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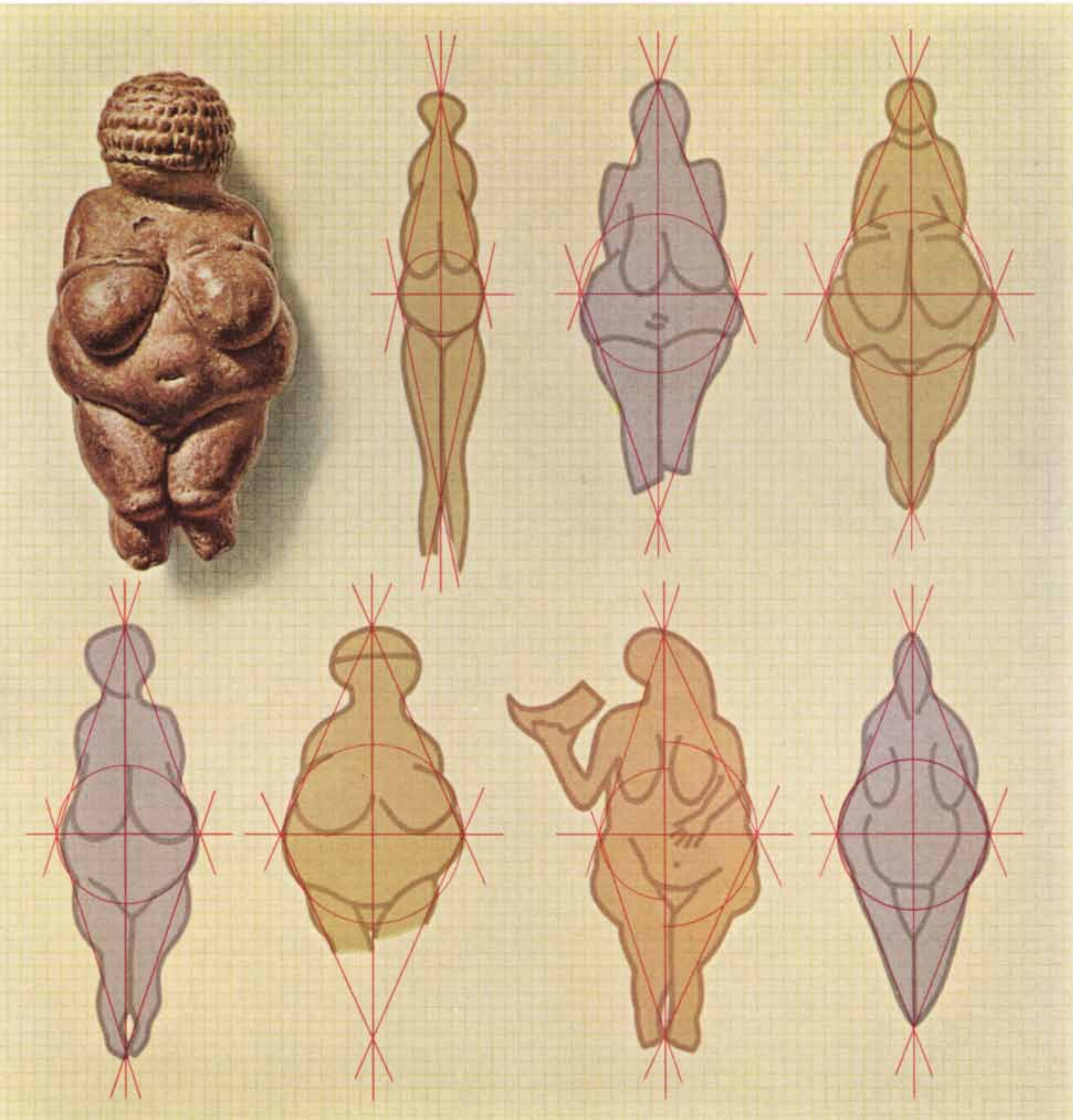

VENUS FIGURINES

SEVENTY-FIVE CENTS

February 1968

Beech Aircraft supplements large computers with Monroe electronic printing calculators for support in working out stress problems.
For other kinds of business stress, we have other calculators.

"Computers are fine when you have long, complex problems," says Roger Stevens, Staff Assistant at Beech Aircraft Company, one of the leading manufacturers of private, military and business aircraft. "But sometimes our engineers need quick answers to less complex, shorter problems. Often a test flight will turn up a stress problem without time to prepare a computer program or available computer time. So the engineers turn to a programmable EPIC® electronic printing calculator and work out the answers themselves, on the spot. It saves time and it saves money. More important, our Monroe EPIC gives the engineer a flexible, figure-work tool under his immediate control."

Beech engineers also appreciate the flexibility of the EPIC calculator. No longer is it necessary to work out problems twice to check the accuracy of a solution; verification is now a simple matter of checking the figures on a paper tape.

Nor does the EPIC end its usefulness there. It does complex calculations and works out square roots in a fraction of a second. And it can perform the most difficult calculations just as easily as it handles the most ordinary problems.

Monroe first introduced its solid-state electronic printing calculators two years ago. Today, we sell more different kinds of calculators than any other company in the world. Which means you're assured of finding the right calculator for your particular operation, without having to pay for more computing sophistication than you actually need.

Write or call your nearest Monroe representative for information on the full line of full-value Monroe calculators. You can depend on them.

MONROE

Can a man fall in love with his car?

That depends.

If the car is a fickle, unreliable, attention-demanding shrew, he's liable to be a little short on affection.

But if she happens to be a slim, lovely thoroughbred that performs like a dream, asks little, and is always ready to give her utmost, well...a man is only human, isn't he?

Nowadays, a lot of men are discovering that one particular car can add a lot of spice to life.

The car is the brilliant new BMW 2-door sedan, built by the Bavarian Motor Works especially for the sportsman.

What's she like?

Dazzlingly fast. Actually cruises at 100 mph. In fact, in Germany, where high-speed driving is a national sport, BMW leads the pack.

Amazingly nimble. Features a fully-independent suspension for surefooted roadholding that makes her as safe as she is fast.

And charmingly well-mannered. Priced under $2600, delivers up to 30 miles to a gallon, and turns up her nose at repair shops.

Can a man fall in love with his car? If the car is the new BMW, how could he help it?

Drop in on your BMW dealer. He'd like to introduce you to a little beauty.

Suggested retail prices start at **$2,597** P.O.E. New York. U.S. Importer: **Hoffman** Motors Corporation, 375 Park Avenue, New York, N.Y., 1862 S. La Cienega Blvd., Los Angeles, Calif. Dealers coast to coast. Advantageous European Delivery Program, Write for free brochure.

Bavarian Motor Works

The Sportsman's Car

Established 1845 **SCIENTIFIC AMERICAN** February 1968 Volume 218 Number 2

ARTICLES

DEPARTMENTS

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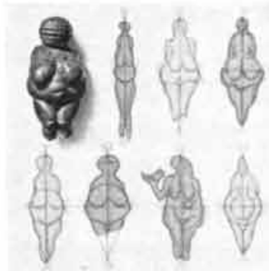

THE COVER

The painting on the cover shows, in whole or in outline, eight of the 100-odd "Venus figurines" that have been found at Paleolithic sites in Europe from western France to the Don valley in the U.S.S.R. The figurine shown in the round is the one uncovered at Willendorf in Austria; it is reproduced two-thirds actual size. The figurines in outline were drawn at a comparable scale by André Leroi-Gourhan to facilitate study (see "The Evolution of Paleolithic Art," page 58). As the red lines show, the figures were modeled according to a common convention whereby the bulk of the trunk—breasts, belly and pelvis—lies within the circumference of a circle, and the figures' sharply tapered legs and narrow shoulders lie close to the limits of isosceles triangles with bases of the same width as the circle's diameter. Although widely distributed in space, the Venus figurines all seem to have been created during the same general time interval in the Upper Paleolithic, between 20,000 and 18,000 B.C. The seven Venus figurines in outline (*left to right and top to bottom*) are from Gagarino in the U.S.S.R., Vestonice in Czechoslovakia, Lespuge in France, Kostenki in the U.S.S.R., Gagarino in the U.S.S.R., Laussel in France and Balzi Rossi in Italy.

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Cover painting by Jack Kunz

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Arnold
Palmer

LETTERS

Sirs:

Dr. J. R. Clamp of Bristol University has drawn my attention to a historical error in my article "The Structure of Antibodies" [SCIENTIFIC AMERICAN, October, 1967], and has supported his evidence with a certified copy of the relevant death certificate.

In discussing the proteins found in the urine of some myeloma patients and now known as the Bence-Jones proteins, I stated that they were observed first at Guy's Hospital by Dr. Henry Bence-Jones. In fact the patient, a grocer named Thomas Alexander McBean, lived and died in his house at 37 Devonshire Street in London. His death was attributed to atrophy from albuminuria. The original observation of the heat-precipitable protein was made by his general practitioner, Dr. McIntyre, who sent urine samples through Dr. Watson to Dr. Bence-Jones, a member of the staff of St. George's Hospital. Dr. Bence-Jones's investigations of the protein were carried out in the laboratories of University College. I am afraid that Guy's Hospital was not involved in any way.

Since Bence-Jones proteins have played such a large part in unraveling the structure of immunoglobulins, it is perhaps worthwhile to get the history of their discovery correct.

R. R. PORTER

University of Oxford
Oxford

Sirs:

In the present epoch our galaxy contains about a billion stars that are at least twice as massive as the sun. The least luminous of these stars will exhaust the nuclear fuel available to them in less than a billion years; the brighter ones can go on shining for less time than that. Among objects having more than two solar masses we may therefore say that "star deaths" must now occur at an average rate somewhat higher than one per year.

This rate is several hundred times faster than the rate of supernova outbursts in our galaxy. Therefore it cannot be true that most of these massive stars evade the fate of gravitational collapse by exploding, as one might infer from Kip S. Thorne's article "Gravitational Collapse" [SCIENTIFIC AMERICAN, November, 1967]. Neither is it necessary to suppose that for all stars more massive than 1.2 solar masses the evolutionary process must terminate in a nuclear explosion or in gravitational collapse. Whereas it is true that such massive stars cannot become white dwarfs, they may nevertheless evade both of the alternatives Dr. Thorne has allowed them. Probably they accomplish this by the simple expedient of mass loss in nonexplosive, quasi-steady stellar winds. Astronomers have long had abundant spectroscopic evidence that most massive stars generate such mass flows during the evolutionary stage when they are red giants or supergiants, and recent observations in the rocket ultraviolet show that comparably massive flows arise from massive stars of high temperature.

Much remains to be learned about these nonexplosive stellar winds. The most familiar example, and the best understood, is the solar wind itself. It appears to be driven by a flux of energy in the form of acoustic waves, or magnetohydrodynamic waves, that are generated in the hydrogen convective zone below the visible surface of the sun. There is some reason to believe that a similar process drives the circumstellar flows we have observed in many more massive stars. The details of these stellar winds remain uncertain, and we find it difficult to estimate accurately with what effi-

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ciency they reduce the masses of the stars from which the winds are known to blow. But there is no doubt that these flows are orders of magnitude more massive than the solar wind, and there can be little doubt that they play a dominant role in transferring matter from stars into the interstellar medium.

The bizarre phenomenon of gravitational collapse may indeed occur, as Dr. Thorne has so skillfully described it. But it is necessary to correct the misapprehension that, for most stars more massive than the sun, gravitational collapse is the only alternative to nuclear explosion.

ARMIN J. DEUTSCH

P.S. *According to Chandrasekhar*
A fully degenerate star
Continues to glimmer,
Forevermore dimmer,
Disdaining what's brusque or bizarre.

But stars that have greater than one
And two-tenths the mass of the sun
Close space in around them—
Which is why no one's found them—
With nuclear fusion all done.

A. J. D.

Mount Wilson and Palomar Observatories
Pasadena, Calif.

Sirs:

I am pleased that Dr. Deutsch has raised the issue of what fraction of all stars in our galaxy die by collapse, what fraction by explosion and what fraction by contraction to the white-dwarf stage. This is an issue I avoided in my article because it is fraught with uncertainties.

I am in substantial agreement with everything that Dr. Deutsch says. Wherever there appears to be a conflict between my article and his letter, it is due merely to our use of different terminology. When I quote stellar masses as the factor that determines the type of death, I always refer to masses at the end point of the normal stages of evolution—after all mass loss is finished but before "death" occurs. When Dr. Deutsch quotes stellar masses, he refers to masses during the main-sequence stage of evolution, before substantial mass loss has occurred.

KIP S. THORNE

California Institute of Technology
Pasadena, Calif.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1918: "Unless the Allies and ourselves exert every effort in turning out airmen and flying machines, we are not going to have that superiority over the German air forces which we look forward to sometime this year. Spurred by the rumors of increased Allied production and the tremendous program of the U.S., Germany has been frantically turning every factory that could possibly be spared from other work into an airplane plant. It is estimated by French authorities that the German air fleet presently numbers about 300 squadrillas, or a total of 2,500 machines. These are probably divided as follows: bombarding squadrillas, 23; chasers, 40; protection squadrillas, 30; patrol squadrillas, 80; artillery squadrillas, 100; total, 273. These only represent the materiél of the armies at the various fronts, and to them must be added the airplanes and seaplanes of the navy. Again, there are a dozen or more garrison squadrillas in the interior of Germany and a dozen or more training camps."

"The Navy is in urgent need of binoculars, spyglasses and telescopes. The use of the submarine has so changed naval warfare that more 'eyes' are needed on every ship in order that a constant and efficient lookout may be maintained. Heretofore the U.S. has been obliged to rely almost entirely on foreign countries for its supply of such articles. These channels of supply are now closed and, as no stock is on hand in this country to meet the present emergency, it has become necessary to appeal to the patriotism of private owners to furnish 'eyes for the Navy.' Several weeks ago an appeal was made through the daily press, resulting in the receipt of over 3,000 glasses of various kinds, the great majority of which have proven satisfactory for naval use. This number, however, is wholly insufficient, and the Navy needs many thousands more. All articles should be securely tagged, giving the name and address of the donor, and forwarded by mail or express to the Honorable Franklin D. Roosevelt, Assistant Secretary of the Navy, care of the Naval Observatory, Washington, D.C., so that they may be acknowledged by him."

"Lieut. Papa has beaten his own world's record for high flying with a passenger, says the Milan correspondent of the London *Times*. In an Italian machine he rose to 7,075 meters (23,200 feet), returning to camp after an hour and five minutes' absence. He broke the record last May, rising to 6,435 meters (21,000 feet). Lack of oxygen prevented an even higher flight this time."

SCIENTIFIC AMERICAN

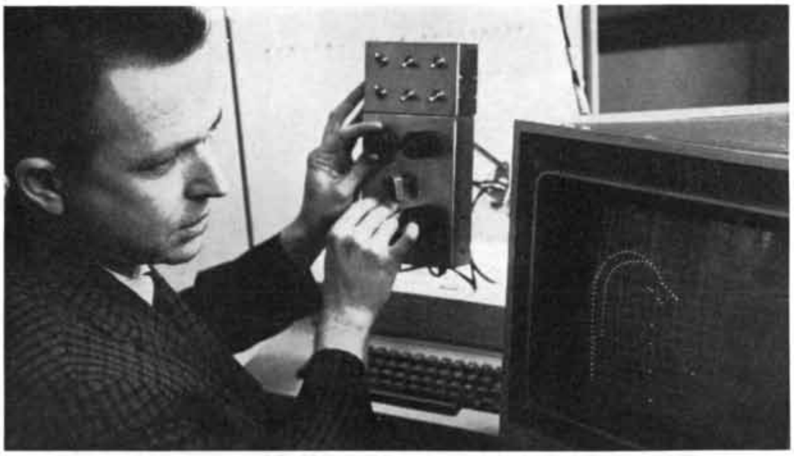
FEBRUARY, 1868: "The inventor of 'blasting oil,' Mr. A. Nobel of Hamburg, writing to the London *Times* relative to the recent nitro-glycerin disaster at Newcastle, Eng., bitterly complains that the introduction of this valuable explosive, owing to the accidents resulting, as he afterwards shows, from gross carelessness, has been systematically opposed, and he thinks it is high time that the public should know that nitro-glycerin has won its battle over prejudice and obtained far too firm a footing in several countries ever to be banished from use unless it be by something better. Then follows a list of nitro-glycerin accidents which have come to his knowledge, and in looking over the list it must be admitted that the substance has been very strangely abused. This list is published that these accidents may serve as a warning against similar attempts to perform these feats, but the inventor protests against the narrow view of trying to check the career of any improvement on the plea of liability to accidents. 'There is,' says he, 'a very easy way of getting rid of them; we need only prohibit the use of steam, fire, poisonous substances, cutting tools, firearms, explosives, etc., and return to those days when ignorance and safety went lovingly hand in hand. But unless civilization is to be stopped, we cannot possibly confine the community to those articles only which it is difficult or even impossible to abuse. Something must be left to the understanding, and it is an excellent regulator.' "

"In a lecture delivered before the British Association at Dundee, Professor Alexander Herschel made the following curious observation:—'A question which at present agitates the minds of physical astronomers is to ascertain

Report from

BELL LABORATORIES

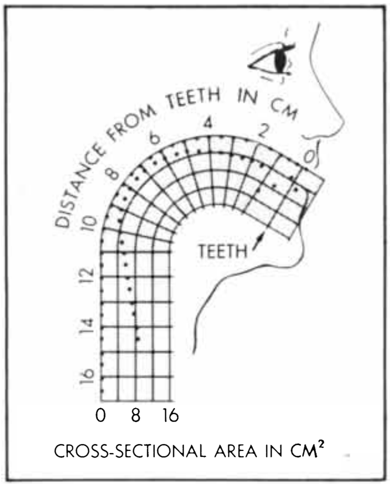
See a computer talk

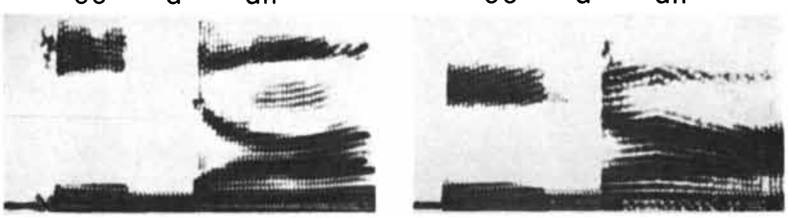


C. H. Coker adjusts controls which change the outline of the "vocal tract" simulated on the oscilloscope. At the same time, he hears the sound corresponding to the displayed shape. Desired vocal-tract shapes (representing sounds) can be stored in the computer memory.

Bell Laboratories' computerized vocal-tract model. (Head outline added.) The various parts can be positioned to imitate any speech sound. The model displays tract length versus cross-sectional area. It is based on anatomical measurements of the vocal tract made by a number of acousticians.

A feature of the model is that it reproduces the transition sounds between word fragments. The nonsense word eedah, for example, consists of ee plus d plus ah. But the d is not the same as in, say, eedee. That is, the d is noticeably affected by context. Coker handles this by storing dynamic properties of the vocal articulators (the tongue, lips and jaw). The program automatically incorporates these properties in assembling word fragments.





Comparison of nonsense word "eedah," pronounced by a human (left) and by Coker's program. These speech spectrographic patterns represent time (horizontal scale), frequency (vertical), and intensity (line density). The dark bars are called "formants" and are characteristic of speech sounds. The technique for making these diagrams was conceived and developed in the early 40's at Bell Telephone Laboratories.

Speech, one of the most complex of human activities, is studied as part of the continuing communications research at Bell Telephone Laboratories. But the speech mechanism has always been difficult to analyze: vocal-tract movements—crucial to the formation of meaningful acoustic signals—are mostly obscured from sight and are not easily measured. Now our understanding of speech is being advanced through a computerized simulation of the vocal tract devised by Cecil H. Coker of Bell Laboratories and Osamu Fujimura of the University of Tokyo, who worked at Bell Labs as a consultant.

The model (displayed on an oscilloscope, left) resembles the actual vocal tract and shows its principal parts. The parts can be moved either automatically by the computer program or by manual controls on the computer panel. The program calculates speech data corresponding to the displayed vocal-tract shape and delivers these data to an electronic speech synthesizer, designed by Coker. The synthesizer then generates a sound corresponding to the tract shape. Hence the researcher can hear the synthetic output at the same time he sees the tract motion.

The model accurately reproduces not only individual speech sounds but, for the first time, the subtle transitions that connect these sounds. It also demonstrates that these transitions are vital to clarity and realism.

The system produces patterns of frequency and energy (spectrograms) very like a human's (left). And it passes a more difficult test: pronouncing speech sounds which are understandable even when taken out of context.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

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whether a slight acceleration of the moon's apparent motion can be attributed to an error in calculation, or whether the earth in the course of ages has lost in its speed of rotation. The lunar tables, which exactly represent the moon's apparent motion at the present time, do not absolutely give the hour of an eclipse which happened when the sun was setting at Babylon some hundred years B.C. The eclipse began, according to the table, when the sun was already below the horizon, and it would be invisible at Babylon. But if the earth's rotation had been a little more rapid in former times than at present, the sun, instead of having set, would have appeared eclipsed before its setting, as was indeed the fact. To account for this change in motion, the friction of the tides having been considered, a slow accumulation of meteorites upon the earth's surface would undoubtedly diminish its speed of rotation. The change of a hundredth part of a second in the length of the day, since the earliest observations, would explain the existing discrepancy."

"M. Lenormant, a member of the French Academy, has been devoting considerable attention to the study of an interesting Egyptian papyrus, just added to the collection of the British Museum. This ancient relic contains a fragment of a treatise on geometry applied to surveying, including a description of the modes of estimating the areas of a square, a parallelogram and various kinds of triangles, as well as a computation of the area of an irregular figure by means of triangles and of the volume of a pyramid, the whole being illustrated by appropriate diagrams. M. Lenormant, in a report to the Academy, refers the production of this papyrus to the period of the 12th dynasty, which would be contemporaneous with the reign of Solomon."

"To the astronomer determining the colors of the stars is a subject of much interest, and different observers vary greatly in their opinions in this respect as to particular stars. For the sake of a more definite and reliable means of determination, a simple contrivance has been recently invented, consisting of a series of vials filled with solutions of known tints and attached to a revolving drum. A platinum wire is rendered incandescent by means of a galvanic battery, and as the vials are brought before the light their colors can be distinctly seen at night, and by successive comparisons with that of the star the exact shade is found."


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THE AUTHORS

JOHN F. HOGERTON ("The Arrival of Nuclear Power") is a consultant on nuclear power. He conducts a two-sided practice, one in economic and market research and the other in communication. In the first he is concerned with the growth of the nuclear power industry and with the supply of and demand for uranium. In this capacity he is currently a consultant to the U.S. Atomic Energy Commission on a study of competition in the nuclear power industry. The study is sponsored jointly by the commission and the Department of Justice. In communication Hogerton serves as a consultant and also writes extensively. Last year the AEC awarded him a certificate of recognition "for outstanding contribution to effective communication in nuclear science and technology." Hogerton was graduated from Yale University in 1941 and began work in the nuclear field a year later. He started his independent consulting practice in 1962.

EFRAIM RACKER ("The Membrane of the Mitochondrion") is Albert Einstein Professor of Biochemistry at Cornell University and chairman of the Section of Biochemistry and Molecular Biology in the university's Division of Biological Sciences. Born in Poland, Racker received an M.D. degree from the University of Vienna in 1938. From 1938 to 1940 he was research assistant in biochemistry at the Cardiff Mental Hospital in Wales. He then spent a year as research associate in the department of physiology at the University of Minnesota and two years as an intern and research fellow in pneumonia at Harlem Hospital in New York City. From 1943 to 1952 he taught microbiology at the New York University College of Medicine. In 1947 he became a U.S. citizen. From 1952 to 1954 he was associate professor of biochemistry at the Yale University School of Medicine. He then served on the staff of the Public Health Research Institute of the City of New York until he went to Cornell in 1966.

KEITH S. PENNINGTON ("Advances in Holography") is on the staff of the Thomas J. Watson Research Center of the International Business Machines Corporation. He was born in England and was graduated in 1957 from the University of Birmingham. In 1961 he obtained a Ph.D. in physics from McMaster University in Ontario. From 1961 to 1967 he was a member of the technical staff at the Bell Telephone Laboratories. He writes that he "became interested in holography as a possible means for mass storage and processing of information toward the end of 1963."

ANDRÉ LEROI-GOURHAN ("The Evolution of Paleolithic Art") is professor of ethnology at the University of Paris (the Sorbonne) and director of the university's Center for Prehistoric and Protohistoric Studies. He is also associated with the Musée de l'Homme in Paris. Leroi-Gourhan has received doctoral degrees in both letters and science from the University of Paris, the degree of doctor of letters in 1945 and the degree of doctor of sciences in 1954. He has participated in archaeological excavations in the Far East, Tunisia and several countries of Europe and is director of the School of Excavations of the University of Paris. The most recent of his numerous books on the prehistoric period is *Treasures of Prehistoric Art,* which was published in English in November.

RAYMOND HIDE ("Jupiter's Great Red Spot") is director of the geophysical fluid dynamics laboratory of the British Meteorological Office. He assumed that position recently after several years as professor of geophysics and physics at the Massachusetts Institute of Technology. Hide was born in England and received a bachelor's degree in physics at the University of Manchester and a Ph.D. in geophysics from the University of Cambridge. He has held appointments at the University of Chicago and, in England, at the Atomic Energy Research Establishment in Harwell and at King's College of the University of Durham (now part of the University of Newcastle upon Tyne).

IAN MACLEAN SMITH ("Death from Staphylococci") is professor of internal medicine at the University of Iowa. After his graduation in medicine from the University of Glasgow in 1944 he served in the Royal Navy. He then studied internal medicine and pathology at the University of Glasgow, the University of London and the University of Sheffield. He moved to the U.S. in 1949 and became a naturalized citizen. Among the positions he has held in the U.S. were a fellowship at Johns Hopkins Hospital and one at Rockefeller University, where he began the studies described in his article. He went to the University of Iowa in 1955. His present work consists in the diagnosis and treatment of patients with infection, research on staphylococcal disease and the teaching of medical students and residents.

STANLEY COOPERSMITH ("Studies in Self-esteem") is associate professor of psychology and chairman of the department of psychology at the University of California at Davis. He was graduated from Yeshiva University in 1946 and obtained a master's degree at Brandeis University in 1955 and a Ph.D. from Cornell University in 1957. Before assuming his present position in 1963 he taught for several years at Wesleyan University and briefly at the University of Copenhagen. During 1966 he was a guest scientist and consultant at the National Institute of Mental Health.

VAGN FLYGER and MARJORIE R. TOWNSEND ("The Migration of Polar Bears") are respectively at the University of Maryland and the Goddard Space Flight Center of the National Aeronautics and Space Administration. Flyger is a research professor and head of the Inland Resources Division of the university's Natural Resources Institute. Born in Denmark, he was graduated from Cornell University in 1948 with a bachelor's degree in zoology and entomology. In 1952 he received a master's degree in zoology and forestry at Pennsylvania State University. Four years later he obtained an Sc.D. in vertebrate ecology from Johns Hopkins University. He has worked for the state of Maryland in various capacities since 1948, going to the Natural Resources Institute in 1962. Besides his work on polar bears he has studied intensively the habits of the gray squirrel and, on a visit to Antarctica in 1963, the habits of penguins and seals. Mrs. Townsend is manager of the small-astronomy-satellite project at Goddard. The project is developing a series of satellites that will map the sky for X-ray sources and make studies in other regions of the electromagnetic spectrum. Earlier she was involved in the development of the satellite communication system described in the present article. Mrs. Townsend was graduated from George Washington University in 1951 with a degree in electrical engineering. She is the wife of an obstetrician in Washington, D.C., and the mother of four boys.

H. BENTLEY GLASS, who in this issue reviews *The Biology of Ultimate Concern,* by Theodosius Dobzhansky, is academic vice-president of the State University of New York at Stony Brook.

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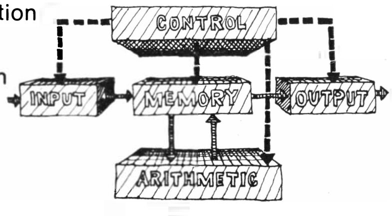

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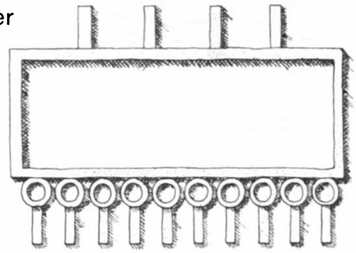

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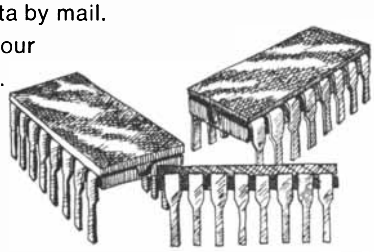

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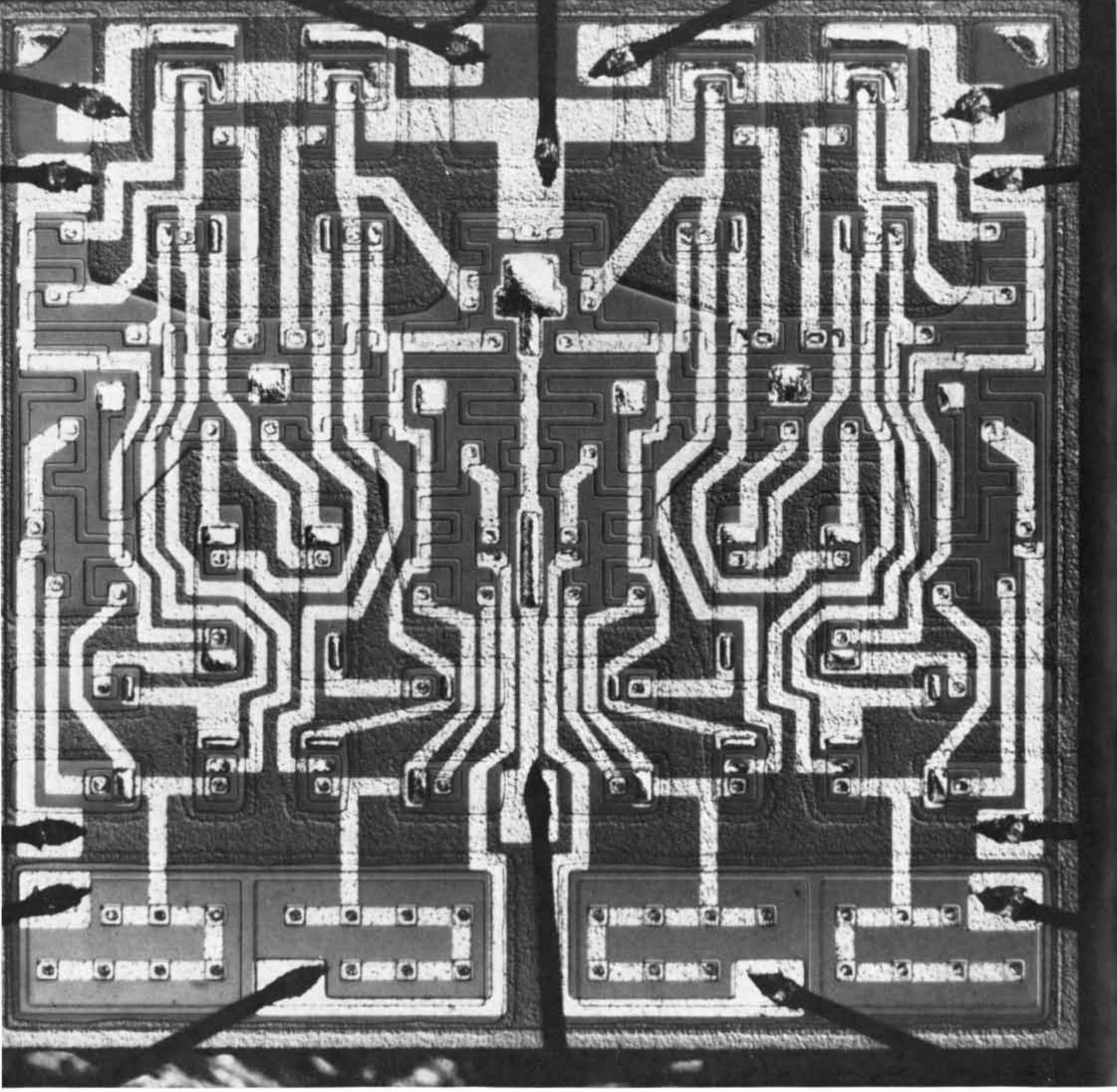

Digital logic circuit, courtesy of Radiation Incorporated (95x enlargement).

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The Arrival of Nuclear Power

Electric power obtained from nuclear fission has made a decisive market breakthrough and now accounts for nearly half of all the new power-generating capacity being ordered by U.S. utilities

by John F. Hogerton

Nuclear power, like the boy next door, seems to have grown up overnight. That it has indeed come of age is incontrovertible. For two years running it has accounted for nearly half of all the new power-generating capacity ordered by U.S. utilities. More than 50 large nuclear generating units, representing a financial commitment of $7 billion, are now under construction or awaiting construction permits. Their combined capacity exceeds 40 million kilowatts, which is as much electrical plant as the U.S. had in service going into World War II.

That maturity came quickly is also incontrovertible. The first truly large-scale nuclear unit—a 428,000-kilowatt installation at San Onofre, Calif.—was licensed for construction as recently as February 24, 1964, and announcements of commercial nuclear power projects did not begin to gain momentum until the fall of 1965; yet by the summer of 1966 nuclear power had drawn abreast of fossil power in the utility marketplace. It is safe to say that no one, not even the most optimistic reactor manufacturer, expected so rapid or decisive a market breakthrough.

This does not mean, however, that nuclear power was spared adolescence. There were many times when its progress seemed erratic and painfully slow, when friends and neighbors (particularly in the financial community) wondered if the boy next door would ever grow up. This review of the course of nuclear power development in the U.S. will explore the reasons for the uncertainty and help to place what has happened recently in better perspective. With this end in mind I have divided the history of the field into five distinct periods, which can be thought of as parts of a play, consisting of a Prologue (1942–1947), Act I (1948–1953), Act II (1954–1962), Act III (1963–1967) and an Epilogue (the present).

Strictly speaking, the years from 1942 to 1947 predate the development of nuclear power; during this period the atomic bomb held the stage almost to the exclusion of other pursuits. There are several reasons, however, for including those years in this account.

For one, 1942 was the year of the first nuclear reactor, or "pile" as it was then called. The array of uranium and graphite bricks assembled by Enrico Fermi, Walter H. Zinn and their coworkers in the famous squash court below the University of Chicago's Stagg Field was a primitive device by today's standards and had the limited objective of demonstrating that a chain reaction of fissioning atomic nuclei could be started, regulated and stopped. The pile operated at room temperature and essentially zero power. The few watts of heat that it generated were dissipated to the surrounding air. There was no reactor coolant.

The reactors built at Hanford, Wash., in 1943 and 1944 to supply plutonium for the Manhattan project ran at a temperature that can be characterized as lukewarm. They were the first water-cooled reactors. The water, drawn from the Columbia River, passed once through the reactor core and was then discharged into a storage basin; there was no recirculation.

During the Manhattan project some experience was obtained with recirculating coolant systems in small reactors built for experimental purposes, but again the temperatures were low. Design concepts for reactors capable of operating at temperatures high enough for power applications were studied as time allowed, and some development work had been started by the time the project ended.

When the civilian Atomic Energy Commission assumed its stewardship of the national atomic energy program in 1947, it was faced with the problem of deciding what avenues of power-reactor development to pursue. After taking stock of its inheritance of low-temperature reactor technology, the AEC tabled the fragmentary development work then in progress until plans could be made for a more systematic effort. By 1948 the AEC was ready to initiate a program and formed a Division of Reactor Development to carry it out. With that action the Prologue ended.

During the period from 1948 to 1953 the foundations of a diversified power-reactor technology were laid, naval-propulsion reactors were developed and, toward the end, the development of reactors for central-station electric power generation emerged as a priority objective.

The AEC's strategy of reactor development was to launch an attack along several main fronts. One front involved the pursuit of fundamental knowledge: the determination of basic physical constants; investigations of the properties of various fuels, coolants and other reactor materials; heat-transfer studies and the like. As part of this work, considerable effort was devoted to the design of supporting facilities for research and materials-testing.

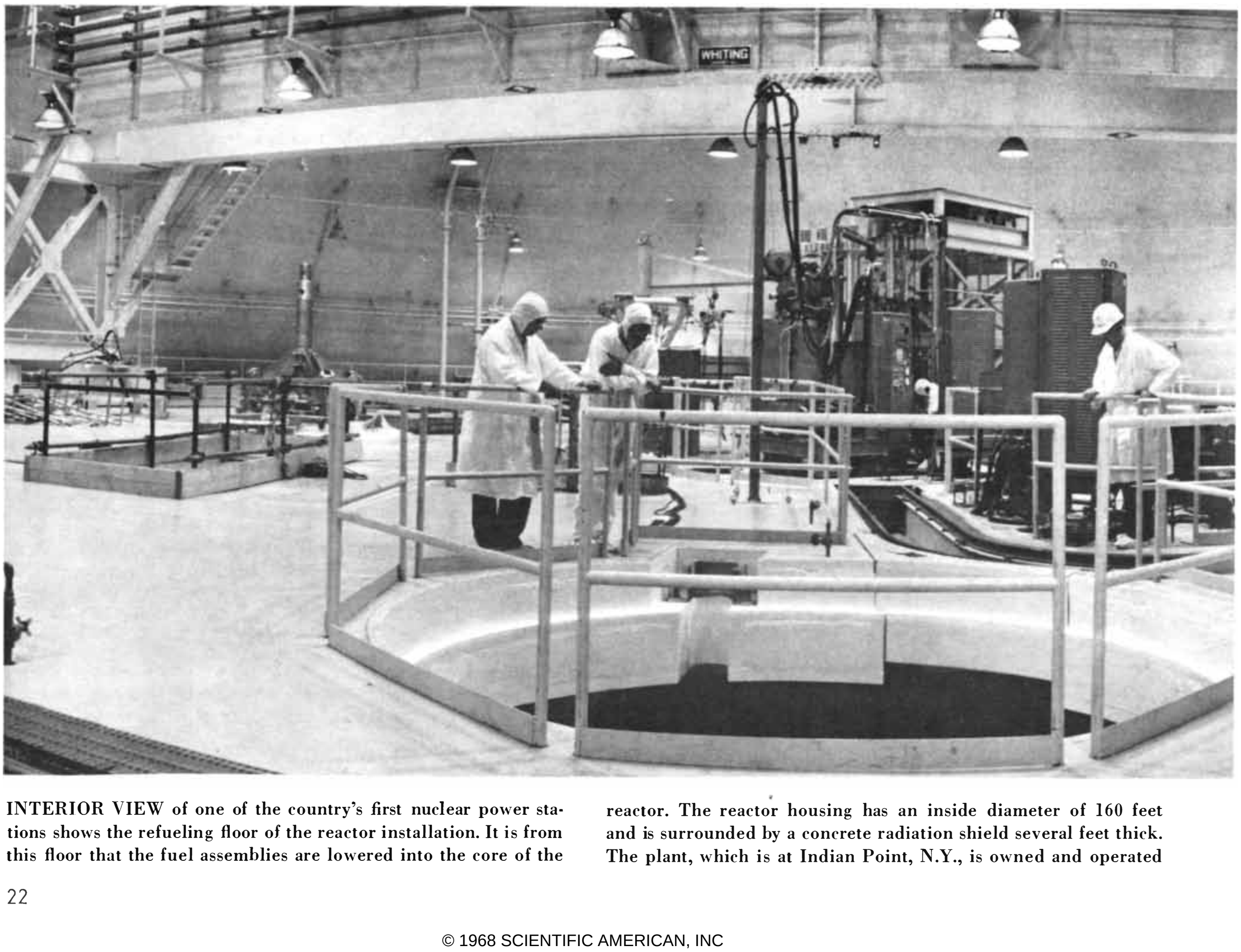
A second front, and the one to which the most money was allocated, was the development of reactors for propelling submarines and aircraft. During that period two different prototype submarine reactors were successfully built, one cooled with pressurized water and the other with liquid sodium, and the submarine *Nautilus* (employing the former system) was commissioned. The attack on the intrinsically more difficult problem of nuclear aircraft propulsion did not fare as well, partly because of the handicap of shifting military requirements and priorities, and this project was later abandoned.

The third front of the AEC reactor-development program was research on reactors for ultimate use in central-station electric power generation. A variety of design concepts were studied and experimental facilities were constructed to probe the relative merit of several of the more promising ideas. Included in the latter category were the pressurized-water and boiling-water reactor systems commonly used by utilities today; a sodium-cooled, graphite-moderated system; a system cooled and moderated with an organic chemical, and a system employing a circulating fluid fuel.

During this period civilian as well as military power-reactor technology had a security classification; access to it was restricted to those with a "need to know." Only the industrial concerns that served the AEC as contractors were in a position to follow the results of the reactor experiments, and in all but a few cases their access to information was compartmentalized. To most of industry, including the electric utilities, nuclear power was a black box.

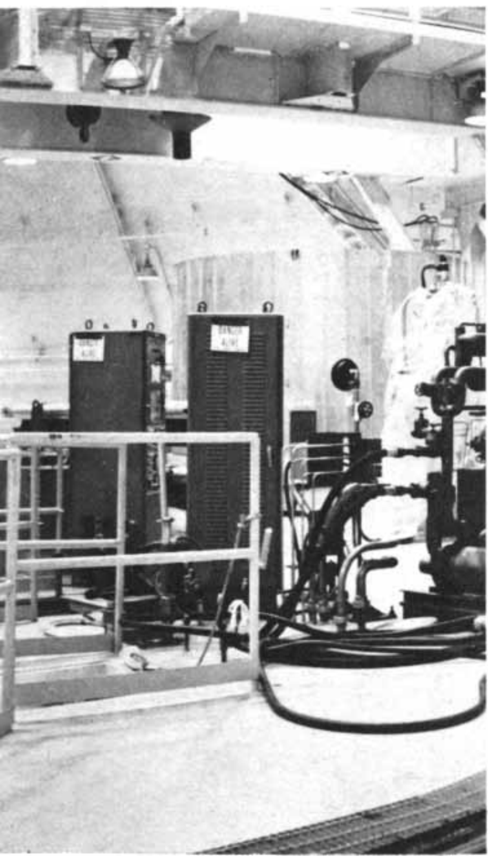
As time went on interest in what the black box contained began to mount. The first opportunity many companies had to peer inside came in 1952, when qualified industry teams were given limited access to classified data to enable them to evaluate the economic outlook of nuclear power. There was a considerable amount of such study in 1952 and 1953. The consensus of the study teams was that if a military value were placed on the by-product plutonium, nuclear power plants could be expected to produce electricity at a cost of roughly seven mills per kilowatt-hour. The cost in conventional thermal power stations ranged at that time from five to 10 mills per kilowatt-hour and averaged about seven; thus, on paper at least, nuclear power held promise of immediate application. There was the difficulty, however, that the atomic energy statute then in force prohibited private ownership of power reactors and thereby precluded private initiative in nuclear power development.

In the spring of 1953 the late Gordon E. Dean, the chairman of the AEC, went before the Joint Committee on Atomic Energy of Congress and urged that the



INTERIOR VIEW of one of the country's first nuclear power stations shows the refueling floor of the reactor installation. It is from this floor that the fuel assemblies are lowered into the core of the reactor. The reactor housing has an inside diameter of 160 feet and is surrounded by a concrete radiation shield several feet thick. The plant, which is at Indian Point, N.Y., is owned and operated development of nuclear power for central-station use be recognized as an important national objective and that the law be changed to allow private initiative. Later that year President Eisenhower, speaking before the United Nations, called for international cooperation in the development of nuclear power and other peaceful uses of atomic energy and for the creation of a system of international controls, backed up by inspection safeguards, to protect against misuse of the materials and facilities involved. An important factor in the President's proposed "Atoms for Peace" program was the hope that it might act to improve the climate for negotiating an effective system of control over nuclear weapons.

Thus the thrust for an accelerated nuclear power program was not sparked by any specific technical development, nor did it develop solely from the buildup of economic pressure within the U.S. power industry. Considerations of national prestige and foreign policy were of central importance. Before 1953 drew to a close the AEC began to implement the new policy of acceleration. A major first step was authorization of the construction of a "full scale" (60,000-kilowatt) demonstration plant at Shippingport, Pa.



by the Consolidated Edison Co. of New York, Inc. The reactor system was supplied by the Babcock & Wilcox Company.

During the period from 1954 to 1962 half a dozen prototype reactors and several fair-sized demonstration plants were placed in operation. The transition from a Government program to a competitive enterprise was made, and along the way optimism about the short-term commercial prospects of the new industry took a severe buffeting.

At the start of the period many utilities and manufacturers were highly optimistic. At hearings on proposed private-ownership legislation held by the Joint Committee on Atomic Energy in the spring of 1954 there was a give-us-the-ball-and-we-will-run-with-it tenor to much of the testimony submitted by industry spokesmen. Industry was promptly given the ball, not in the sense of the Government's handing it over and retiring from the field but in the sense that a private-ownership law was promptly passed that enabled—indeed encouraged—industry to proceed with nuclear power projects. The law reserved to the Government the ownership of nuclear fuel but provided for supplies to be made available to industry under a lease arrangement. The AEC was charged with regulatory responsibility and given sole authority to grant licenses for the construction and operation of nuclear power facilities and for the possession of nuclear fuel.

The enactment of the new law triggered a good deal of behind-the-scenes industrial activity, but firm plans for actual power projects were slow in developing. Nearly seven months elapsed between the time the law became effective (August 31, 1954) and the date of the first industry application for a license to build a nuclear power plant (March 22, 1955). It would have been unrealistic, of course, to have expected an immediate flurry of license applications. Planning nuclear power projects takes time; moreover, in the fall of 1954 civilian power-reactor technology was still classified, which was doubtless a delaying factor. Yet there is little question but that industry's initial response was disappointing to a Joint Committee and an AEC bent on accelerating the national nuclear power effort.

By winter the AEC decided there was need to prime the industry pump. Accordingly, in January, 1955, it announced the "first round" of a Power Demonstration Reactor Program designed to stimulate demonstration projects. To utilities prepared to finance the construction of full-scale plants the AEC offered research-and-development assistance and waiver of fuel inventory charges for the first five years of plant operation. Three projects were undertaken on this basis. In addition, two other projects were undertaken on a wholly privately financed basis outside the framework of the Power Demonstration Reactor Program. It is worth stopping the clock a moment to examine a little more closely the situation in which the utility industry found itself at that time.

By early 1955 there had been time and opportunity for industry to probe deeper into the status of nuclear power development, and it was quite clear that the first nuclear plants would not be economic. The word "acceleration" had taken on a new meaning: it meant pressing forward with nuclear power development at a faster pace and on a larger scale than the immediate economic outlook warranted. Since it was clear that the Government was committed to a policy of acceleration, the investor-owned segment of the electric-utility industry, representing about 80 percent of the total electric industry, faced a difficult choice—to build or not to build. To build full-scale noneconomic nuclear plants promised to be a costly way of speeding the development of a technology for which only a few farsighted utility executives could see a pressing need. On the other hand, not to build meant running the risk of having the Government do the job by itself. In a collective sense what the utility companies did at that critical time was to follow a middle course: they committed themselves to building a sufficient number of plants and took enough other initiatives to maintain their position with respect to the Government in an accelerated effort. In most cases the financial risk was shared by a number of companies through the device of joint projects; in one case, however, a single company (the Consolidated Edison Co. of New York, Inc.) undertook a pioneer project entirely on its own. That the collective interests of the utility industry were served was attributable to the leadership of a small number of individuals, all of whom believed strongly in the future of nuclear power and some of whom were doubtless also strongly motivated by power-policy considerations.

