the personal items of her impressed peasant crew. Eighteen skeletons or parts of skeletons were found; two were of women (wives aboard for the celebratory voyage) and the rest of men, none taller than five feet seven inches. Quarters below deck were cramped.

Franzen's book is an interesting introduction to a now considerable literature on the *Vasa*, a ship whose voyage turned out to be through time.

THE MYSTERIOUS WORLD OF CAVES, by Ernst Bauer. Franklin Watts, Inc. ($4.95). A TALE OF TWO CAVES, by François Bordes. Harper & Row, Publishers ($5.95). Caves present a world of darkness and mystery reached from the bright day in a few steps. They have become the arena of sportsmen and scientists no less than they have offered shelter under special circumstances, from the earliest days of the human genus to contemporary dwellers and even industrial and military organizers. The first of these books is a straightforward account of caves, largely from the point of view of the Central European limestone lands, where there are caves large enough to accommodate cathedrals, let alone the playful natural architecture of dripstone. There is a river in the Yugoslavian highlands that has five names; each time the stream reappears aboveground the local people give it a name of their own as a new feature. Nowadays cavers have followed the entire length of the river, boating, climbing, diving and swimming as the circumstances indicate. The Danube itself sinks below the surface in the Black Forest near its source; indeed, the river Aach, which flows into Lake Constance, is interconnected underground with the bigger stream and follows its changes. The book is never hard to read, and it is richly illustrated in color, both with photographs and paintings. It deals well with the life in caves, the strange fresh springs in the sea, some famous caves and other matters (including a Greek mystery, where water flows from the sea to turn a mill and then reappears to flow back to the sea three feet above sea level). The topic is broadly viewed, and the illustrations include many informative paintings of three-dimensional block sections, which make strikingly clear many phenomena in the curious geology of caves and in their origin.

The second book is not easy at all, but it is remarkable. It is the presentation of a problem in archaeology, so sharp in detail, so personal in tone, so wide in viewpoint that it transcends the textbook it is meant to be. It cannot serve as anyone's first book in the search for our ancestors who wrought in stone, but it can be the second book for any serious reader of high school age and beyond. The two caves are a few miles apart in the valley of the Dordogne. There on and off for 25 years the au-

thor, evolving from a young graduate student to a distinguished professor at Bordeaux, has painstakingly worked in the jigsaw puzzles of the rock and soil of a hundred millenniums. He does not work alone but with a shifting international team from Nigeria or Japan, Peru or the U.S.S.R. Experts from the laboratory are involved too, but they first come to the site. "We do not believe in the 'experts' studying in a laboratory samples of a site they have never or barely seen." It works; a careful three-dimensional notebook method plots not only the flint scraps worked by human hands but also every stone as big as a fist. The microscope and the analyst's reagents tell the story of climate and change, of frost-cracking, rockfall, wind and water, not to mention animal bone and pollen grain. In this way Bordes has built up a long history of mankind in the two complementary sites.

There is controversy too. He disagrees with the American theorists who hold that the statistical variations among the thousands of tool parts to be found in such careful digs indicate occupational differences: some sites are used for one purpose, some for another. He believes (and he tells why) that his related statistical treatment suggests rather that our Neanderthal ancestors had several distinct cultural patterns at one and the same time. He found an enigmatic engraved bone, just about the oldest marking made by man, that merits the working title Doodle I. These old people used plenty of mineral-pigment stone; the blunt ends show a rounding off by being used on a soft surface. Skin? We cannot say if it was their own skin or that of animals. If they painted themselves, perhaps they were light-skinned, since much the most popular color was the blue-black manganese dioxide. It is still a doubtful conclusion, but it is a fair sample of the tantalizing possibilities that lie in every site.

Let Bordes finish: "To excavate is to destroy. [It] must go on, since it is the only way really to learn. But it is sacred work... disturbing the dead, violating sepulchers, and our only excuse is this hunger to know what separates man from the animals. Yes, the work goes on.... To do something seriously does not mean it must be done gloomily. There is a good deal of fun and laughter at the excavation.... This year, we had eight different nationalities and three different races.... There will be other caves, other shelters. And other archaeologists. Someday, why not you?"