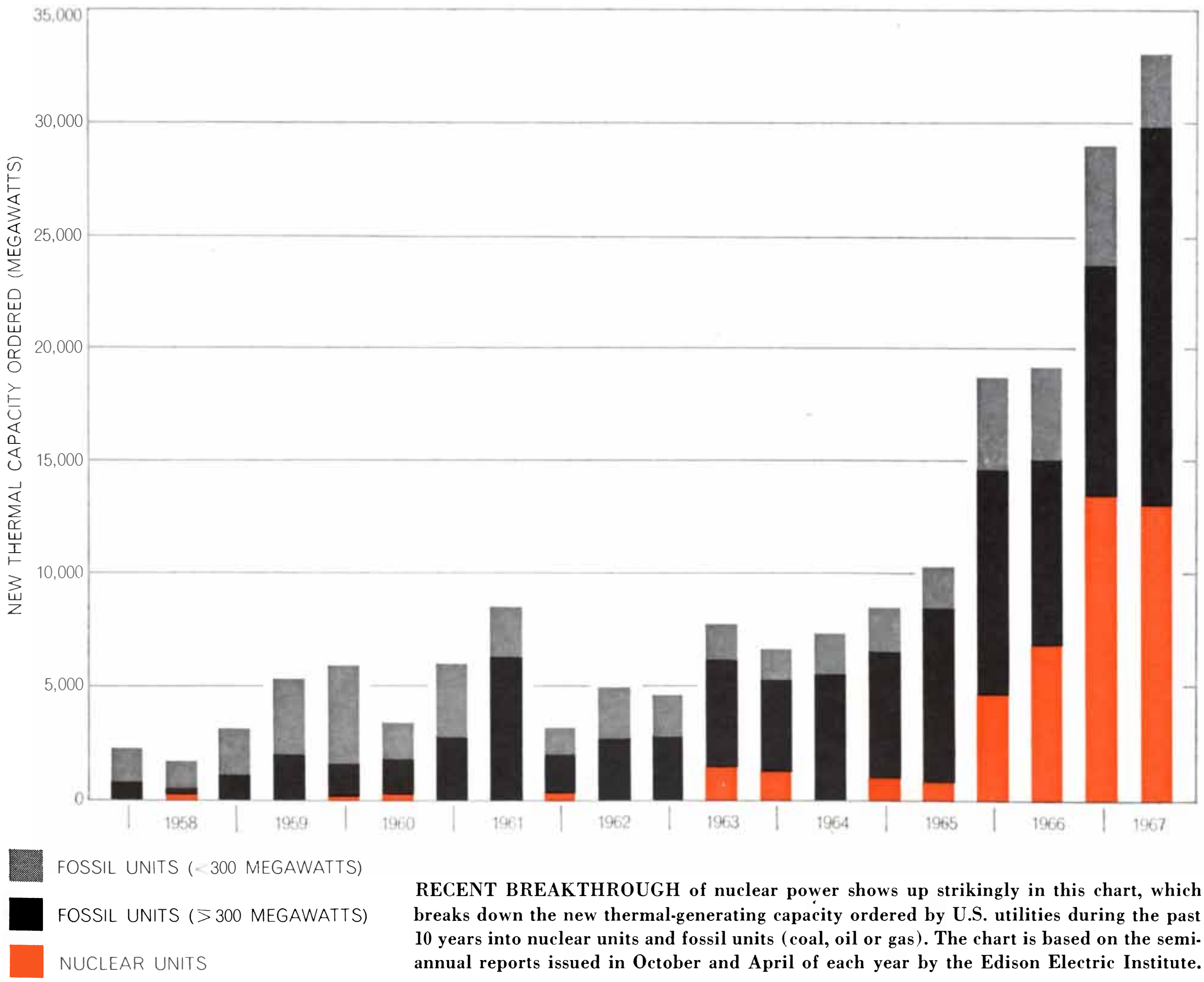
In subsequent months and years the AEC extended its Power Demonstration Reactor Program. The "second round" of the program, invitations for which were issued late in 1955, was designed to encourage the construction of small-scale prototypes of novel reactor systems and also to facilitate the participation of small publicly owned power entities such as rural cooperatives and municipal power authorities. To the latter end the AEC undertook to finance the reactor portion of the plant, thereby limiting the financial risk incurred by the utility participant. Five projects were proposed on this basis, but in the course of evaluation the list was reduced and only three second-round plants were actually built.

The "third round" came in 1957 and resulted in the construction of four small-scale plants, each of which broke some new technical ground either in overall design concept or in a key feature of its system. The next and, at this writing, last "round" of the Power Demonstration Reactor Program came five years later in 1962. Before describing this round the stage should be set by relating the events that led up to it.

Thus far in this account of the 1954–1962 period the focus has been on decision-making. The actual accomplishments of the period merit at least equal time, but in the interests of brevity they will be compressed into a brief summary. During 1955 and 1956 civilian power-reactor technology was comprehensively declassified by the U.S., acting in concert with the United Kingdom and Canada. Late in 1956 the first power-reactor system designed expressly for electric-power generation—an experimental boiling-water unit at the Argonne National Laboratory—went into operation. A year later the 60,000-kilowatt Shippingport pressurized-water plant was completed. In 1960 two of the pioneer utility plants—one a 180,000-kilowatt boiling-water unit in Illinois (Dresden) and the other a 140,000-kilowatt pressurized-water unit in Massachusetts (Yankee)—began commercial service.

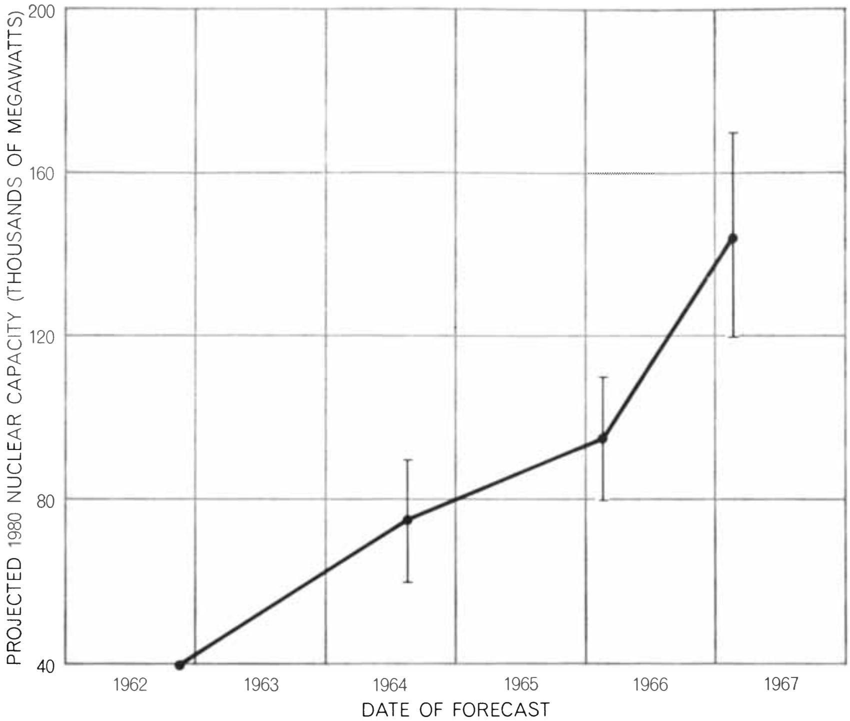
As operating experience was acquired with these and other early-vintage nuclear units, a favorable pattern began to emerge. Most of the debugging problems stemmed from auxiliary equipment; the reactors themselves gave surprisingly little trouble and, once they had been checked out for routine operation, generally performed with a high degree of dependability. The plants proved to be easy to operate in a utility system, under both steady-state and fluctuating-load conditions. Reactor designs were found to be conservative; in several cases it proved possible to operate the plants at power levels substantially higher than their nominal ratings. In the wash of operating experience many technical uncertainties associated with the different reactor concepts were removed and the basic validity of nuclear power was, from the technical standpoint, categorically established.

The same could not be said from the economic standpoint. Although one of the pioneer plants (Yankee) was brought in under budget, most of them cost more to build than had been anticipated, and in at least one case the final construction cost was nearly double the original estimate. The lowest generating costs achieved in these plants in their initial years of operation were 50 percent higher than the figure of seven mills per kilowatt-hour postulated by the early gener-



RECENT BREAKTHROUGH of nuclear power shows up strikingly in this chart, which breaks down the new thermal-generating capacity ordered by U.S. utilities during the past 10 years into nuclear units and fossil units (coal, oil or gas). The chart is based on the semiannual reports issued in October and April of each year by the Edison Electric Institute.

alized studies. Moreover, the costs for conventional power generation were improving. Savings achieved by building larger, more efficient generating units had been sufficient to offset rising costs of labor and materials, and the cost of coal—the principal utility fuel and nuclear power's chief competitive target—had reversed a prior trend and was beginning to come down. No longer would a generating cost of seven mills per kilowatt-hour ensure nuclear power a large market. (Lest the wrong impression be given, it should be added that the builders of the pioneer plants did not expect to achieve anything like seven-mill power. Yankee's target, for example, was in the 11-to-13-mill range. It should also be noted that through successive core-design improvements and increases in power output, several of these plants have been able to achieve substantial reductions in generating cost. Taking Yankee again as an example, the cost has recently been running slightly under eight mills per kilowatt-hour, which in high-cost-fuel areas such as New England is not too far out of line with the cost of power today in conventional power stations of comparable size and vintage.)



FORECASTS of the nuclear power generating capacity the U.S. will have in 1980, made periodically by the Atomic Energy Commission, have increased sharply in recent years.

Of course, the power costs achieved by the nuclear plants placed in service at the start of the 1960's were not a true indicator of the state of the art at that time. Considerable technical progress had been made since they were designed. Moreover, the experience gained in operating the "first generation" plants would bear fruit only when successor plants were designed and built. From the vantage point of the reactor manufacturers it appeared that a "second generation" of nuclear plants, larger in scale and improved in design, would prove to be economically competitive in those parts of the country where the cost of coal or other fossil fuels ran above the national average. Some utility leaders shared this belief; the majority, however, needed to be convinced.

Late in 1960 a West Coast utility expressed interest in building a large-scale pressurized-water plant in southern California and approached the AEC for assistance in what was later to become the San Onofre project. Early in 1961 another West Coast utility announced plans for a 310,000-kilowatt boiling-water plant to be located at Bodega Bay on the northern California coast and to be built without any financial assistance from the Government. The announcement of the Bodega Bay project was accompanied by cost estimates indicating that the plant would be economic under the utility's particular circumstances, the central one being that fossil fuel costs in the area were already very high and were expected to rise.

In 1962, at the request of President Kennedy, the AEC made a comprehensive study of the outlook for nuclear power. The resulting report, issued in December, 1962, concluded that nuclear power had arrived at the threshold of commercial application and had a bright future. It forecast that 40 million kilowatts of nuclear generating capacity would be in service by 1980, and that by the end of the century nuclear power would account for half of the national electrical output and for essentially all subsequent power plant construction. In the light of this projected growth pattern, the report took stock of the country's nuclear fuel resources and stressed the long-range importance of using them efficiently. It went on to define three goals for the national nuclear power effort: the immediate construction of some commercial-scale plants employing reactors of already proved technology; the development of reactors with improved fuel-utilization characteristics (called "advanced converters"), and, as a long-range objective, the development of practical "breeder" reactors, which produce more fissionable material than they consume.

At the time the report to the President was being written the two California projects were enmeshed in site problems; it was not certain that either would go forward (indeed, the Bodega Bay project was subsequently canceled), and no other utility projects were in the offing. Concluding that there was need once again to prime the industry pump, the AEC announced a new round of its Power Demonstration Reactor Program aimed at stimulating the construction of commercial-scale plants of proved technology. The financial incentives offered included design as well as research and development assistance, plus waiver of initial fuel-inventory charges. At the end of the year the AEC was awaiting industry's response when, as a completely independent proposition, it received an application (later withdrawn) for a permit to build a million-kilowatt plant in metropolitan New York on a 1970-completion schedule. This was a remarkable development. Not only was the proposed plant three times larger than any previously considered but also the proposed location in the center of a densely populated area was without precedent and posed a major test both of AEC site policy and community acceptance. The proposal was several strides ahead of its time; it served, however, as a welcome affirmation of industry's confidence in nuclear power.

The period from 1963 to 1967 witnessed the breakthrough of nuclear power into the commercial market and, as something of an anticlimax, the start-up of the country's first truly large-scale nuclear plants.

Events moved swiftly in 1963. Early in the year two pressurized-water projects in the range of 400,000 to 500,000 kilowatts were undertaken within the framework of the AEC's Power Demonstration Reactor Program—one in New England (Connecticut Yankee) and the other in California (Malibu). Soon thereafter the long-pending San Onofre project finally advanced to the point of filing for a construction permit. And by the end of the year two more projects, both boiling-water plants with capacities of between 500,000 and 600,000 kilowatts, had been undertaken on a straight commercial basis—one in New York (Nine Mile Point) and the other in New Jersey (Oyster Creek). A detailed report on the economics of the latter project, released in February, 1964, by the sponsoring utility (the Jersey Central Power & Light Company), gave the first intimation that a breakthrough might be in prospect.

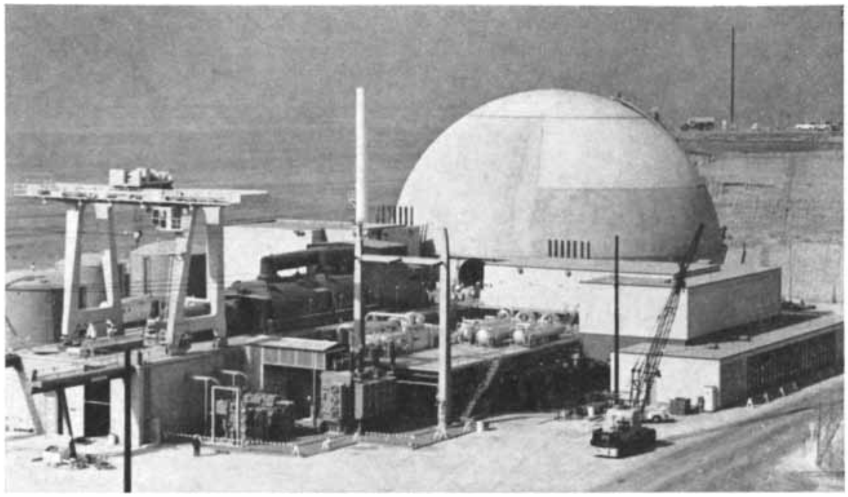
Jersey Central had made an analysis of the comparative costs of power generation for three alternatives open to them: (1) building the proposed nuclear plant, (2) building a coal-fired plant of the same capacity at the same site and (3) long-distance transmission of electricity from a coal-fired plant at a "mine mouth" location. The nuclear-cost estimates were based on a fixed-price "turnkey" bid submitted by the General Electric Company; those for the coal alternatives were based on engineering studies and reflected the best coal price offering the utility had been able to obtain from its suppliers. In the months preceding the Oyster Creek evaluation, Jersey Central had been contracting for coal at a delivered price of 30 to 31 cents per million B.T.U.'s of energy content. Under the pressure of nuclear competition coal was offered for the Oyster Creek site at a price of 26 cents. It was a remarkably good offer, but it turned out to be not good enough.

COMPETITION between nuclear power and fossil power depends on the cost of fossil fuel in different localities. In this chart vertical bars indicate the range of fossil-fuel costs in the systems of the 75 largest investor-owned electric utilities in the U.S. (Gas and oil costs have been adjusted to show the equivalent coal cost.) The utilities that have made one or more commitments for a large nuclear plant are indicated in color. The solid colored horizontal line represents the average coal cost for 1966 (24.7 cents per million B.T.U.'s). The light colored horizontal band covers the range of coal prices within which nuclear power is today competitive. The missing entries correspond either to utilities with thermal plants smaller than 300 megawatts or to utilities that are 100 percent hydroelectric.

The findings from the utility's cost analysis were, first, that if one assumed operation of the nuclear plant at its nominal capacity (515,000 kilowatts), coal would have had to have been available at the Oyster Creek site at a price slightly below 26 cents to be competitive; second, that if the nuclear plant were to achieve the higher output of which it was believed capable and for which its turbine generator had been designed (620,000 kilowatts), the price would have had to have been below 20 cents. To place these figures in perspective, the average price paid by U.S. utilities for coal in 1964 was a fraction above 26 cents, and only those utilities operating in or close to coal-mining areas enjoyed coal prices as low as 20 cents. It should perhaps be added that the Oyster Creek report placed the cost of nuclear power generation not at seven mills per kilowatt-hour, not at six mills, but at four to five mills, depending on the level of output achieved. The message, whether in terms of cents per million B.T.U.'s or mills per kilowatt-hour, was clear: If the Oyster Creek findings were at all indicative, nuclear power had arrived. The question was, how indicative was Oyster Creek?

This question quickly became a burning issue. Jersey Central spokesmen emphasized that their analysis was specific to their circumstances and might not apply under other circumstances. The company sponsoring the Nine Mile Point project, which was a parallel effort involving the same reactor manufacturer and virtually the same reactor design but a different site and different contract arrangements, did not publish a comparable cost analysis but did release some general cost estimates that indicated a much more conservative assessment.

Philip Sporn, past president of the country's largest coal-burning utility (the American Electric Power Company, Inc.) and long regarded as one of the country's ablest power men, was asked by the Joint Committee on Atomic Energy to appraise the economic position of nuclear power based on the information contained in the Oyster Creek report. His judgment was that there was insufficient margin for profit in the turnkey contract and that for this and other reasons the estimates of power cost were probably an overly optimistic indicator of the immediate outlook for nuclear power. Allowing for differences in utility circumstances, his estimate of break-even coal prices in an investor-owned system was 25 to 29 cents per million B.T.U.'s. Essentially this estimate meant that he too saw immediate market opportunities for nuclear power but thought they would be limited for the time being to the higher-cost-fuel areas.



FIRST LARGE-SCALE NUCLEAR PLANT, located at San Onofre, Calif., was completed last year. A pressurized-water installation capable of generating 428,000 kilowatts of electric power, it was built by the Westinghouse Electric Corporation and is operated jointly by the Southern California Edison Co. and the San Diego Gas & Electric Co. The dome-shaped building, which houses the reactor, is characteristic of a pressurized-water installation.

Thus in the spring of 1964 there were among experts substantial differences of opinion as to the general level of costs that a utility contemplating a nuclear project might expect to encounter in building and operating a plant. The nuclear-cost picture was further complicated by differences in what the published cost estimates covered and by differences among utilities.

Even if by some magic there had been unanimity on the subject of nuclear costs, there still would have been ample room for differences of opinion on the market outlook. One reason was that important changes were taking place in coal costs, notably in the cost of transportation. In many parts of the country the expense of transporting coal from the mine to the power plant accounts for from a third to half of the utility's fuel cost, or, to put it another way, for roughly a fifth of the total cost of power generation. Most utility coal has traditionally moved by rail. Over the past decade there has been a substantial reduction in rail transportation costs, thanks to three successive innovations in rail practice. The first came in the mid-1950's when the railroads received sanction from the Interstate Commerce Commission to offer incentive rates to utilities. The second came in 1959 when the first trainload rates became effective. (Prior to that time freight rates had been based on carload quantities.) The third and by far the most important innovation came in 1962 with the introduction of the "unit train," that is, a train that shuttles constantly back and forth between the mine and the power station, thereby achieving optimum equipment utilization. By 1964 the use of unit trains was spreading rapidly and substantial reductions in rate tariffs were being made on this basis. As with all new developments, it was difficult to foresee how far the trend might be carried and how it might affect the competitive balance between coal and nuclear power.

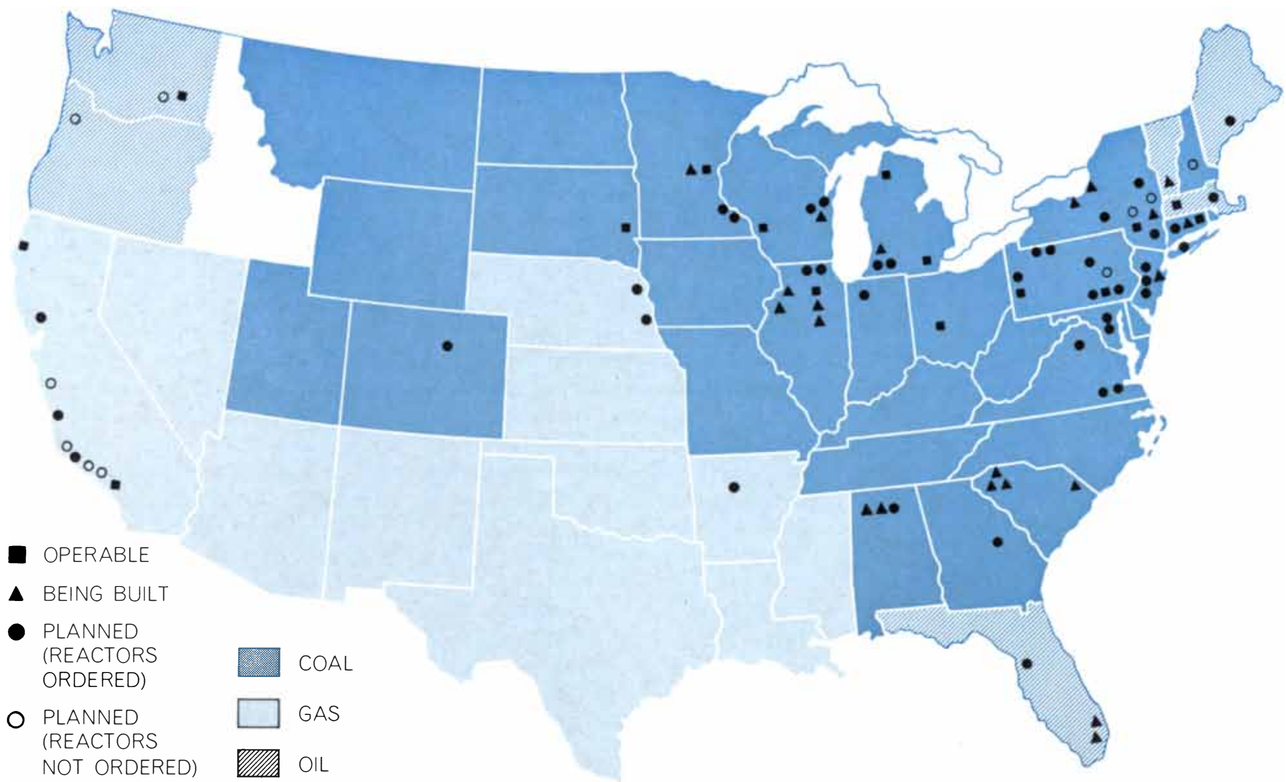
There were still other basic factors in the 1964 decision-making equation. The power industry was beginning to move rapidly toward interconnection, one of the benefits of which is that it often enables utilities to build larger, more economic power plants than they could manage on a single-system basis. It is characteristic of nuclear power that its competitive position improves as the size of plant increases. At the same time the larger the plant is, the more severe are the economic consequences of an unscheduled shutdown, and so a premium is placed in large installations on dependability of service. By 1964 there was conclusive evidence that utilities were experiencing a higher-than-expected rate of forced shutdown in the operation of their newest, largest and most sophisticated conventional power plants. On the other hand, nuclear power was to most utilities a completely new technology and its dependability in commercial service was a factor they had to evaluate most carefully.

Finally, in the back of every utility executive's mind were the indications, which by 1964 were beginning to become prevalent, of increased public interest in the environmental aspects of the power industry. There were then, as there are now, two diametrically opposed public attitudes regarding nuclear power. Some people resisted nuclear power because of reservations about its safety. Other people, particularly those concerned about the health implications of air pollution, favored nuclear power because of its cleanliness. At that time neither point of view commanded a large following, which meant that the "average citizen" had not yet taken a position. This left open what promised to become the most powerful factor in the utility equation.

The same month the Oyster Creek report was released the San Onofre project received its construction permit, ending a seven-year dry spell during which the only construction licenses issued in the U.S. were for experimental or prototype installations of 75,000-kilowatt capacity or less. Fortunately major plants of American design had been built overseas or were at an advanced stage of construction, and so there was not the experience gap that this statement might imply. Another notable event in 1964 was the enactment by Congress of private-ownership legislation covering nuclear fuel. Under the new law private ownership of fuel supplies for nuclear power will be permitted at the start of 1969 and will be mandatory by mid-1973.

The leading reactor manufacturers (notably General Electric and the Westinghouse Electric Corporation) had started up their marketing machinery in 1963 and by the end of 1964 it was running in high gear. Over the 18-month period following the Oyster Creek announcement, however, only one firm sale was made. With that one exception (the Commonwealth Edison Company) utilities were not yet buying nuclear power. This doubtless meant in part that they had not yet wholly accepted the Oyster Creek message. There was another, more tangible explanation, which was that coal interests were making a valiant forestalling effort. Again and again, in situations where utilities were known to be seriously considering a nuclear project, substantial cuts were made in coal prices, mainly through the granting of favorable unit-train rates for coal delivery. In a number of cases the price concessions extended to other coal-burning plants on the same system, thereby benefiting the utility's overall power-generating economy. This practice reached a point, one suspects, where some utilities with at best a marginal interest in nuclear power went through the procedure of getting and evaluating bids from reactor manufacturers principally for the leverage this gave them in their coal negotiations.

In the late summer and early fall of 1965 the situation started to change, and by the summer of 1966 it had altered completely. Not only did utilities begin to place orders for nuclear units but also some ordered them two at a time. As was brought out at the start of this article, nuclear power rapidly built up its market position to the point where during 1966 and 1967 it accounted for nearly half of all the new power-generating capacity ordered by U.S. utilities. In the process, unit sizes leapfrogged from 500,000 to 800,000 to 1.1 million kilowatts and there was a progression of major design improvements, all of which took place before the forerunner of the 500,000-kilowatt class (San Onofre) was completed. Apart from one commitment for a 300,000-kilowatt demonstration plant of the high-temperature gas-cooled type, all the market traffic was in pressurized-water and boiling-water plants.



NUCLEAR POWER PLANTS IN THE U.S. are indicated by the black symbols; the map also shows by shading the principal fuel burned in conventional thermal-power plants in each state. (Idaho depends almost entirely on hydroelectric power). The plants represent a combined nuclear capacity of 59,778,300 kilowatts, which breaks down into: operable, 2,810,100 kilowatts; being built, 14,657,400 kilowatts; planned (reactors ordered), 32,210,800 kilowatts; planned (reactors not ordered), 10,100,000 kilowatts.

AERIAL VIEW of Millstone Point #1, a nuclear power station of Northeast Utilities, Inc., in Waterford, Conn., was made in September, 1967, when the plant was 35 percent complete. The reactor will be housed in the large steel dry well at right, which in turn will be completely enclosed by a rectangular building. The superstructure at left will contain the turbines. The 600,000-kilowatt boiling-water unit is scheduled for completion by the summer of 1969. The reactor system is being supplied by the General Electric Company.

Initially the sales were divided, in approximately equal measure, between General Electric and Westinghouse, which had long dominated the manufacture of turbine generators and related electrical equipment for the power industry and saw in reactor manufacture an opportunity to move in on the steam-equipment side of the industry and, perhaps even more important, to establish a position in the potentially lucrative business of supplying replacement fuel cores. Later two more companies established themselves in the water-cooled-plant market, namely the Babcock & Wilcox Company and Combustion Engineering, Inc., the two leading suppliers of conventional steam-generating systems.

The nuclear breakthrough is too recent a phenomenon to allow a definitive diagnosis, but it seems reasonably clear that there were two main factors at work. One was a divergence in marketing tactics. It cannot be documented, but there is little doubt that coal interests hardened their pricing policy sometime in the fall or early winter of 1965. With a record volume of business in hand and a record number of coal-burning power plants under construction, they may have decided to let nuclear power have its day in court, hoping all the while that it would fail to live up to its advance notices. Moreover, nuclear power was then threatening only the higher-cost-coal areas and, with the national market doubling every 10 years, the coal industry could write off these areas and still look forward to excellent growth prospects. Nuclear interests, on the other hand, kept their marketing drive going at peak intensity long after the breakthrough occurred, partly in order to achieve deeper penetration into coal territory and partly because of the stimulus of competition among reactor manufacturers. It was not until the latter part of 1966 that nuclear-equipment prices began to seek higher ground and not until 1967 that they increased substantially, and by then it was too late for coal to stem the tide of nuclear sales.

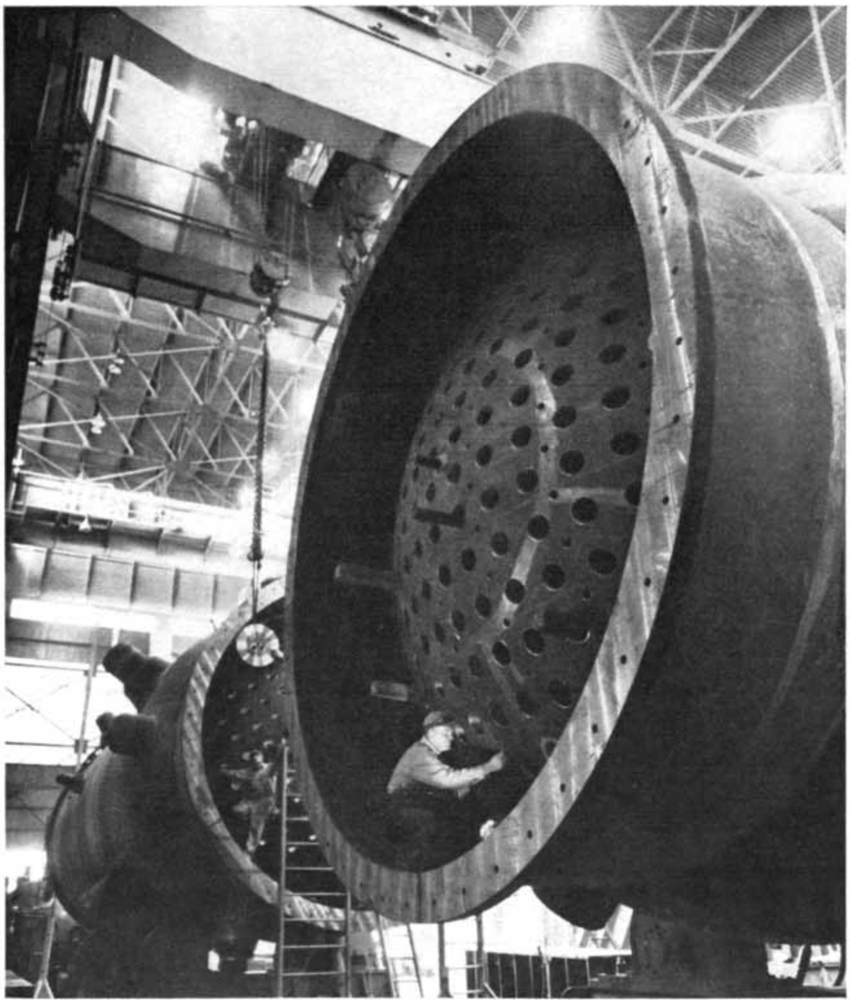
The second factor in the nuclear breakthrough was intangible and can only be described as a growing conviction among utilities that nuclear power would be the way of the future. This was particularly true of the utilities that operated coal-fired or oil-fired power stations in urban or highly industrialized areas. They could see almost daily signs of public concern about air pollution, and in not a few instances they were being confronted with new local ordinances setting stringent limits on the emission of sulfur dioxide and other stack gases. Low-sulfur fuels quickly commanded premium prices, and if the short-term outlook was poor, the long-term outlook was worse. The nation's coal resources, vast in the aggregate, were beginning to look less than vast as utilities sought to locate deposits that were cheap to mine, favorably situated and large enough to ensure a long-term supply for a large power station. It was obvious that they would look much smaller if the search had to be restricted to deposits of low sulfur content. The alternative of removing sulfur from run-of-the-mine coal, either at the mine or in the operation of the power plant, promised to present a serious cost problem. The only other alternative (apart from building nuclear plants) was to think in terms of long-distance transmission of electricity from plants located at the mines, which would usually place them at a distance from population centers. This of course had been done on a limited scale but, barring a major breakthrough in transmission technology, would be expensive as a general practice; moreover, the problems that could be anticipated in obtaining right-of-way for a multiplicity of cross-country transmission lines were formidable. In addition to all this, coal mining was itself encountering increasing public criticism on environmental issues, such as stream pollution and land despoliation, and cost increases were already beginning to be experienced on this account.

In short, utilities began to see the handwriting on the wall for coal. At the same time (and doubtless as a kind of mirror image) they began to see positive signs of growing public sentiment in favor of nuclear power.

If these were indeed the thoughts that were running through the minds of utility men, they could easily have swung marginal decisions in favor of nuclear power, particularly in cases where a company had not yet made a nuclear commitment. In effect they would have placed the burden of proof not on the new technology, where one would normally have expected it to be put, but on the old one. And even if a utility president took his staff's nuclear cost estimates with a grain of salt, he could still justify going ahead with a nuclear project on the grounds that it would give his organization essential training and experience in what seemed destined to be the coming technology.

As nuclear sales gained momentum, projections of the growth of nuclear power climbed rapidly. By mid-1967 most forecasters were predicting that there would be somewhere in the neighborhood of 150 million kilowatts of nuclear power capacity in service in the U.S. by 1980, an amount nearly four times greater than the AEC had forecast four years earlier. This translates into the expectation that, on a capacity basis, nuclear power will account for at least 50 percent of the new-plant market over the next decade and for an even higher share of base-load (as distinct from peaking) additions. By 1980 nuclear plants would then account for about 30 percent of the country's total installed capacity and for as much as 35 to 40 percent of the gross electrical output.

This outlook is all the more remarkable when one recalls that as recently as the summer of 1967 nuclear power accounted for less than half of 1 percent of the electrical output. The amount of nuclear capacity then in service barely exceeded a million kilowatts, and the largest units were operating at power levels in the neighborhood of 200,000 kilowatts. (This statement does not take into account a large plutonium-producing reactor at Hanford, which produces electricity as a by-product.) San Onofre, the first of the truly large-scale units, did not begin preliminary operation until June 14 and did not reach full power until December. The second large-scale unit (Connecticut Yankee) followed quickly and also reached full power in December. The next two in line (Oyster Creek and Nine Mile Point) are scheduled to begin service in 1968, and three others are scheduled for completion in 1969. It will be 1970, however, before a really large block of nuclear capacity is added to the national power grid. By then, but not much before, enough operating experience will have been accumulated to make possible a meaningful assessment of the performance of the first graduates of the 500,000-kilowatt class. In the meantime the size of the U.S. commitment to nuclear power will doubtless continue to grow, and it would not be surprising if the first member of the 1.5-million-kilowatt class will have matriculated.

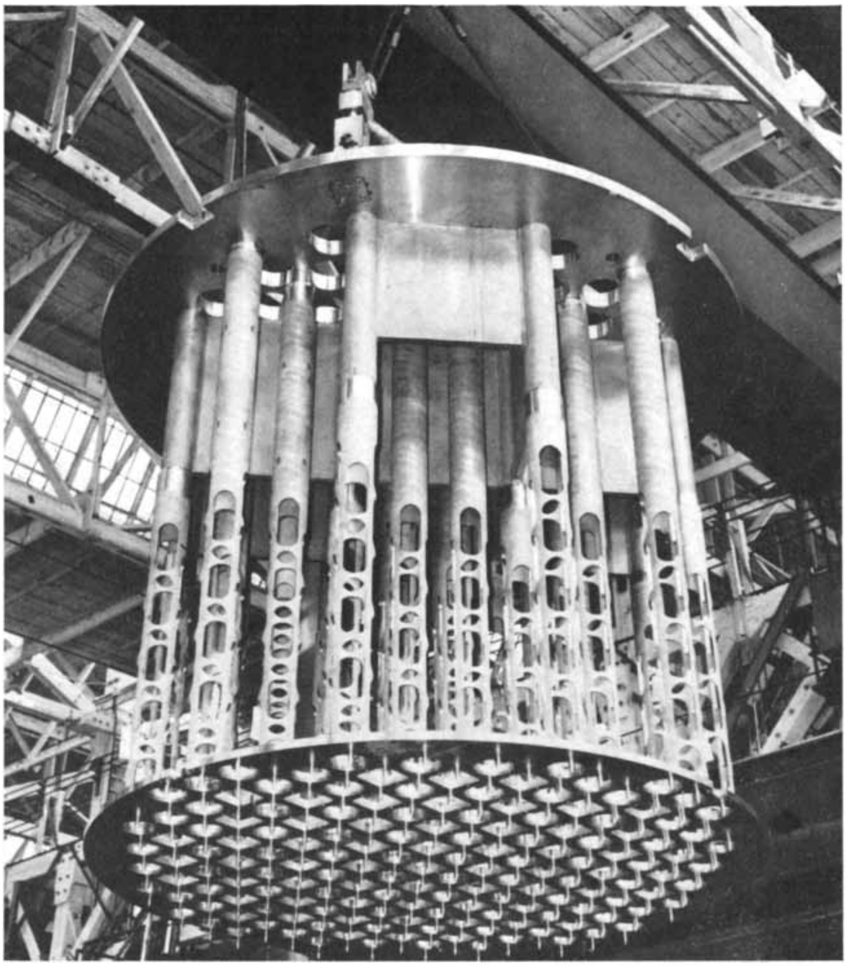


REACTOR VESSELS for two large-scale commercial boiling-water installations are shown undergoing final checks at the factory of the manufacturer, Combustion Engineering, Inc. Each vessel weighs more than 650 tons. The one at left is for the Niagara Mohawk Power Corporation's Nine Mile Point plant in New York; the one at right is for the Jersey Central Power & Light Company's Oyster Creek plant in New Jersey. In boiling-water reactor systems the control rods enter the core of the reactor through the holes in the bottom of the vessel.

Central to this account of the coming of age of nuclear power have been the pressurized-water and boiling-water reactors, which outpaced other entrants in the power-reactor sweepstakes and today dominate the commercial market. This situation might well be expected to continue indefinitely if it were not for two limitations inherent in the use of ordinary water as a reactor coolant. One is that it is impractical to achieve high enough operating temperatures inside a straightforward water-cooled system to produce high-pressure superheated steam. Power plants employing these systems are thus obliged to operate with low-quality steam and as a result are not as efficient in converting heat to electricity as the more modern conventional power plants. This means that a proportionately greater amount of waste heat is discharged into the plant's environment—in other words, into the river, lake or ocean that supplies the water used to cool the turbine condenser. Today's nuclear power plants typically discharge 30 percent more waste heat per kilowatt-hour of electricity generated than conventional plants. This could conceivably become a serious handicap. As the scale of power generation increases, utilities are finding it increasingly difficult to find suitable sites for new generating stations, and more often than not the limiting factor is the large flow of cooling water required. Of late, concern expressed by conservationists and others about the possibly adverse ecological effects of the warm-water discharge from large-scale power operations (the "thermal pollution" issue) has added a new dimension to the problem of finding suitable sites for thermal power plants. The use of cooling towers offers a way around the problem but adds to the power costs and has other disadvantages.

The other limitation of pressurized-water and boiling-water reactors is that they are not efficient utilizers of nuclear fuel. Uranium 235, which is the only readily fissionable material found in nature, represents a very small fraction of the huge energy potential of the world's nuclear fuel resources. The rest is associated with the "fertile" materials, which are not themselves readily fissionable but which can be converted into fissionable form by irradiation with neutrons. For example, the fertile isotope uranium 238, which accounts for more than 99 percent of the uranium found in nature, is converted (by capturing a neutron) into fissionable plutonium 239. Water-cooled reactor systems, which are fueled with "slightly enriched" uranium (2 or 3 percent uranium 235), obtain part of their power output from plutonium formed during operation, but most of it comes from uranium 235 supplied in the reactor fuel.

The reason why greater advantage is not taken of the predominant fertile component of the fuel is that water has a pronounced tendency to absorb neutrons, and in passing through the reactor core it soaks up enough of these precious particles to prevent the system from achieving a high ratio of conversion of fertile material to fissionable material. Pressurized-water and boiling-water plants manage in spite of this handicap to achieve very low fuel costs and will continue to do so as long as reasonably priced supplies of uranium are available, which will probably be the case for at least another decade. In the long run, however, and in the interest of conserving energy resources, the nuclear power industry will need reactors that are more efficient in fuel utilization. This translates into a need to strive for better neutron economy, and since the efficiency with which heat is converted into electricity also affects fuel utilization, it makes it desirable to achieve higher operating temperatures as well.



PART OF CORE-SUPPORT STRUCTURE of a large pressurized-water reactor consists of control-rod guide tubes and the upper core grid plate. The part is made by Westinghouse.

Over the years several "advanced converters" have been carried quite far down the road of development, but at this writing only one stands in a position to challenge the water-cooled systems in the utility marketplace. That is the high-temperature gas-cooled reactor, a development of Gulf General Atomic, Inc., a subsidiary of the Gulf Oil Corporation. A 40,000-kilowatt prototype reactor of this type (Peach Bottom) was built under the "second round" of the AEC's Power Demonstration Reactor Program, and a 300,000-kilowatt demonstration plant (Fort St. Vrain) is scheduled for construction. This system combines the attributes of good neutron economy and high temperature; however, until bids based on this approach have been submitted for large-scale nuclear power projects, its competitive position cannot be gauged.

If neutron losses are kept to the very minimum, it is possible for a reactor to operate at a conversion ratio high enough to achieve a net gain of fissionable material, in which event the reactor is known as a breeder. Using breeders in nuclear power generation would ensure maximum exploitation of fertile-fuel resources as well as fissionable ones. The technical feasibility of building a reactor with a sufficiently refined neutron economy to achieve breeding was demonstrated more than a decade ago. Much development work remains to be done, however, before this can be reduced to commercial practice. The AEC is sponsoring a major breeder-reactor development effort with the objective of having prototype plants in operation by the mid-1970's and of achieving full-scale commercial application by the early or mid-1980's. Reactor manufacturers hope to improve this schedule by several years.

There are two basic approaches to breeding: a fast neutron system operating on the uranium-238/plutonium-239 cycle, and a slow neutron system operating on the thorium/uranium-233 cycle. Higher breeding gains are possible in the first cycle, and most of the current development efforts follow this approach. All of the five reactor manufacturers that have been mentioned so far in this article, plus a sixth (Atomics International, a division of North American Rockwell Corp.), are active in breeder development. Some utilities (notably the Detroit Edison Company) have a long history of active support of breeder development, and of late there have been signs of heightened utility interest in this exacting field of reactor technology.

It will be evident by now that this epilogue is in reality a second prologue, and that the most important history of nuclear power remains to unfold.

The Membrane of the Mitochondrion

The folded inner membrane of this intracellular body is the site of the major process of energy metabolism in the living cell. It is studied by taking it apart and attempting to put it together again

by Efraim Racker

The seat of oxidative phosphorylation, the process by which most plant and animal cells produce the energy required to sustain life, is the inner membrane of the intracellular particles called mitochondria [*see bottom illustration on page 34*]. Associated with this membrane are the enzymes of oxidative phosphorylation, embedded in a complex matrix that binds them tenaciously in an ordered array. The mechanism of energy production in mitochondria has long defied analysis, since a complex chemical pathway in a living organism cannot really be understood until its intermediate products have been identified and the enzymes that catalyze each step of the process have been individually resolved as soluble components. A decade ago my colleagues and I set out to attack the problem by trying to take the inner membrane of the mitochondrion apart and put it back together. We have been partially successful in the attempt, and along the way we have made some exciting discoveries and developed new methods of studying enzymes bound in membranes.

The universal energy carrier of the cell is adenosine triphosphate (ATP). This molecule functions by transferring its energetic terminal phosphate group to another molecule. In so doing it is converted to adenosine diphosphate (ADP), which in turn can be transformed into ATP by energy-generating systems in the cell. This regeneration of ATP occurs at several stages in the course of the breakdown and cxidation of foodstuffs. Some ATP is formed during glycolysis, a well-understood metabolic pathway utilizing soluble enzymes that break carbohydrates down to simpler compounds.

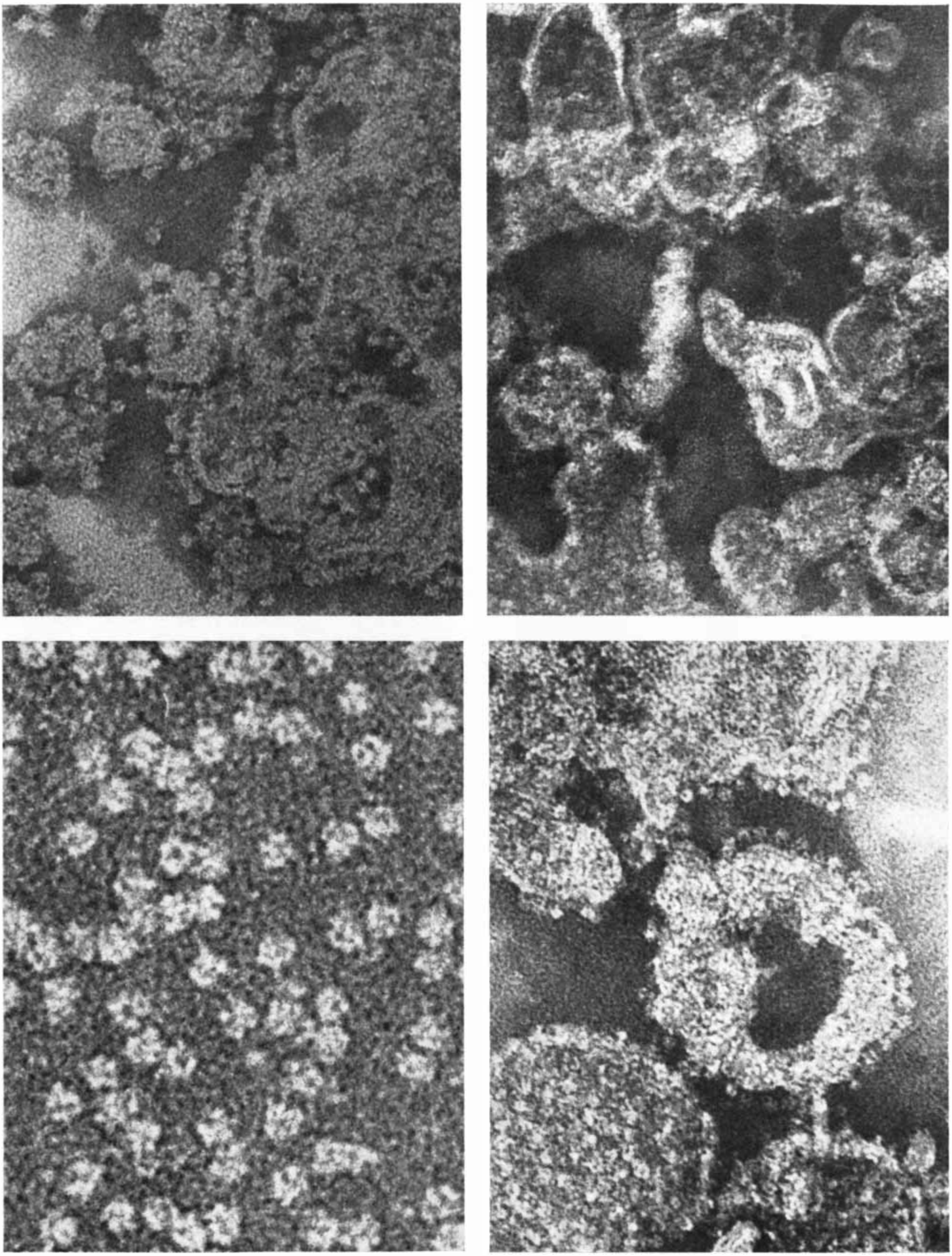
Most of the ATP is formed, however, during the course of oxidative phosphorylation in mitochondria. Pyruvate, the end product of glycolysis, is delivered to the mitochondria, where it is oxidized to carbon dioxide and water by the enzymes of the Krebs cycle [*see top illustration on pages 34 and 35*]. As hydrogen is removed from the successive intermediate products, it is captured by the coenzyme diphosphopyridine nucleotide (DPN), which contains the vitamin nicotinamide. The electrons of hydrogen are passed along a series of respiratory enzymes, notably yellow flavoproteins and red cytochromes, ultimately combining with protons and oxygen to form water. The energy of this oxidation process is utilized at three sites to regenerate ATP from ADP and inorganic phosphate. Under physiological conditions such "coupling" of oxidation with phosphorylation is compulsory, and respiration takes place only when ADP and phosphate are available, which is to say when ATP is being utilized. This "tight coupling" represents an ingenious control mechanism through which energy production is regulated by the rate of energy consumption.

Two chemicals that affect oxidative phosphorylation serve as tools with which to analyze the process. One is dinitrophenol (DNP), which uncouples oxidation from phosphorylation so that respiration proceeds but produces heat instead of ATP. The other is the antibiotic oligomycin, which acts differently. It interferes with the production of ATP, thereby inhibiting respiration as long as the system is tightly coupled. When dinitrophenol is added, the inhibition by oligomycin is overcome and respiration returns to its original rate, although it produces no ATP.

The enzymes that catalyze electron transport had been isolated and characterized, but only after the disruption of mitochondria with detergents. This process left the oxidation enzymes able to function but damaged the phosphorylation system severely. It was accordingly believed for a long time that the intact mitochondrial structure was essential for oxidative phosphorylation and that the component parts could not be separated without destroying them.

In 1956 the system did begin to yield to fractionation. Independent experiments reported almost simultaneously from the laboratories of Albert L. Lehninger, Henry A. Lardy, David E. Green and W. W. Kielley showed that chemicals such as digitonin and physical methods such as sonic oscillation would break mitochondria into "submitochondrial particles" much smaller than mitochondria and yet able to catalyze oxidative phosphorylation. This accomplishment was an important step forward, and yet there was still no indication that a true resolution—a separation of soluble components—would ever be possible. Such resolution was the task we undertook at the Public Health Research Institute of the City of New York.

In 1957 the first successful resolution of the system of oxidative phosphorylation was achieved when Harvey Penefsky, Maynard E. Pullman and I fragmented beef-heart mitochondria by agitating them with glass beads in a powerful device called a Nossal shaker. We removed the heavier unbroken mitochondria by centrifuging the mixture at low speed and then respun the lighter fraction at high speed [*see top illustration on page 36*]. The resulting sediment—the submitochondrial particles—still contained the respiratory enzymes but could not produce much ATP; the remaining fraction contained a soluble



RECONSTITUTION of the mitochondrial membrane begins with submitochondrial particles lined with inner-membrane spheres (*top left*). Treatment with a molecular sieve (Sephadex) and urea produces "*SU* particles" without spheres (*top right*). When coupling factor F_1 (*bottom left*) isolated from mitochondria is added, the characteristic shape of submitochondrial particles is restored (*bottom right*). F_1 spheres are enlarged about 600,000 diameters, other preparations about 300,000 in these electron micrographs.

component that was necessary for the coupling of phosphorylation to oxidation. We called this soluble component a coupling factor, F_1. In time various treatments of mitochondria separated other coupling factors that were also required for phosphorylation, and these we called F_2, F_3 and F_4.

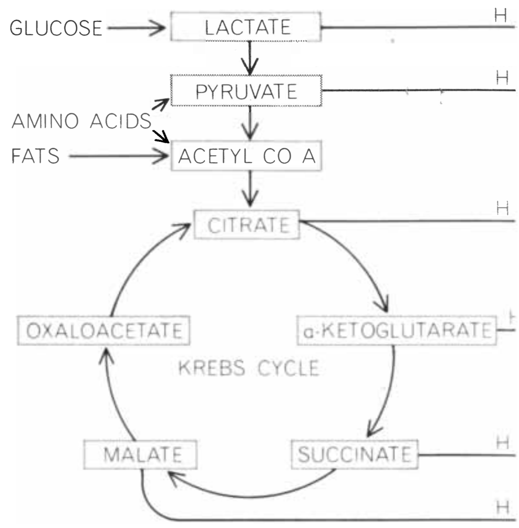
The experiments demonstrating the resolution of F_1 were difficult to reproduce. In laboratory jargon our data were "in the right direction"—and that is always a sign of trouble. F_1 as much as doubled phosphorylation, but that was not enough stimulation to provide a reliable assay of its coupling activity. And a reliable assay was required if we were to purify F_1 and characterize it. Now, it was known that mitochondria could catalyze the splitting of ATP into ADP and inorganic phosphorus. In fact, as early as 1945 Lardy, working at the University of Wisconsin, had suggested that this enzymatic ("ATP-ase") activity might be the inverse of some step in oxidative phosphorylation. We discovered that partially purified F_1 did in fact exhibit ATP-ase activity.

Since this was the first time ATP-ase had been extracted as a soluble component from mitochondria, we decided to go after this enzyme. We realized it was a gamble that might not shed any light on oxidative phosphorylation, but the ATP-ase assay was simple and accurate and at least we had had experience in purifying soluble enzymes. We felt that it should not take long to establish whether or not the ATP-ase and the coupling-factor activity were related.

Yet sometimes experience gets in one's way. Working in a "cold room," as one ordinarily does in enzyme research, we found the ATP-ase to be quite unstable (in contrast to the ATP-ase activity of submitochondrial particles, which was quite stable) and we made little progress. One day we discovered that this enzyme was "cold labile": at 0 degrees centigrade it lost all activity in a few hours, but at room temperature it was stable for days. That was a turning point in our investigations; from then on purification was simple. Furthermore, we had a decisive tool for determining the relationship between ATP-ase and coupling factor. The fact that both activities decayed at the same rate at 0 degrees indicated that the same protein was responsible for both.

Chemical fractionation of F_1 gave us a pure enzyme in good yield. In fact, at first the yield seemed to be too good: often our final preparation had more units of ATP-ase than we had estimated were present in the crude preparation. Moreover, the ratio of coupling activity to ATP-ase activity was not constant during purification. An examination of these discrepancies by Pullman revealed that the crude mitochondrial extract contained a protein that inhibited ATP-ase activity but not coupling activity, and that the removal of this inhibitor during purification explained the unexpected increase in total ATP-ase activity.

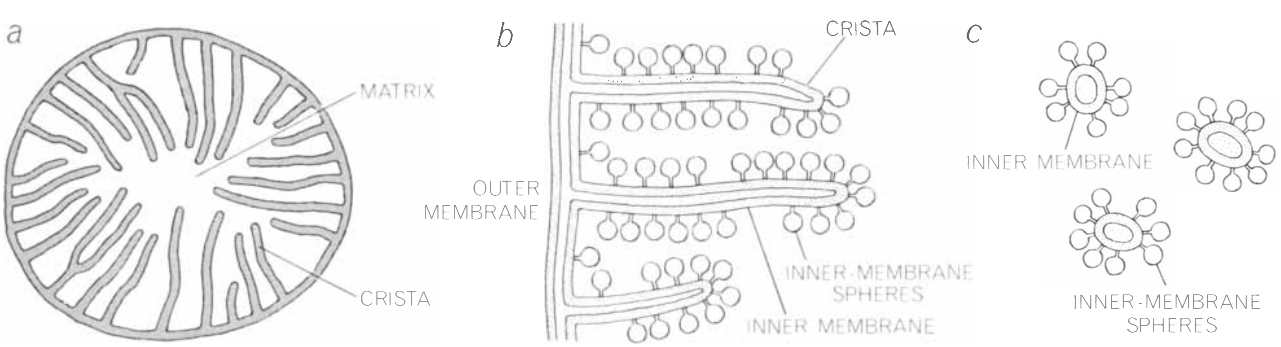
The purified F_1 had one puzzling property. Whereas Lardy and his collaborators had shown that both oxidative phosphorylation and the ATP-ase activity of mitochondria were very sensitive to oligomycin, our soluble enzyme was completely insensitive. This apparent discrepancy caused some of our colleagues to challenge the significance of our observations with the soluble enzyme. I had heard that the late Oswald T. Avery had once said: "It doesn't matter if you fall down, as long as you pick up something from the floor when you get up." And so we accepted the challenge and embarked on a project to find



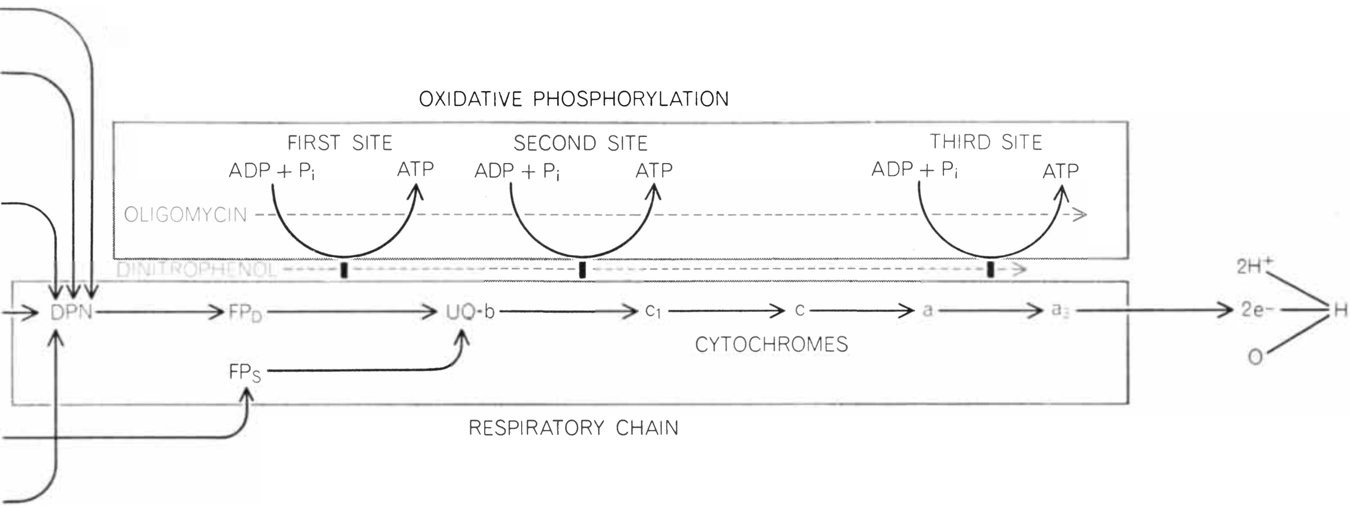
OXIDATIVE PHOSPHORYLATION is the process whereby energy from the oxidation of foodstuffs is harnessed to produce ATP, the energy carrier of the cell. Sugars, fats

out why oligomycin inhibited the enzyme in mitochondrial particles but not the soluble enzyme.

We started with the working hypothesis that there must be a component in mitochondria that confers oligomycin sensitivity on the enzyme. To show this we first had to prepare submitochondrial particles from which all the bound, oligomycin-sensitive ATP-ase had been removed, then add F_1 to them and observe what happened. We were able to eliminate the ATP-ase activity from particles by treating them with urea at 0 degrees, but to our surprise oligomycin-sensitive ATP-ase activity kept reappearing on dilution or aging. It developed that most of the ATP-ase in submitochondrial particles was latent—masked, apparently, by Pullman's inhibitor—and was more resistant to urea than the manifest enzyme was. We had to learn how



MITOCHONDRION, seen in a schematic cross section (*a*), has two membranes, each about 60 angstrom units (six millionths of a millimeter) thick. The inner membrane is deeply folded into "cristae" covered with the inner-membrane spheres, each about 85 angstroms in diameter (*b*). The inner membrane, with its spheres, is the site of oxidative phosphorylation. Mitochondria exposed to sonic oscillation become fragmented into small submitochondrial particles (*c*), which are still capable of oxidative phosphorylation.



and proteins are partially metabolized and then, in mitochondria, enter the Krebs cycle, in which they are broken down to carbon dioxide. In the process hydrogen atoms are accepted by the coenzyme diphosphopyridine nucleotide (*DPN*). The chain of respiratory enzymes, including flavoproteins (*FP*) and cytochromes *b*, c_1, *c*, *a* and a_3, catalyze a stepwise transfer of electrons to form water. At three sites phosphorylation is "coupled" to electron transfer. It can be uncoupled by dinitrophenol and inhibited by oligomycin.

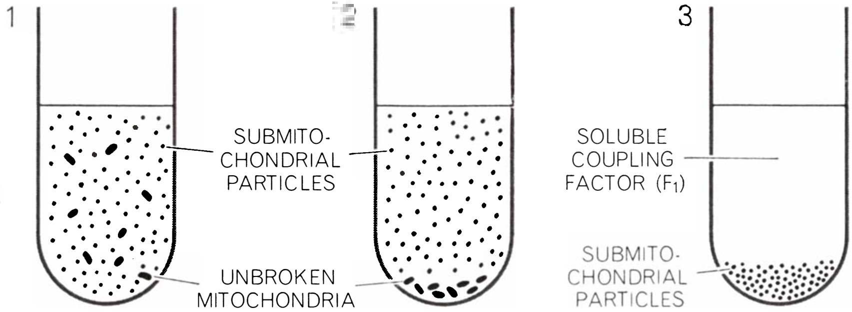
to unmask this ATP-ase by removing the inhibitor before urea treatment. We found that if submitochondrial particles were first treated with trypsin, a digestive enzyme, and only then with urea, the resulting "*TU* particles" were depleted of virtually all ATP-ase activity [*see middle illustration on next page*]. More recently, when we found that the trypsin was damaging the mitochondrial membrane, Lawrence Horstman of our laboratory discovered that the inhibitor could be removed more gently by passing the submitochondrial particles through a column of Sephadex, a molecular sieve that separates small bodies from large ones. When this procedure is followed by treatment with urea, the resulting "*SU* particles" are analogous to *TU* particles but are much more effective in reconstitution experiments.

When we added F_1 to *TU* or *SU* particles, the enzyme was bound to the particles and the ATP-ase activity became not only sensitive to oligomycin but also stable at 0 degrees. Thus our working hypothesis was confirmed: mitochondria contain a component or components that alter the properties of F_1. We have become increasingly aware that this phenomenon is not unusual. Enzymes bound to membranes almost invariably have some properties that are different from those of the same enzymes in solution. Gottfried Schatz of our laboratory suggested the word "allotopy" (from the Greek for "other" and "position") to designate this phenomenon. We observed, furthermore, that the properties not only of the enzyme but also of the membrane to which it is attached are changed depending on whether they are separate or bound to one another [*see top illustration on page 37*]. An allotopic property of an enzyme can be used to devise a quantitative assay to serve during the purification of the membrane, since one can test successively purer membrane preparations to see if they are still capable of changing the properties of the added enzyme.

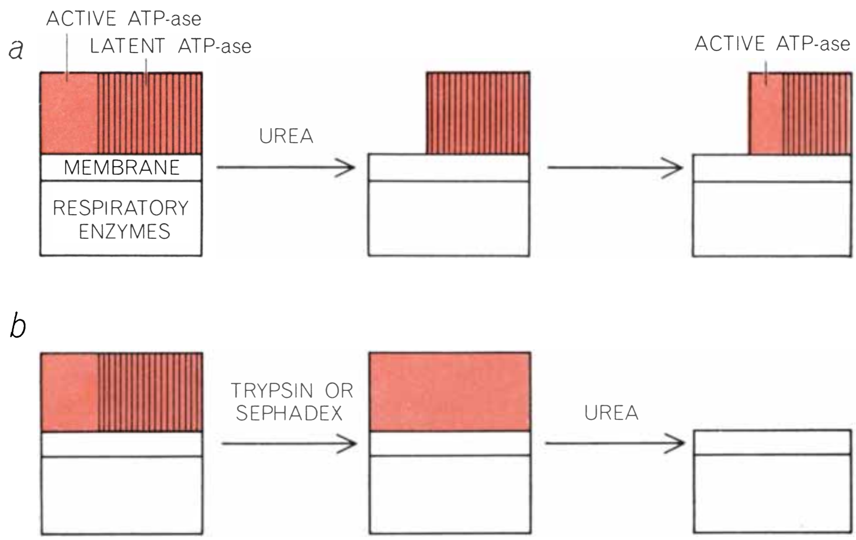
The *TU* particles that conferred oligomycin sensitivity on F_1 still contained the entire electron-transport chain, and we went on, with the allotopic property of F_1 as the tool, in an attempt to further resolve this membrane system. One day I subjected *TU* particles to sonic oscillation without including the usual salt buffer. Centrifugation of the resulting mixture at high speed yielded a soluble extract that conferred oligomycin sensitivity on F_1. We called the factor responsible for this property F_0. The discovery seemed even more exciting when the soluble preparation turned out to contain the entire electron-transport chain and even some residual phosphorylating activity: it appeared that we had actually rendered the entire system soluble. Then the addition of salt solution made the preparation turbid, which meant that particles had formed from the soluble system. In other words, in the presence of salt buffer—which must be added in biological experiments to keep the medium constant—F_0 was still particulate. At the time this was disappointing, but the observation led us into new investigations of the relation between membrane structure and function.

In collaboration with Donald F. Parsons of the University of Toronto Faculty of Medicine and Britton Chance of the University of Pennsylvania School of Medicine, we examined all our membranous preparations of F_0 by negative staining in the electron microscope. We saw, first, that the submitochondrial particles we had started with were similar to those prepared by earlier investigators: sac-shaped structures outlined by a membrane that was covered with the characteristic "inner-membrane spheres" that had been discovered by Humberto Fernandez-Moran of the University of Chicago. The treatment with trypsin caused little change in structure. Subsequent treatment with urea, however, had a dramatic effect: although it left the membrane intact, it removed the inner-membrane spheres [*see bottom illustration on next page*]. This was unexpected, since David Green had once maintained that these spheres, which he called "elementary particles," represented groups of enzymes of the electron-transport chain [see "The Mitochondrion," by David E. Green; SCIENTIFIC AMERICAN, January, 1964]. We had found, on the contrary, that the *TU* particles (which lacked spheres) contained the entire electron-transport chain!

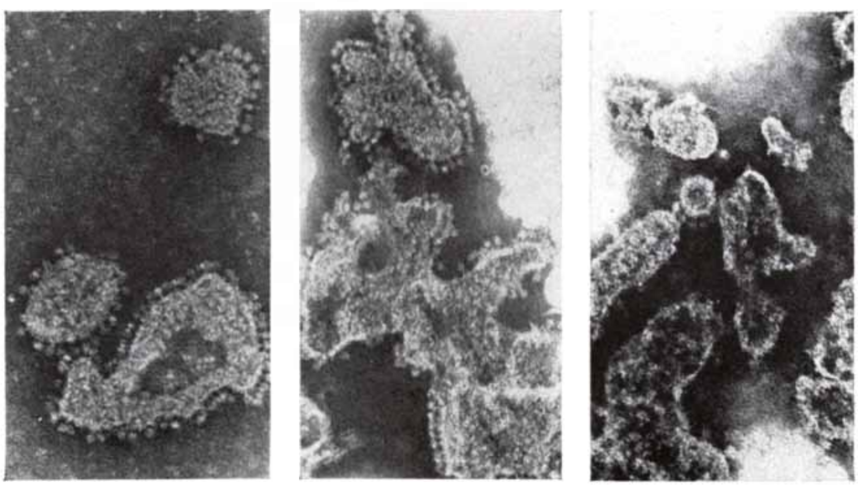
If the spheres did not contain respiratory enzymes, what did they contain? We calculated that most of the protein removed by urea treatment could be accounted for by the removal of ATP-ase,



COUPLING FACTOR F_1 is separated by centrifugation. Mitochondria subjected to sonic oscillation (*1*) are centrifuged at low speed to separate particles from intact mitochondria (*2*). Then the particles are spun at high speed. The resulting light fraction (*3*) contains a soluble component (F_1) that is required for ATP production in the course of oxidation.



ENZYMATIC ACTIVITY (ATP-ase activity) of soluble F_1 was found resistant to oligomycin, unlike that of the intact membrane. To see if the membrane conferred this sensitivity on soluble F_1, it was first necessary to remove all native F_1 from the membrane. Most of the F_1 is masked by an inhibitor (*bars*), however; treatment with urea removed only exposed F_1, and ATP-ase activity reappeared (*a*). The destruction of inhibitor by trypsin (*b*) exposed the latent F_1 to removal by urea. Later Sephadex was substituted for trypsin.



ELECTRON MICROGRAPHS trace the procedure diagrammed in the preceding illustration. The membrane of submitochondrial particles, enlarged about 100,000 diameters, is lined with inner-membrane spheres (*left*). Trypsin has little effect on appearance (*center*). Urea removes the spheres from the particles, leaving "*TU* particles" without spheres (*right*).

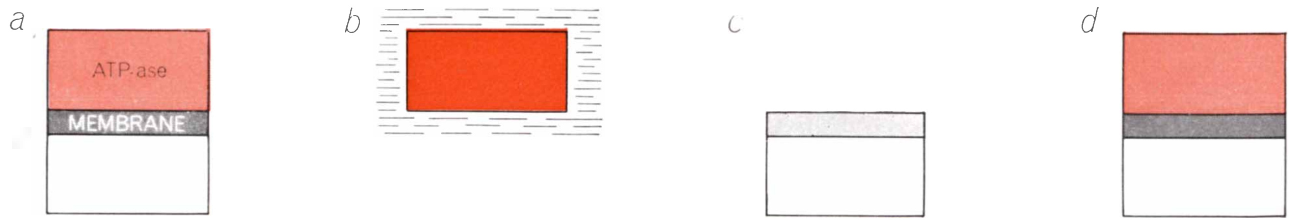
and so we suspected that the spheres were identical with F_1. We were encouraged in this belief when a preparation of pure F_1 turned out to have the characteristic appearance of the 85-angstrom-unit inner-membrane spheres [*see micrograph at bottom left on page 33*].

One further experiment was needed to identify F_1 unambiguously with the spheres: the reconstitution of a depleted particle by the addition of F_1, resulting in the restoration of the submitochondrial particle's typical shape and function. This was accomplished only recently, after the development of the *SU* particles. The addition of F_1 to these particles yielded a preparation that was indistinguishable in structure from fully functional submitochondrial particles [*see illustration on page 33*] and confirmed that coupling factor F_1 is identical with the inner-membrane spheres.

The morphological reconstitution was not paralleled by restoration of function, however. In an effort to regain oxidative phosphorylation we added three more coupling factors, F_2, F_3 and F_4—proteins that had been obtained from mitochondria by various extraction procedures. *SU* particles reconstituted with all four coupling factors oxidized succinate, a compound of the Krebs cycle, with a high efficiency of ATP synthesis: for each molecule of oxygen consumed, up to 1.8 molecules of ATP were formed. That is very close to the best value—two molecules—that can be achieved with intact mitochondria.

With these experiments one of the aims of our investigation had been achieved: a resolution of soluble components and a reconstitution of structure and function. Another aim has been to get some insight into the mode of action of the coupling factors. How do they fit into the mechanism of oxidative phosphorylation?

There are currently two views of the general nature of that mechanism. One is a chemically oriented hypothesis originally suggested by E. C. Slater of the University of Amsterdam in 1953, in analogy to the mechanism of ATP formation in glycolysis. It proposes that during electron transport high-energy intermediate compounds ($A{\sim}x$, $B{\sim}x$, $C{\sim}x$) are formed at each coupling site, composed of a member of the respiratory chain (A, B, C) and an unknown (x). These compounds are transformed into a common intermediate by interaction with another unknown (y) to form $x{\sim}y$. This intermediate in turn combines with inorganic phosphate to yield $x{\sim}P$, which



ALLOTOPIC PROPERTIES of purified F_1 and the mitochondrial membrane are indicated. The ATP-ase activity of particles (*a*) was known to be sensitive to oligomycin (*light color*). When soluble F_1 was discovered (*b*), it was found to be resistant to oligomycin (*dark color*), and membrane from which F_1 had been removed (*c*) was sensitive to trypsin (*light gray*). When the enzyme and membrane were bound (*d*), each was changed: the F_1 became sensitive to oligomycin, the membrane resistant to trypsin (*dark gray*).

ultimately transfers its energetic phosphate group to ADP to form ATP.

Recently Peter Mitchell of the Glynn Research Ltd. laboratories in England has challenged this chemical hypothesis with some new and provocative ideas. Instead of a high-energy intermediate compound of the respiratory chain, he proposes that an electrical potential develops during respiration that provides the energy for ATP production: The positively charged hydrogen ions (protons) are moved to one side of the membrane while the negatively charged electrons are channeled to the other side. The separation of charges is utilized by a complex mechanism to give rise to the high-energy intermediate $x \sim y$, which powers the formation of ATP. At the core of this hypothesis is an ATP-ase located in the inner membrane.

In some respects the two hypotheses are not much different: both include a high-energy intermediate, $x \sim y$, to generate ATP from ADP and phosphate. In the Mitchell hypothesis, however, $x \sim y$ is formed by means of an electrical membrane potential. This requires a much higher integrity of the membrane structure than is required by the chemical hypothesis. Indeed, Mitchell considers that uncouplers such as dinitrophenol act by making the membrane "leaky" to protons, thus preventing a separation of charges. It is apparent, therefore, that further studies of the inner membrane are of utmost importance for the evaluation of the two hypotheses.

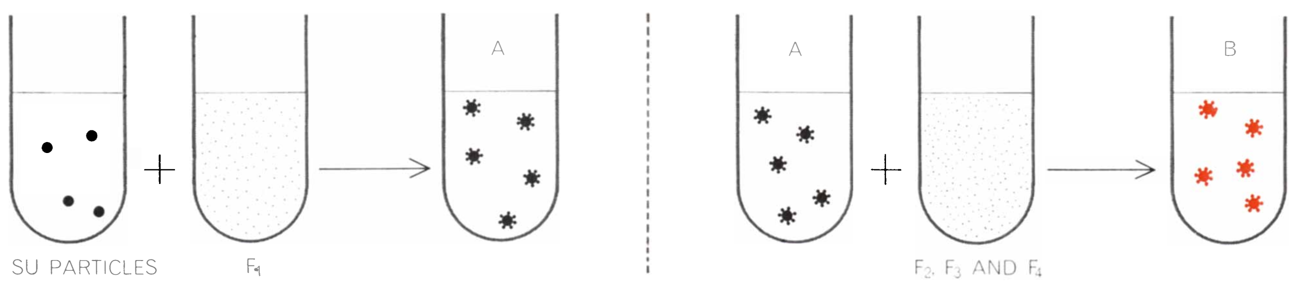
What is the role of coupling factor according to these two formulations? Mitchell proposes that F_1, together with F_0, represents the reversible ATP-ase that utilizes the electrical potential to generate ATP. According to the chemical hypothesis, F_1 catalyzes the last step in ATP formation, the "transphosphorylation" from $x \sim P$ to ADP. Indeed, every reaction associated with oxidative phosphorylation that requires ATP can be shown to be dependent on F_1. June Fessenden-Raden in our laboratory has prepared an antibody against F_1 and has found that these ATP-dependent reactions are inhibited by the antibody.

In collaboration with Mrs. Fessenden-Raden, Richard McCarty and Gottfried Schatz, I have recently found that a coupling factor may have, in addition to a catalytic function that is inhibited by its antibody, a second, "structural" function that is not impaired by the antibody. Our first example was the stimulation by F_1 of a reaction that is catalyzed by mitochondria but does not involve ATP. The second example was the observation that in chloroplasts, the energy-generating particles of plant cells, a coupling factor (chloroplast F_1) is required not only for all reactions that involve ADP or ATP but also for a "proton pump" that is driven by light energy without ATP. In contrast to the ATP-dependent reactions, however, this proton pump was not inhibited by an antibody against the chloroplast coupling factor. The factor therefore appears to contribute to the integrity of the chloroplast membrane, which is required for proton transport.

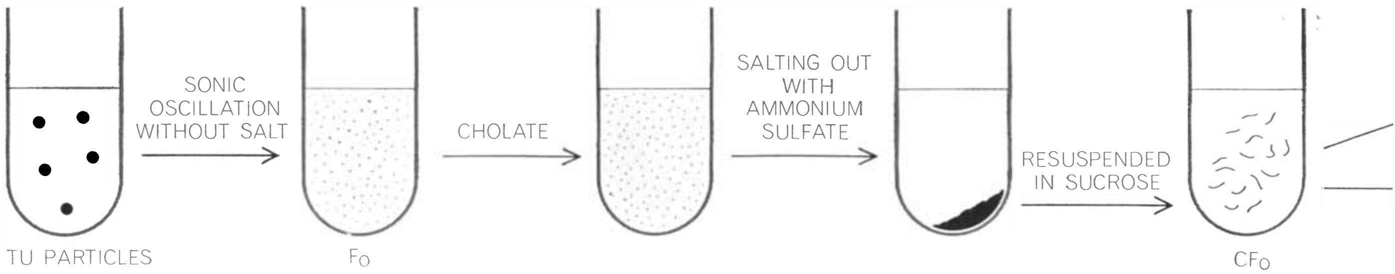
A third example of the "structural" role of a coupling factor was observed with a preparation of F_1 from yeast mitochondria, which stimulated phosphorylation in beef-heart particles that still contained some residual beef F_1. This stimulation was apparently due to a structural effect of yeast F_1, since it was not inhibited by an antibody against yeast F_1. In beef-heart particles (*SU* particles) that were completely devoid of native F_1, the yeast factor had no effect; apparently it could not fulfill the catalytic functions of native coupling factor.

We are beginning to suspect that the dual role played by F_1 is representative of a common occurrence in the interaction of enzymes and membranes and is an important expression of the allotopy phenomenon. The contribution of F_1 to the integrity of the mitochondrial membrane and the fact that it is required for the operation of the proton pump of the chloroplast have obvious bearing on the Mitchell hypothesis, and may lead to a clarification of the role played by the membrane in oxidative phosphorylation.

While the work with F_1 was going forward as described above, we therefore



***SU* PARTICLES**, from which coupling factor F_1 had been removed, were reconstituted to the shape of submitochondrial particles (*A*) by the addition of F_1 (*see micrographs on page 33*). To restore function as well as structure it was necessary also to add F_2, F_3 and F_4. When this was done, the reconstituted particles (*B*) were capable of generating ATP almost as well as intact mitochondria.

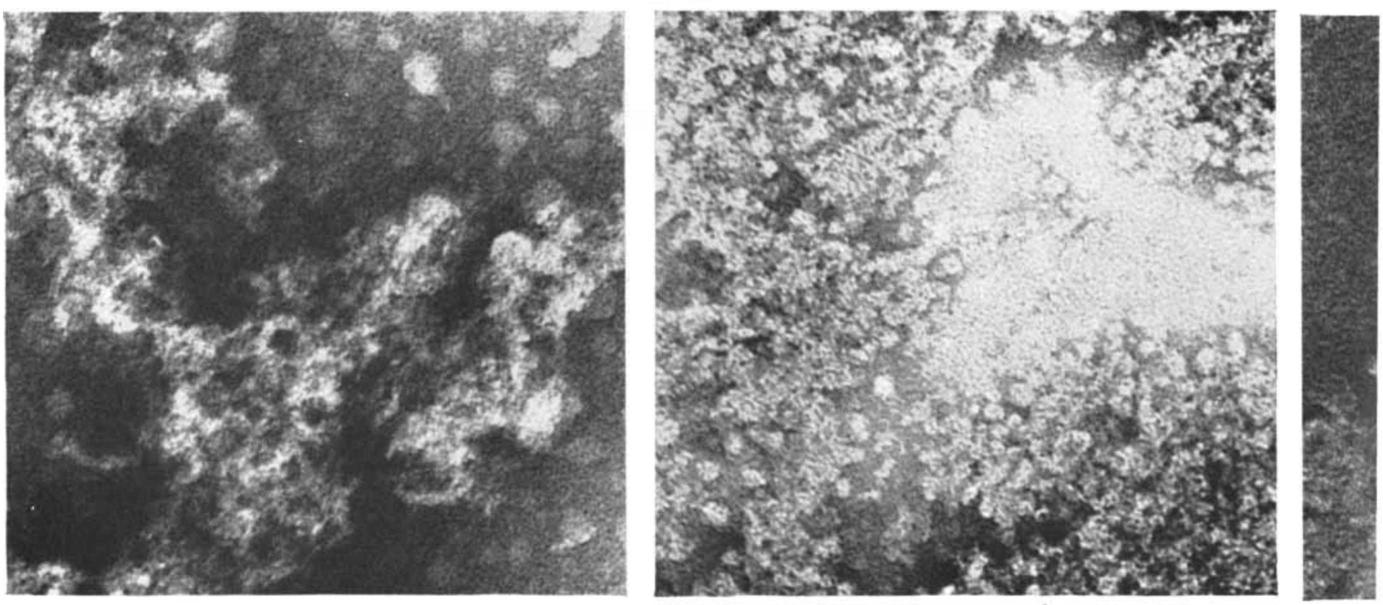


MEMBRANE OF MITOCHONDRION was isolated as shown here. *TU* particles were subjected to sonic oscillation, producing F_0, which had the capacity to bind F_1. When F_0 was dissolved in cholate and fractionated by "salting out," the colorless precipitate CF_0 was obtained. It lacked respiratory enzymes and lipids; added to F_1, it inhibited ATP-ase activity. Addition of phospholipid

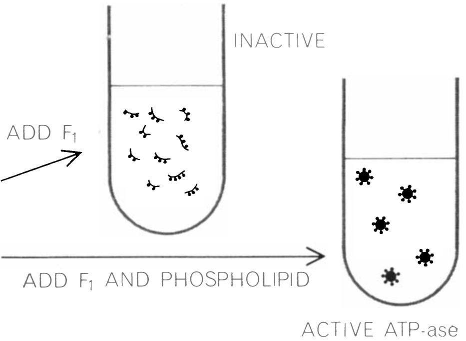
also pursued the problem of resolving the inner mitochondrial membrane. F_0 had turned out to be a yellow-brown complex of many components including the entire electron-transport chain. By chemical fractionation in the presence of a bile salt, Yasuo Kagawa isolated a virtually colorless fraction (CF_0) with some interesting properties. It lacked respiratory activity, having lost almost all the flavoproteins and cytochromes present in the original submitochondrial particles, and it contained only traces of phospholipids, the fat constituents of the membrane.

When F_1 was added to CF_0, the ATP-ase activity of F_1 was almost completely inhibited. The subsequent addition of phospholipid to this inactive complex fully restored ATP-ase activity, which was now sensitive to oligomycin! Equally striking results were observed in the electron microscope. CF_0 was amorphous. After the addition of F_1 numerous inner-membrane spheres became attached to CF_0, which remained amorphous. Then, with the addition of phospholipid, the characteristic saclike membranous structures covered with spheres became apparent [*see illustration below*]. They could not be distinguished from functional submitochondrial particles, even though they lacked major components of such particles, the respiratory enzymes. These enzymes had always been assumed to be an integral part of the inner membrane—and now they were found not to be present in what appears to be the isolated membrane. How, then, are the respiratory enzymes associated with the membrane? What are the constituents of the inner membrane itself? How are they organized?

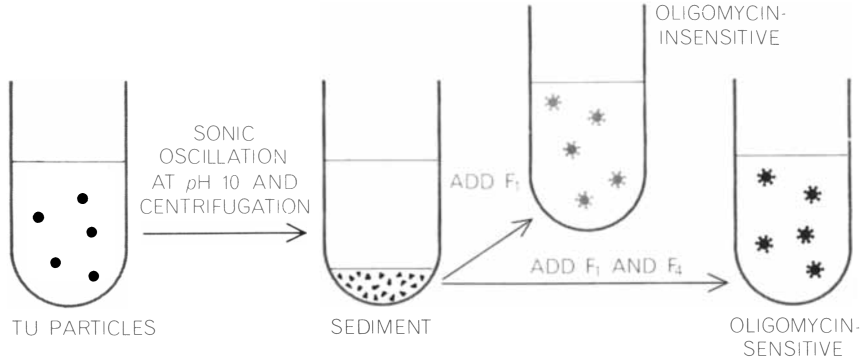
To answer some of these questions we proceeded to disrupt the membrane further to see which constituents were necessary for the interaction with F_1. Several years ago Thomas E. Conover and Richard L. Prairie in our laboratory had separated a coupling factor, F_4, that was necessary for phosphorylation in particles obtained by sonic oscillation of mitochondria under highly alkaline conditions. When Kagawa exposed *TU* particles to sonic oscillation under alkaline conditions, after high-speed centrifugation he obtained a sediment ("*TUA* particles") that no longer made F_1 sensitive to oligomycin. The addition of F_4 to *TUA* particles restored oligomycin sen-



CF_0 FRACTION, enlarged about 250,000 diameters in an electron micrograph, appears amorphous (*left*). When F_1 is added to the CF_0 preparation, it appears that the F_1 spheres attach themselves to the CF_0, but no distinct structure is seen (*center*). When phospholipids are added, the distinct structure that emerges (*right*) resembles that of submitochondrial particles. In other words, CF_0



restored ATP-ase activity, which was now oligomycin-sensitive. CF_0 and phospholipid may thus comprise the membrane proper.

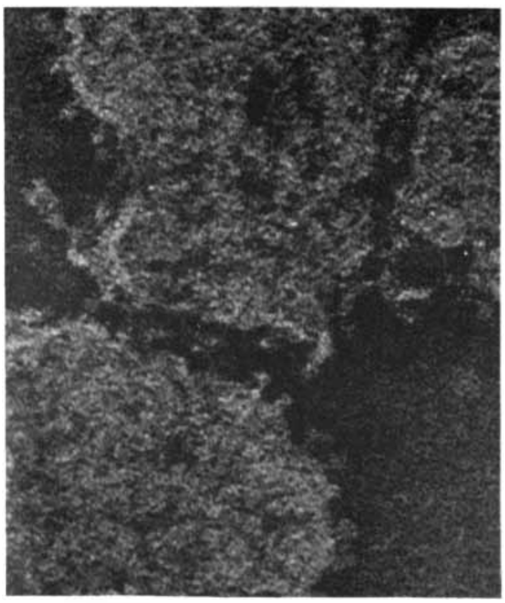


COUPLING FACTOR F_4 is apparently required for oligomycin sensitivity. When *TU* particles are broken down under alkaline conditions, the sedimented particles cannot confer oligomycin sensitivity on F_1. Addition of F_4 in the presence of salt restores this capacity.

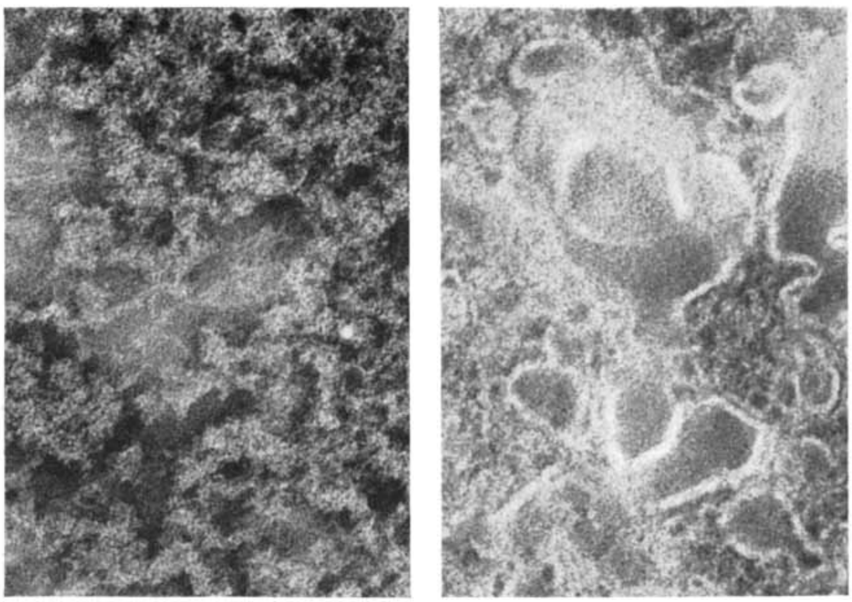
sitivity to the complex. Recent experiments by Bernard Bulos in our laboratory at Cornell University revealed that F_1 is bound by *TUA* particles in the presence of salt but is nevertheless not inhibited by oligomycin. On addition of small amounts of a highly purified preparation of F_4, he observed a time-dependent restoration of oligomycin sensitivity, suggesting that an enzymatic process may be taking place. This is the first clue to the mode of action of F_4.

Several years ago Richard S. Criddle, Stephen H. Richardson and their collaborators at the University of Wisconsin isolated an insoluble "structural protein" from mitochondria with the help of detergents and solvents. Our crude preparation of F_4 was similar to that protein in its capacity to combine with some flavoproteins and cytochromes of the respiratory chain but, not having been exposed to damaging chemicals, it remained soluble. In the electron microscope it appeared quite amorphous. When phospholipids were added to soluble F_4, however, a precipitate formed that appeared to be membranous and shaped into sacs [*see illustration at right below*]. We have therefore proposed that F_4 may have a function as an organizational protein in the mitochondrial membrane—a kind of backbone for the association of the respiratory enzymes and the coupling factors involved in the transformation of oxidative energy into ATP.

With this concept as a working hypothesis we have embarked on what promises to be a long and venturesome journey. Taking the membrane-like complex of F_4 and phospholipid as starting material, we are adding isolated soluble flavoproteins and cytochromes of the respiratory chain step by step, checking at each stage to see if some of the allotopic properties of the respiratory chain are restored. In our laboratory Alessandro Bruni and Satoshi Yamashita have constituted sections of the respiratory chain with the appropriate allotopic properties (such as sensitivity to the respiratory poison antimycin). These experiments have given us confidence that we shall eventually achieve a complete reconstitution of the respiratory chain from soluble components. Then we shall turn to the final task: the reconstitution of the system of oxidative phosphorylation from its individual components.



and phospholipid seem to suffice, without respiratory enzymes, to bind F_1 and reconstitute the shape of submitochondrial particles.



F_4 PREPARATION, seen in an electron micrograph at a magnification of 250,000 diameters, appears to be amorphous (*left*). The addition of phospholipid to soluble F_4 yields particles with a sac-shaped structure similar to that of submitochondrial particles (*right*).

ADVANCES IN HOLOGRAPHY

The range of possible uses of this remarkable photographic technique has grown considerably in the past four years. In spite of the many problems that remain, some applications appear feasible at present

by Keith S. Pennington

As is now widely known, the photographic technique called holography records a subject not by the direct process of ordinary photography, but by recording the pattern of wave fronts of light from the subject. This recorded information is then used to reconstruct an image of the subject.

Although these basic principles of holography were described as early as 1947 by Dennis Gabor, it was only after the introduction of the laser that this novel technique became truly practical. Indeed, the introduction of the laser, together with a modification of the original holographic technique, enabled Emmett N. Leith and Juris Upatnieks of the University of Michigan to record holograms that produced highly realistic images of three-dimensional objects [see "Photography by Laser," by Emmett N. Leith and Juris Upatnieks; SCIENTIFIC AMERICAN, June, 1965].

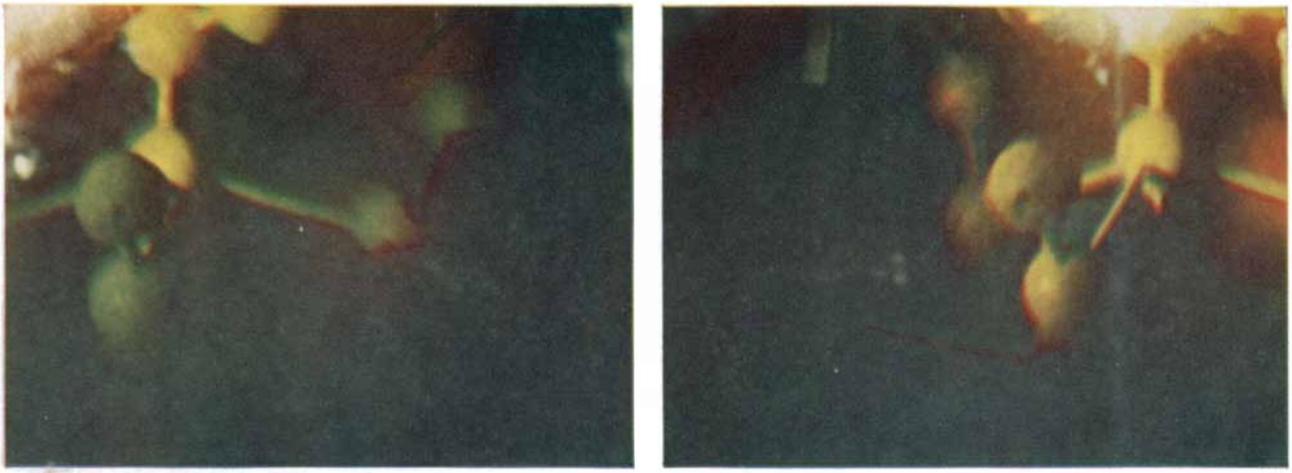
Since that time further exploration, actively undertaken in a number of research laboratories, is demonstrating that holography is even richer in possible applications than was at first supposed. In particular, techniques have been developed for making holograms that can be viewed with white light, and also holograms that reconstruct multicolored images. Holography has introduced additional flexibility into microscopic investigations and promises to be of particular importance in the study of biological subjects. Furthermore, holographic techniques have expanded the uses of interferometry into new areas and at the same time have introduced a new simplicity in some of the existing areas. At present a considerable amount of effort is being devoted to the possible use of holography in data-processing and the display of information.

In essence holography is not difficult to understand, and it is fairly easy to put into practice. Consider a beam of coherent laser light (in which all points on the wave fronts are related in phase) that is split in transit into two beams [*see upper illustration on page 43*]. One beam illuminates the subject to be recorded, and the light reflected from this subject falls on a photographic plate. The other beam, called the reference beam, is reflected from a mirror to the same photographic plate, where its wave fronts are superposed on those from the subject. This results in an interference pattern that, when the plate is developed, is recorded in the form of points of varying density—increased in density where the wave fronts arrived in phase and augmented each other, reduced in density where they were out of phase. The record on the photographic plate (the hologram) is simply a pattern of interfering wave fronts and shows no resemblance to the recorded subject. Nonetheless, the record contains "all the information" about the subject. When the record is "played back" by shining the reference beam alone through the hologram, the reconstructed wave fronts appear to diverge from an image of the subject. This image can then be viewed with the eye or other optical instruments or recorded with a camera [*see lower illustration on page 43*].

Since the hologram records all the information contained in a wave front, the images produced by means of holography are extremely realistic. With a single hologram one can examine a subject from different points of view and even focus at different depths throughout the image. Further, it is possible to observe the reconstructed images with such optical techniques as phase-contrast microscopy, schlieren techniques and interferometry. In fact, for optical purposes a hologram of a subject can often be as useful as the actual subject, and in many instances it can prove even more useful. In this article I shall review the areas in which holography has already been developed to working usefulness, namely microscopy, interferometry and multicolor holography (which is called "volume holography," referring to the technique employed).

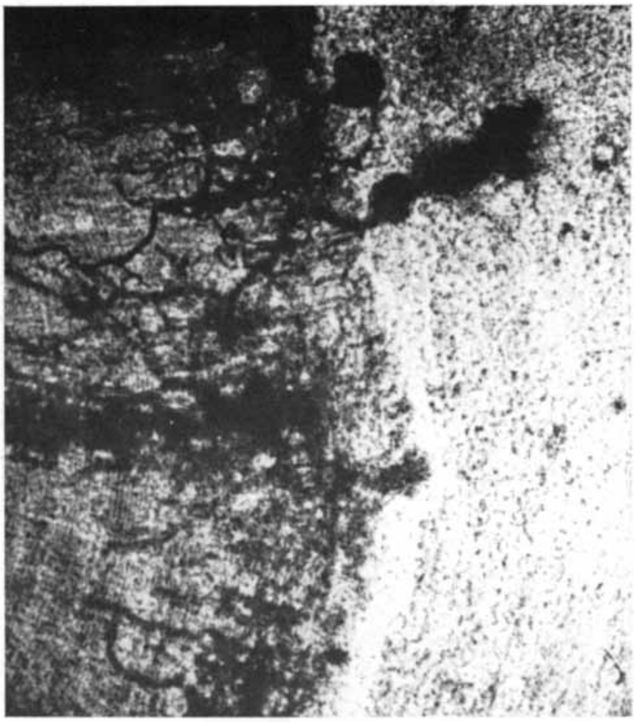
In microscopy the holographic technique makes it possible to overcome a serious limitation. Subjects such as biological specimens suspended in a fluid must often be viewed under very high magnification. In studies of this type the microscope is restricted to an extremely small depth of field, which means that for any particular setting of the instrument only those parts of the subject in the immediate vicinity of a single plane will be in sharp focus. Consequently if the sample is to be viewed without drifting in and out of focus, it must be either thinned down to almost two dimensions or "frozen" into a solid. Often such sample preparations modify and distort the specimen.