INDEX OF ADVERTISERS

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ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1972. Also indexed are "Mathematical Games," "The Amateur Scientist" and an essay book review.*

AUTHORS

ARTICLES

MATHEMATICAL GAMES

THE AMATEUR SCIENTIST

BOOKS

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

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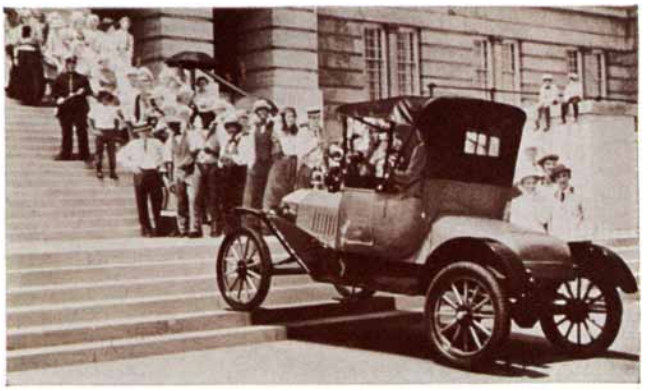

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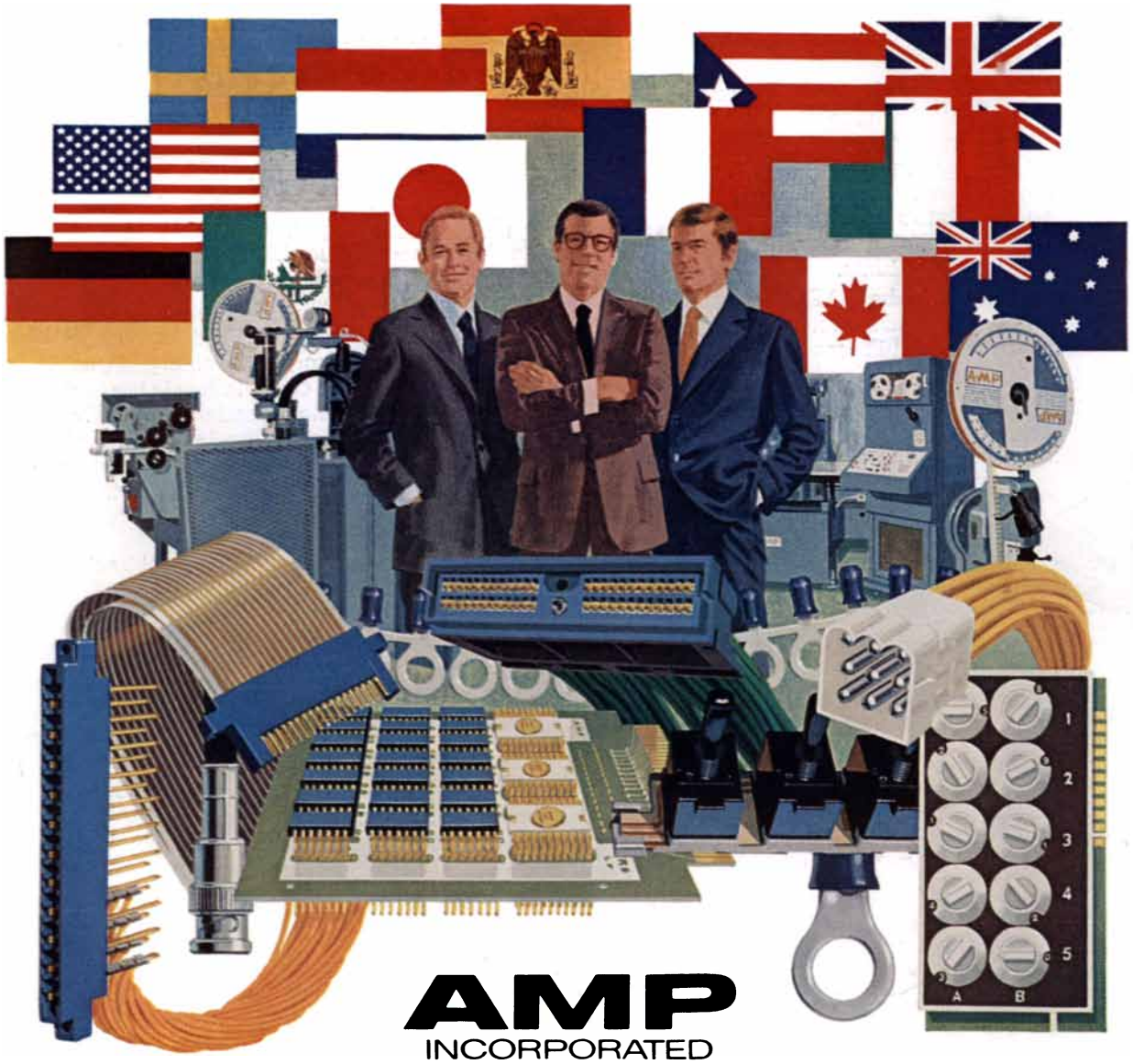

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