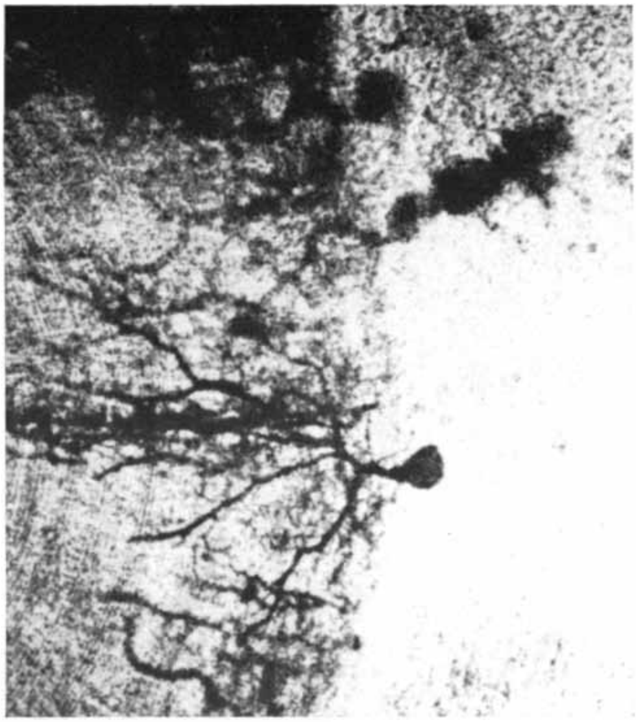
Holographic techniques can remove these difficulties in a fairly straightforward manner. All that is necessary is to make a short-exposure hologram of the sample. This will freeze any motion and also ensure the formation of a hologram of good quality. Since the hologram records all the three-dimensional characteristics of the sample, it is not necessary to prepare samples artificially; thus the possibility of degrading the specimens contained in the sample is reduced. The resulting hologram image can then be examined at leisure with a microscope. The microscope can be focused at various planes throughout the depth of the hologram image; in this way the entire undistorted specimen can be studied. Moreover, in the reconstruction of the image from the hologram, it is still pos-



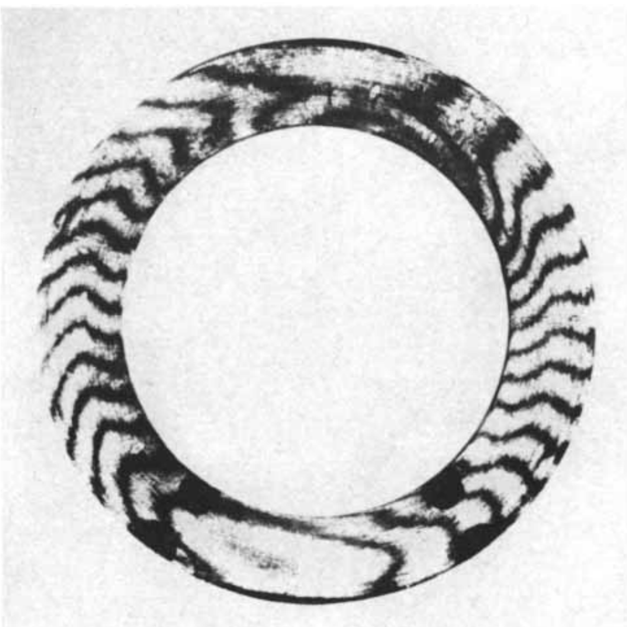
MONOCOLOR HOLOGRAM of a three-dimensional molecular model was illuminated with reflected white light from a zirconium-arc lamp and then photographed from two different angles to demonstrate the parallax effect, one of the distinguishing features of holography, or photography by wave-front reconstruction. In making the original hologram, the model was illuminated with a beam of coherent light from a helium-neon laser and the reflected incoherent wave fronts were made to interact with a reference beam of coherent laser light to form an interference pattern, which was recorded throughout the depth of the photographic emulsion. The resulting "volume" hologram, in this case one that can be "read out" in white light, was made by G. W. Stroke and A. E. Labeyrie, then at the University of Michigan. The development of this technique has led to "white light" holograms that reconstruct in several colors.

MULTICOLOR HOLOGRAM of a small vase was illuminated with a pair of laser beams in order to make this photograph. The same wavelengths were used in recording and reconstructing the hologram: 6,328 angstrom units (red) from a helium-neon laser; 5,145 angstroms (green) and 4,880 angstroms (blue) from an argon-ion laser. The superposed volume holograms (one for each color) have color selectivity adequate to eliminate interaction between the red and the blue components and between the red and the green components. The faint "spurious" images displaced to the sides of the bright reconstruction at center, however, indicate a slight interaction between the blue and the green components. The hologram was made by A. A. Friesem and R. J. Fedorowicz, also at Michigan.





MICROSCOPIC HOLOGRAM of a stained biological specimen preserves the three-dimensional structure of the specimen, unlike an ordinary two-dimensional photomicrograph. The entire undistorted specimen can later be observed at leisure by selectively focusing the microscope at different depths in the holographic reconstruction of the specimen. In this case the reconstruction at left shows a network of nerves in which two "heads," or synaptic knobs, and some of the finer detail are in acceptable focus. The reconstruction at right, focused at a depth 40 microns away from that at left, shows a third "head" and its associated fibers more clearly. The smallest fibers visible are less than a micron in diameter. Hologram was made by Raoul F. van Ligten of the American Optical Company.



INTERFERENCE PATTERNS created by superposing the wave fronts from the holographic reconstruction of an object and the reilluminated object itself can reveal minute variations between the original dimensions of the object and its dimensions at some later time; the technique can also be used to distinguish between the original master of a machine tool and subsequent versions. In this case the object is an automobile cylinder viewed almost end on. The interference pattern observed on the inside surface of the cylinder wall at left is caused by interference between the reconstruction of the cylinder and the same cylinder viewed from the other end. The pattern at right is caused by interference between the reconstruction of one cylinder and an entirely different cylinder. Such interference patterns can be analyzed to detect slight differences in the radii of the two cylinders along their entire length. The tests were carried out by a group that included E. Archbold, J. M. Burch and A. E. Ennos of the National Physical Laboratory in England.

sible to use schlieren and phase-contrast techniques to bring out various details in the sample. Hence holography may provide an inexpensive and often preferable alternative to present techniques of sample preparation.

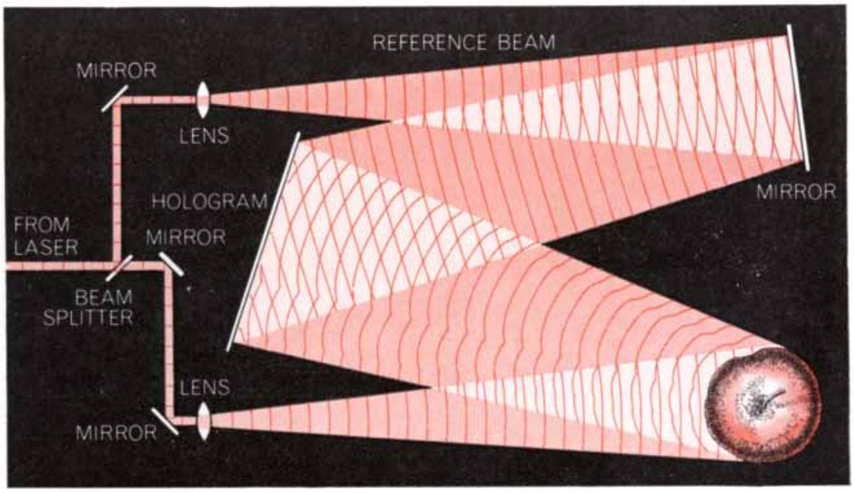
Holography promises to be an effective way to keep detailed records of biological and physical phenomena. It also gives one the opportunity to conduct many optical observations a second time on the "original" sample; similarly, it will allow one to make detailed comparisons of samples recorded at totally different times. The observation that one picture may be worth a thousand words can now be extended to say that one hologram may be worth a great many pictures.

Several investigators have applied holography to the study of biological specimens and have succeeded in producing highly magnified three-dimensional images of such subjects [*see top illustration on opposite page*]. Among those exploring this field of application are G. W. Stroke of the State University of New York at Stony Brook (formerly of the University of Michigan) and John F. Burke of the Harvard Medical School, who have used white-light-reconstructing holograms, and Raoul F. van Ligten of the American Optical Company, who has conducted some particularly interesting and varied work on biological samples.

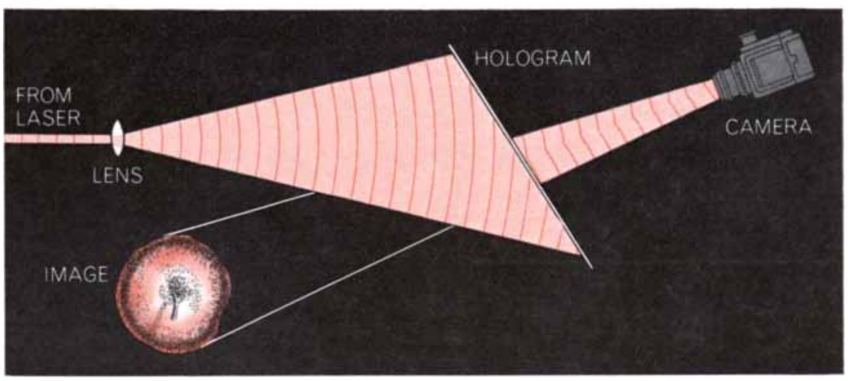
In the area of microscopic examination of physical phenomena, Brian J. Thompson, George Parrent, Jr., and their co-workers at Technical Operations, Inc., have demonstrated that holography can be a powerful instrument for studying the properties of a gas containing a suspension of microscopic particles. By making high-speed holograms of particle suspensions with the light from a pulsed laser, and then examining the reconstructed image with a microscope, they were able to measure the distribution of the particles according to size and various other properties. Heretofore detailed information of this kind has not usually been available to direct observation; it could only be deduced in statistical terms. It appears that holography may now provide a means of checking theories concerning the scattering of light by suspensions of small particles.

Since holography consists of recording an interference pattern, it has probably occurred to the reader that it bears an uncommonly close resemblance to interferometry, that traditional field of physical optics. This resemblance, of course, is not a coincidence. The only basic difference between holography and conventional interferometry is that in holography one generally records extremely complex interference patterns. Perhaps even more important, holography at its conception was meant to be a technique for recording wave fronts, in contrast to the more common use of interferometers for analyzing wave fronts.

As is often the case, one of the first areas to benefit from the new technique was the area that gave rise to it. So it was that holography was responsible for introducing a new range of powerful methods to interferometry. Interferometry has commonly been used for the precise measurement and comparison of wavelengths, for measuring very small distances or thicknesses (of the order of wavelengths of light), for detecting disturbances or inhomogeneities in optical mediums, for determining the refractive indexes of materials, and so on. To these functions the technique of holographic interferometry adds capabilities for studying phenomena that were formerly considered virtually inaccessible. Furthermore, holography makes interferometry less complicated by relaxing some of the exacting requirements that have attended this technique. For example, holography eliminates the necessity of using optical components of extremely high quality. This advantage is particularly useful when the phenomena under study take place in a closed vessel and must be measured interferometrically through windows. Holography makes it possible to distinguish the relevant information from the spurious, and thus it permits accurate interferometric experiments on any material and in almost any environment.

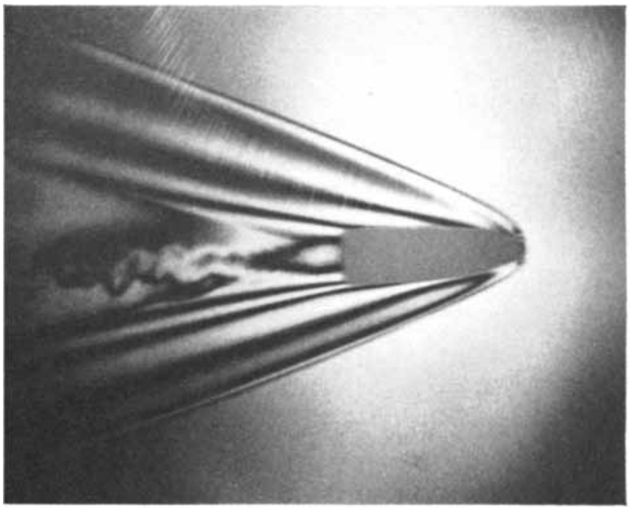


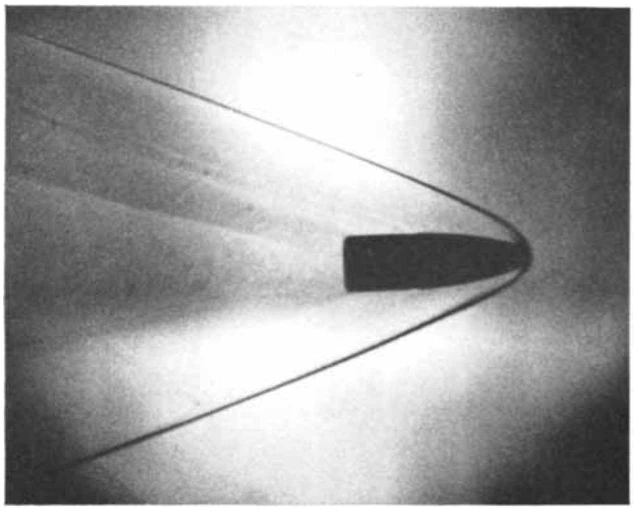
RECORDING STAGE of a simple holographic process is shown in this schematic drawing. Two beams are derived from a single laser by means of a beam splitter, such as a half-silvered mirror. One beam is used to illuminate the object, while the other is used as a reference beam. The reference beam and the light reflected from the object are then allowed to interfere, and the resulting interference pattern is recorded on a photographic plate, forming the hologram. Microscope lenses broaden both beams without affecting their coherence.



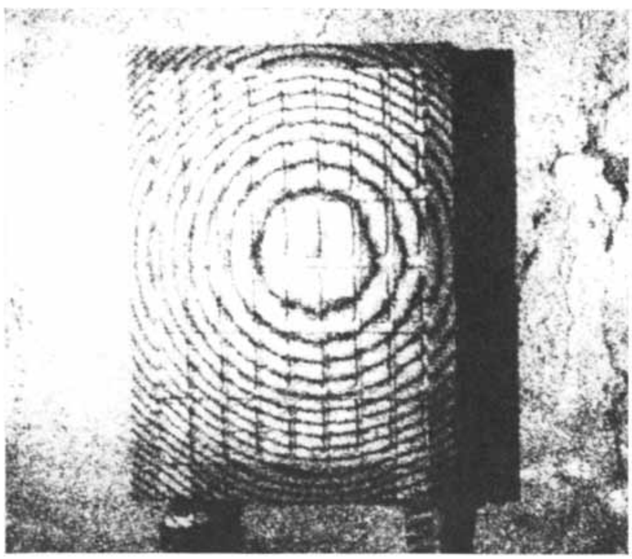
RECONSTRUCTION STAGE of the simple holographic process begun at top is shown here. The hologram is illuminated by the reference beam alone, producing replicas of the wave fronts reflected from the original object, even though the object may long since have been removed. The reconstructed wave fronts can be observed either visually or with a camera.

Let us consider, for example, a rerun on the reconstruction of a subject's image from a hologram. If the hologram and the subject are returned to precisely the same relative positions they had occupied during the original exposure, and both are again illuminated by the same direct and reference beams as before, we will observe the wave front from the subject superposed on the reconstructed wave front from the hologram. These two wave fronts are coherent and could interfere. If any change has taken place in the phase distribution of the light from the subject, there will be light and dark interference fringes that indicate the degree to which the phase of the light distribution has changed. This change will measure precisely any alteration that has taken place in the subject or in the density of the medium through which the beams have passed. Like other kinds of interferometry, the technique readily detects changes that produce optical-path differences of the order of a fraction of the wavelength of light. Unlike other kinds of interferometry, however, the technique makes it possible to perform experiments quite readily with almost any type of material.





DOUBLE-EXPOSED HOLOGRAM of a bullet in flight (*left*) was made by a method called time-lapse interferometry. A pulsed ruby laser was used to record two high-speed exposures, the first with the bullet absent and the second with the bullet present. The resulting hologram (which actually consists of two superposed holograms) was then illuminated to reconstruct both the original and the changed wave fronts simultaneously. The interference of these respective wave fronts produced the image of the shock wave and the turbulence in the wake of the bullet. A singly exposed hologram of an identical bullet in flight is shown at right for contrast. Very little structure is visible in the shock wave and the wake is no longer discernible. Both bullets were traveling at a velocity of approximately 3,500 feet per second. The holograms were made by R. E. Brooks, L. O. Heflinger and R. F. Wuerker of TRW Inc.



TWO OTHER EXAMPLES of double-exposed holograms made by the time-lapse interferometric technique are shown here. At left is a photograph of the reconstructed image of a fruit fly in flight, also made by the group at TRW Inc. A pulsed ruby laser was again used for the two exposures, the first with the fruit fly present and the second with it absent. The vertical streaks are part of the compressional wave produced by the beating of the fly's wings. At right is the reconstructed image of a bismuth-telluride thermoelectric device. The exposures were made with and without current passing through the device. The "bow type" distortion characterized by the circular interference fringes arises from the temperature gradient set up between the front and back surfaces when a current is applied. This work was performed by the author with R. A. Wolfe, R. J. Collier and E. T. Doherty of the Bell Telephone Laboratories.

The importance of this feature is more easily appreciated if one considers the degree of difficulty involved in studying any everyday object with the previously existing interferometric techniques. The surfaces of the subject are normally rough in terms of wavelengths of light, and there are often hundreds of such surface details per square millimeter of surface area. Consequently the interference between a wave front from such a subject and a simple plane wave would be extremely complex. We have all these interference fringes to observe even before we have deformed the object in some way. Deformation of the subject would likewise produce a highly complex interference pattern. The use of normal interferometric techniques has therefore left us with the difficult task of comparing and analyzing two extremely complex interference patterns.

The hologram, on the other hand, records all the information contained in the wave front of the subject even down to the smallest surface details. The interference between the reconstructed wave front from the hologram and the wave front from the deformed subject will show an overall interference pattern that reflects the manner in which the subject has changed as a whole. In short, the technique of holographic interferometry extracts the relevant information from a mass of spurious information and displays any changes in a readily observable way. By the same token, a holographic picture is not confused by minor flaws in the window or any other optical medium through which the subject is observed, as long as the flaws do not change.

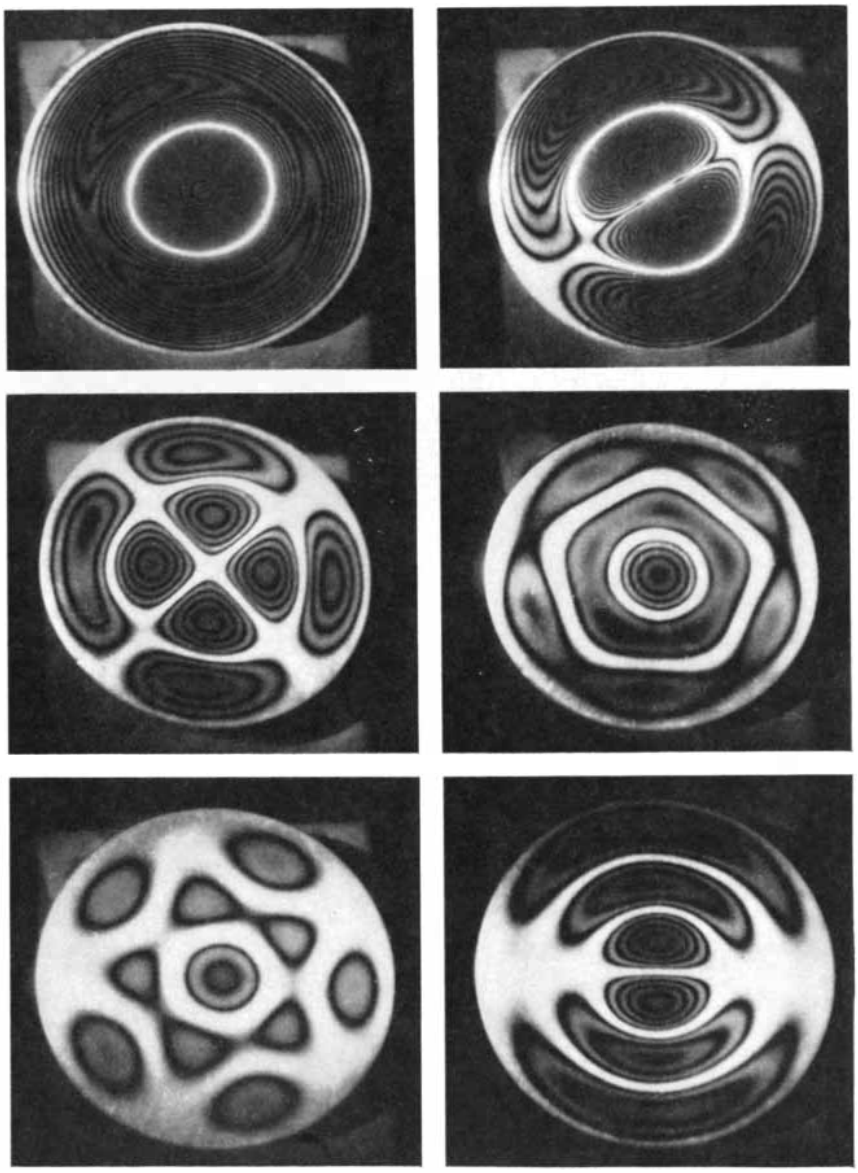
This ability of holography to deal with complex subjects makes it feasible to conduct interferometric experiments on a great variety of materials and phenomena, such as concrete, rock specimens, metal objects, electronic components, flow lines and shock waves in wind tunnels, and so on. It should even be possible to follow the course of chemical reactions and diffusion.

Three techniques for employing holography in interferometric studies have been explored. They are called real-time interferometry, time-lapse interferometry and time-averaged interferometry. I have already described the method used for studies in real time; it allows us to observe changes in a subject as they occur.

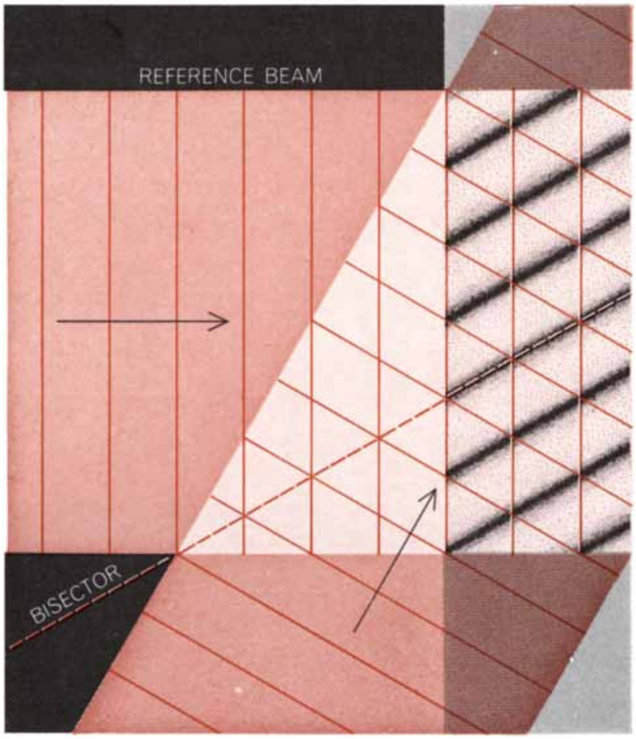
The time-lapse technique records the situation before and after a change has taken place. Both views of the subject are recorded in the same hologram. The hologram is a double exposure, with the second pattern of wave fronts superposed on the first; it reconstructs both wave fronts simultaneously. These wave fronts interfere and in doing so exhibit the changes that have occurred in the subject between the first and the second exposure.

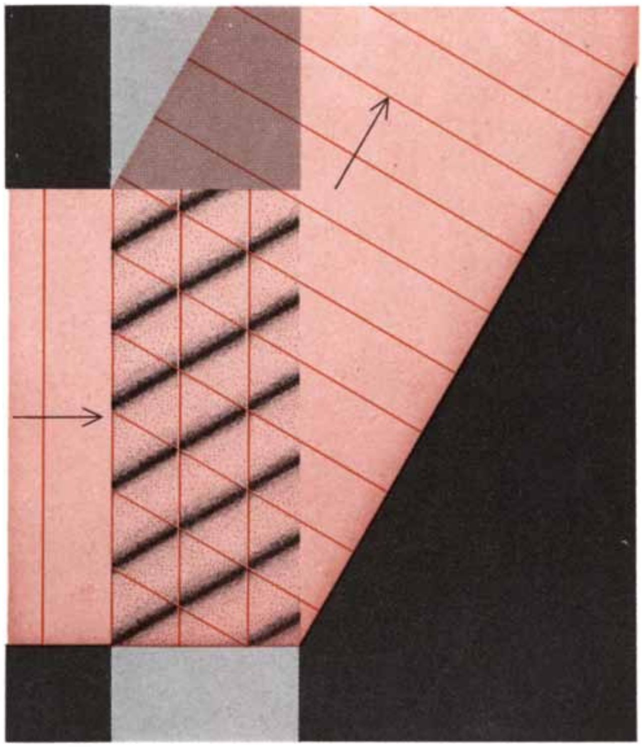
Robert E. Brooks, Lee O. Heflinger and Ralph F. Wuerker of the TRW Systems Group have made several spectacular time-lapse holograms of subjects in very rapid motion. Using ruby lasers that emitted extremely brief pulses of light to freeze the motion, they obtained detailed pictures of the shock waves and the wake from a bullet in flight [*see upper illustration on opposite page*]; they also photographed the compressional wave produced by a fruit fly beating its wings [*see illustration at lower left on opposite page*]. With time-lapse holography a group of us then working at the Bell Telephone Laboratories were able to picture the slight distortion that took place in a thermoelectric device as a result of temperature gradients that were set up when a current was applied [*see illustration at lower right on opposite page*].

The third area, time-averaged interferometry, was actually the first of the



"TIME-AVERAGED" HOLOGRAMS of the vibrating bottom of a 35-millimeter film-can record the interference patterns associated with the modes of vibration of the can at six different resonant frequencies. The amplitude of each vibration can be measured by counting the number of fringes. The difference in amplitude in going from one bright fringe to the next bright fringe is approximately a half-wavelength of the light used to expose the hologram. The holograms were made by R. L. Powell and K. A. Stetson, then at Michigan.





IN A VOLUME HOLOGRAM the fine details of the interference pattern are much smaller than the thickness of the photographic emulsion and hence are recorded throughout the depth of the emulsion. This makes it possible to record several colors as variations in the opacity of the emulsion throughout the depth. In the diagram at left two plane waves are shown interfering at a large angle in a silver-halide emulsion. The resulting hologram consists of a sinusoidal distribution of silver grains deposited in planes throughout the emulsion. The interference maxima lie along the bisector of the angle between the interfering beams. Reconstruction is accomplished by Bragg reflection from the interference planes (*right*). The volume hologram is illuminated with a plane wave that strikes the hologram at the same angle as the original reference beam did. At those wavelengths that satisfy the Bragg-reflection condition the waves reflected from successive planes are in phase and give rise to a replica of the other original plane wave.

three techniques to be demonstrated. This technique, which was reported by Robert L. Powell and Karl A. Stetson while they were at Michigan, is based on the use of long exposures to record an object's motion. It is used primarily to study a subject in rapid vibration. The technique is analogous to a time exposure of a swinging pendulum in ordinary photography. Whereas a long time exposure of a speeding car results in a photograph that is little more than a smear, a similar exposure of a pendulum produces recognizable images of the pendulum at the two ends of its swing. The reason, of course, is that the pendulum spends more time there than at any other point in the swing, so that the record in the photographic emulsion is densest at those two positions. Similarly, a hologram made with a long exposure (long in relation to the subject's oscillation period) will record wave fronts most densely at the two extreme positions of the subject's vibratory motion. It is natural to expect that the reconstructed wave front from a time-averaged hologram should approximate a double-exposed hologram in which the subject is recorded at the two extreme positions of its vibrating motion. The interference pattern would then provide a precise measure of the amplitude of vibration of the subject. It should be added that whereas the rigorous analysis of the subject is somewhat more complex, the general conclusions are similar. This technique, although not widely applicable, is highly useful for detecting and examining extremely rapid, short-amplitude vibrations [*see illustration on preceding page*].

In the applications I have discussed so far the hologram, or interference pattern, recorded in the photographic emulsion is essentially two-dimensional. Under certain conditions, however, the finest details of the interference pattern can be made so small that they have dimensions close to the wavelength of the light. In most cases this is far smaller than the thickness of the photographic recording medium. The recorded interference pattern must then be considered to possess depth, since the fringes are recorded throughout the thickness of the recording medium. We thus have a "volume hologram" that is in effect a three-dimensional diffraction grating. Such a hologram will diffract light in much the same way that a crystal diffracts X rays. This property introduces new possibilities in the technique and applications of holography.

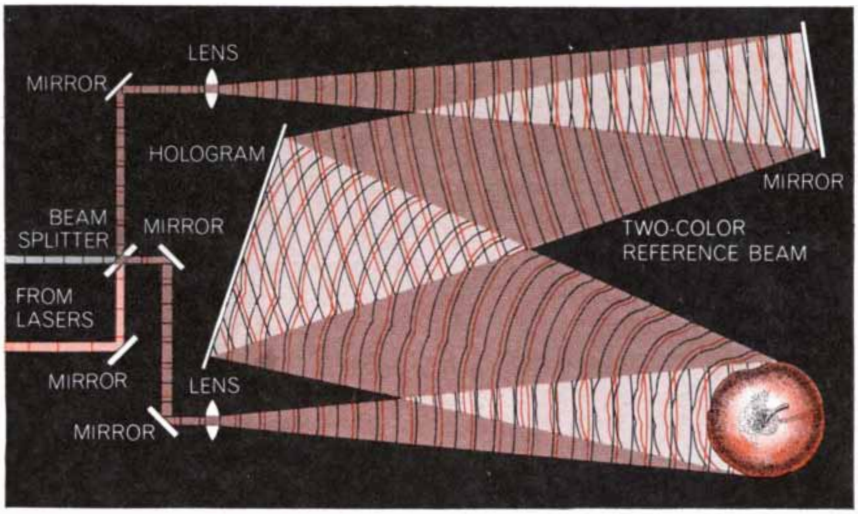
A volume hologram can be produced by directing the reference beam to the photographic plate from a direction such that the angle between the reference beam and the rays of light from the subject is fairly large [*see illustration above*]. The interference pattern will then have details smaller than the thickness of the photographic emulsion. As long as the emulsion has sufficient resolving capabilities, it will record these details throughout its entire thickness. As was indicated earlier, the resulting hologram diffracts light in the same way that a crystal diffracts X rays. As a result we can apply the classic Bragg reflection equations (derived from X-ray crystallography) to predict the nature of the wave front that will be reconstructed when we illuminate such a hologram.

The Bragg-reflection condition places restrictions on the reconstructed wave front. Unlike two-dimensional holograms, which will diffract all colors regardless of the angle of the incident illumination, volume holograms are both angle-selective and color-selective. When illuminated at a particular angle, volume holograms reconstruct in a particular color. By the same token, to reconstruct a volume hologram with a particular color beam it is necessary to illuminate the hologram at a particular angle. It is this relation between the angle of illumination and the wavelength of the illuminating source that is determined by the Bragg-reflection condition.

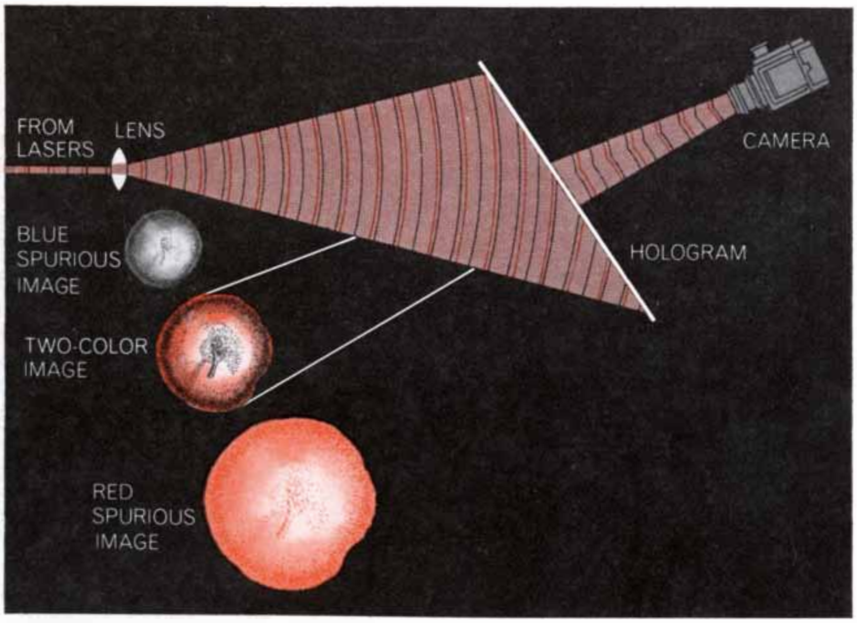
This can be illustrated by considering the simplest form of a volume hologram, which consists of a set of periodic planes of silver deposited in the photographic emulsion. Such a hologram could be formed by allowing two plane wave fronts to interfere at large angles in the photographic emulsion. If this volume hologram is illuminated by a beam containing a mixture of wave fronts (for example white light), a small fraction of the light will be "reflected" from each of the silver planes. At those wavelengths that satisfy the Bragg condition, however, the waves reflected from successive planes are in phase and give rise to a large diffracted amplitude. At other wavelengths the waves are not reflected in phase and therefore do not contribute appreciably to the total diffracted wave front.

The thicker the volume hologram, the narrower the spectral band of light that is diffracted at a given angle of illumination, that is, the more selective the hologram will be with respect to wavelength, or color. Hence a volume hologram of adequate thickness will select a narrow band of wavelengths from the beam of mixed light and yield a good reconstruction of the original recorded wave front. This situation differs considerably from the case of the two-dimensional hologram. As I have pointed out, such holograms will diffract all the wavelengths present in the illuminating source. The total diffracted wave front will give rise to a superposition of reconstructions at all wavelengths. Since the different wavelengths are diffracted at different angles, the resulting reconstruction will be an unrecognizable "rainbow" smear. This can be avoided and a good reconstruction obtained simply by passing the white light through a color filter. A volume hologram in effect performs this function of color-filtering internally.

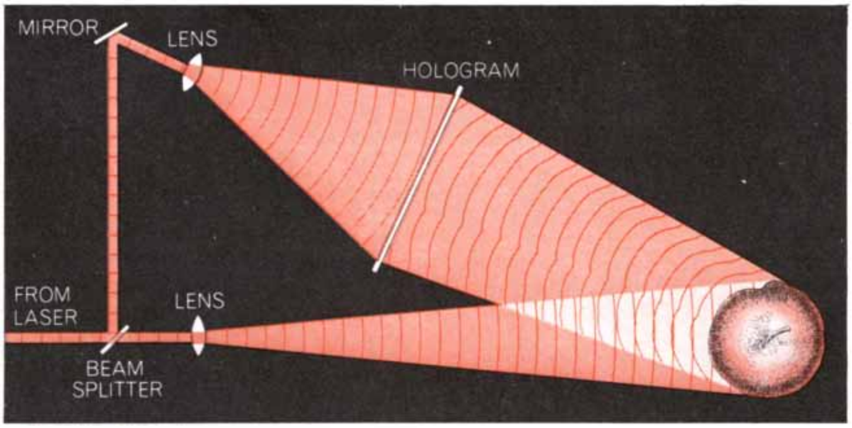
L. H. Lin of Bell Laboratories and I were able to use these principles to form volume holograms in two colors that yielded a clear image of the subject. We used a beam containing blue light from an argon laser and red light from a helium-neon laser. The light from the subject and the reference beam made an angle of approximately 90 degrees with each other at the photographic plate [*see upper illustration below*]. The emulsion in effect contained two holograms superposed on each other, one made by interference in red, the other by interference in blue. If the hologram had been made in a single plane, the reconstructed picture would have contained three images: a correct image combining red and blue, a spurious image in red and a spurious image in blue [*see lower illus-*



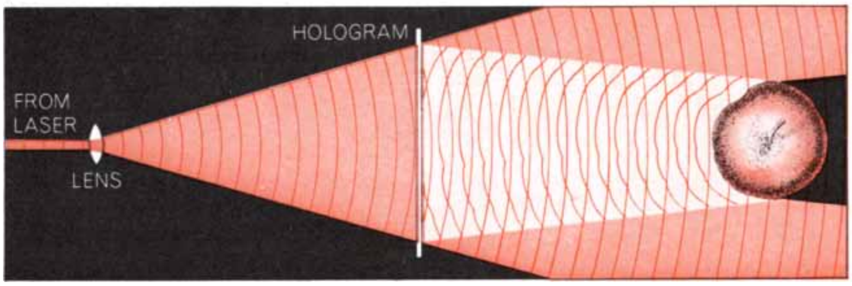
SIMPLE ARRANGEMENT for making multicolor volume holograms is represented in this schematic drawing. The subject is illuminated with a beam of light containing a blue component from an argon-ion laser and a red component from a helium-neon laser. The diffracted light from the subject is then allowed to interfere with a mixed reference beam derived from these two lasers. The large angle between the diffracted beam and the reference beam ensures that the smallest detail of the interference pattern is far smaller than the thickness of the photographic emulsion. The resulting hologram is actually a superposition of two holograms, one made by interference in red and the other by interference in blue.



SPURIOUS IMAGES are generated in the reconstruction of a multicolor hologram when the photographic emulsion is insufficiently thick, as in the case of the so-called planar hologram shown here. The spurious blue image in this case is caused by the diffraction of blue light by the red part of the hologram, and the spurious red image is caused by the diffraction of red light by the blue part of the hologram. For an original n-color hologram the reconstruction would consist of one image with the correct color mix and $n(n-1)$ spurious images. The spurious images are eliminated by making the hologram sufficiently thick.



WHITE-LIGHT-RECONSTRUCTING HOLOGRAMS differ from other volume holograms in that the reference and subject beams are introduced from opposite sides of the photographic plate. The interference pattern recorded in the emulsion in this case will take the form of a series of planes almost parallel to the surface of the emulsion. Reconstruction of such holograms will again take place by Bragg reflection from the developed silver planes in the emulsion. However, because of the large angle at which the reconstructing beam will be reflected from the silver planes, interference will occur between waves that are backscattered by the planes. As a consequence the resulting hologram will diffract a fairly narrow band of wavelengths when illuminated by a small white-light source.



FIRST VOLUME HOLOGRAMS were made in 1962 by Yu. N. Denisyuk of the U.S.S.R., using an optical arrangement in which the light reflected from the subject interferes with the light traveling toward the subject. The resulting interference pattern is then recorded in the photographic emulsion. Although his technique was adequate to form volume holograms of simple subjects, the absence of a separate reference beam limited its applicability.

tration on preceding page]. This relation would hold for a two-dimensional hologram in any number of colors; such a hologram in n colors would yield $n(n-1)$ spurious images. Because of the Bragg-reflection condition our volume holograms eliminated spurious images. These early volume holograms could not reconstruct a clear image with white-light illumination. The emulsion we used was not thick enough to provide sufficient color selectivity at the angles of beam intersection we employed.

Experimenters at Michigan have also reported successful efforts in volume holography. A. A. Friesem extended the techniques of multicolor holography to compose a volume hologram in three colors: red, blue, and green [*see bottom illustration on page 41*]. He also successfully used volume holograms to suppress the conjugate real image that appears in normal monocolor planar holograms. Leith and his co-workers have produced a sequence of volume holograms with the recording photographic plate set at different angles, so that when the plate was later rotated in the reference beam, the series of reconstructed pictures made an animated movie.

As work on volume holograms proceeded, Stroke and A. E. Labeyrie at Michigan, Charles M. Schwartz at the Battelle Memorial Institute and Leith and his colleagues at Michigan reported success in producing holograms from which good images could be reconstructed with white light. They achieved this not by increasing the thickness of the photographic emulsion but by enlarging the angle between the reference and subject beams. The beams were directed at the photographic plate from opposite sides, forming an interference pattern whose planes were nearly parallel to the surface of the emulsion [*see upper illustration at left*]. Reconstruction of these holograms again takes place by Bragg reflection. Under these conditions, however, the holograms diffract a fairly narrow band of wavelengths when illuminated with a small white-light source. The subsequent development of this technique has led to formation of white-light volume holograms that reconstruct in several colors. Stroke and Burke have also used white-light holography to photograph specimens of biological tissue and have been able to produce high-resolution images over a wide field of view.

Historically the recording of interference patterns throughout the volume of a photosensitive material is a very old subject. As early as 1891 the eminent French physicist Gabriel Lippmann discovered a way to store information throughout the volume of a photographic emulsion. By recording standing waves in an emulsion (produced by a beam of light reflected back on itself), he was able to develop an early form of color photography. This technique, although interesting, proved to be impractical and for many years remained merely a scientific curiosity. In 1962 Yu. N. Denisyuk of the U.S.S.R. combined the Lippmann technique of recording standing waves with the original techniques of holography to make volume holograms [*see lower illustration at left*]. With this technique he was able to record holograms of fairly simple subjects. Denisyuk's technique, like the original holographic technique, had several disadvantages; it was the advent of the separate reference beam that indicated the way to a more general applicability of volume holograms.

Holography has been the scene of considerable activity in the past few years. It is perhaps needless to say that the activity has not been confined to the limited areas discussed in this article. Considerable effort has been expended in the area of data-processing and related subjects. These areas are exceedingly interesting in themselves and may yet prove to be the pot of gold at the end of the holography rainbow. Except for a few isolated cases, however, these areas of holography are also the ones that are presenting the most severe problems. In the meantime there are many areas in which holography could be exploited to great advantage by an investment in the necessary adaptation or further development of the techniques already available.

Kodak

In hope of doing each other some good

Seth's shield

Seth C. Hilton, Jr. of Nashville, Tenn., a purchaser of plastic sheet extruded from our TENITE Butyrate, wears on his right arm a shield which he has fashioned from this tough, highly transparent material. For two ten-hour periods each week, the shield comes off while the two indwelling shunts in his forearm are in use. They serve to attach him to a hemodialysis machine, for Mr. Hilton has no functioning kidneys of his own. The shield protects the shunts from hazards unknown to those who go about their work with flesh unpunctured by hardware. The shield takes a nasty rap now and then around the shop, and it resists crazing that would cut down the transparency which allows Hilton to keep an eye out for dangerous blood clots.

We know about Mr. Hilton because he buys the butyrate sheet from an extruder in quantities to meet his production needs as a manufacturer. Fortunately from his viewpoint as a businessman, unfortunately from his viewpoint as a sympathetic human being, and comfortingly from his viewpoint as a patient, there are many other forearms fitted with indwelling arterial-venous shunts. Marketing problems—bane of the small and ingenious producer, flaw in Mr. Emerson's better-mousetrap theory—do not trouble Mr. Hilton. His output is marketed by a company in the rapidly growing business of devices like heart valves, brain implants, and other mechanical aids against grave physical impairment.

1. That company is Extracorporeal Medical Specialties, Inc., Mount Laurel Township, N. J. 08057. It invites correspondence from the medical profession. The firm attempts to serve as a source of information on renal dialysis.

2. A newly updated collection of data on the properties that combine to keep TENITE *Butyrate plastic in the fore is available from Eastman Chemical Products, Inc., Kingsport, Tenn. 37662 (Subsidiary of Eastman Kodak Company). Ask for Materials Bulletin 33.*

Progress through photopolymerization

New applications of photopolymerization phenomena stir the pot in the electrical-electronic manufacturing industry's effort to meet public demand for cleverer frying pans and faster weather-forecasting computers. We have news both for those whose circuits have to handle a little power and for those who have no power-dissipation problems to bar the way into large-scale integration ("LSI") on silicon chips.

1. The world-wide physical volume of printed-circuit production for appliances, communication, entertainment, instrumentation now justifies a type of photo resist which better fits the roller-coating production machinery that has turned electrical manufacturers into printers. The new stuff, to be known as KODAK Photo Resist, Type 4 (KPR-4), combines the proper viscosity, solvent system, and solids content with the unexciting but terribly important factor of Kodak product predictability. Predictability reduces costs, which tend to remain higher than they could be as long as the daughters of the ladies who used to do the wiring sit in similar long rows touching out pinholes in printed circuits and picking out nodules of metal where electroplating solution has found its way through chinks in a resist coating.

2. One month a few people want to understand a concept like LSI, and three months later the term is heard from every table in the steak house. Identifiable circuit components fade dimmer into the complexities of the chip's architecture. The number of circuit functions on the chip rises by a power or two of ten, while the tolerance on placement and width of the elements of the pattern moves on down toward the wavelength of light itself. Creation of the original "artwork" for optical reduction to masks is getting to be a little too much to ask of the human hand and mind. Interconnections in the pattern, we are further told, will have to be determined by testing each separate chip—such is the combined-reliability problem. Presumably the proper image will be generated and somehow imposed on a resist of sufficient resolution. To have a good one ready will be our part. For the present we wish to advise that if the new KODAK Photosensitive Metal-Clad Plate is flooded with nitrogen gas during the exposure, the 0.6µ photopolymer layer over the chrome acquires what might be considered projection speed, given a strong source.

Those who want details on this or on KPR-4 can get them from Eastman Kodak Company, Industrial Photo Methods, Rochester, N.Y. 14650.

False color for the serious worker

The frankly false colors in which EKTACHROME Infrared AERO Film, Type 8443, depicts the face of the land are now widely recognized to help significantly in the hunt for truth. Whether the truth be sufficient unto itself (as in investigating possible Viking contacts with the peoples of the Missouri River Valley in the 14th century) or is being pursued by such unromantic types as plant pathologists, the daily flow of discourse about this product in our mail and in the literature of several scientific disciplines induces within us a warm glow. To have had impact on science while directly, if moderately, benefiting the shareowners feels good. The euphoria is further enhanced by the technical depth of the product and the depths still to be plumbed in making it work better.

We supply this film both in the spoolings required by various aerial cameras* and in 20-exposure 135 cassettes† for processing with a KODAK EKTACHROME Film Processing Kit, Process E-3.†

The 710-910mµ band will come out in red tones, and so will live foliage, because of its high infrared reflectance. Without such an overload of infrared, the band of the visible spectrum seen as green by the eye comes out blue on the film. The red of the spectrum comes out green. The true blue and ultraviolet of nature had better be cut out with a KODAK WRATTEN Filter No. 12 in front of the camera lens.

There will also be some other filters brought into play by a user prepared to go to some lengths to wring out maximum amplification of his color sensitivity for the sake of his particular brand of objective truth about the world beneath his feet. Norman L. Fritz of the Kodak Research Laboratories gives details on the selection of these filters in a paper in Photogrammetric Engineering *for October, 1967. Fourteen pages further on in that journal is a paper on this film in photoarcheology.*

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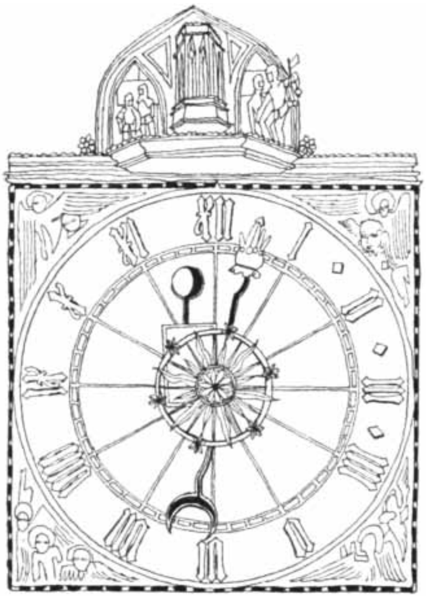
*For information on ordering and processing, write Eastman Kodak Company, Industrial Photo Methods Division, Rochester, N.Y. 14650.

†Stocked by some Kodak dealers serving scientific clientele. Can be ordered for you by almost any camera shop.



SCIENCE AND

The Attacker's Advantage

Unless the present Administration, or a new one, reverses the decision announced in September by Secretary of Defense Robert S. McNamara, the U.S. is committed to building a "light" anti-ballistic-missile system, ostensibly to defend against the limited ballistic-missile capability that China will possess in the 1970's. During the December meeting of the American Association for the Advancement of Science, Hans A. Bethe of Cornell University, who had just received the Nobel prize in physics for 1967, explained his opposition to the proposed ABM system.

His basic premise is that the multiple stratagems available to an attacker can make it almost impossible for the defender to design an adequate ABM defense. He explained, by way of background, that defensive missiles with thermonuclear warheads can attack incoming reentry vehicles (RV's) in three general ways: with neutrons, X rays and blast, all products of a thermonuclear explosion. The neutrons can penetrate the warheads of incoming vehicles and cause their fissile material to fission, with the release of enough heat to destroy the firing mechanism. X rays can cause the surface layer of the RV's heat shield to evaporate, thereby making it impossible for the vehicle to pass safely through the atmosphere. Within the atmosphere blast can throw an RV off course and possibly damage it internally. The attacker, of course, will try to design his weapons to withstand these three sources of potential damage.

Above and beyond this, however, the attacker can employ a wide variety of "penetration aids" to interfere with the operation of the defender's ABM system. One general scheme is to confuse the radar and computers of the ABM system by concealing the actual RV's in a mass of objects that superficially resemble RV's. These objects can be fragments of the launching vehicle or deliberately designed decoys. The latter might be nothing more than balloons with an internal wire mesh to reflect radar waves. As long as they are outside the atmosphere, balloons will travel as fast on ballistic trajectories as heavy metallic objects. Although the defensive system can wait for the atmosphere to sort out RV's from balloon decoys, the time for interception is then much shortened. Moreover, complex decoys can be designed to reenter the atmosphere in a manner that makes them not easily distinguishable from RV's.

A second general stratagem that is open to the attacker is to directly nullify the effectiveness of the defender's radar system. This can be done, for example, by dispersing a myriad of tiny wires ("chaff") that can reflect radar signals over such a large part of the sky that the RV's cannot be picked out. Another technique would be to design some decoys to generate radio noise in the frequency range of the defender's radar. The radar can also be neutralized by blackouts resulting from the huge clouds of electrons released by nuclear explosions above the upper atmosphere. In fact, the defender must contend with the blackouts caused by his own defensive weapons. Another type of blackout is produced by the fireball when a nuclear device is exploded within the upper atmosphere. Such fireballs could black out large areas of the radar sky for more than 15 minutes.

Weighing the cost and practicality of such penetration aids, Bethe concludes that the overwhelming advantage lies with the designer of offensive weapon systems. The defender's best hope is to develop "terminal" systems—systems that work as close to the defender's cities and military installations as possible. To protect large sections of the country, however, such systems would be exceedingly costly (on the order of $50 billion) and would, in Bethe's opinion, almost surely upset the precarious strategic balance

THE CITIZEN

that now exists between the U.S. and the U.S.S.R.

Meaningful Message

"It's the best example I know of someone who set himself a remote and difficult goal and finally reached it." Thus did one molecular biologist describe Arthur Kornberg's recent success in synthesizing biologically active molecules of deoxyribonucleic acid. The DNA molecules made at the Stanford University School of Medicine by Kornberg and his co-worker Mehran Goulian climax nearly 11 years of single-minded effort. The DNA re-created in the test tube is the genetic core of the bacterial virus designated ϕX174. This virus normally perpetuates itself by replicating its core and its protein jacket inside a cell of *Escherichia coli,* a common bacterium found in sewage. The DNA of ϕX174 is unusual in being a single molecular strand rather than a double-strand helix. Moreover, the single strand is in the form of a ring. The ring is built up of some 5,500 nucleotides, the structural subunits whose sequence specifies the information needed for the synthesis of proteins. The 5,500 nucleotides in the DNA of ϕX174 represent five or six genes, enough to specify as many proteins.

In 1959 Kornberg shared the Nobel prize in physiology and medicine for discovering an enzyme that will cause a mixture of synthetic nucleotides to assemble into DNA-like molecules when it is placed in a test tube together with an energy source and a sample of natural DNA to act as a template. For various reasons, however, Kornberg's synthetic copies of DNA failed to display the biological activity of the original molecule.

Kornberg's present success depended on a number of developments. First, he succeeded in removing contaminating enzymes that had degraded chains of newly formed DNA. Second, he selected the single-strand DNA of ϕX174 to serve as a template. Robert L. Sinsheimer of the California Institute of Technology, who had characterized the DNA of ϕX174, participated in the experiment by running assays on Kornberg's synthetic material. Third, Kornberg was able to employ a new polynucleotide-joining enzyme to link the two ends of the synthetic molecule into a ring. The new enzyme, called DNA ligase, was first reported in January, 1967, by Martin Gellert of the National Institutes of Health. It was discovered independently by four other research groups: two at Stanford, one at Harvard and one at the Albert Einstein College of Medicine in New York.

In the Kornberg-Goulian experiments the original DNA template was denoted the (+) strand. Synthetic strands, in which each nucleotide in the molecule is complementary to one in the original, were called (−) strands. When the (−) strands were gently separated from the (+) strands, they proved able to infect cells and produce complete virus particles. Kornberg and Goulian then used the synthetic (−) strands as templates for making synthetic (+) strands, and these too proved potent. The various strands were identified by the use of radioactive labels. The experiments are described in *Proceedings of the National Academy of Sciences.*

Kornberg believes the way is now open to copying the DNA of other viruses and ultimately the much longer DNA of cells. In such experiments it should be possible to insert alternative building blocks to create new forms of DNA and to test their effect.

The Glass Switch

The electronic properties of semiconducting crystals are now well understood and have given rise to a prodigious family of solid-state electronic devices. The electronic properties of amorphous materials, notably certain glasses, are still not well understood but have already led to a few devices with unusual characteristics.

In a recent issue of *Science* Jan Tauc of the Czechoslovak Academy of Sciences describes how electronic theories developed for crystals have proved inadequate to explain the electronic properties of amorphous materials. A considerable effort to devise adequate theories for these materials is being made in Czechoslovakia and in the U.S.S.R.

Interest in such theories has been stimulated largely by the appearance on the market of two electronic devices employing the semiconducting properties of amorphous materials. They are the "Ovonic" threshold switch and the "Ovonic" memory switch invented by Stanford R. Ovshinsky of Energy Conversion Devices, Inc. Both switches employ thin films of chalcogenide glasses, the name given to glasses containing elements from group VI of the periodic table: oxygen, sulfur, selenium and tellurium.

The threshold switch consists of a thin film of chalcogenide semiconducting glass between two conductive electrodes. Below a certain threshold voltage the glass exhibits exceedingly high resistance (as high as 5×10^8 ohms); when the voltage is raised above threshold, the glass becomes an excellent conductor. The switching time can be less than 150 picoseconds (150×10^{-12} second). The Ovonic memory switch differs from the threshold switch in one important respect: the latter returns to its resistant state as soon as the current falls below threshold, whereas the memory switch can be kept in either a conducting or a resistant condition indefinitely. The two devices can be made with threshold voltages from several volts to many hundreds of volts. Unlike conventional solid-state devices that operate only with direct current, the new amorphous devices are inherently symmetrical and thus can be employed in alternating-current circuits. Other advantages are simplicity of manufacture and low cost.

At present the amorphous switches have found use in a limited number of civilian applications and are being intensively studied by the military. One promising potential use is to provide an economic way to switch hundreds or thousands of individual electroluminescent elements in visual displays.

3-D Brain Cells

The ability to see things in three dimensions evidently exists because objects at different distances from the eye excite different neurons in the brain. This conclusion is reached by H. B. Barlow and two of his colleagues at the University of California at Berkeley in a study that recorded how 87 separate "neuron units" in the primary visual cortex of the cat brain were triggered by various visual stimuli. Reporting in *The Journal of Physiology,* Barlow and C. Blakemore of Berkeley and J. D. Pettigrew of the University of Sydney note that depth perception involves two processes. It is necessary not only to sense which among many pairs of images in the two eyes are recording the same single object but also to sense the pair's different location on each retina due to binocular parallax. The retinal displacement is the key clue to the object's distance from the viewer. Both requirements could be satisfied at once, Barlow and his co-workers state, if individual neurons receiving inputs from both eyes responded to only a few out of the large number of visual stimuli and of these few only to the ones that fall within a small part of the whole spatial field under observation. Noting that a very large number of neurons would be needed to record all possible variations in shape as well as direction and distance from the eyes, they point to the fact that the neurons in the primary visual cortex outnumber the incoming optical nerve fibers many thousands of times.

The experimenters painstakingly immobilized their cats so that variations in response due to eye movement were eliminated, and projected bands of light on a screen in front of the animals. They found not only that neuron unit response to stimulation of both eyes was greater than response to stimulation of either eye alone but also that each retinal-image displacement, simulating a change in binocular parallax and hence in distance from the cat, produced maximum response from a different neuron unit.

Induced Interferon

An approach by which the potential of interferon as a defense against viruses may be more fully realized is described by Thomas C. Merigan of the Stanford University School of Medicine and William Regelson of the Medical College of Virginia. They report in *The New England Journal of Medicine* their finding that injections of certain synthetic polymers stimulate the production of interferon by the body. Merigan, discussing the situation in an editorial in *The American Journal of Medicine,* says that "nonviral inducers of interferon seem to have promise in protecting against viral infection."

Interferon is a protein that is normally produced by cells of the body when they are infected by a virus. When interferon takes effect, the virus fails to multiply in other cells and the viral infection is thus inhibited. The discovery of interferon 10 years ago led to the hope that it could be produced in quantity and then administered as a defense against viral infections. The hope has not been realized, because interferon from other animals does not function in human beings, and human interferon cannot yet be produced in clinically useful quantities. Nor can interferon be synthesized readily in the foreseeable future; it has a molecular weight of 30,000, compared with a weight of 6,000 for insulin, which has been synthesized only recently after intensive efforts.

Merigan and Regelson report that injections of synthetic anionic copolymers, particularly one named pyran, induced the manufacture of interferon in mice and in human patients with cancer who

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Each wheel moves up or down without affecting all the other wheels. So when one wheel hits a bump, only one gets bumped. The other 3 keep the car and you going in a level position.

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This matches the speeds of the engine and transmission to allow the gears to mesh easily. Which makes shifting a lot easier on you and your transmission.

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Our heater uses the same hot water that circulates in the engine. So our heater heats faster and produces a more even temperature than any air-type heater.

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Most economy cars have 13″ or less. Our larger wheel makes fewer revolutions to go the same distance. Which saves rubber. Which saves money.

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If you get a flat you don't have to unload the trunk and get everything dirty.

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We're not the biggest in this department, but neither are we the smallest. The smallest only has 2.3 cubic feet, which is about as much space as we have behind our back seat alone.

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That's pretty surprising considering the mileage we get.

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participated in a study conducted by several hospitals on the East Coast. The mice were protected for several weeks against a leukemia-producing virus and a virus resembling the agent of poliomyelitis. Antiviral activity was also evident in serum from the human patients.

Merigan writes that the structure required of a polymer that can stimulate the production of interferon "appears to be a saturated linear polymer" with a molecular weight of 17,000 or more and "with carboxylate groups on two of every four or five carbons in either alternate or adjacent positions." Other investigators have found that certain types of ribonucleic acid (RNA) can induce the production of interferon in animals. Pyran resembles RNA in some features of molecular structure, which is perhaps the reason that it stimulates the output of interferon.

Merigan points out that pyran has certain drawbacks because it is not easily broken down by the body and accumulates in the tissues at certain doses. It also can induce high fever. Merigan and Regelson emphasize that "much more extensive pharmacologic studies will have to be carried out" before any large-scale investigation of the interferon-producing effects of polymers on human beings will be possible.

Glassy Carbon

A new form of carbon that resembles glass is described in the *Journal of Materials Science* by F. C. Cowlard and J. C. Lewis of the Plessey Co. Ltd. in England. The "vitreous carbon" has high strength, hardness and resistance to corrosion. It also shows extreme chemical inertness, impermeability and nonporosity. The material has proved useful in several ways, including the manufacture of laboratory vessels and the encapsulation of nuclear fuel elements.

The two basic natural crystalline forms of carbon are diamond and graphite. They differ fundamentally in structure. Each carbon atom in the crystal lattice of diamond is joined by covalent links to four others surrounding it at the corners of a regular tetrahedron; the covalent bonding gives diamond its hardness, high density and high melting point. Graphite consists of carbon atoms arranged as hexagons in flat parallel sheets, which are held together by the much weaker van der Waals forces. Graphite is soft and flaky. Vitreous carbon, which is made by breaking down certain organic polymers with heat, apparently has a structure of hexagonal layers with some tetrahedral cross-links. The material can be shaped in the way plastics are shaped.

Cowlard and Lewis write that vitreous carbon "combines some of the properties of glass and silica with some of those of normal industrial carbons." They add: "It has significant advantages over silica and glass in its resistance to corrosion, and over other carbons in its impermeability and its resistance to both corrosion and erosion. It is more resistant to oxidation than other carbons and can be used safely in air at temperatures 100 to 200 degrees centigrade higher than graphite.... Vitreous carbon is intermediate between glasses and carbons in respect to both thermal and electrical conductivity and can be described as a conductive ceramic."

The Sound of Thunder

One might suppose that the rumbling that accompanies electrical storms was noise distributed randomly across the audible spectrum. Two groups of investigators have now shown that every thunderclap's dominant sound has a wavelength characteristic of the suddenly evacuated cylinder of air through which a lightning stroke has passed. Hoping to discover in what part of the sound spectrum most of the energy of thunder is concentrated, one group from Rice University and another from the New Mexico Institute of Mining and Technology used wide-frequency recording systems to monitor the sounds produced by 26 ground-to-cloud and cloud-to-cloud strokes of lightning. In a joint report in *Journal of Geophysical Research* the investigators note that the dominant energy peak in each recording fell in the frequency region around 200 cycles per second. This, they point out, is the frequency predicted by theory in the case of sound radiation from a cylindrical source with an energy input per unit length approximating that delivered by a lightning stroke.

Induced Anxiety

The first demonstration in medical history that a specific stimulus can predictably induce attacks of anxiety, including such physiological symptoms as heart palpitations, blurred vision, difficulty in breathing, dizziness and headache, has been achieved by two psychiatrists at the Washington University School of Medicine. The stimulus was the injection of enough sodium lactate to cause a tenfold increase in the normal level of lactic acid in the blood of 24 volunteers. The substance was chosen because people suffering from anxiety neurosis frequently show a rapid increase in blood lactic acid at the time of an attack. In the Washington University experiment all 14 neurotic volunteers and some of the 10 non-neurotics who comprised a control group suffered anxiety symptoms following the injections.

Ferris N. Pitts, Jr., and James N. McClure, Jr., report in *The New England Journal of Medicine* that the 24 volunteers received three injections at intervals of five to 10 days. Neither subjects nor controls knew in advance which injections contained sodium lactate and which contained either lactate with a calcium chloride inhibitor or a neutral saline solution. The experiment was "double-blind" because the physician who administered the 72 injections in random order was also ignorant of their identity. Two hours after the injection members of both groups responded to a 50-item symptom checklist in which 21 typical symptoms that may mark an anxiety attack were randomly distributed. They were also asked to report any aftereffects noted during the next 48 hours, although the blood lactic acid level in all 24 volunteers returned to normal 90 minutes after receipt of either lactate injection.

Analysis of the responses show that both subjects and controls rated the straight lactate injection the most troublesome, the saline injection innocuous or even "helpful," and the lactate-calcium mix in-between. Among the 14 neurotics the straight lactate brought on substantially more than half of the 21 symptoms, whereas the lactate-calcium mix produced only a quarter of the symptoms. As many as eight of the 21 symptoms were reported by half of the control group after receiving straight lactate and a lesser number after the lactate-calcium injection.

Pitts and McClure suggest that a normal individual under stress may encounter anxiety symptoms because of the intracellular production of lactate ions in response to an increased release of epinephrine (adrenalin) by the adrenal gland. They postulate that the lactate ions would produce a hypocalcemic condition by immobilizing ionized calcium in the interstitial fluid at the surface of excitable cell membranes. The chronically anxious, they assume, are particularly subject to the operation of this same biochemical mechanism because of consistent overproduction of epinephrine, central nervous system overactivity, some metabolic defect resulting in either excess lactate production or inadequate calcium production, or a combination of any of these factors.

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The driver is a scientist from our Esso Research laboratory. The man next to him is a Chrysler Corporation engineer. They are part of a new joint research effort aimed at finding ways to eliminate air pollution from automobiles.

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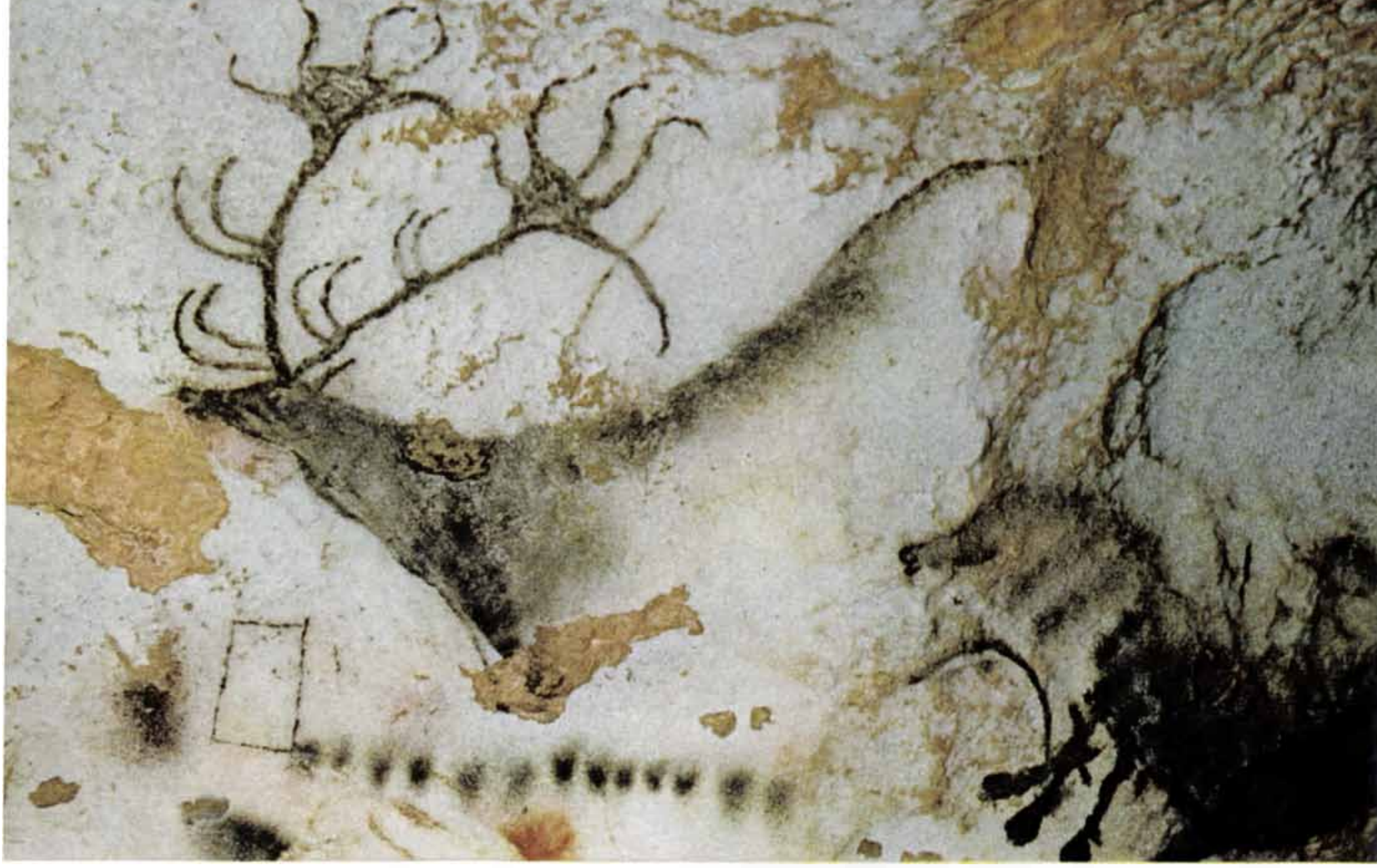
They are studying catalysts that can change pollutants into nonpollutants. They're working on better ways to get the air and fuel into the combustion chamber. And better lubricants to make all these things keep working better.

These are some of the ways Jersey and Chrysler are attacking one of today's many sources of air pollution.

It's not an easy job. But the solutions will be coming. And two heads are better than one.

Standard Oil Company (New Jersey)



RED DEER STAG (*above*) appears on a cave wall at Lascaux, a French Paleolithic site discovered in 1940. Both the stag and the two abstract signs below it, a rectangle and a row of dots, were painted on the rock surface with a manganese pigment; the stag is about five feet high. The painting was made some 15,000 years ago.

SPOTTED HORSE (*below*) dominates a cave wall at Pech-Merle, another French Paleolithic site. A hand seen in negative outline indicates the scale of the painting, which, like the stag, belongs to the early Magdalenian period of European prehistory. Abstract signs include many dots and a grill-like red rectangle by the hand.

The Evolution of Paleolithic Art

The first artistic tradition occupied two-thirds of the period spanned by the entire history of art. How it evolved is studied by the classification of its works in terms of time and space

by André Leroi-Gourhan

The earliest forms of art, at least among those art forms that can be dated with any certainty, were created in Europe between 30,000 and 10,000 B.C. They belong to a time before the oldest civilizations and the earliest agriculture—the Upper Paleolithic period at the end of the last continental glaciation. Paleolithic art has manifested itself in two principal forms: engraved or sculptured objects found by the thousands in excavations from the Urals to the Atlantic, and the awe-inspiring decorations of more than 100 caves in France and Spain. It has now been studied for nearly a century, and such caves as Lascaux and Altamira have become as well known as the most famous art works of historic times.

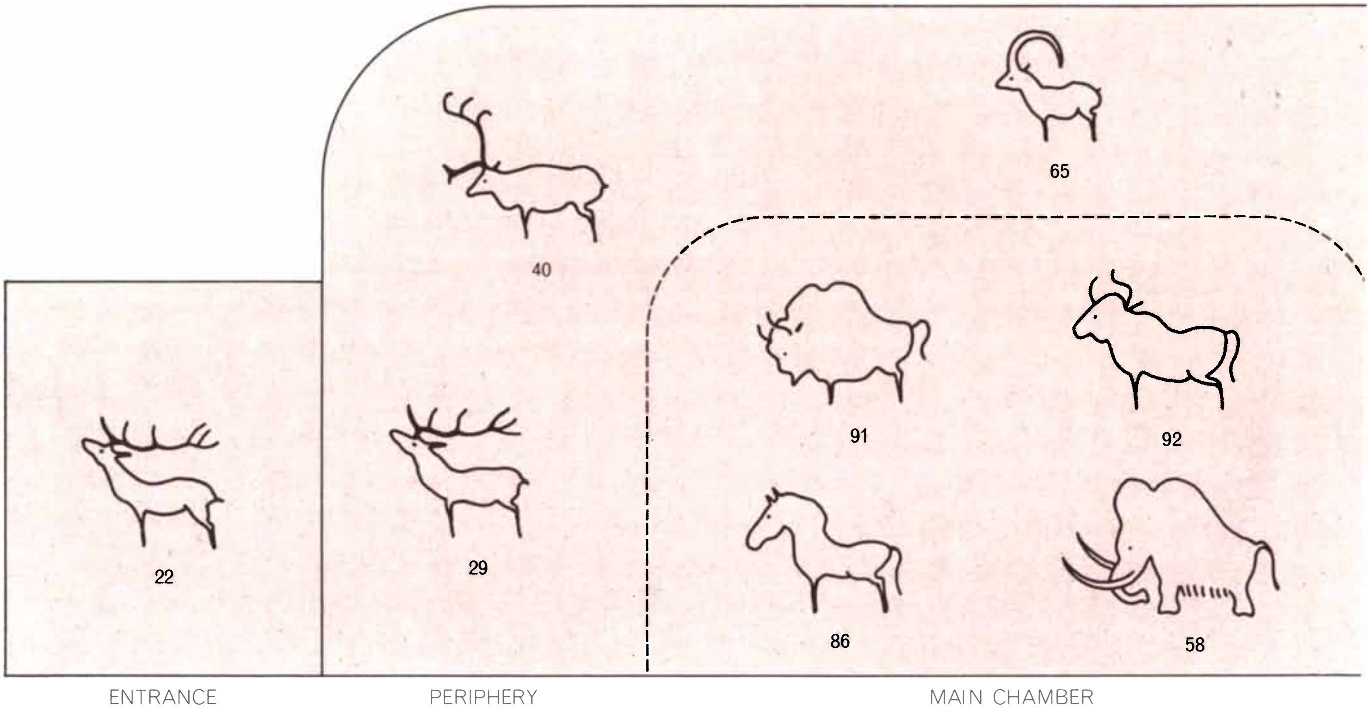
Until recently studies of Paleolithic art were focused largely on its aesthetic and magico-religious significance. Today attention has turned to the relations among such art forms—to their classification in terms of time and space. As a result we can now begin to perceive how Paleolithic art evolved from its appearance in Aurignacian times to its inexplicable disappearance in Magdalenian times 20,000 years later.

Can an art that embraced all Europe for such a mighty span truly be considered a single art? Should we perhaps speak of prehistoric arts, as we speak of the arts of Africa? The analogy provides the answer to our question: The living arts of Africa south of the Sahara, with all their nuances, are clearly subdivisions of one wholly African art. They cannot be confused with the art of any other region. In the same sense Paleolithic art also constitutes a single episode in art history. Such is the unanimous opinion of its students. This view is based on the continuity that Paleolithic art exhibits in region after region over a span of 20 millenniums. Greek art or Christian art is so identified because its images continuously translate its ideologies. In the same way the term "Paleolithic art" serves to relate various techniques of representation that have undergone changes over a long period of time to a body of figurative themes that has remained remarkably constant. Indeed, consistency is one of the first facts that strikes the student of Paleolithic art. In painting, engraving and sculpture on rock walls or in ivory, reindeer antler, bone and stone, and in the most diverse styles, Paleolithic artists repeatedly depict the same inventory of animals in comparable attitudes. Once this unity is recognized, it only remains for the student to seek ways of arranging the art's temporal and spatial subdivisions in a systematic manner.

The Problem of Chronology

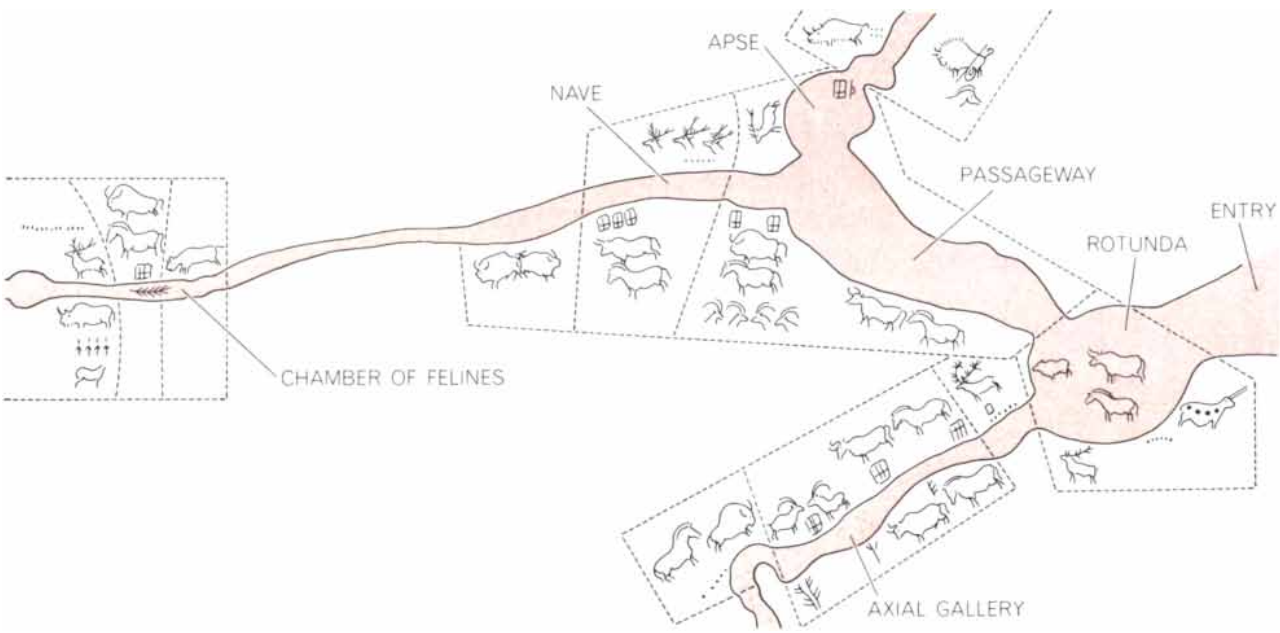
The task of temporal subdivision is by no means an easy one. To understand its difficulties, let us imagine an art historian who must arrange in their correct chronological order 1,000 statues belonging to every epoch from 500 B.C. to A.D. 1900. Imagine further that his only points of reference are five or six of the statues that are by chance correctly dated. The prehistorian's position is the same—or worse. The large majority of the Paleolithic period's small sculptures (which we classify as "portable art" to distinguish them from "wall art," the paintings, engravings and sculptures of the caves and rock-shelters) were discovered at the beginning of this century, a time when precision in the excavation of stratified sites was far from absolute. As a result there are very few instances in which associations are established between excavated works of art and implements such as scrapers and projectile points that have been firmly dated on the basis of stratigraphy. Even in the few cases where such dating is possible, the style of the object is not always so clear-cut as to allow strong conclusions. Finally, the thousands of wall paintings and engravings created during the period are not stratified at all. If the earth floors of their caves contain the remains of more than one Paleolithic culture, it is difficult to decide to which of these culture periods the art should be assigned. For all these reasons classifying Paleolithic art is a task considerably harder than the classification of prehistoric man's other material remains.

The work of the Abbé Breuil over more than half a century provides the principal source of traditional views concerning the evolution of Paleolithic art. This pioneer prehistorian undertook a prodigious labor of inventory and classification with the limited means available in his day. Except for a few instances in which specific dating was possible, his method of establishing the relative chronology of wall art rested on three assumptions. The first was simply that when two wall paintings are superimposed, the one underneath must be the older. The second, based on the probability that the caves where wall art is found were inhabited continuously for many centuries, was that one should find examples of work from many periods among the decorations. The third assumption was that, since the animal and human forms depicted in the caves were executed individually for magical purposes, there is no order in their arrangement. It follows from this last assumption that such works are not necessarily contemporaneous and that they are not, when taken together, evidence of any organized body of thought.

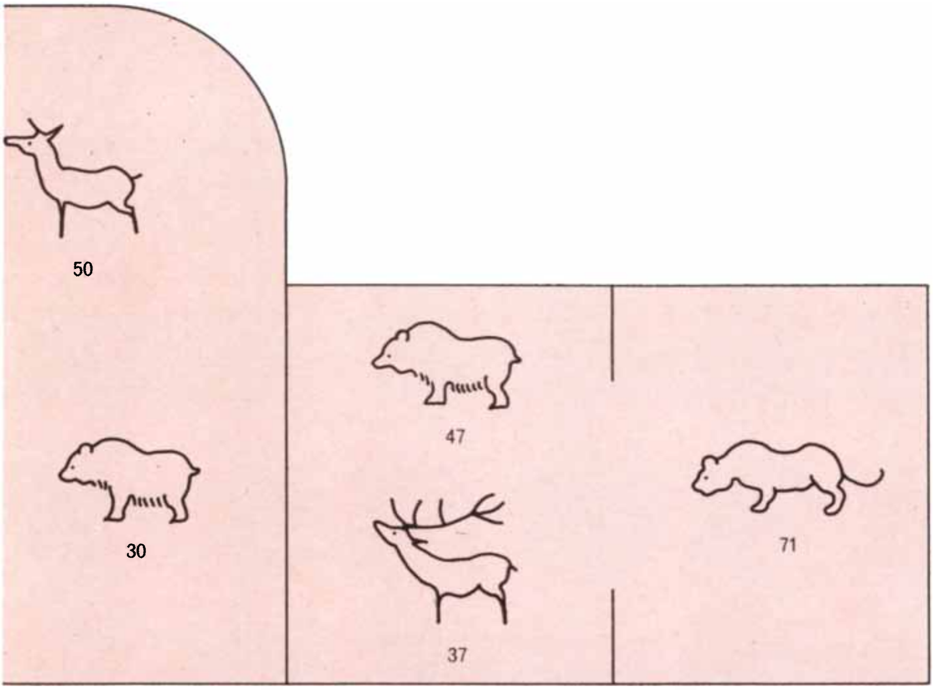


METHODICAL ARRANGEMENT of the animal depictions at various Paleolithic sites was revealed by the author's survey of 62 caves. The diagram shows an idealized cave with an entrance, a main chamber and its periphery and, finally, a back passage to a deep inner area. Numbers below each animal figure show the percent of depictions of that animal present in that part of all the

From this viewpoint (which is still held by some prehistorians) wall art represents the gradual accumulation of isolated pictures, each created by the need of the moment. When one stands before the great wall paintings of Lascaux in France or Altamira in Spain, however, it is hard to imagine how the random accumulation of isolated subjects could possibly have led to an assemblage that impresses the most naïve viewer with its overall balance. Doubts on this score are what inspired Annette Laming-Emperaire to publish her important study of 1962: *The Meaning of Paleolithic Wall Art*. There she vigorously challenges the traditional theories. My own work has been motivated by a similar conviction and is based on the following postulate. If, rather than working haphazardly, the men of the Paleolithic consciously—or



LASCAUX CAVE, a famous Paleolithic site in France, is shown in plan view; more than 300 feet separate the cave's deepest recess (*left*) from the entrance (*right*). The broken lines enclosing the groups of depictions suggest how the cave's many decorated areas were originally subdivided. The stag and the two abstract signs just inside the Axial Gallery are reproduced in color on page 58.



caves surveyed. More than 90 percent of all bison and wild-ox paintings appear in main chambers, as do most horse paintings. Most stag paintings are located elsewhere: nearly 40 percent are in inner areas, 22 percent are in entrances and 29 percent are in peripheral areas.

even unconsciously—introduced order into the way their pictures are positioned, then an analysis of where various animal paintings are located in a sizable number of caves (say 50 or more out of the 100-odd sites) should reveal what general scheme, if any, the artists had in mind.

To test this postulate I have reviewed the topography of some 60 caves, established the position of more than 2,000 individual animal pictures in them and tabulated the results. The following related facts can be perceived: (1) If one defines "central position" either as the middle of a painted panel or as the most prominent chamber within a cave, it is in this position that more than 85 percent of all pictures of bison, wild oxen and horses are found. (2) The next most prominent animals—deer, ibex and mammoth—appear in positions other than a central one. (3) Three other species—rhinoceros, lion and bear—are found only in the deepest parts of the cave, or far from the central position [*see bottom illustration on page 65*].

A similar analysis can be made of the subjects other than animals that are depicted in Paleolithic art: representations of humans, male and female, and signs that are more or less abstract. More than 80 percent of all the female figures—and of the symbols that I call "wide" abstract signs, which are evidently related to female figures—are found in the same central places where bison and wild oxen are depicted. Other symbols designated "narrow" signs are in the same areas where the remaining animal figures are found; that is to say, nearly 70 percent of them are in positions that are peripheral.

This is not the place to consider what such patterns may be able to tell us about the religious beliefs of Paleolithic man. For anyone who is trying to establish a chronology of Paleolithic art, however, the orderliness of these arrays has its own significance. First, one is led to the conclusion that in most of the wall art in most of the caves the separate elements belong to a single period, and that later works were executed in other parts of the cave. Even in those caves where the wall art clearly represents the accumulation of several periods, the later works repeat the elements and order of the earlier ones. Second, in any single assemblage of pictures the wide abstract signs are all much the same, whereas in caves that contain a number of separate picture groups the wide signs differ from group to group. The existence of these differences suggests that the wide signs can serve as chronological guideposts, or at the very least as guides to the relations between the various styles in which the animal figures are executed. Thus, regardless of any hypotheses concerning prehistoric religion, the fact that there is order in Paleolithic man's art provides a basis for investigating its evolution.

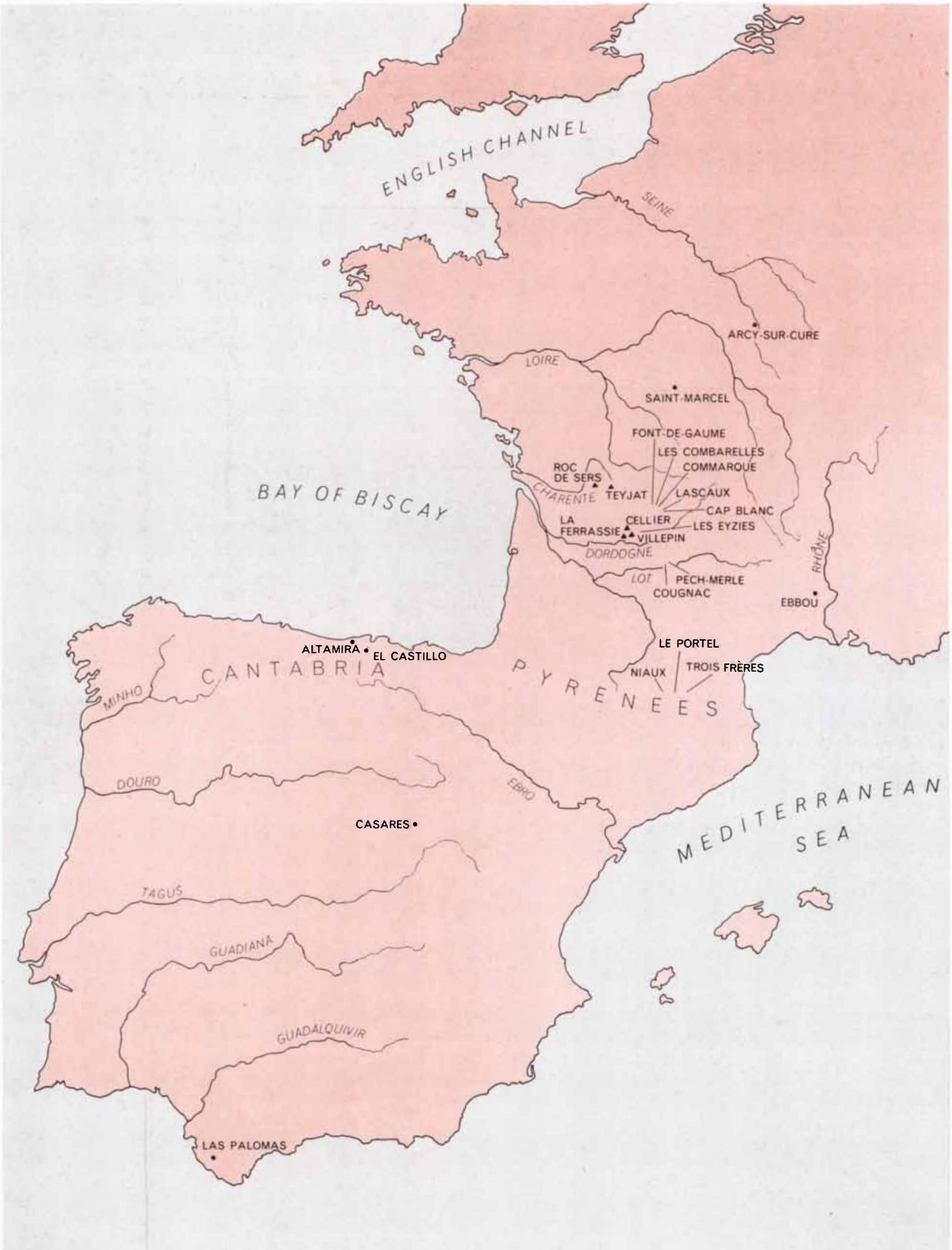
Discovering Points in Time

All such problems of chronology would have vanished long ago if only one of two things had happened. Each Paleolithic site could have yielded stratified sequences of buried sculptures and the style of the material from each stratum could have shown it to be unmistakably contemporaneous with one after another of the cave's displays of wall art. Alternatively, the examples of the wall art in a number of caves could all have been executed in a single style, and the artifacts excavated from the floors of the same caves could all have been attributed to a single interval of time. In actuality very few examples of wall art can be firmly attributed to a specific period during the many millenniums in which prehistoric art flourished. Still, the few examples that do exist provide us with some degree of chronological framework.

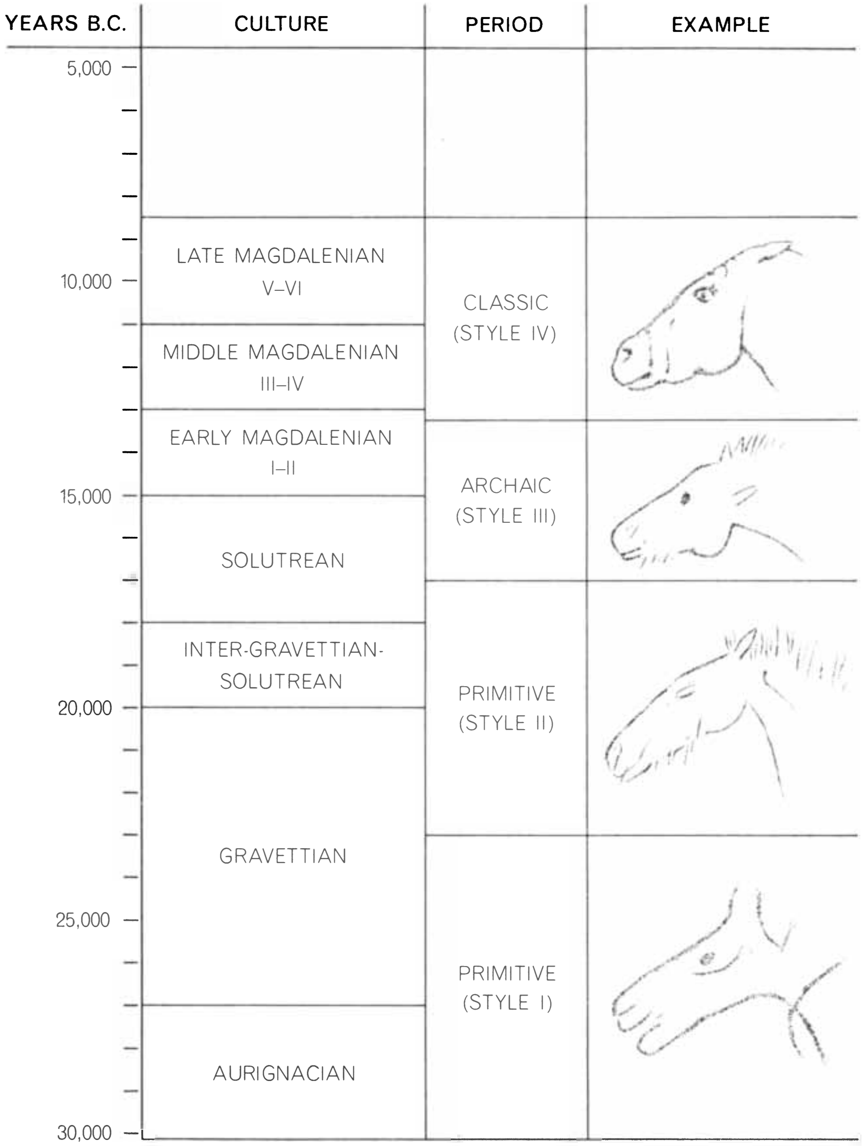
As a starting point, there are no known examples of representational art before the Aurignacian period, beginning about 30,000 B.C. There are, however, firmly dated pieces of Aurignacian sculpture. They are found, for example, in the Aurignacian strata of two sites in the Dordogne valley of France: the Cellier rock-shelter and La Ferassie. They are crudely engraved figures of animals and wide and narrow signs.

Our next bench mark in time is found in strata of Solutrean age (about 15,000 B.C.) at the Roc de Sers site in the Charente valley of France: a low-relief frieze rendered in a vigorous style. It depicts horses, bison, ibexes and men. The date is firmly established because the rock of the frieze had fallen from its original position and was discovered lying face down between two strata containing Solutrean artifacts.

A third bench mark is provided by a number of engraved stone plaques discovered in strata of Upper Magdalenian age (about 10,000 B.C.) in the caves of Teyjat in the Dordogne. The animals depicted on the plaques are the same as those in the Roc de Sers frieze, but they are executed in a more detailed, almost photographic style. The final bench mark, denoting the end of Paleolithic art, is also found in the Dordogne. At Villepin engraved pebbles from strata dating to the very end of the Magdalenian period (about 8000 B.C.) display sketchy, often barely identifiable animal figures.



HEARTLAND of Paleolithic cave art was western Europe south of the Loire River. Sites mentioned by the author in the valleys of the Charente, the Dordogne and the Lot and in the foothills of the French Pyrenees are shown, as are some with cave art in Cantabrian, central and southern Spain, in France north of the Charente and in the Rhône valley. Cave art has also been found at three sites in Italy and Sicily. Five Charente-Dordogne sites marked with triangles contained sculpture in strata with well-established dates.



EVOLUTION of Paleolithic art took place during the era's final 20,000 years, a period known as the Upper Paleolithic. The first examples are dated around 30,000 B.C., when the Aurignacian culture makes its appearance. They were crude outlines cut into rock (*bottom figure is unidentified; the others portray horses*). This Style I work, as it is classified by the author, and later work in Style II comprise the primitive period. The best-known cave art was produced during the archaic (Style III) and the classic (Style IV) periods.

Four points in time, all found in the same Dordogne-Charente region, scarcely suffice to establish a chronology for all Europe. Fortunately a number of less exact bench marks are available in France, Spain and Italy. Although these bench marks can be fixed no more exactly than around the start, the middle and the end of the Upper Paleolithic, they are in general accord with the Dordogne-Charente reference points and allow us not only to recognize the entire period's major chronological subdivisions but also to perceive a new and very important fact. Up to now it has been thought that the portable art and the wall art of the Upper Paleolithic evolved in a strictly parallel manner, and that one could find pictures characteristic of each of the period's subdivisions in the caves. It is now apparent that, on the contrary, wall art was extremely rare or even nonexistent early in the Upper Paleolithic, that most of it belongs to a middle phase during which the portable art becomes less abundant, and that portable art catches up with wall art once more in the period's final phase.

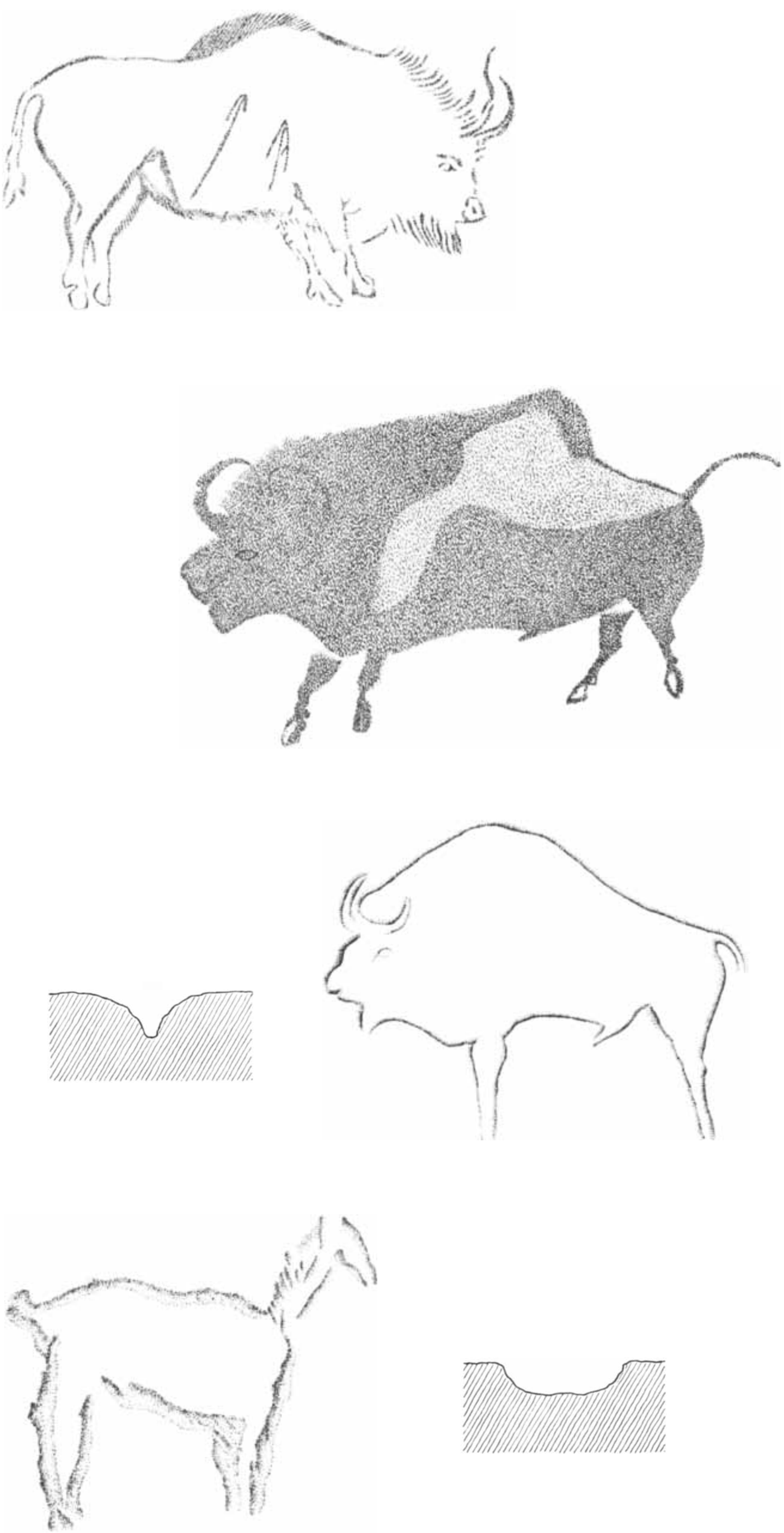
The Evolution of Abstract Signs

Students of Paleolithic art have always been intrigued by certain abstract signs that appear in wall art almost from its beginning to its end, although not so commonly as pictures of animals. In the opinion of some investigators some of the signs represent huts or tents; other signs are interpreted as representing weapons and traps, shields and even primitive heraldic designs. It would seem, however, that only a few signs out of the hundreds known can be explained by their resemblance to actual objects. If instead of selecting a few such examples one makes an inclusive inventory of all the things found in wall art that do not obviously portray animals, a rather different picture emerges. One can even group such representations into general categories.

One category is men and women, sometimes pictured whole and sometimes reduced to a head or torso. To this category can be added numerous realistic representations of the male and female sexual organs, which evidently have the same significance as the fuller figures. The existence of these drawings has suggested to some scholars that a fertility cult existed in Paleolithic times. This is hard to disprove, but given the fact that the male and female representations are as often separate as they are together, they would appear to be at best quite abstract fertility symbols.

By far the largest number of signs belong to one or the other of the two groups I have mentioned: the wide and narrow signs. The wide signs include rectangles, triangles, ovals and shield shapes. Most of them clearly belong to the category of human representations; they are quite realistic depictions of the female sexual organ. The narrow signs include short strokes, rows of dots and barbed lines. Some of them clearly suggest male sexual organs, although they are extremely stylized. For that matter, the entire inventory of abstract signs could well be nothing but animal and human figures rendered symbolically.

These abstract signs are strikingly diverse in both time and space. One kind of rectangle, for example, accompanies animal figures that themselves have a number of stylistic features in common: the rectangle appears in the Dordogne, in the nearby Lot valley and in Cantabria, beyond the Pyrenees in Spain. This enables us to assign all the cave art in which the rectangle appears to the same time period. At the same time how abstract decoration is used to embellish each rectangle varies sufficiently from cave to cave to establish the fact that the art of Lascaux in the Dordogne, of Pech-Merle in the Lot valley and of Altamira in Spain each belongs to a distinct ancient province. Such a distinction

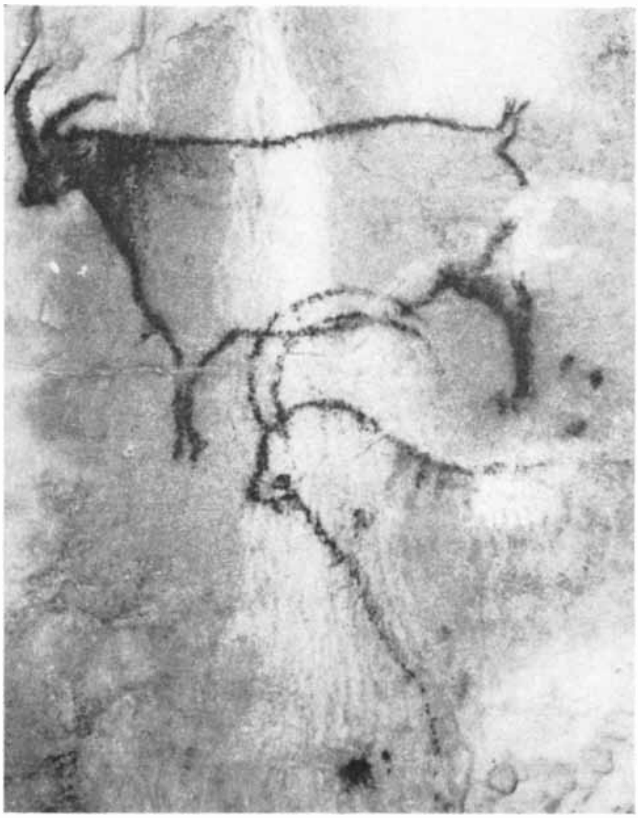


FOUR QUADRUPEDS, three of them bison, show how styles evolved. Work in Style I (*bottom engraving, cross section at right*) seldom depicted entire animals as here; both line and workmanship are rough. Style II technique (*second from bottom, cross section at left*) remains primitive but forms are more powerful. In Style III (*painting second from top*) line and color have been mastered although anatomical details are unperfected. The work in Style IV (*top painting*) shows both anatomical fidelity and a sense of movement.

cannot be made with equal precision when one must base one's judgment on the style in which the animals are depicted. As a matter of fact, signs remote from realism are a better mirror of local influences than animal portraits are. I have therefore based my use of abstract signs on a twofold principle: first, that as generalized forms they are contemporaneous and, second, that in their details they reveal regional influences.

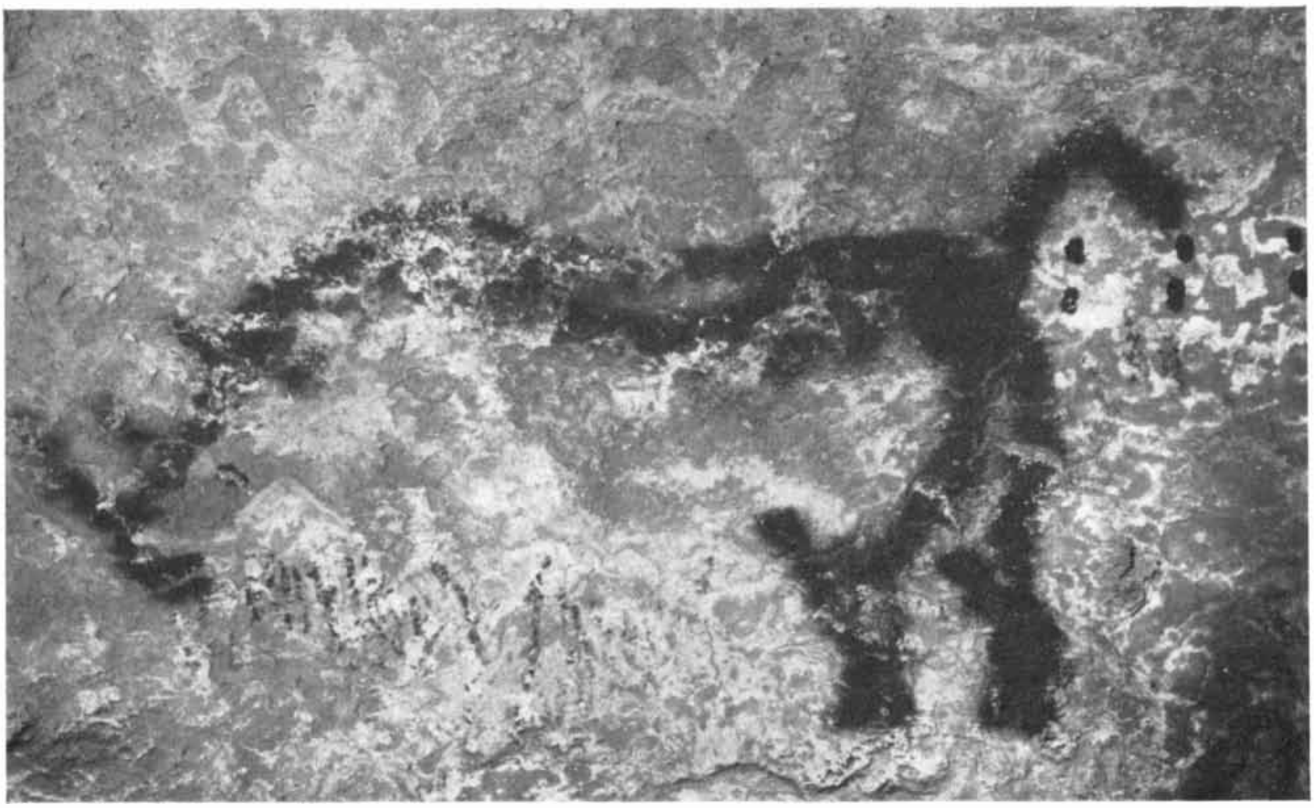
As in the pictures of animals, the abstract signs do not establish much in the way of precise chronology. Most of the sites where they are found contain nothing that can be rigorously dated. Nonetheless, they make it possible to establish a sequence that is about as reliable as the one based on animal figures. For example, the oldest known abstract signs appear about 30,000 B.C., in Aurignacian times. The wide signs are realistically feminine; the narrow ones are either realistically masculine or are stylized into a series of strokes or dots. In Solutrean times, roughly from 20,000 to 15,000 B.C., full figures of men and women seem to predominate; the style of the latter is familiar to us from the numerous "Venus figurines" that have been found in both western and eastern Europe. The transition between Solutrean and early Magdalenian times (between 15,000 and 13,000 B.C.) is a period of rectangular signs, followed closely by bracket-shaped ones. At this point regional differences in abstract signs make their classification difficult, although a revival in the popularity of small sculptures provides a precise means of determining the chronological position of other animal representations. During the Magdalenian proper, from 13,000 to 9000 B.C., the most important group of abstract signs are "key-shaped" ones, derived from the representation of a woman in profile [*see illustration on page 66*]. In the Dordogne and the Lot valley it is possible to trace the evolution from early to middle Magdalenian by means of the key-shaped signs. Thereafter these signs become increasingly stylized, both in space (as one moves south) and in time (as the end of the Magdalenian approaches).

Key-shaped signs are by no means the only abstractions of this period. Here a variety of influences appear to have crisscrossed in space and time. At Les Eyzies in the Dordogne, for example, roof-shaped signs (which apparently evolved out of the bracket-shaped ones) seem to take the place of the key shapes. Another trend in symbolism is marked by the appearance of what some scholars have assumed are representations of



PAINTED IBEXES of the archaic period, a female (*top*) and a male, were done in red ocher at Cougnac, a Lot valley site in France. Painting, engraving and combinations of both are known.

ENGRAVED IBEX, also executed during the archaic period, is one of scores of animal figures cut into the cave walls at Ebbou, a Rhône valley site in France that contains engravings exclusively.



PAINTED RHINOCEROS, one of the animals typically found in the back areas of caves, occupies a niche opening off the main chamber at Lascaux. The work, in manganese, is transitional between Style III and Style IV. Dots by the tail form an abstract sign.

wounds on the bodies of animals. Both symbolic wounds and realistic representations of the female sexual organ are found in a comparable setting in a large number of caves. Since the realistic female representations of the Magdalenian are executed differently from the earliest female representations, it seems likely that the "wounds" are a different kind of female symbol.

The Time Scale

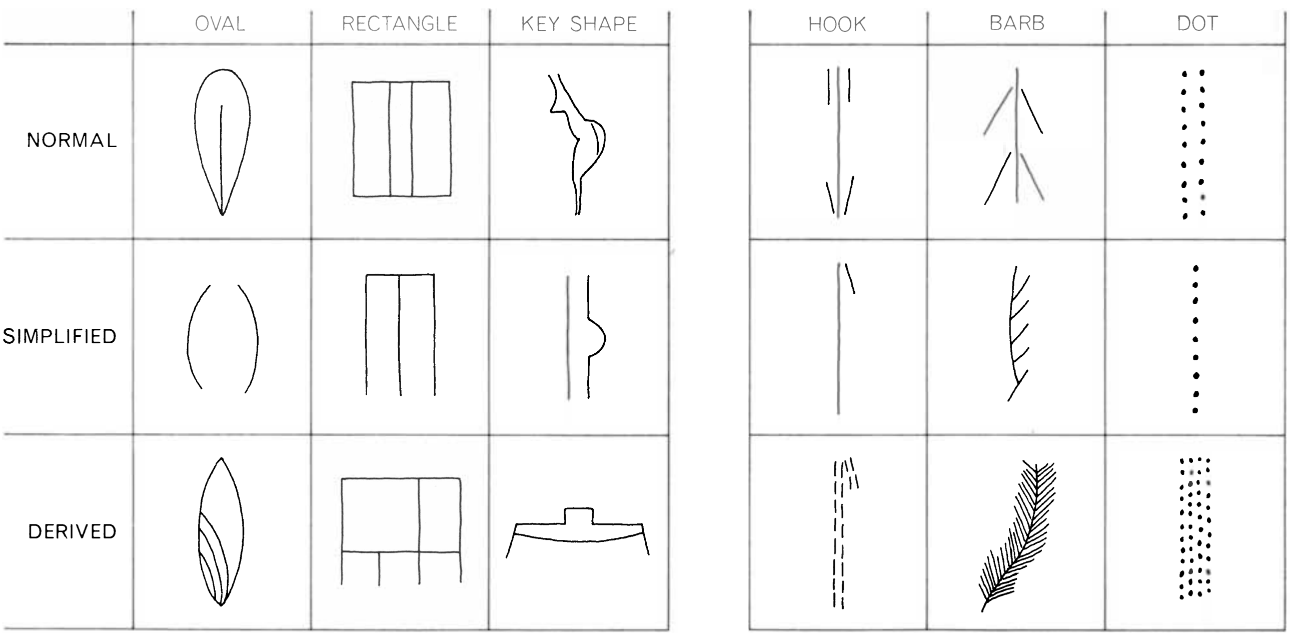
By putting together all three classes of evidence—from excavations, from the study of reasonably well-dated wall art and from the evolution of human figures and abstract signs—a chronological framework can be erected that begins to approximate reality. The most attractive of all Paleolithic art works, the animal pictures, remain the most difficult to interpret directly. The reason is that any analysis of their evolution is founded on criteria of style, and judgments of style are primarily subjective. When details that allow objective evaluation are scanty, only the most general conclusions are possible. What appears to be an important criterion may reflect nothing more than a regional characteristic or the relative skill of the artist.

In spite of such qualifications, it can be said that the evidence in general allows us to discern the emergence of three great periods of Paleolithic art during the 20,000 years from the Aurignacian to the end of the Magdalenian. They are, first, a primitive period, then an archaic period (in the same sense that one speaks of archaic Greek art: a well-developed body of art rapidly approaching maturity) and finally a classic period. Where the conditions are most favorable, as in the Dordogne-Charente region, we can point to the succession of four styles in the course of the three major periods. These I have designated Styles I and II (in the primitive period), Style III (in the archaic) and Style IV (in the classic). Even finer subdivisions are possible: the wall art of Lascaux and Pech-Merle, for example, is divisible into early and late Style III, and elsewhere Style IV shows similar early and late stages.

What are the characteristics of each period and style? Style I embraces history's oldest examples of representational art, examples that are precisely dated to the Aurignacian period by virtue of the fact that they are found in association with Aurignacian tools. The Aurignacian sculptures of Cellier and La Ferassie are Style I. As I noted earlier, the representations of animals from this time are very crude; sometimes the whole body is shown but more often the rendering is limited to a head or a forequarter. The inventory of animals includes the horse, the bison, the wild ox, the ibex and the rhinoceros—in other words, the main cast of characters found throughout Paleolithic art. The representations include realistic depictions of the female sexual organ as well as such male symbols as lines and rows of dots.

A long interval, extending from 25,000 to 18,000 B.C. and thus from the late Aurignacian through Gravettian times to early Solutrean ones, is the setting for Style II. In a chronology based on the evolution of techniques this 7,000-year interval is a confused period. One can assume that a number of cultures succeeded one another, but it is hard to equate the changes in one region with those in another. In any case, this was the period in which Paleolithic art attained its greatest geographical range, from the Atlantic coast on the west to the valley of the Don on the east. It is also the period in which the first wall art appears: paintings and engravings executed on the walls of open rock-shelters or on those cave walls that were illuminated by daylight.

The animal forms of Style II are powerful, but the technique of rendering remains quite primitive. The stereotyped curved line representing the neck and back and the line representing the belly are drawn first; the details characteristic of each animal species are then roughly connected to the generalized torsos and are often left unfinished. The abstract signs that are included in the wall art remain close to realism and generally consist of ovals and series of strokes. In the realm of small sculptures the numerous female figurines of this period, usually made of stone or of mammoth ivory, all have much the same shape. The trunk is corpulent and rendered in some detail but the extremities and the



"WIDE" AND "NARROW" SIGNS are considered by the author to be symbolic of the sexes and to have evolved from earlier depictions of female and male figures or sexual organs. Three groups of symbols are shown for each sex, in normal and more abstract forms.

head are stylized and often quite reduced in size.

Style III, which is typical of the entire archaic period, finds its most eloquent expression in the great frieze of the Roc de Sers in Charente, in the equally impressive murals at Lascaux and in some of the Spanish cave paintings. The representations of animals retain a primitive flavor: the bodies are bulky and the small heads and hooves are joined to the bodies without much care for detail or proportion. Line, however, is now handled with great sensitivity, and the control of painting and sculptural technique is complete. The interplay of manganese blacks and ocher reds and yellows in the paintings and the use of color accents on the low reliefs reflect a mastery of both mediums. Representations of humans are scarce and do not compare in quality with the animal pictures. On the other hand, the abstract signs characteristic of Style III, which are rectangular or bracket-shaped, show such a diversity of embellishment that they have been compared to heraldic coats of arms.

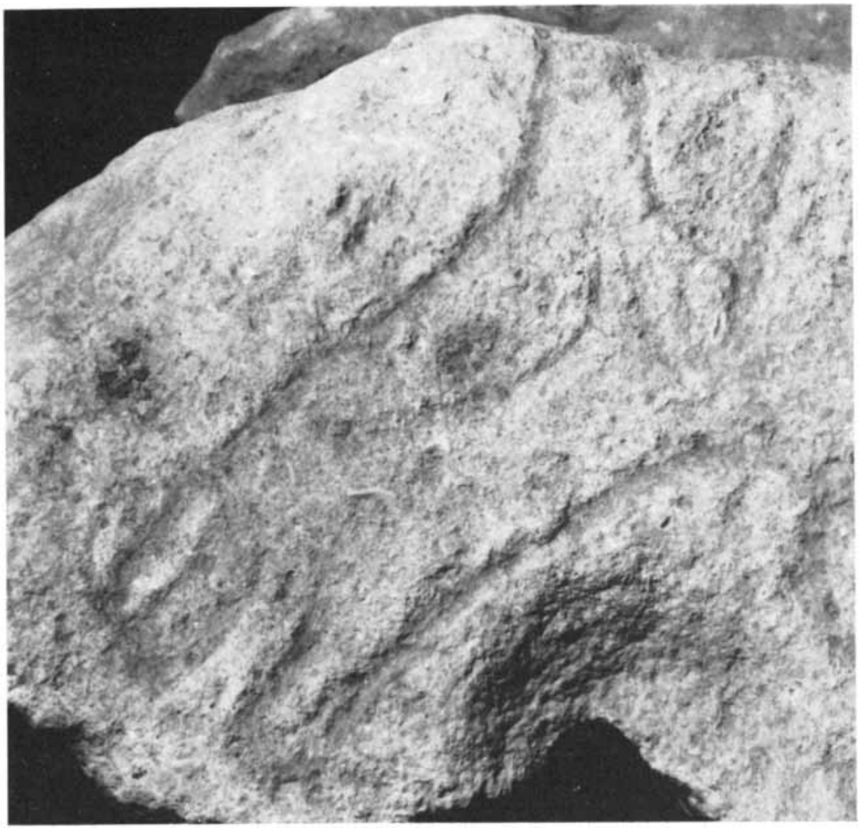
Chronologically the style of the archaic period occupies the interval between 18,000 and 13,000 B.C., thus including the late Solutrean and the early Magdalenian. The evolution of animal portrayal can be traced through all five millenniums. At Lascaux and at Pech-Merle, for example, one can differentiate between early Style III animal paintings that are still close to Style II and late Style III paintings that already verge on Style IV.

In western Europe small sculptures are notably rare during the archaic period; of the few works in the category of portable art most are engraved plaques. In eastern Europe, on the other hand, there is no Style III wall art at all but there is a trove of animal and human figurines. Such regional differences probably correspond to ethnic ones. Thus one can readily distinguish between an eastern domain (from what is now Czechoslovakia to the U.S.S.R. west of the Urals) and a western one. Although we are a long way from knowing all the schools of Style III in the western domain, variations in rectangular signs and associated animal figures enable us to detect shades of difference between works from the Dordogne, the Lot valley, the central Pyrenees, Cantabria and the Rhône valley.

The whole of the Magdalenian proper, from 13,000 to 9000 B.C., provides the stage for the classic period of Paleolithic art and Style IV. Outside of western

THE TWO SEXES are represented by this array of wide and narrow signs painted on the wall of a cave at El Castillo in Cantabrian Spain during the archaic period. The embellished rectangles belong to one of five groups of female symbols recognized by the author and the rows of dots to one of four male groups (*see illustration on opposite page*).

"WOUNDED" BISON, painted during the classic period at Niaux in the French Pyrenees, is interpreted by the author as neither a hunting scene nor a sorcerer's spell but instead as a combination of animal figure and abstract female sign found only in Style IV. Female signs are usually found with bison and wild-ox pictures in the caves' central chambers.



CRUDELY OUTLINED HEAD of an animal from the earliest Aurignacian stratum at the Cellier rock-shelter in the Dordogne valley is typical of the art of the primitive period.

LOW-RELIEF SCULPTURE of a horse's head from Commarque, a Middle Magdalenian cave site in the Dordogne, shows the sophistication of classic period art, 15,000 years later.

Europe, Style IV is not particularly well represented at present, but within that area it is rich in wall art and especially rich in portable art. Small sculptures were widely disseminated in western Europe during the classic period. Toward the end of the period, when an increasingly mild climate allowed occupation of the northern and mountainous areas of Europe, examples of portable art reached the areas of Switzerland, Germany and even Britain. Wall art also extended its boundaries, appearing in Italy for the first time.

The wealth of classic small sculptures makes possible many comparisons between them and Style IV wall paintings that illuminate the main features of the period's art evolution. One result is that a distinction can be made between early and late Style IV animal pictures. In the early period faint traces of the archaic models still remain; regardless of the correctness of their proportions, the animals give the appearance of being suspended in midair. Body contours are filled in with incised lines or splashes of color that convey the texture of the coat. This surface modeling is present in figures found from Spain to the Loire valley in France; each animal species—horse, bison, ibex, reindeer and the like—is rendered by means of the same conventions from one end of this region to the other. In late Style IV representations the rendering of texture is less clear and many animals are presented in simple outline. It is now that anatomical fidelity and a sense of movement reach their peak. If the final art of the Paleolithic lacks the rather solemn grandeur of Lascaux, it nonetheless possesses an extraordinary vitality.

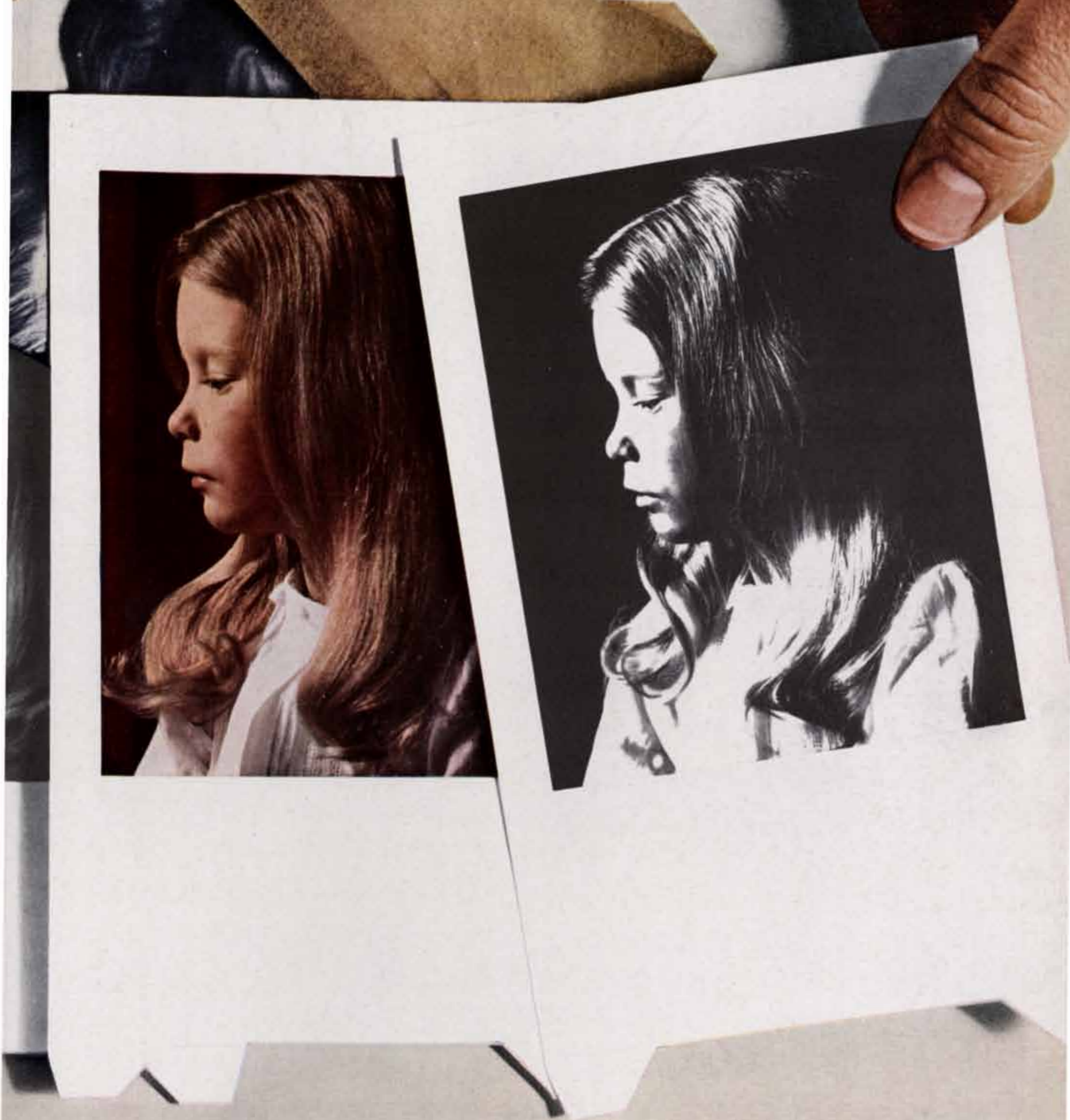
Most of the best-known examples of cave art are either early or late Style IV. These include the wall paintings at Font-de-Gaume, Les Combarelles and Cap Blanc in the Dordogne, the paintings at Le Portel, Trois-Frères and Niaux in the Pyrenees, the great painted ceiling at Altamira and paintings in several other cave sites in Biscay, Cantabria and Asturias. Because Style IV animal pictures are handled in a remarkably uniform manner all the way from Spain to central Europe, regional subdivisions are much harder to establish in the classic period than in the archaic one. Indeed, the uniformity of the classic period suggests not only the existence of contacts between various regional populations but also the existence of a firmly based cosmopolitan artistic tradition. One subdivision that can be detected is a single cohesive Franco-Cantabrian body of

early Style IV art; it extends from the Loire valley to the Pyrenees and Asturias and is reflected in the rendering of females in profile and in associated abstract key-shaped signs. The distribution of small Style IV sculptures demonstrates a connection between the Pyrenees-Loire region and areas to the north and east as far as Germany.

What are the main developments during the huge span in which Paleolithic art flourished? At the foot of the evolutionary path a master plan already existed even though techniques were virtually unformed; this was the primitive period. In the extended period of refinement in technique that followed, the key developments involve the delineation of those characteristics that distinguish one species of animal from another; this was the archaic period. Finally both technique and delineation were progressively united in a more and more realistic portrayal of shape and movement; this was the classic period. Then it is all gone, much as the mammoth and the woolly rhinoceros disappeared from the same region. The ideological line uniting an artistic tradition of 20,000 years comes to an end.

Obviously both the long lifetime of Paleolithic art and its disappearance are topics that will occupy generations of investigators. Today, although we know only a fraction of what remains to be learned, we have made some progress. It might be said that historians of Paleolithic art have reached a level of precision comparable to the level achieved by historians of Christian art when they were at last able to fix the date of some object within a century or two. They could be justly criticized for a lack of precision, but they had achieved a clear view of the path along which Christian art had evolved.

ANATOMICAL FIDELITY is characteristic of Style IV work, produced during the classic period of Paleolithic art. The deftly rendered outline of a wild-ox cow's head is one of the animal engravings in the cave at Teyjat, an Upper Magdalenian site in the Dordogne valley.



GREAT RED SPOT appears somewhat orange in this remarkably detailed photograph made at the Lunar and Planetary Laboratory of the University of Arizona. During the century or so that Jupiter's great red spot has been closely observed its color has reportedly ranged from "full gray" and "pinkish" to "brick red" and "carmine." The photograph was made on December 23, 1966, by Alika Herring and John Fountain, who used a 61-inch reflecting telescope. The exposure was one second on High Speed Ektachrome.

JUPITER'S GREAT RED SPOT

There is evidence to suggest that this peculiar marking is the top of a "Taylor column": a stagnant region above a bump or depression at the bottom of a circulating fluid

by Raymond Hide

The surface markings of the planets have always had a special fascination, and no single marking has been more fascinating and puzzling than the great red spot of Jupiter. Unlike the elusive "canals" of Mars, the red spot unmistakably exists. Although it has been known to fade and change color, it has never entirely disappeared in the 130 years it has been regularly observed. The red spot appears to be embedded in the banded clouds of Jupiter's atmosphere, and its period of rotation about the axis of the planet undergoes slight but persistent fluctuations. For this reason astronomers have generally thought that the spot could not be attached to the solid planet (assuming Jupiter has a solid surface underlying its atmosphere) and that it must be a solid object rather like a huge raft floating in the atmosphere.

An alternative suggestion was put forward in 1961: I proposed that the great red spot might be visible evidence of a hydrodynamic phenomenon essentially similar to a "Taylor column." This is a more or less stagnant cylinder that can be produced in a rotating fluid by either a protuberance or a depression at the base of the fluid. Such columns, which tend to be parallel to the axis of rotation of the fluid, are named for their first investigator, Sir Geoffrey Taylor of the University of Cambridge. According to my hypothesis, the presence of even a shallow topographical feature on the surface of the solid planet, if indeed it be solid, would give rise to a pronounced disturbance in the atmosphere because the planet is rotating so rapidly (one revolution in less than 10 hours). This hypothetical disturbance could well give rise to a permanent marking, such as the red spot, at the top of the cloud layer, where it would be visible to outside observers.

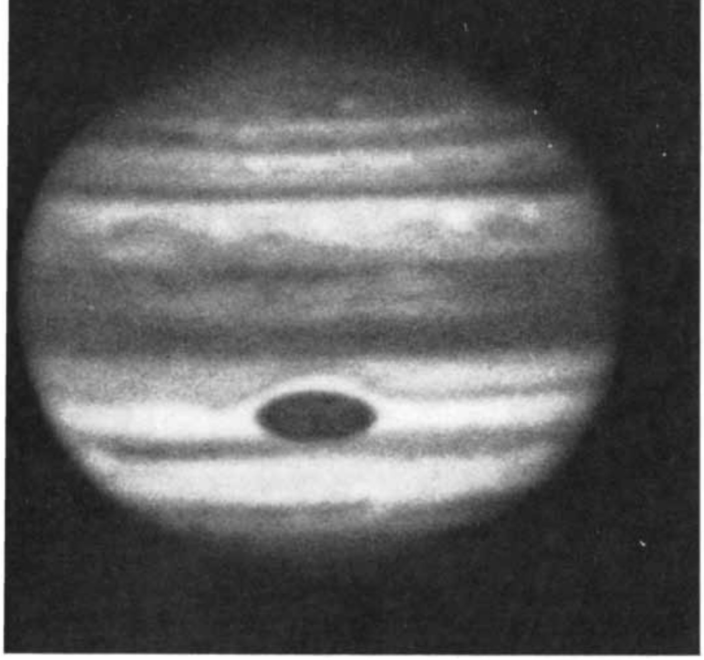
To explain the fluctuations in the red spot's period of rotation one must assume that there are forces acting on the solid planet capable of causing an equivalent change in its rotation period. In other words, the fluctuations in the rotation period of the red spot are to be regarded as a true reflection of the rotation period of the planet itself. Theoretical studies suggest that the fluid regions of Jupiter—its atmosphere and its fluid core, assuming there is one—are together sufficiently massive and well agitated to create the forces needed to alter the planet's speed of rotation. At the same time the topographical feature responsible for the red spot would be kept from wandering in latitude because of the planet's great gyroscopic stability. Indeed, one of the principal objections to the "raft hypothesis" is its apparent inability to explain why the latitude of the spot has remained fixed.

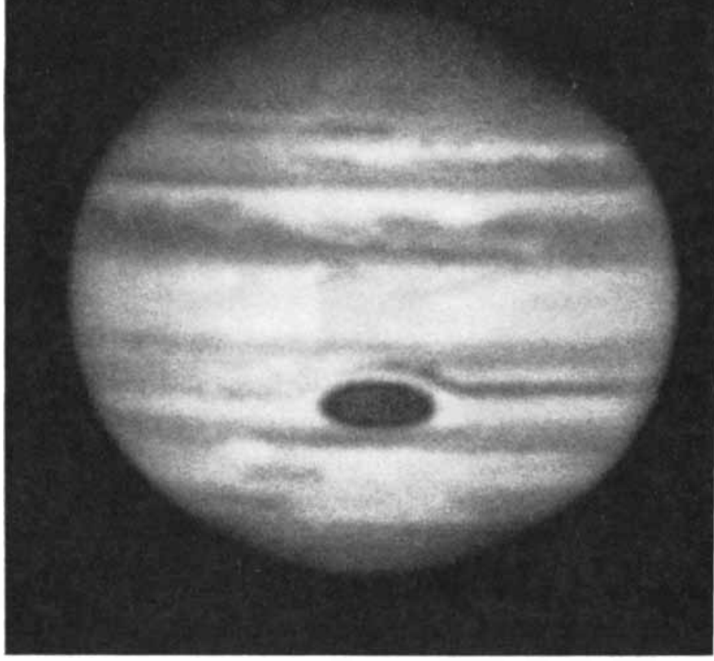
Fifth in order of distance from the sun, Jupiter is a giant among the planets. Its diameter is some 138,000 kilometers (about 86,000 miles), or roughly 11 times the diameter of the earth. Jupiter circles the sun once every 11.8 years. It can be observed profitably for about 10 months out of every 13; the rest of the time it is on the far side of the sun from the earth and its apparent diameter is much reduced. At opposition, when both planets are in line with the sun on the same side of it, Jupiter is twice as bright as Sirius, the brightest star, and its apparent diameter reaches 50 seconds of arc. This corresponds to a 33rd of the diameter of the moon. Among the planets only Venus and occasionally Mars exceed Jupiter in brilliance.

Studies of various kinds indicate that the visible surface of Jupiter is made up of clouds of ammonia and ammonia crystals suspended in an atmosphere that is mainly hydrogen admixed with water and perhaps methane and helium. Other lines of evidence, particularly the fact that Jupiter's density is only 1.3 times the density of water, suggest that the main constituents of the planet are hydrogen and helium. It was once conjectured that Jupiter had a metallic core similar to the core of the earth, jacketed by a thick mantle of ice. Ideas changed in 1951 when William H. Ramsey, then at the University of Manchester, pointed out that the high pressures prevailing deep inside the planet would have the effect of converting hydrogen from its ordinary liquid or solid form into a metallic, electrically conducting form.

Theoretical models of Jupiter's structure based on Ramsey's ideas have since been constructed by a number of workers. Although these models give a fairly complete description of the distribution of density and pressure within the planet, they do not lead to predictions about such important properties as temperature, thermal and electrical conductivity, viscosity and mechanical strength. Moreover, they cannot predict whether the material at the base of the atmosphere is a solid or a liquid. Thus for all anyone knows Jupiter could be fluid throughout [*see illustration on page 79*].

In 1610 Galileo turned his primitive telescope on Jupiter and discovered the four largest of the planet's 13 satellites. Twenty years later Nicolas Zucchi and Daniel Bartoli observed and recorded the large-scale features of Jupiter's visible disk. The most prominent are a series of bright and dark bands, numbering 14 or more, that run parallel to the planet's equator. The bright bands are usually called zones, the dark ones belts [*see top illustration on page*





JUPITER THROUGH BLUE FILTER confirms the visual impression that the light reflected by the great red spot is primarily yellow to red. The equatorial zone brightened markedly in blue light between October 23, 1964 (*left*), and December 12, 1965 (*right*). Photographs on these two pages were taken at New Mexico State University Observatory with either a 12-inch or a 24-inch telescope.

78]. Because the zones and belts present a continually changing pattern it is obvious that they are cloudlike structures in a fluid atmosphere, not markings on the surface of a solid planet. Isolated dark spots and brilliant white areas frequently appear in the zones. At other times an entire belt or a large portion of it will disappear from view and reappear after several weeks or months.

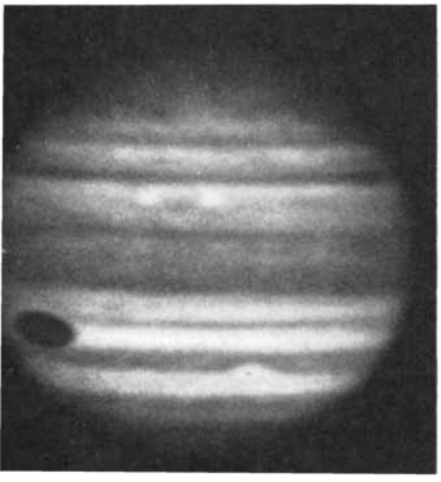
The great red spot was probably first observed in 1664 by Robert Hooke. That same year Giovanni Cassini made drawings of the spot and began recording its period of rotation. He found that it speeded up slightly between 1664 and 1672, when its rotation period, originally nine hours 55 minutes 59 seconds, decreased by five seconds. "Hooke's spot," as it was later called, was observed intermittently until 1713.

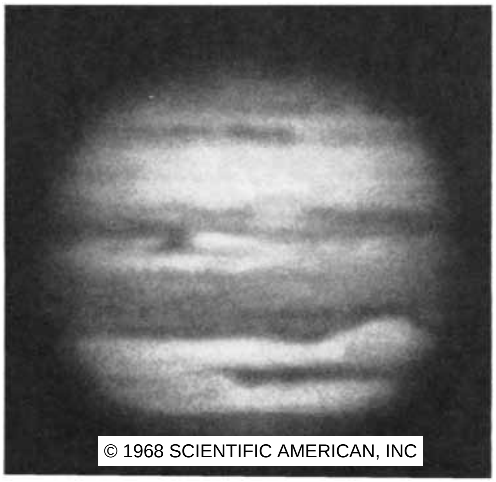
The next known record of the spot is a drawing made in 1831 by Heinrich Samuel Schwabe, the German apothecary who is best known for his discovery that sunspots wax and wane on a cycle of roughly 11 years. Drawings of Jupiter showing the spot were made in 1857 by William Rutter Dawes, an English clergyman, in 1870 by Alfred M. Mayer, an astronomer at Lehigh University [*see bottom illustration on page* 78] and thereafter by many other observers.

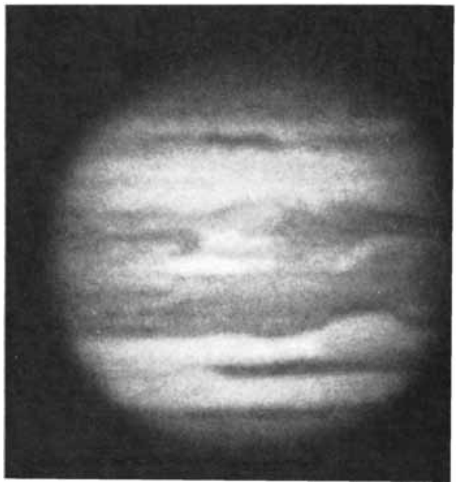
Mayer described his observation of Jupiter with a 15-centimeter refracting telescope in January, 1870, as follows: "I was struck with the beautiful definition and steady sharpness of outline of the details of [Jupiter's] disk, and especially was my attention riveted on a ruddy elliptical line lying just below the South Equatorial belt.... This form was so remarkable that I was at first distrustful of my observation; but... I perceived that the ellipse became more and more distinct as it advanced toward the centre of the disk." Mayer believed the feature he was recording had "never before been noticed."

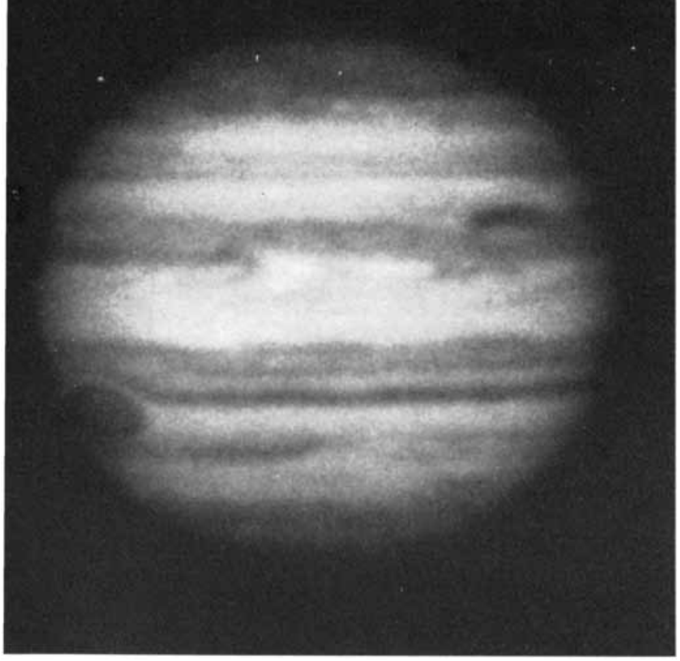
The great red spot became so conspicuous in 1879 that it was widely publicized; it was then that the spot received its present name. In 1882 the spot began to fade. Its decline was so steady that by 1890 astronomers believed it would eventually disappear. By 1891, however, the fading had halted and was

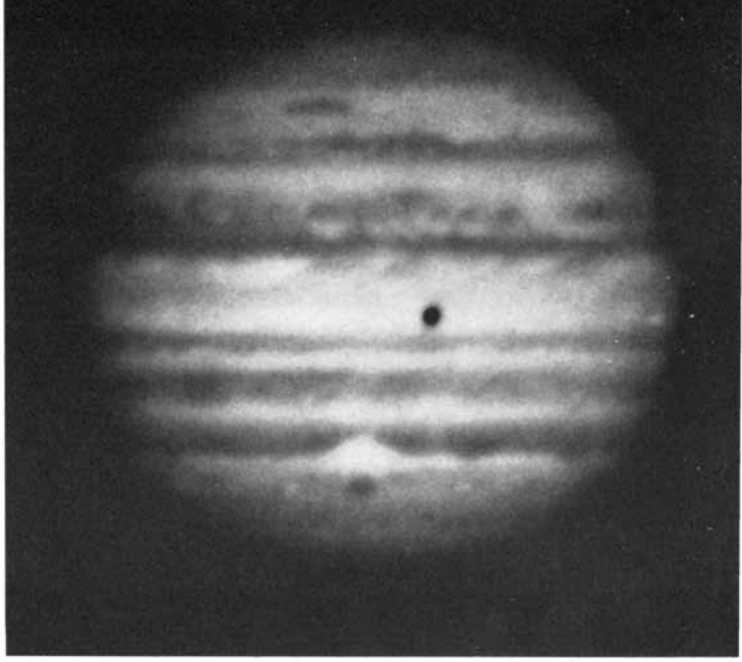
TWO-COLOR SERIES taken on November 8 and 9, 1964, makes it possible to compare the markings on Jupiter as seen in blue light (*left*) and in red light (*middle and right*). The two photographs at the right, which were taken only 30 hours apart, show how cloudlike structures in the equatorial zone can change quite considerably in the time required for the planet to make only three rotations.











JUPITER THROUGH GREEN FILTER shows the planet with the red spot visible (*left*) and out of sight on the far side of the planet (*right*). Extensive changes in band structure took place between October 29, 1965 (*left*), and March 2, 1967 (*right*). The dark spot near the equator at right is the shadow of Jupiter's third largest satellite Io, which is a barely visible white spot near the right limb.

soon reversed. Although the spot has varied since then, it has never disappeared from view.

Any acceptable theory of the great red spot must account for its principal properties without being at variance with what is known about the planet as a whole. These properties can be listed as follows.

First, the spot has a specific size, position and form. It is an ellipse about 40,000 kilometers long and 13,000 kilometers wide, centered on about 22 degrees south latitude. The spot is roughly equal in area to the entire surface of the earth. Its shape, size and orientation undergo slight fluctuations.

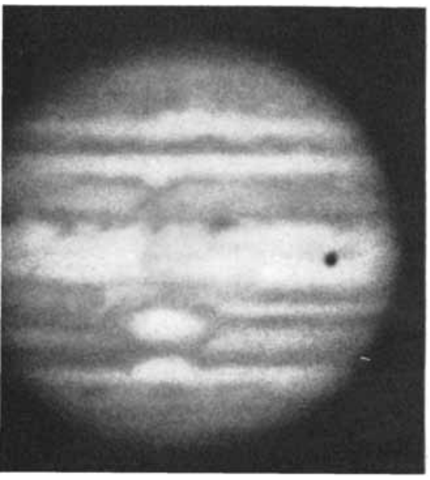
Second, the spot has a rotation period that fluctuates by more than 10 seconds [*see top illustration on page 80*]. These fluctuations, when plotted as variations in longitude with respect to a mean period, show that the spot has at times advanced or fallen back as much as 500 degrees. Significant accelerations of this motion occurred in 1880, 1910, 1926 and 1936, years when the spot was also very conspicuous.

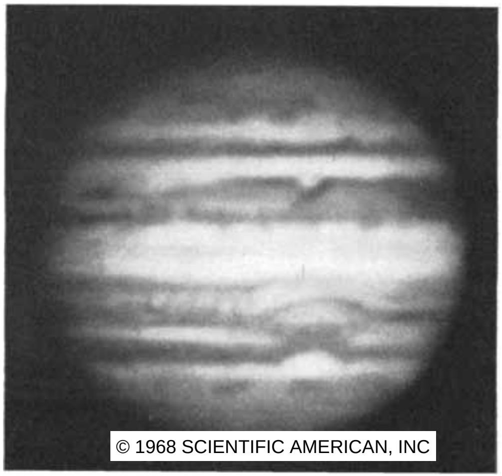
Third, the spot exhibits only slight excursions in latitude. In fact, variations in the latitude of the center of the spot have never exceeded the probable error of measurement.

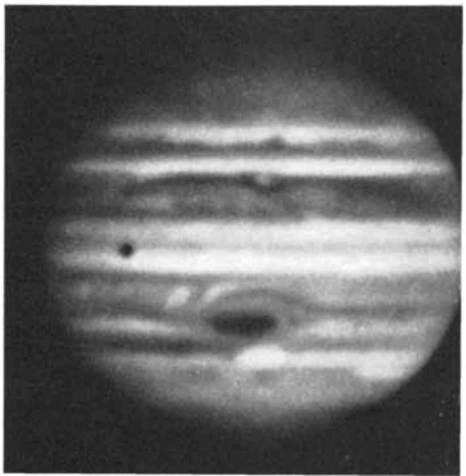
Fourth, the spot is associated with a persistent indentation, known as the red spot hollow, in the southern boundary of the south equatorial belt. On no occasion have the hollow and the spot been simultaneously absent.

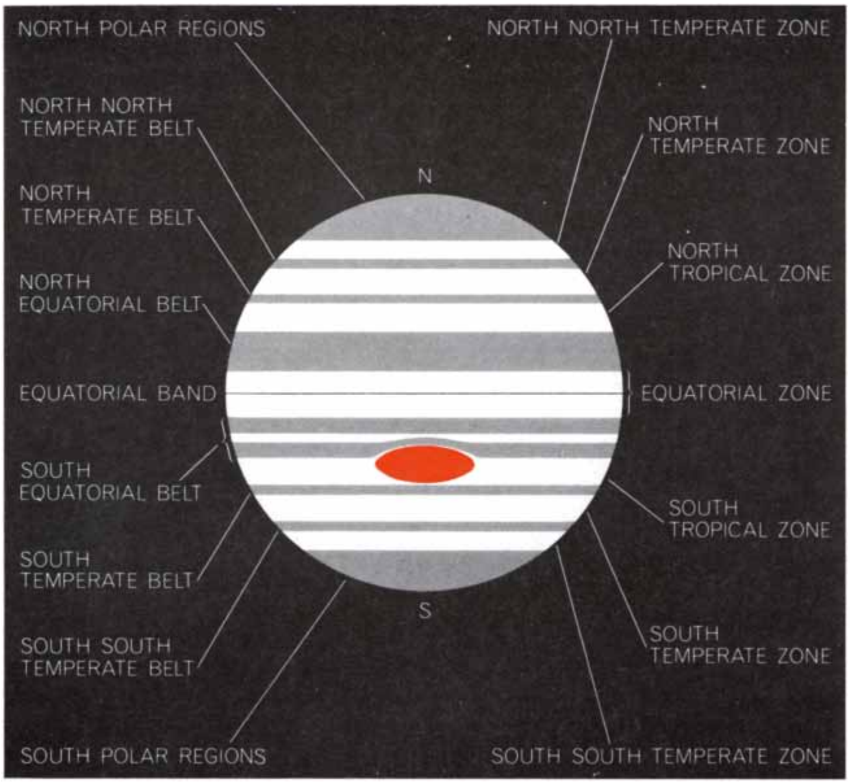
Fifth, the spot has interacted in a specific way with a phenomenon called the south tropical disturbance. The disturbance made its appearance in 1901 as a short dark streak in the south tropical zone some distance from the red spot. Eventually it grew in length until it stretched nearly two-thirds of the way around the planet. In 1939 the disturbance vanished, seeming to give way to three "bright ovals" that can still be seen in the belt just south of the red spot. The rotation period of the disturbance was somewhat less than that of the red spot, and the two features came in contact on nine occasions. The most remarkable behavior at these conjunctions was

THREE-COLOR SERIES was made in March, 1967. The red-light view (*left*) was taken on March 4, only 32 minutes before the green-light view (*middle*). The elliptical shape below the great red spot is one of three "bright ovals" in the south temperate belt. The blue-light view (*right*), taken 17 rotations after the green-light view, shows that the ovals travel slightly faster than the spot.

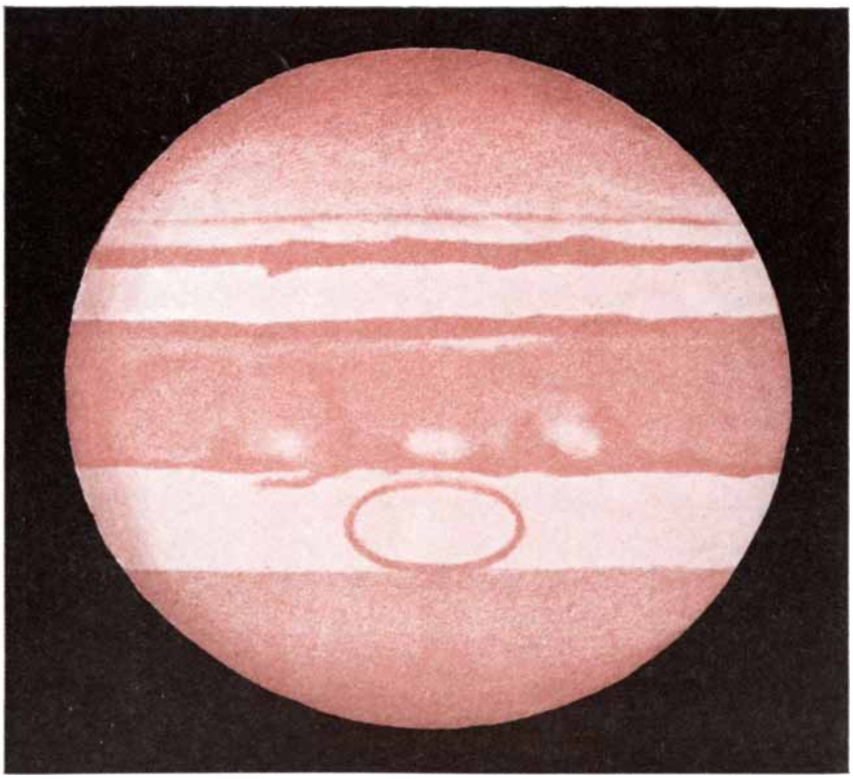








JUPITER'S BANDS are commonly called zones if they are bright and belts if they are dark. At any given time some of the bands may be indistinct or even absent. Nevertheless, most of the zones and belts shown here can be identified in the photographs on the preceding pages.



THE RED SPOT IN 1870 was drawn by Alfred M. Mayer of Lehigh University and published in a paper titled "Observations of the Planet Jupiter." A feature now believed to be the red spot was first reported in 1664 by Robert Hooke. For more than 200 years the spot had attracted so little attention that Mayer wrote in his account that the "ruddy elliptical [feature] lying just below the South Equatorial belt . . . has never before been noticed."

the tendency for the disturbance to skirt around the edge of the red spot at about 10 times the speed with which it approached the spot and receded from it.

Sixth, the color of the spot seems to fluctuate, although the changes are hard to measure. At its faintest the spot has been described as "full gray" and "pinkish" and at its most prominent as "brick red" and "carmine." In black-and-white photographs made through colored filters the spot usually shows up very dark when the filter is blue and is almost invisible when the filter transmits only red or infrared. In 1963, using the 200-inch telescope on Palomar Mountain, Bruce C. Murray and his colleagues at the California Institute of Technology compared the infrared emission of the spot with the emission of surrounding areas. They found that the temperature of the spot was about 127 degrees Kelvin (degrees centigrade above absolute zero), or about two degrees cooler than the adjacent regions.

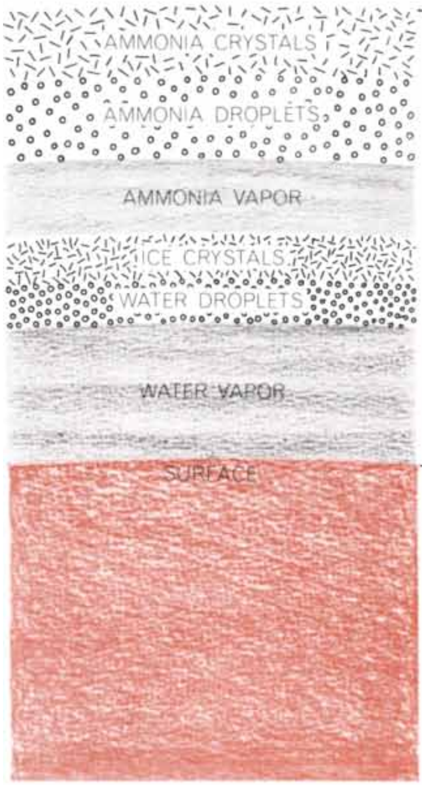
Finally, a truly satisfactory theory of the great red spot should be able to explain its uniqueness. Why are there not several spots of various sizes? Until evidence to the contrary is provided, the theorist must also assume that the red spot is a permanent feature that has existed for thousands or millions of years.

The great red spot is such a weird phenomenon that few serious attempts have been made to account for it. The raft hypothesis seems to have been first proposed in 1881 by G. W. Hough in his annual report for the Dearborn Observatory. One of its strongest advocates was Bertrand M. Peek, an amateur astronomer whose book *The Planet Jupiter* contains a valuable collection of visual observations of the planet. He proposed that the raft was mainly made up of several solid forms of water that have been produced in the laboratory at high pressures. Peek suggested that the fluctuations in the red spot's rotation period might be due to slow variations in the depth at which the raft floated in the planet's atmosphere. He also proposed that as the raft rose and fell one form of ice would change into another form with a consequent absorption or release of heat that might account for the variations in the appearance of the spot.

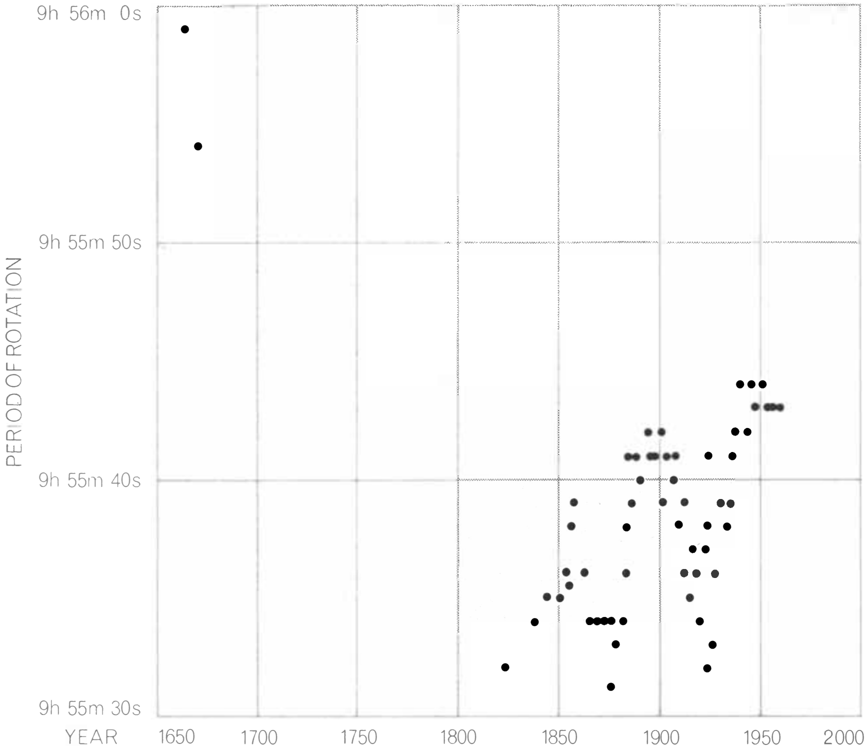
In a recent appraisal of the raft hypothesis Wendell C. DeMarcus of the University of Kentucky and Rupert Wildt of the Yale University Observatory said: "It has proved difficult to conceive of an object able to float in a surfaceless ocean of . . . hydrogen gas." They assert, however, that in principle the red spot could be a solid object with the same density as the fluid surrounding it and having the same constituents but in different proportions.

When the hypothesis has been fully tested against observation and when its other consequences have been carefully examined, it may well look more attractive than it does now. For example, Robert H. Dicke of Princeton University has suggested that Jupiter's atmospheric winds, being strongly channeled in zones parallel to the equator, might inhibit any tendency for a raft to drift in latitude. If this is so, one of the strongest objections to the raft hypothesis would be removed. One would still be puzzled, however, as to why Jupiter's atmosphere contains only one such object and how it resists disruptive forces.

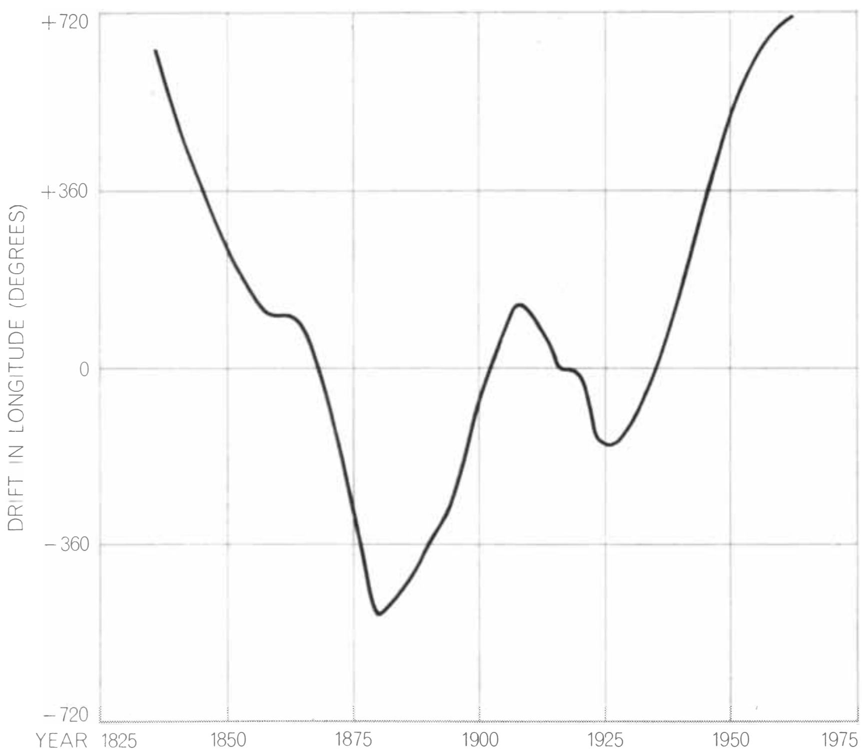
The Taylor-column hypothesis avoids many of the problems that beset the raft hypothesis. I should point out, however, that a raft could also give rise to a Taylor column. In what follows, therefore, I shall use "Taylor-column hypoth-



STRUCTURE OF JUPITER has been inferred from various lines of evidence. Although Jupiter is about 11 times the diameter of the earth and has more than 1,300 times the volume, its total mass is only 318 times that of the earth. In consequence Jupiter's density is only a third greater than the density of water. The structure and composition shown here follow studies made by P. J. E. Peebles of Princeton University. The composition of the cloud layer (*above*) is based chiefly on the work of R. M. Gallet of the National Bureau of Standards. The various substances indicated are probably suspended in an atmosphere that is mainly hydrogen. Helium and methane may also be present. At the pressures prevailing inside Jupiter it is thought that hydrogen would be crushed to a metallic form. According to one hypothesis the great red spot is a raftlike solid body floating in the atmosphere.



ROTATION PERIOD OF GREAT RED SPOT has varied considerably in the 135 years since it has been recorded with care. The variation is even greater if the earliest observations of Giovanni Cassini, made between 1664 and 1672, are regarded as accurate. It was long thought that a feature with such a variable period could not be connected in any way with the surface of the "solid" planet below, which one would expect to rotate with great constancy. But if the author's hypothesis is correct, the red spot is produced by a surface feature, either a raised area or a depression, and the planet's rotation rate is indeed variable.



LONGITUDINAL WANDERING OF RED SPOT can be visualized by defining a mean period of rotation and plotting in degrees how much the spot advances or retreats with respect to the mean. The diagram is based on one in *The Planet Jupiter*, by Bertrand M. Peek.

esis" to mean a hydrodynamic phenomenon caused by an irregularity on the surface underlying Jupiter's atmosphere.

In the simplest conceivable fluid system, in which the fluid has uniform density and zero viscosity, the effects of rapid rotation on hydrodynamical flow can be expressed in terms of a theorem first proposed in 1916 by James Proudman of the University of Liverpool. This theorem simply states that the flow must be the same in planes perpendicular to the axis of rotation.

In 1921 Sir Geoffrey Taylor recognized, and verified by experiment, an important implication of Proudman's theorem: If a solid object were to be moved slowly through a rotating tank of fluid, the object would carry with it a relatively stagnant column of fluid aligned parallel to the axis of rotation. Taylor columns can also be created by irregularities such as bumps and corrugations at the bottom of a rigid container when the fluid is in motion with respect to the container.

In considering whether a topographical feature on the surface of Jupiter might give rise to a Taylor column it is important to know how high (or alternatively how deep) the feature must be to be effective. It turns out that the height (h) must exceed a value determined by a relation involving the total depth of the fluid (D), the horizontal dimension of the topographical feature (L), the speed of the fluid over the feature (U) and finally the angular speed of rotation of the entire system (Ω). Specifically, the value of h must exceed $D(U/2L\Omega)$, all expressed in appropriate units.

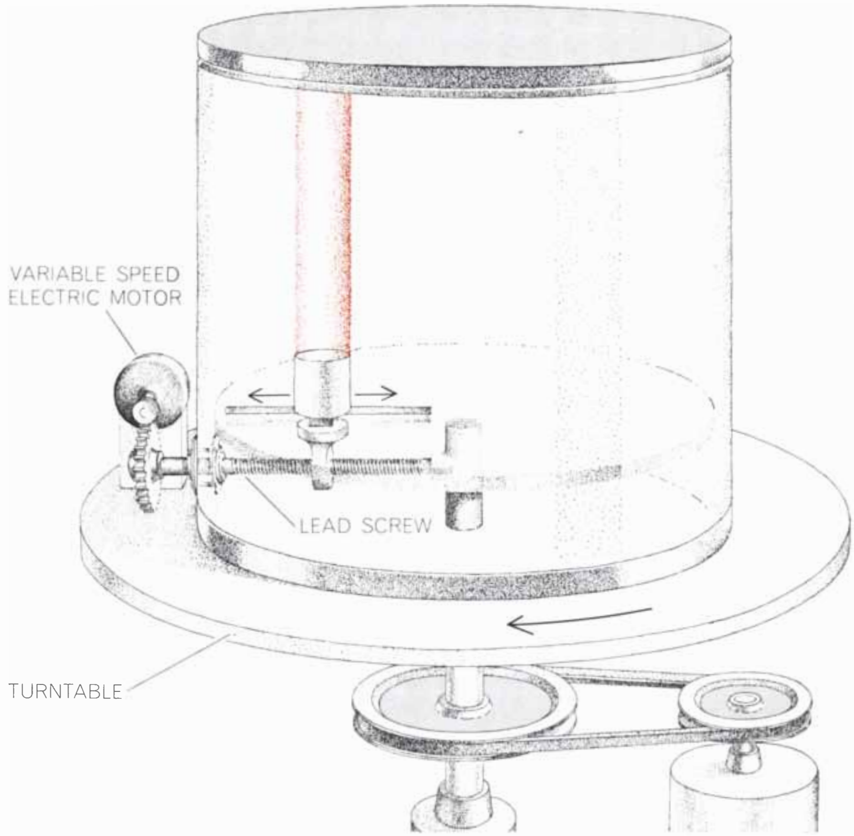
To investigate this relation, one of my students, Alan Ibbetson, and I conducted a series of laboratory experiments [*see illustrations on opposite page*]. In addition to confirming the relation, we found that some of the details of the flow patterns we observed have their counterparts in the theoretical studies of Taylor columns in fluids of zero viscosity conducted by Keith Stewartson of University College London and by Michael J. Lighthill of the Imperial College of Science and Technology. Nevertheless, certain questions concerning Taylor columns remain unanswered; both theoretical and experimental work are being continued.

The extent to which a planet's rotation influences the flow of its atmosphere depends chiefly on its size and rotation speed. The linear speed of Jupiter's surface owing to the planet's rotation is more than 25 times that of the earth. Consequently Jupiter's rotation dominates the winds in its atmosphere even more effectively than the earth's rotation dominates terrestrial winds. A measure of this "domination" is the Rossby number (R), named for the Swedish meteorologist Carl-Gustaf Rossby. This number is equal to $U/2L\Omega$, which is the factor multiplied by D in the equation given above. The smaller the Rossby number, the larger the dominance of rotation. R for large-scale motions in the earth's atmosphere is about .1. The corresponding value of R for Jupiter's atmosphere is .0002 (except near the equator, where R is .01).

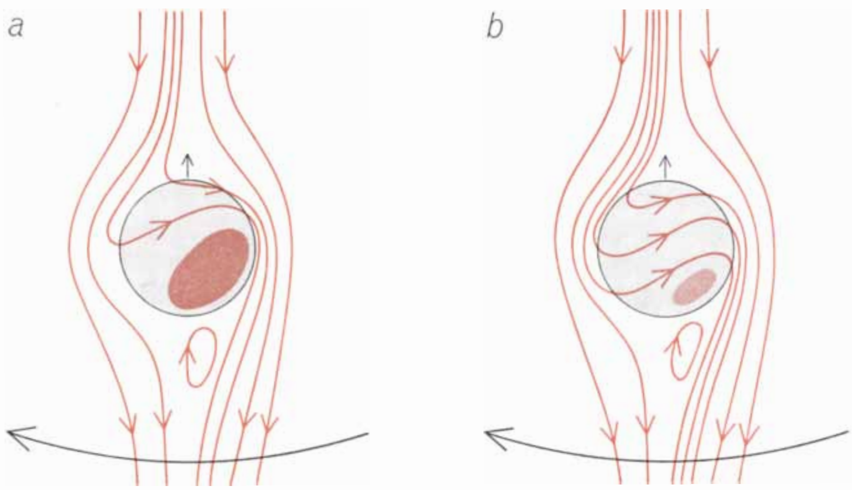
Any realistic discussion of Jupiter's meteorology would have to take account of many complicating factors, such as the nonuniform density of the planet's atmosphere and the possible effects of magnetic fields. In a first approximation, however, the complicating effects are not expected to vitiate the essential idea behind the Taylor-column hypothesis. In any case, the banded appearance of Jupiter makes it clear that large-scale winds on Jupiter must blow mainly parallel to the equator along circles of latitude, showing that the rotation of the planet indeed dominates the motions of the atmosphere.

In order to estimate the height (or depth) of a topographical feature capable of creating a Taylor column in Jupiter's atmosphere, we proceed as follows. We begin with the assumption that the atmosphere is underlain by a material of such high viscosity that it flows very much more slowly than the atmosphere; this material is the "solid" planet.

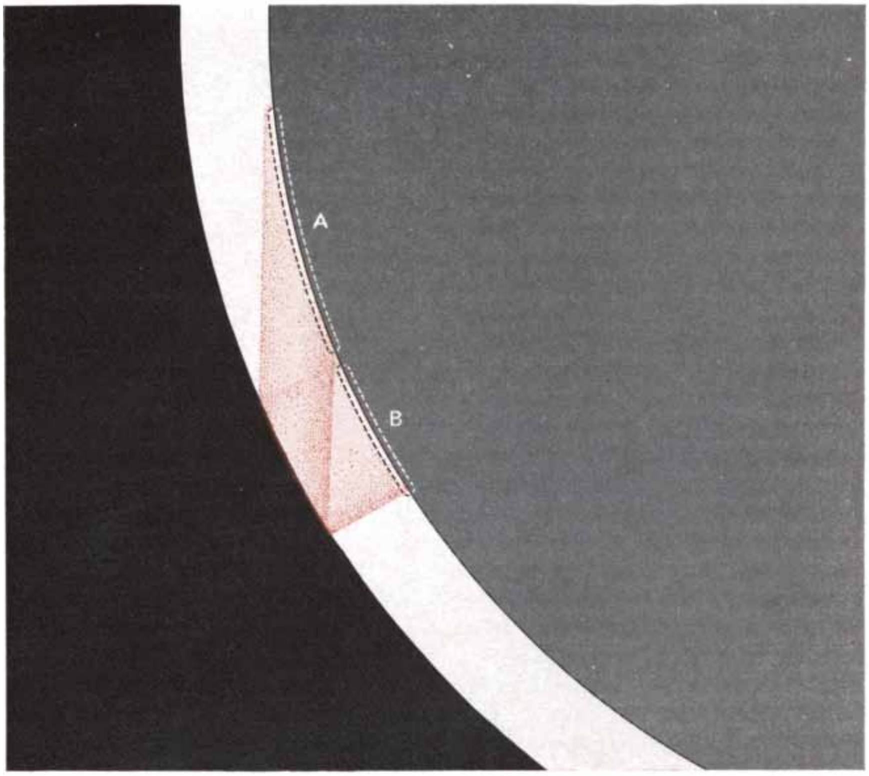
For the sake of carrying out a fairly definite calculation let us make the innocuous assumption that the depth (D) of Jupiter's atmosphere is 3,000 kilometers. Since the red spot itself is about 40,000 kilometers long let us use this as the value of L, the major horizontal dimension of the topographical feature. A plausible value for the velocity (U) of the wind passing over the surface might be two meters per second, or about four miles per hour. For this value of U the Rossby number is .0004. If one inserts these values into the preceding equation, one finds that a Taylor column will be produced if the height (or depth) of the topographical feature exceeds only one kilometer. By earth standards this is a very modest dimension, but until more is known about the mechanical properties of the "solid" part of Jupiter one cannot be sure that a topographical feature one kilometer high could in fact be supported against gravitational forces nearly three times those on the earth. The Tay-



TAYLOR-COLUMN EXPERIMENT was carried out by the author and Alan Ibbetson, using the apparatus diagrammed here. A liquid, usually water, was rotated at a uniform speed in a cylindrical tank 12.2 centimeters deep and 14.5 centimeters in radius. A short cylindrical obstacle of variable height was mounted so that it could be driven slowly across the radius of the rotating tank. The author and his colleague established the conditions under which a stagnant column of liquid, a Taylor column, would form above the obstacle.



FLOW PATTERNS OVER OBSTACLE in the experimental tank were drawn by the author and Ibbetson, who observed the streaks made by a dye tracer about 10 centimeters above the obstacle, which projected about two centimeters from the base of the tank. The obstacle was moved toward the center of the tank at various speeds while the tank and liquid rotated at about 40 r.p.m. A Taylor column formed (*colored ellipse in "a"*) when the obstacle was moved at 1.2 centimeters per minute. When the rate was increased to nine centimeters per minute (*b*), flow was diverted but no pronounced Taylor column was visible.



TAYLOR COLUMN ON JUPITER, which the author believes accounts for the great red spot, might assume various orientations with respect to either a plateau or a depression on the surface of the planet. In the simplest theoretical case (*A*) the axis of the column would be parallel to the planet's axis of rotation. But depending on the characteristics of the planet's atmosphere and other variables, the Taylor column might rise more or less vertically (*B*) above the surface feature. The depth of the atmosphere is unknown, hence not to scale.

lor column would not necessarily rise vertically over the surface feature. In the simplest case the column would have its axis parallel to the axis of rotation of the planet [*see illustration above*].

Perhaps the most obvious weakness of the Taylor-column hypothesis is one it shares with the raft hypothesis: Why should there be only one such feature or object? There is, however, a lead toward an explanation of the uniqueness of the Taylor column in Jupiter's atmosphere that has no ready analogy in the case of a raft. The conditions for creating a Taylor column discussed above show that for a given wind speed a column would not form over a topographical feature of a kilometer in height if its horizontal dimensions happened to be much less than 40,000 kilometers.

If, however, Jupiter's atmospheric winds are sufficiently variable and occasionally shift from one semistable pattern to another, it should be possible for such topographical features to give rise temporarily to Taylor columns. Clark Chapman, working in my former laboratory at the Massachusetts Institute of Technology, recently made a search for such columns, using a large amount of observational data supplied mainly by Bradford A. Smith and his colleagues at New Mexico State University. He found none. However, J. H. Focas of the Meudon Observatory in France has reported seeing "false red spots" in various locations not far from the red spot itself. Conceivably these are eddies in the downstream wake produced by the Taylor column underlying the red spot.

The other properties of the great red spot are in principle readily accounted for by the Taylor-column hypothesis. For example, the variable rotation rate of the red spot must reflect the variable rotation rate of the main mass of Jupiter. This may seem difficult to accept, involving as it does huge changes in the planet's angular momentum, but a variable rotation rate is by no means inconceivable. Since Jupiter does not rotate as a solid body, it must be constantly agitated by some energy source or other. Various lines of evidence suggest that Jupiter may still be contracting. Although the contraction would be much too slow for verification by direct observation, it could still convert gravitational energy into internal heat energy at a significant rate (a rate comparable, in fact, with the amount of solar energy received by the planet).

If the changes in the rotational energy of Jupiter were brought about entirely by frictional processes, the associated dissipation of heat would be quite excessive. The mechanical coupling between different parts of the planet need not, however, be due only to friction. The electrical conductivity of most of Jupiter's interior and lower atmosphere should be high enough for the internal magnetic field of the planet to contribute significantly to mechanical coupling. In contrast to frictional coupling, which transforms rotational energy irreversibly into heat, magnetic coupling transforms rotational energy reversibly into magnetic energy. The magnetic field involved will be mainly of the toroidal type, with a strength probably exceeding 1,000 gauss.

Observations of the intense bursts of radio emission from Jupiter provide information about the part of the magnetic field whose lines of force pass through the surface of the planet and out into surrounding space. This part of the magnetic field (the "poloidal" part) is probably much weaker than the internal toroidal field. The significance of the external field for this discussion is that the pattern of radio emission associated with it has its own period of rotation, which differs slightly from the rotation period of the great red spot. This difference, which amounts to several seconds, is expected on the Taylor-column hypothesis because the red spot motion is the motion of the "solid" planet, whereas the radio emission is related to the motion of the fluid parts of the planet where the magnetic field originates.

It will be interesting and most important, therefore, to compare future observations of the radio period with those of the red spot period, with the expectation of learning more about the dynamics and magnetohydrodynamics of Jupiter's interior. As one investigator has remarked: "This is the first instance in astronomy [where] the distribution of angular momentum within a rotating body . . . manifests itself in observational effects measurable within a short time scale." Meanwhile observers will continue to find the red spot a fascinating object. Their studies can hardly fail to turn up evidence that will help to support either the raft hypothesis or the Taylor-column hypothesis. And, of course, there is always the chance that someone will have a still better idea.

Statue of Benjamin Franklin by James Earle Fraser in The Franklin Institute, Philadelphia

Death from Staphylococci

When someone dies of staphylococcal infection, what is the specific cause of death? The answer is sought by study of the chemical events that accompany the course of fatal infection in laboratory animals

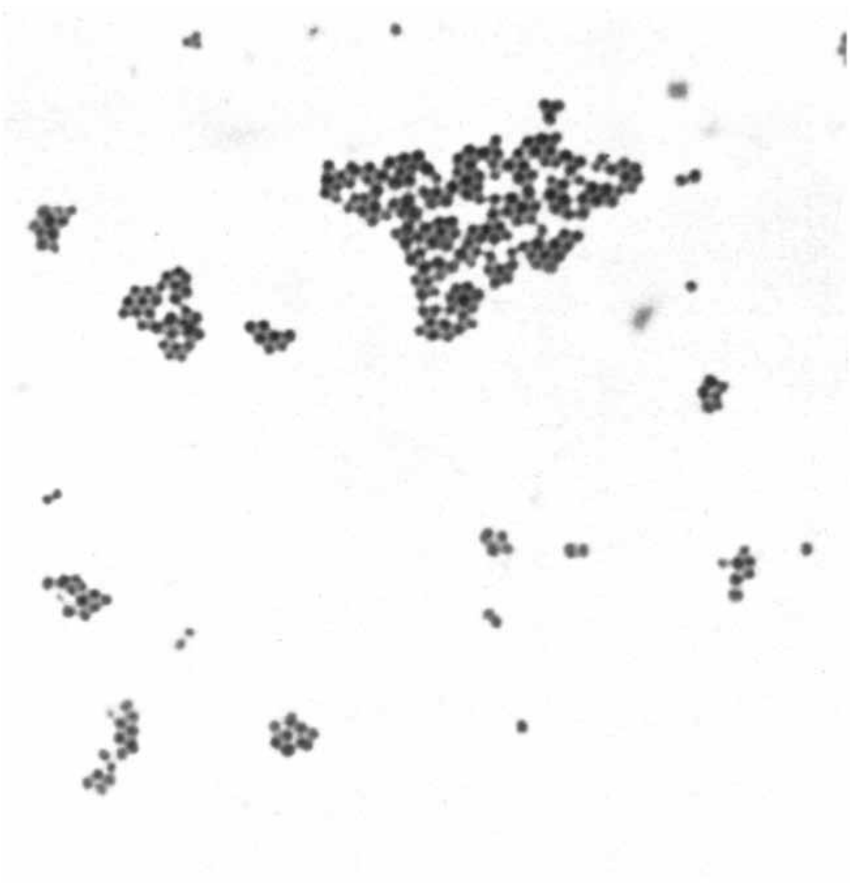
by Ian Maclean Smith

In 1879 Alexander Ogston, a Scottish professor of surgery at Aberdeen University, was given a grant of 50 pounds to do "research into the relation between bacteria and surgical disease." Infections, both those requiring the surgeon's knife and those arising from surgery, were of course a major clinical concern of the time. Ogston used the money to build a small shed as a laboratory in his backyard and to purchase some simple equipment, including a microscope with an Abbe condenser and an oil-immersion lens. He proceeded to isolate the various organisms he found in abscesses and to study them by growing them in hens' eggs or sterile urine.

Ogston was particularly intrigued by the round bacteria he discovered in pus-producing abscesses. In his cultures he found that the organisms grew in clumps like bunches of grapes, and he therefore named them staphylococci, from the Greek word for "bunch of grapes." (He also observed cocci growing in the form of twisted chains; these were later named streptococci.) Ogston was able to demonstrate that virulent forms of the staphylococcus coagulated blood, produced abscesses in guinea pigs and mice and were present in the heart blood of mice dying from blood poisoning.

Since Ogston's revealing discoveries the staphylococci and the diseases they cause have been investigated intensively—by clinicians, immunologists, microbiologists and pathologists—and there is now an enormous literature on these organisms and their interactions with their hosts. Most commonly the staphylococcus simply produces a relatively harmless boil or sty. In the lungs or the bloodstream, however, the infection can be extremely dangerous. Before the advent of antibiotics the death rate from staphylococcal pneumonia was 35 percent and from septicemia 90 percent. Treatment with antibiotics has reduced the fatality rates to 15 percent for pneumonia and 25 percent for septicemia. The staphylococci have nonetheless shown considerable chemical ingenuity in developing resistance to antibiotics. Moreover, as the noted bacteriologist René J. Dubos has shown, individual patients vary a great deal in their defenses against the infection.

It is a matter of crucial importance, therefore, to learn just how the staphylococcus kills its human host. What lethal substance or substances does the bacterium produce, and how do they act on the chemical processes of the host? Until these facts have been established



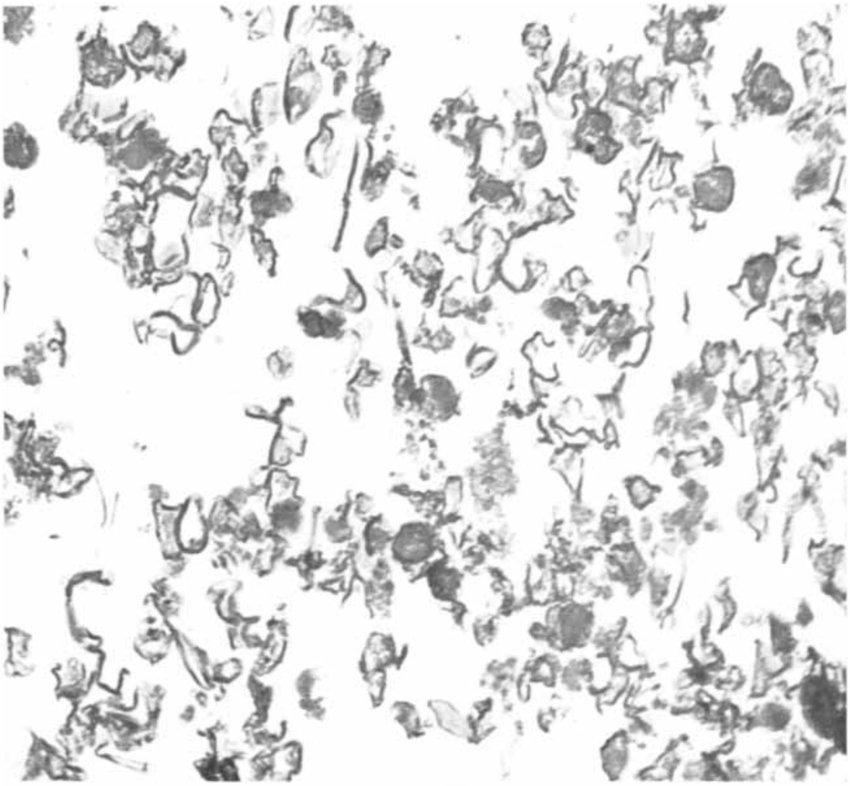
STAPHYLOCOCCI from a laboratory culture clump together like bunches of grapes, for which they were named by Alexander Ogston. These cells, enlarged 1,000 diameters, were photographed by Frederick W. Kent in the author's laboratory at the University of Iowa.

to provide a basis for definitive control, staphylococcal infection will continue to be a sizable and ever present hazard to human life.

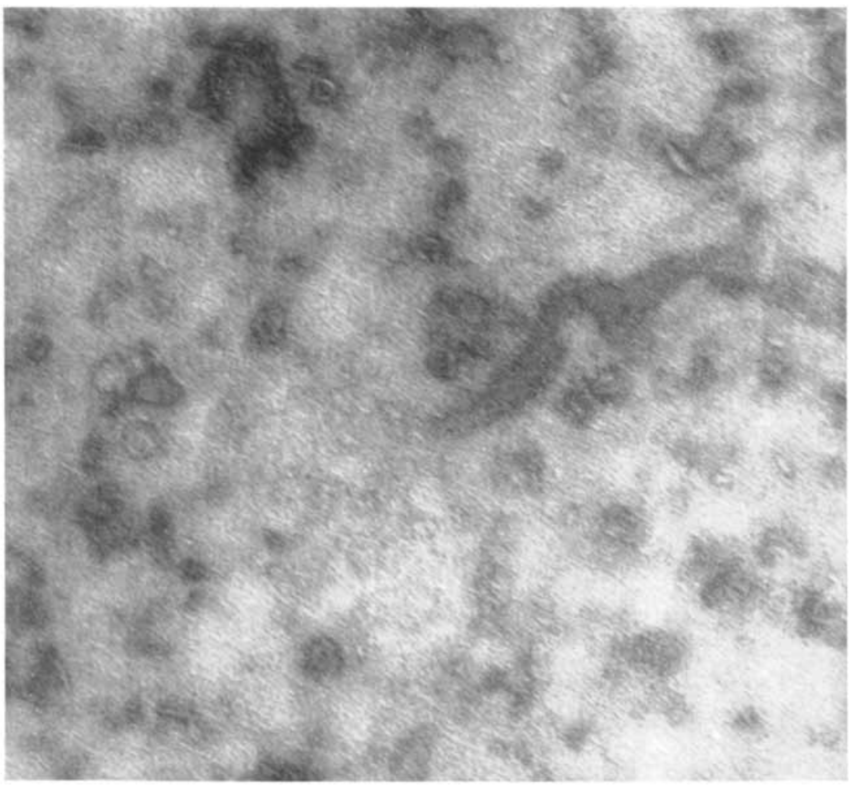
Any infection can be regarded as a chemical contest between the invader and the infected host. The best way to investigate the nature of the contest in detail is to study the reactions of the host's chemical systems to a measured challenge by the infectious agent. In the case of the staphylococcus the character of the attacker has been fairly well established. The staphylococcus cell, a small organism only a micron in diameter (about a seventh of the diameter of a human red blood cell), is a chemical factory that produces a number of potentially toxic substances. This chemical versatility greatly complicates the problem of identifying the particular chemical agent that causes the death of the host.

My colleagues and I at the University of Iowa have been conducting a systematic investigation of the effects of staphylococcal infection, using white mice as the experimental animals. We use mice rather than guinea pigs or rabbits because they are small and inexpensive, can be tested in statistically significant numbers and provide certain other advantages, such as an opportunity for chemical analysis of the ground-up carcass of the whole animal.

We first experimented with various routes and modes of infection in order to arrive at a norm, or standard, of infection that would produce death within a predictable time and would result in a typical picture of symptoms and typical involvement of organs. The minimal lethal dose was found to be from a million to 10 million staphylococci (using a strain of the bacterium Dubos had obtained from a child with osteomyelitis). We began by injecting 10 million staphylococci intravenously. Careful study of the tissues of the mouse after death showed a high concentration of the organisms and abscesses in the animal's kidneys. It turned out, however, that when the dose was inoculated directly into the brain, the kidneys did not develop abscesses; hence kidney failure was ruled out as the general cause of death in staphylococcal infection. All told we tried 11 different routes of infection, each of which resulted in a different pattern of growth of the bacteria and a different time of death. Apparently the organisms did not seek out a particular target organ where they grew at a preferential rate. The route of inoculation



CELL WALLS of *Staphylococcus aureus* do not produce lethal infections when they are injected into mice. The bacterial cells are disrupted and the cell walls are separated from the internal protoplasm by centrifugation. In this electron micrograph made by J. M. Layton of the University of Arkansas the empty cell walls are enlarged some 7,000 diameters.



PROTOPLASM of staphylococci is as lethal as the intact bacteria but does not replicate in the host, so that chemical changes in the host can be differentiated from changes caused by growing bacteria. This electron micrograph of protoplasm was also made by Layton.

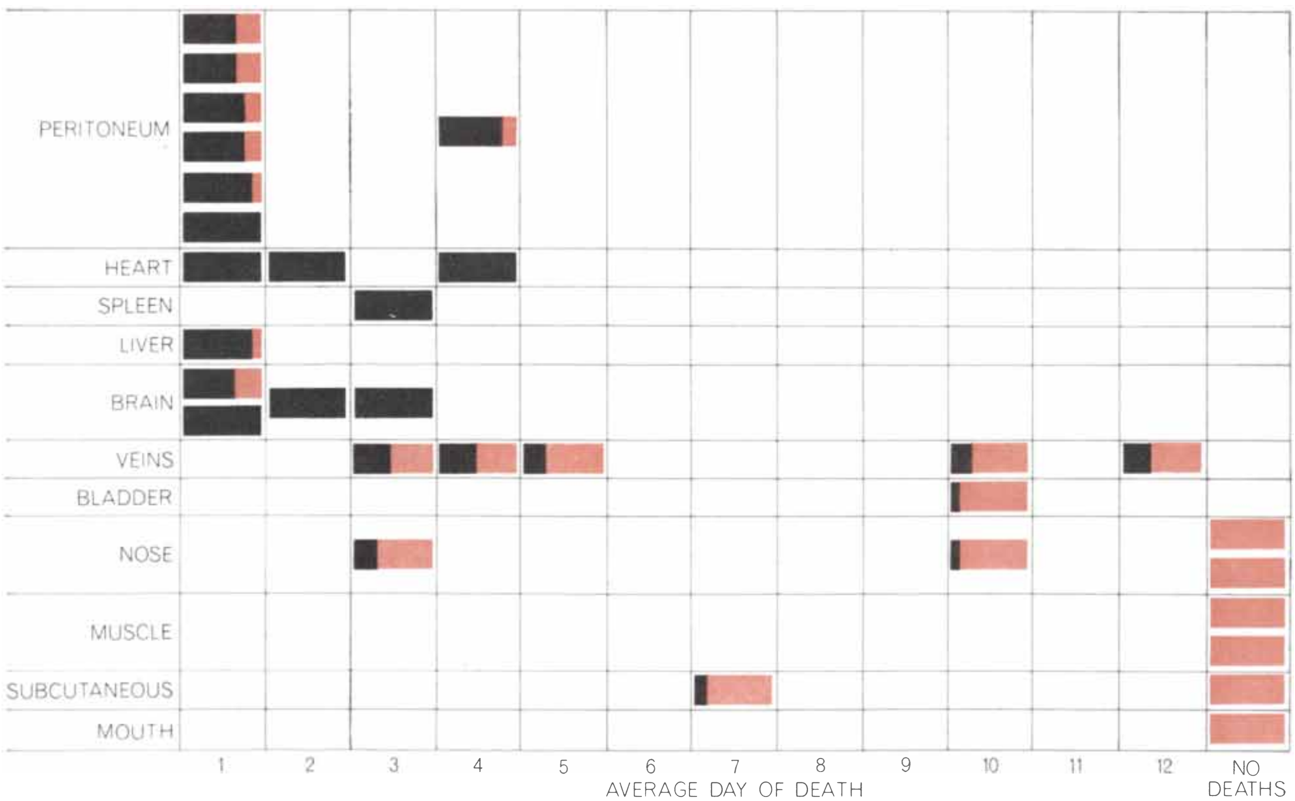
did, however, make a considerable difference in the animals' survival time. When the dose was inoculated into the peritoneum, for example, from 90 to 100 percent of the mice died overnight; on the other hand, injection of the same dose into a vein did not produce death until after the third day and did not kill all the mice.

Further analysis showed that, regardless of the route of injection, death usually occurred shortly after the total number of staphylococci in the mouse's body reached a billion. We were also able to establish that death was associated with the action of live bacteria rather than with the bacterial products alone. The mice usually survived when they were injected only with filtrates from the bacterial culture or with heat-killed staphylococci, or when live bacteria were enclosed in a filter chamber (implanted in the mouse's abdomen) that allowed the bacterial products but not the bacteria themselves to pass through. Bacteria that had been stored for seven days beforehand at 37 degrees centigrade (98.6 degrees Fahrenheit) also failed to kill the mouse. This, along with other evidence, indicated that the lethal material in staphylococci (in contrast to that of some other bacteria) is subject to breakdown by heat.

As a standard procedure for producing a lethal infection that would serve as a "model" for study of how death was brought about we settled on an injection of a billion bacteria of the *Staphylococcus aureus* strain into the mouse's peritoneum. This dose resulted in death within four and a half hours, so that we were able to proceed with chemical analyses and other studies the same day. The toxic effect of the dose on mice closely resembled the picture presented by an overwhelming and fatal staphylococcal infection causing peritonitis or septicemia in man.

We began with "bedside" observations, so to speak, of the symptoms shown by the dying mice. One striking symptom was difficulty in breathing. The cause of this difficulty is still unclear. Other symptoms indicated that the mice were reduced to a state of profound chill. They huddled together, with rufflike erections of the neck hair, and also showed bursts of overactivity (running and jumping) that ended finally in convulsions and death. Now, convulsions in an animal may be brought about by any of several causes, such as a low level of calcium or of sugar in the blood or poor oxygenation. The calcium factor was quickly ruled out as a cause of death in our mice: injection of calcium salts in the infected mice did not prolong life. Sugar, as we shall see, proved to be a significant factor. Interestingly the oxygen supply was found to have a definite effect, but opposite to what might have been expected. Patricia Barnwell found that the administration of oxygen at normal or elevated pressure did not help the infected mice, but reduction of the oxygen pressure to below normal doubled their expected survival rate! Indeed, next to penicillin this is the most effective treatment for staphylococcus-challenged mice that we have discovered, although the reason for its effectiveness is not clear.

We found that as a result of the infection the mean blood pressure of a mouse fell from the normal 112 millimeters of mercury to 76 millimeters just before death, and the mouse's bleedable blood volume dropped from .38 centimeter to .27 centimeter. Examination of the organs at autopsy showed some blood congestion, indicating a stagnation of the circulation. There was no increase of lac-



FATALITY RATE and time of death are shown for mice challenged with 10 million staphylococci administered by different routes. Each bar represents a group of 10 mice and shows how many died (*black*) and how many lived (*color*). The location of each bar shows the average day of death for those animals that died. Peritoneal injection was selected as the standard procedure.

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Electronic troubleshooter takes pulse of giant plane • Ultra-fast memory system speeds handling of huge data quantities • Statistical approach reduces Lunar Orbiter photo information • Compression techniques now can reduce telemetry data by 80%

Ways to cope with exploding masses of data—by storing it, speeding it, reducing it, converting it, analyzing it—together with new methods for gathering still more vitally needed facts, are becoming prime concerns among scientists, businessmen and administrators alike. Lockheed's involvement in this great numbers game is producing new kinds of hardware and fresh approaches to growing problems. Below are some samples of current Lockheed information projects.

Madar. In 1968, the maiden flight of the largest airplane ever built also will mark a first in airborne information systems. MADAR (malfunction detection analysis and recording), a maintenance management tool, was chosen by the U.S. Air Force to monitor the giant C-5A.

Lockheed's MADAR system is a combination of sensing, computing and recording components. It automatically provides information on dozens of a plane's critical subsystems through hundreds of test points. It monitors and records conditions, making comparisons between actual and expected data. It classifies performance usually as either "go" or "no go."

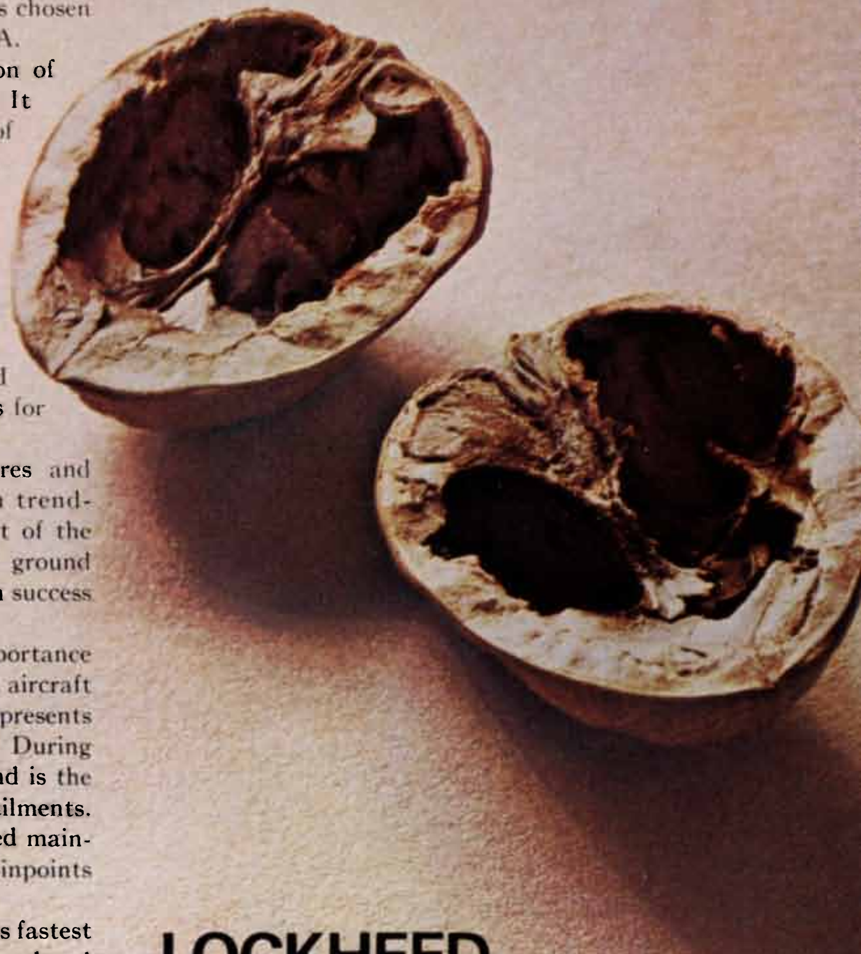
When a "no go" condition is found, MADAR records the LRU (line-replaceable unit) number, time and date. It alerts the flight engineers and pinpoints the problem, printing out instructions for immediate repair.

At programmed intervals, MADAR measures and records all instrumented functions to obtain trend-significant data. This information becomes part of the ship's statistical history. After processing by ground equipment, these data are used to predict mission success and improve maintenance cyclic rates.

The value of MADAR, besides the obvious importance of in-flight repairs, is considerably increased aircraft utility. The total picture of capability MADAR presents adds to the accuracy of readiness evaluations. During flight, the system confirms success prediction and is the basis for determining mission extensions or curtailments. It also lowers operating costs by reducing needed maintenance man-hours for troubleshooting and pinpoints the skill level of maintenance men required.

500 nanosecond memory system. The world's fastest ferrite core memory system now has been developed and put into production by Lockheed. Complete memory

Putting information in its place



LOCKHEED
LOCKHEED AIRCRAFT CORPORATION

cycle time is 500 nanoseconds (2 million storage and retrieval functions per second) and storage capacity is in excess of 1 million bits.

Section showing 18 mil ferrite memory cores wired in 2½D organization. Magnified 12 X.

At the heart of the system are Lockheed-produced 18-thousandth-inch-diameter lithium ferrite memory cores. Through each of these toroid-shaped cores pass 3 wires—X drive, Y drive and sense—utilizing a 2½D organization for storage and retrieval of binary digital data.

The 2½D organization provides inherently greater operating margins by eliminating the inhibit current required in 3D organization. This is because absolute current tolerance, dictated by the knee of the memory core, is divided between only X and Y currents, rather than X, Y and inhibit currents.

Another advantage of 2½D organization is that the Y lines essentially are driven on a bit by bit basis. Because both the number of cores linked is small and the length of each Y line is short, resultant circuit requirements are considerably less stringent, permitting simpler, more economical circuit designs.

The most important advantage gained from the new system—higher speeds—stems from eliminating the inhibit current. Without this current, associated transient current on the sense line disappears, thereby removing a major obstacle to faster operation.

Now available, large-scale, ultra-fast 2½D memory systems offer definite economies for applications where capacity is 16,000 words and above. In total, the 2½D organization's advantages add up to the most significant innovation in high-speed memory technology during the past decade.

Lunar orbiter data conversion. To define a single high-resolution photograph (covering 20 square miles of the moon's surface) beamed back by the Lunar Orbiter takes approximately 30 million computer words of 36 bits each. That is unless the computer can use statistical analysis on selected portions of the photograph, thereby greatly reducing the number of words needed.

Achieving this end, Lockheed designers have created the Lunar Orbiter Data Conversion System. Incorporated in the system is electronic equipment carefully integrated to provide the accuracy and intricate timing required by the statistical approach. Besides equipment to transfer data from magnetic tape into the computer, the LODCS features a display system used to visually evaluate and photograph both raw data and computer-reconstituted data.

The immediate application for the LODCS is to help find the best landing site for Apollo astronauts. In the future, the system holds promise for use in other fields.

Data compression. With every successful space shot, mountains of new technical data pour in for processing. So much that stored masses of information are overflowing archives. Ground networks are reaching the saturation point; their ability to handle vital real-time data is becoming overtaxed. Among the consequences are increasing preflight checkout times...and costs.

Well aware of this growing dilemma, Lockheed researchers have been pursuing techniques to compress amounts of data since 1960. An idea once used only by human analysts and for processing data off-line, data compression now has been made workable for on-line service—including space vehicle telemetry data.

Basically, compression minimizes data by eliminating redundant samples. The number of total data samples to the actual number used is the compression ratio.

Lockheed's studies, both theoretical and computer-simulated, produced a telemetry data compressor that can handle up to 1,024 separate data channels. It will accept inputs either directly from a telemetry multiplexer-encoder or from a telemetry decommutation station...and at more than 50,000 words per second.

Besides telemetry data, a wide variety of inputs can be compressed effectively—such as facsimile and video information, biomedical data and industrial process data. Currently, compression ratios of 4:1 to 6:1 are being achieved. And with new improvements in techniques, ratios of 50:1 or more can be reached without significantly degrading data.

Television picture taken during GEMINI mission. Left: as originally taken. Right: reconstructed from 6:1 compressed data.

The activities mentioned here are only a few of Lockheed's current R&D projects in data handling. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California. An equal opportunity employer.

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tate in the blood, however, and this suggested that in spite of the slowing of circulation the oxygenation of the tissues had remained adequate during the infection.

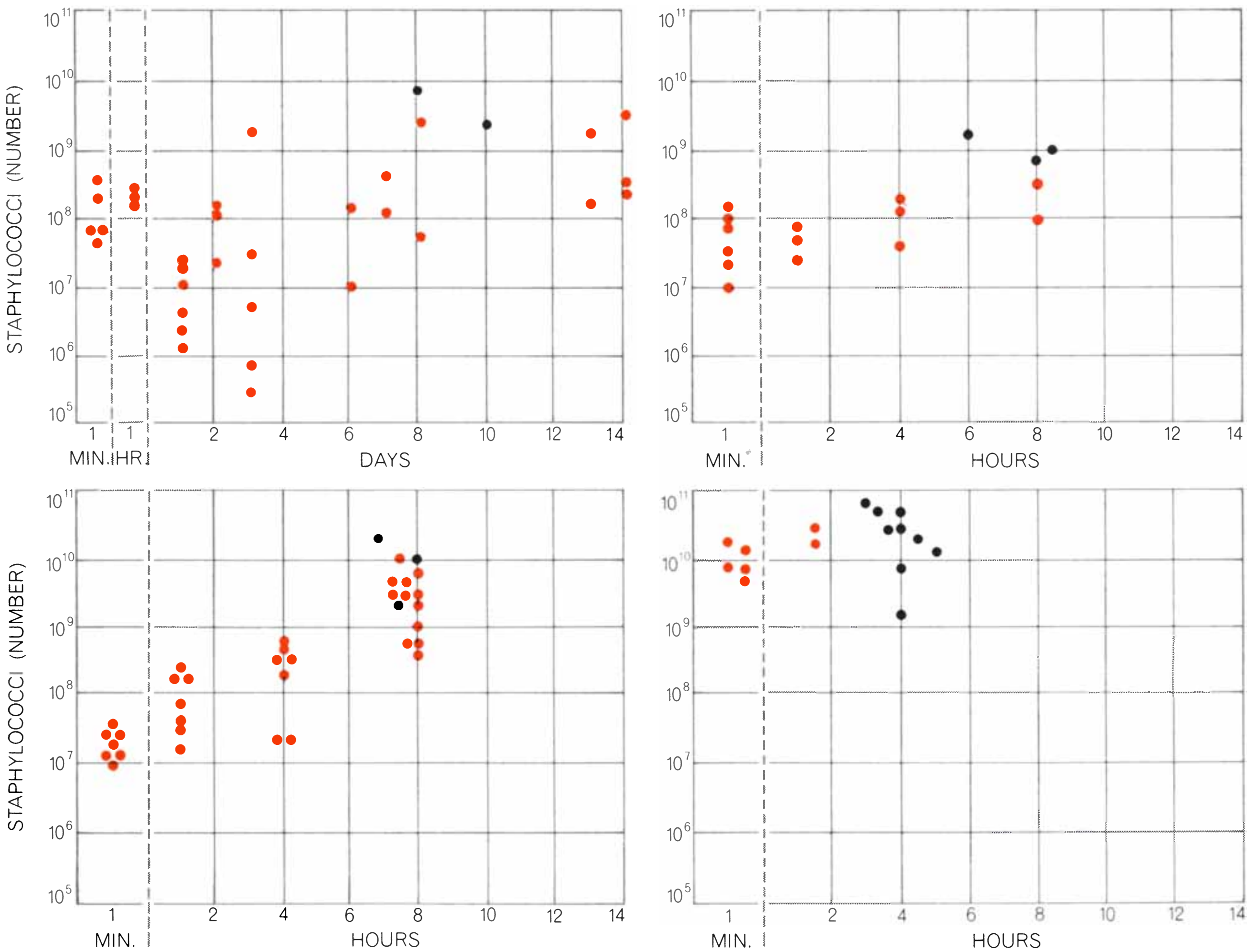
The liver and spleen lost from 5 to 10 percent of their normal weight, and the adrenal glands gained 40 percent. Apart from this and the blood congestion, however, there were no obvious changes in the vital organs that could be detected even by careful microscopic inspection. Our group next proceeded to search for changes in the chemical makeup of the challenged mice.

By various techniques Shirley S. Lindell, George W. Counts and Joseph I. Routh discovered an extensive complex of alterations in the body chemistry of the mice. The total amount of protein declined, and there were certain subtle changes in protein metabolism; for example, the liver and spleen showed an increase in saline-insoluble protein, and the kidney showed a concomitant decrease. There were similiar fluctuations in the lipid content of the body organs. The total amount of lipids rose in the first two hours after injection of the staphylococcal dose, but by the time of death the amount of cholesterol had fallen to below the normal level. The liver and heart had a deficiency of total lipids, the kidney and muscles an excess. Another chemical change was an increase in the acidity of the blood.

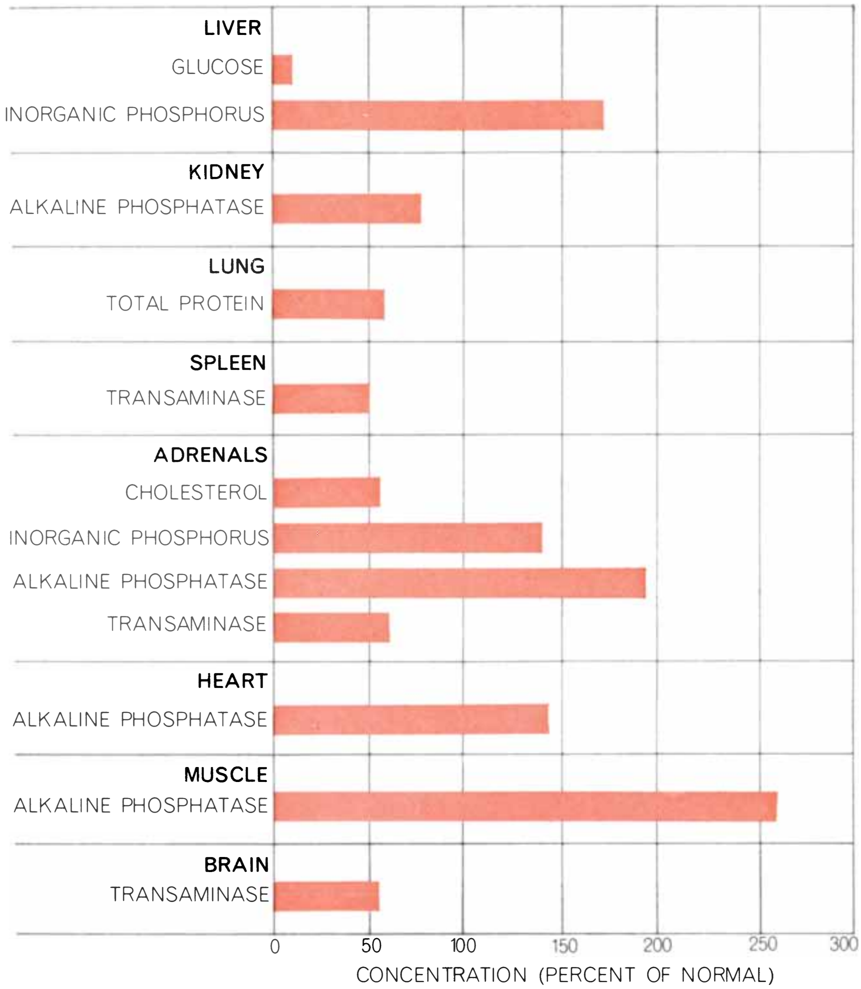
The most significant of the chemical changes, however, were a marked decline in the total body glucose (sugar) and increases in the amounts of inorganic phosphates and transaminase, an enzyme involved in phosphate reactions. We concentrated most of our research on these changes, because there were several indications that carbohydrate metabolism might hold the key to the interaction of staphylococci and the living body. For one thing, we found that the glucose content did not decline in a mash of ground-up mouse tissue exposed to the challenging number of staphylococci. Further, treatment of an infected mouse with penicillin not only led to the mouse's recovery but also stopped its loss of glucose. On the other hand, when the animal's sugar supply was depleted in advance by diet, treatment with insulin or forced exercise, a given dose of staphylococci produced a markedly more severe infection.

The most dramatic change involving sugar took place in the animal's liver, the body's principal reservoir of sugar in the form of glycogen (animal starch). Judith Nelson found that in mice near death from staphylococcal infection the liver had lost a considerable amount of glycogen. Glycogen had also dropped to a low level in the brain, presumably because the disease process had used up the supply in those organs.

The fact that sugar, one of the body's



ACCUMULATION of staphylococci in the bodies of mice varied with the site of injection. The charts give results for injection in a vein (*top left*) and in the brain (*top right*) and for normal (*bottom left*) and massive (*bottom right*) injections in the peritoneum. Each dot gives the whole-body bacterial count for a mouse that was killed (*color*) or that died (*black*) after the indicated elapsed time.



CHEMICAL CHANGES in the organs of infected mice are charted. Each bar shows the concentration of a substance as a percent of the normal amount. Note glucose and inorganic phosphorus changes in the liver and increased alkaline phosphatase in adrenals and muscle.

chief chemical sources of energy, played so important a role in the disease process led to studies by K. L. Mukherjee, a visiting professor from India, of the effects of staphylococcal infection on the energy-producing machinery, particularly on the production of adenosine triphosphate (ATP) by oxidative phosphorylation. As I have mentioned, infected mice showed a substantial rise in the level of inorganic (that is, degraded) phosphate, and this was especially marked in the liver (as well as in the blood). A corresponding decrease in the level of high-energy organic phosphates accompanied this increase. Did staphylococcal infection, then, interfere in some way with the synthesis of high-energy phosphate?

The mitochondria of the liver cells are important sites for the synthesis of ATP by oxidative phosphorylation in animals. The fuel for energizing the cycle of synthesis is derived in large part from glucose. The cycle consists in a series of oxidation and reduction reactions that pass along pairs of electrons, and ordinarily each pair generates the formation of three molecules of ATP, with one oxygen atom consumed for each synthesis. Under some circumstances, however, part of the energy released during the passage of the electrons down the respiratory chain is lost as heat, and in such cases fewer than three molecules of ATP are formed. This situation is called the "uncoupling" of oxidative phosphorylation [see "The Membrane of the Mitochondrion," by Efraim Racker, page 32].

The oxidative activity of infected mouse liver tissue was investigated by Curtis H. Rhoden in our laboratory in tissue suspensions in a Warburg flask. It was found that such tissues, when taken from a mouse dying of staphylococcal infection, showed a markedly higher than normal uptake of oxygen. Presumably this reflected a hyperactivity of the mouse's metabolic defenses against the infection. Most significant, we found evidence suggesting that staphylococcal infection may cause uncoupling of oxidative phosphorylation in the mouse liver. We also found that the administration of dinitrophenol, a chemical that is known to produce such uncoupling, hastens the death of staphylococcus-infected mice.

Consideration of possible countermeasures against the staphylococcus raised an interesting question. Of the various chemical changes that occur in an infected mouse, which ones could be attributed to activities of the multiplying staphylococci and which to the defensive metabolic activities of the animal itself? Obviously in order to investigate this question it would be helpful to establish a form of staphylococcal infection that did not involve multiplication of the bacteria. Yu-lin Kong of our laboratory succeeded in doing this. The staphylococcus cells are broken down by means of agents that weaken and rupture the cell walls, so that the internal protoplasm can be separated from the wall material. The separated materials cannot by themselves reproduce complete cells. We have found that injection of the cell-wall material into mice does not kill the animals, but the internal protoplasm, when injected, has proved to be as lethal as the injection of intact staphylococcus cells. (This situation is somewhat unusual; in gram-negative bacteria, for example, the cell walls contain the lethal material.) The staphylococcal protoplasm kills mice as quickly as living staphylococci do and produces approximately the same biochemical disorders in the animals. We are now in a position to investigate the animals' chemical defenses in detail and perhaps to determine how the induced biochemical disorders may lead to death.

In the meantime Sergio Rabinovich and Elia Hazard have carried on an empirical search for chemical treatments that might counteract staphylococcal infection in mice. Much of this research has been directed toward replacing body substances that are depleted by the infection. Among the obvious deficiencies the only one that has responded to treatment is the glucose deficiency: an injection of sugar after a mouse has received a lethal dose of staphylococci significantly lengthens the animal's life. A general search for possible other deficiencies turned up a few new suspects that had not previously been detected. Injections of testosterone and of extracts from the liver and adrenal glands proved somewhat effective in prolonging the life of infected mice, which suggests that the infection may destroy some hormones and other trace substances.

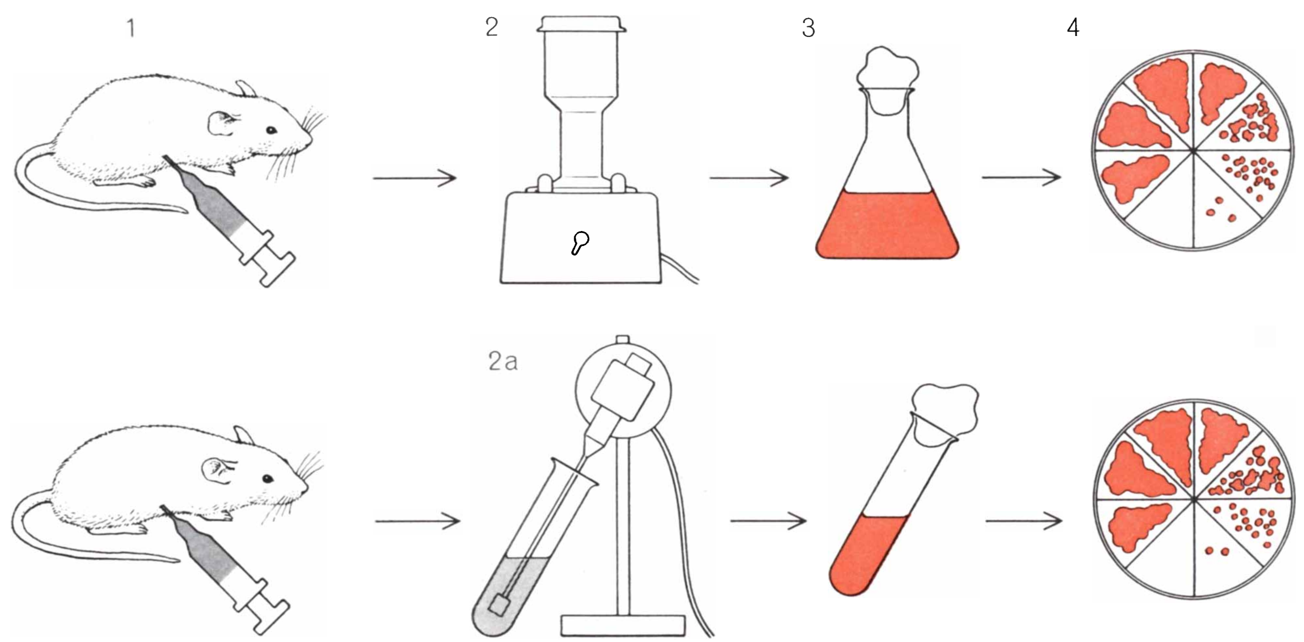
Correction of the infection-induced acidosis of the blood (by injection of sodium lactate, sodium phosphate or sodium bicarbonate) has also proved effective in delaying death, and so has the administration of sedatives that control convulsions. Cortisol, a drug that is known to enhance the general defenses of the body against stress, provided interesting results when it was applied to the staphylococcus-infected mice. In the doses customarily used for other stresses it had no effect, but very large doses (five milligrams for a mouse weighing 15 grams) markedly increased the mice's resistance to staphylococcal infection if the drug was injected after the animals had been inoculated with the bacteria. When the drug was administered two to three hours before the staphylococcal challenge, however, it gave the animals no protection, although the treatment did raise the liver-glycogen and blood-sugar levels. This suggests that the drug's protective mechanism does not involve sugar metabolism.

Studies of the chemistry of staphylococcal infection have been done on other animals besides mice. For example, a group at Texas Christian University recently reported the results of extensive chemical investigations with chick embryos as the experimental subject. They found that staphylococcal infection brought about increases in the levels of glucose, glycoprotein and cholesterol in these embryos—in contrast to what we had found in mice. Another marked discrepancy emerged in their observations of respiration, or the uptake of oxygen. Whereas we had found that the liver tissue of mice showed a distinct rise in oxygen uptake after staphylococcal infection, the Texas Christian investigators observed no such effect in the liver tissue of the chick embryos, although respiration did increase in the embryos' brain tissue. Very likely at least some of the discrepancies between our findings in mice and those in chick embryos are explainable by chemical differences between the animals. It is well known, for example, that egg yolk is particularly rich in cholesterol.

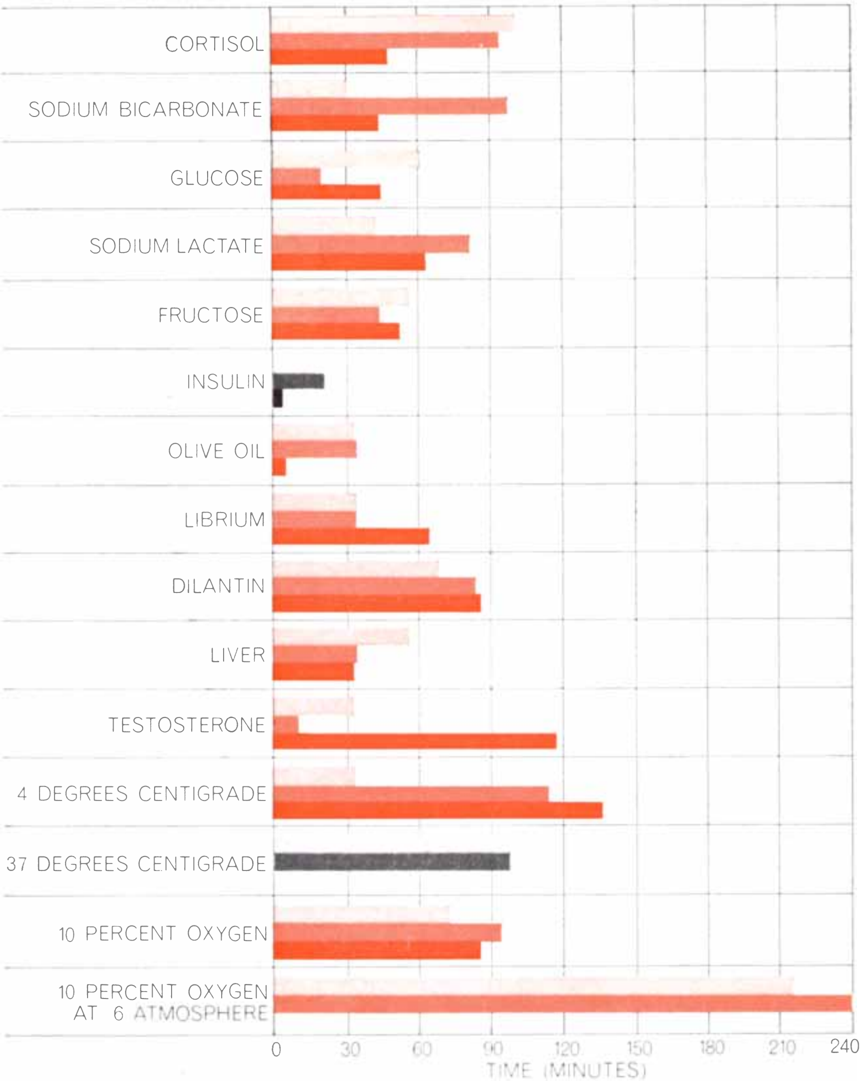
What conclusions can be drawn from the animal studies that may be applicable to fatal staphylococcal infections in man? Unfortunately it is very difficult to obtain similarly detailed information about the chemistry of the human patients. We have managed to collect some chemical data by analyzing records of blood tests from 273 patients dying of septicemia or pneumonia caused by *Staphylococcus aureus*. They proved to have a high level of sugar in the blood. Although this does not necessarily mean the total amount of sugar in the body was elevated, it did indicate that such patients probably are afflicted by some kind of chemical disturbance involving sugar. We also found that, as in the mouse, the patients had deficiencies of protein and albumins and showed a marked rise in certain breakdown products from protein: urea nitrogen and creatinine. We were unable to determine whether or not the infection had caused any change in the patients' levels of inorganic phosphates, cholesterol or transaminase, as there were not enough data on these substances in the blood for accurate assessment. The patients' blood contained higher than normal levels of potassium and chloride, which is not the case in mice.

Burton A. Waisbren and François Abboud of the Marquette University School of Medicine compared the blood chemistry of patients who died of incurable staphylococcal septicemia with that of patients who recovered after treatment. Their main finding was that the fatal cases were distinguishable from the others by a rise of nonprotein nitrogen in the blood. We had noted that such a rise was an unfavorable prognostic sign in septicemia patients.

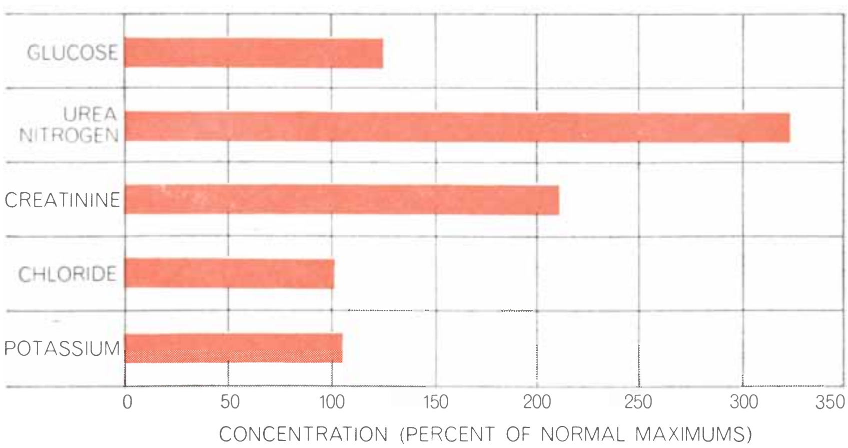
So far only a few investigators—too few—have taken up the fundamental search for the chemical answers to fatal staphylococcal infection. As Ogston remarked more than 80 years ago, the subject is still "only in its infancy." There is good reason to believe that a coordinat-



GROWTH OF BACTERIA in infected mice was studied as shown in these drawings. The mouse received an injection of a billion staphylococcus cells in the peritoneum (*1*). After death the entire carcass or a dissected organ was homogenized in a blender (*2*) or with a grinding device (*2a*) respectively. The resulting preparations (*3*) were plated on cultures (*4*) for a count of staphylococcus cells.



EFFECTS OF TREATMENT are shown. Each bar represents a group of 10 mice infected with a billion staphylococcus cells and either injected an hour later as shown or kept in a modified environment as shown. The length of the colored bars shows how much longer treated animals lived than control animals infected at the same time but not given any treatment. Both insulin and the warm environment shortened life instead of prolonging it (*gray bars*).



HUMAN PATIENTS who had died of staphylococcal infections were studied through analysis of blood tests made either the day before death or on the day of death. Statistically significant data could be obtained for only a few chemicals, for each of which the concentration in the blood is indicated as a percent of the maximum of the normal range.

ed attack by people trained in microbiology, physiology and biochemistry could now lead to answers that would bring this particular hazard to life under control.

The infection model applied to mice has defined the problems to be solved rather clearly. Let me summarize what has been learned so far. Infected with a lethal dose of staphylococci injected into the peritoneum, mice respond with rapid and deep breathing, profound cold, convulsions and death within a few hours. Death comes only after the bacteria have multiplied to a certain total number in the body, regardless of the particular sites of their growth. There are pronounced changes in the body chemistry of the host and some elements of shock in its general reactions. We have learned that the survival of the infected mice can be lengthened significantly by restoring their lost sugar, by neutralizing their acidosis, by reducing their hyperactivity, by giving them very large doses of cortisol or (most enigmatically) by lowering the oxygen content of the air they breathe.

The infected animal shows a profound loss of glucose and has an increase of inorganic phosphate at the expense of organic phosphates. These changes are most marked in the liver. Many signs indicate that the answer to the ultimate cause of death probably lies in the liver, and that it is intimately related to carbohydrate metabolism. The biochemical evidence suggests that the staphylococci or some active chemical produced by the living bacteria may upset oxidative phosphorylation at the mitochondrial level, possibly by uncoupling. We are hopeful that it will be possible to hunt down the specific material in the staphylococcal protoplasm that does the fatal damage and to identify the vital target in the host cells that it attacks.

It is tempting to speculate on the possibility that the precise point of attack is the respiratory chain of enzymes. If more fuel (glucose) is provided at one end of the chain and if electron transfer is hindered at the other end by lack of oxygen, perhaps the wasteful burning of oxygen without energy transformation is delayed, thus explaining why the mouse lives longer. In the treatment of a moribund human patient, perhaps substances affecting this metabolic process might delay the lethal effects of staphylococci, thus giving antibiotics a chance to act. Anything that will stave off irreversible changes in the patient's physiology can eventually contribute to the saving of lives.

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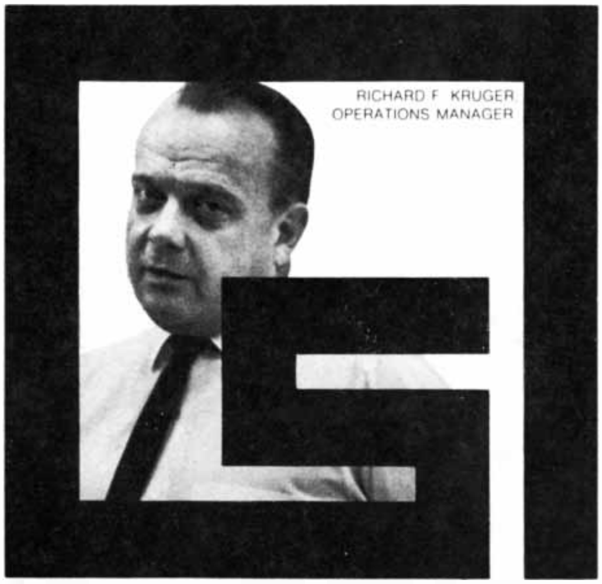

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STUDIES IN SELF-ESTEEM

The opinion an individual has of himself is clearly an important component of his behavior. How this component is shaped and how it influences personal conduct is investigated in a group of boys

by Stanley Coopersmith

One of the more significant concerns of modern society is how to produce competent and self-respecting citizens. Faced with conditions of poverty, increasing expectations and changing values, the public has turned to psychologists and other behavioral scientists for guidance. The question is no longer how to avoid maladjustment and insecurity but rather how to generate those capacities that enable an individual to function effectively in his private, personal and public activities. This emphasis on the constructive aspects of personality marks a change from the traditional ways of thinking about mental and behavioral disorders. Whereas earlier theories focused on difficulties that were already present and sought to determine how they arose, current efforts are concerned with the processes by which healthy and effective individuals develop. This "approach to health" orientation rather than the "avoidance of illness" one is consistent with views in the modern medical sciences. According to such views procedures that develop the resistance of the organism are far preferable to attempts to treat symptoms after they have arisen. It is much more sensible, for example, to immunize the population against poliomyelitis or smallpox than to try to treat the ravages produced by these infections.

Applying the same reasoning to the problem of psychological health, we should devote more attention to finding specific ways to build up the constructive capacities of human personality so that it can deal effectively with the stresses to which it will inevitably be subjected and can eliminate those conditions that have destructive consequences. The strategy of strengthening the organism is the same for psychology as it is for medicine, with the major difference that psychology focuses on the acquisition of socially learned capacities and skills rather than taking physiological measures.

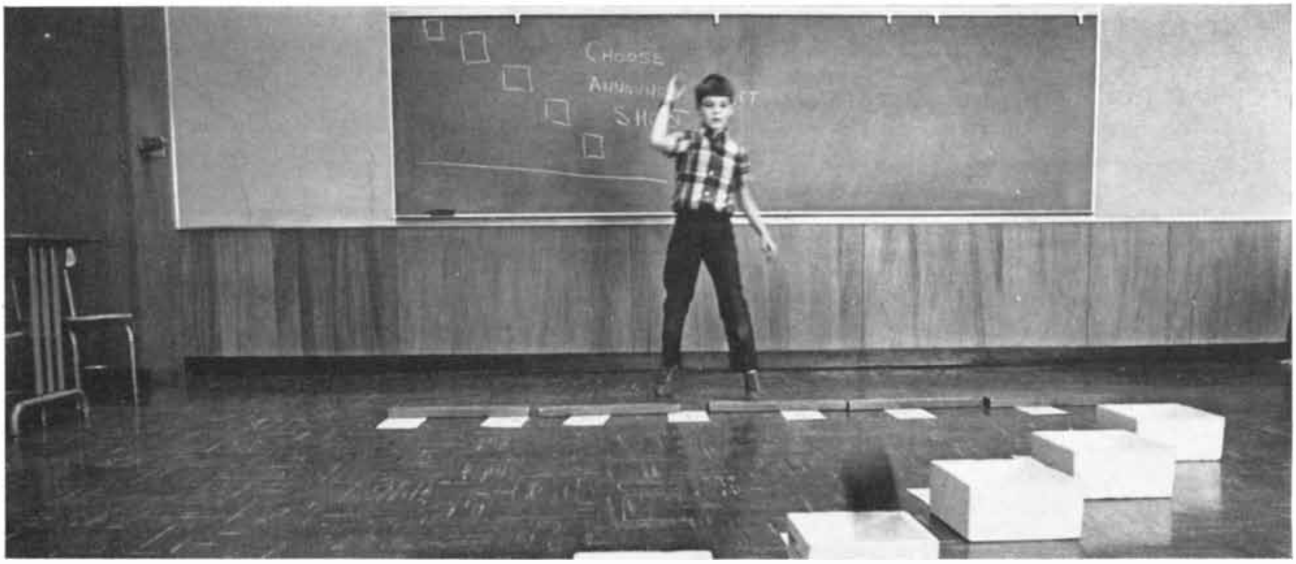
This requires first of all that we identify more specifically than has been done in the past just what those constructive resources and potentialities are. We also need more detailed and accurate knowledge of what kinds of experience are necessary for the development of competent and effective behavior and feelings of inner comfort and acceptance. The main requirements for such development are rather obvious. They include expectations of success (hope), motivation to achieve, initiative and the ability to deal with anxiety. Probably the most important requirement for effective behavior, central to the whole problem, is self-esteem.

Philosophers from time immemorial have recognized that the feeling of personal worth plays a crucial role in human happiness and effectiveness. Only recently, however, have self-esteem and its effects received systematic study. Among the first modern thinkers to write on this subject, early in this century, were the psychologist William James, the philosopher George H. Mead and the psychologist Alfred Adler. The last, of course, founded his system of diagnosis and treatment on the negative aspect of this theme: that feelings of inferiority and inadequacy underlie many neurotic disturbances.

James shrewdly observed: "A man ... with powers that have uniformly brought him success with place and wealth and friends and fame, is not likely to be visited by the morbid diffidences and doubts about himself which he had when he was a boy, whereas he who has made one blunder after another and still lies in middle life among the failures at the foot of the hill is liable to grow all sicklied o'er with self-distrust, and to shrink from trials with which his powers can really cope."

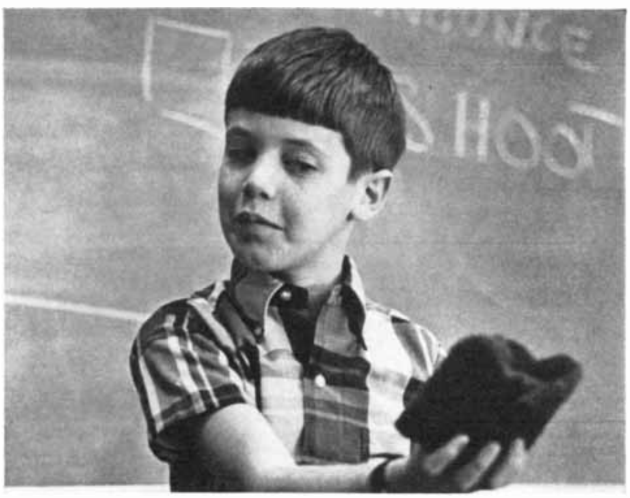
Although the importance of self-esteem in influencing behavior is widely appreciated, most of the ideas and evidence on the subject remain rather vague and intuitive. Clinicians are well aware in a general way that many of the disturbed patients who come to them for treatment feel themselves to be incompetent and socially rejected. It is universally recognized that self-confidence and an optimistic assessment of one's abilities contribute markedly to business success and the formation of friendships. There is also a popular belief, less firmly based, that the development of self-esteem depends on physical attractiveness, ability, social status and material welfare.

Objective and scientifically organized research is now beginning to produce a body of tested information on the subject. Over the past eight years a group of us, working with the support of the National Institute of Mental Health first at Wesleyan University and then at the University of California at Davis, have conducted a series of studies of self-esteem, applying the techniques of modern clinical, laboratory and field investigation. The social scientists involved in these studies were Betty James Beardslee, David G. Lowy, Alice L. Coopersmith and myself. Our subjects were a representative sample of normal boys whom we followed from preadolescence to early adulthood. Starting with thorough examinations of their self-esteem (as indicated by various criteria) and their abilities, personality traits, attitudes, behavior and family background, we later observed how they fared in dealing with school, job and social demands as they grew up.

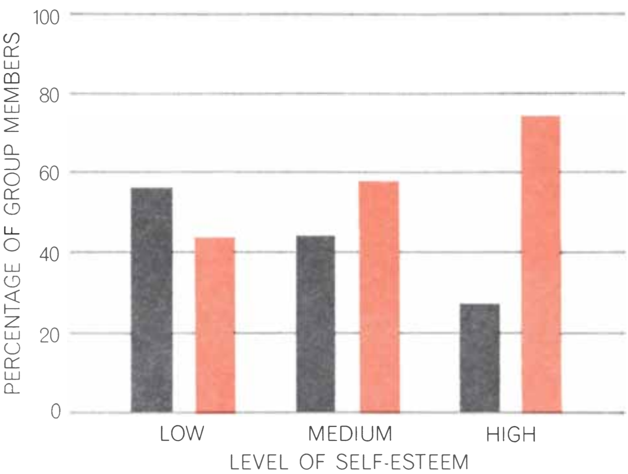


BEANBAG EXPERIMENT was designed to explore the relation between a subject's level of self-esteem (as determined from other tests) and the level of the goals he sets for himself. A higher score could be won by tossing the beanbag into a more distant target.

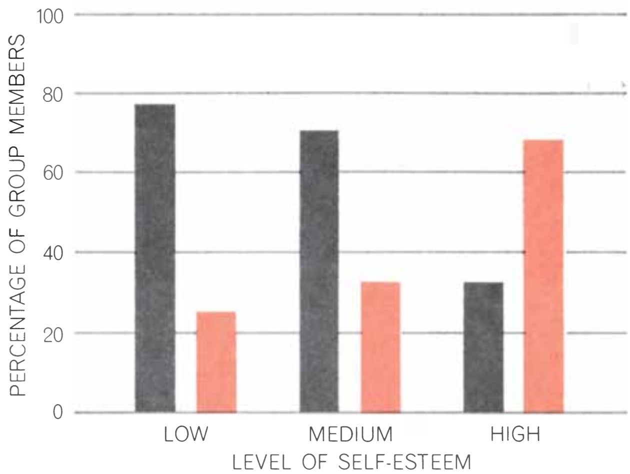
THE CHOICE of which target he would shoot for had to be made by the boy before he proceeded to aim and toss. He could try for a safe shot but one that would win him a low score or he could aspire to achieving a high goal, although one with more risk attached to it.



THE SHOT followed the boy's announcement of the target he had selected. All the boys who participated in the experiment agreed as to what the ideal score would be but those with high self-esteem displayed greater assurance that they could actually achieve the ideal.



THREE GROUPS OF SUBJECTS, judged to be low, medium and high in self-esteem, behaved differently in the presence of a social group. The high-self-esteem subjects participated (*color*) the most, whereas boys of the low-esteem group listened (*gray*) the most.



AVOIDANCE OF DISAGREEMENT during a discussion was displayed oftener by boys of the medium- and low-esteem groups. In contrast to the high-level group, they tended to withdraw from argument (*gray*) rather than express an independent opinion (*color*).

The subjects—middle-class, urban boys aged 10 to 12—were normal in the sense that they had no pathological personality disturbances and came from intact families. Our first problem was to obtain reliable measures of their levels of self-esteem. Since one's own evaluation of his self-esteem may be far from accurate, we resorted to two additional indexes. One was the teachers' report on those aspects of each boy's behavior—such as relative self-assurance or timidity and reactions to failures and criticism—that presumably reflected the boy's level of self-esteem. For the other index we employed psychological tests (the Rorschach and the thematic apperception test) that indicate a person's unconscious self-evaluation. We found that in more than 80 percent of the cases the ratings by these indexes were substantially in accord with the boy's own estimate of his self-esteem.

After determining the individual boys' levels of self-esteem and rating them according to three categories—high, medium or low in self-esteem—our investigations proceeded along three lines. These were (1) laboratory tests of the subjects' memory, perception, level of aspiration, conformity and responses to stress; (2) clinical tests and interviews designed to show their levels of ability, personality traits, attitudes, insights and styles of response; (3) studies, including interviews with their parents, that looked into factors of upbringing or experience that might be related to each boy's self-esteem.

From these items of information we were able to draw a fairly detailed picture of the formative influences and personal characteristics associated with each level of self-esteem. I shall describe them at the three levels, but since we were primarily concerned with identifying the constructive aspects of psychological health our main interest was in the high-self-esteem group, and the following descriptions are largely in terms of comparison with that group.

We found, not very surprisingly, that youngsters with a high degree of self-esteem are active, expressive individuals who tend to be successful both academically and socially. They lead rather than merely listen in discussions, are eager to express opinions, do not sidestep disagreement, are not particularly sensitive to criticism, are highly interested in public affairs, showed little destructiveness in early childhood and are little troubled by feelings of anxiety [*see illustrations above and on page 102*]. They appear to trust their own perceptions and reactions and have confidence that their efforts will meet with success. They approach other persons with the expectation that they will be well received. Their general optimism stems not from fantasies but rather from a well-founded assessment of their abilities, social skills and personal qualities. They are not self-conscious or preoccupied with personal difficulties. They are much less frequently afflicted with psychosomatic troubles—such as insomnia, fatigue, headaches, intestinal upset—than are persons of low self-esteem. (This immunity of people with high self-esteem has also been observed in adults by Morris Rosenberg of the National Institute of Mental Health, who reported on a hospital study of normal patients.)

The boys in our group who were characterized by a medium level of self-esteem were similar to high-esteem subjects in most qualities of behavior and attitudes. They tended, for example, to be optimistic, expressive and able to take criticism. In certain respects, however, they were distinctly different from both the high-esteem and the low-esteem subjects. They showed the strongest tendency to support of the middle-class value system and compliance with its norms and demands. They were also the most uncertain in their self-ratings of their personal worth and tended to be particularly dependent on social acceptance. The dependent attitude of the medium-self-esteem subjects and their behavior gave evidence that uncertainty about one's worth should not be confused with low self-esteem; the consequences are markedly different. Whereas persons with low self-esteem, convinced of their inferiority, are fearful of social encounters, persons who are unsure of their worth tend to be active in seeking social approval and experiences that will lead to enhancement of their self-evaluation.

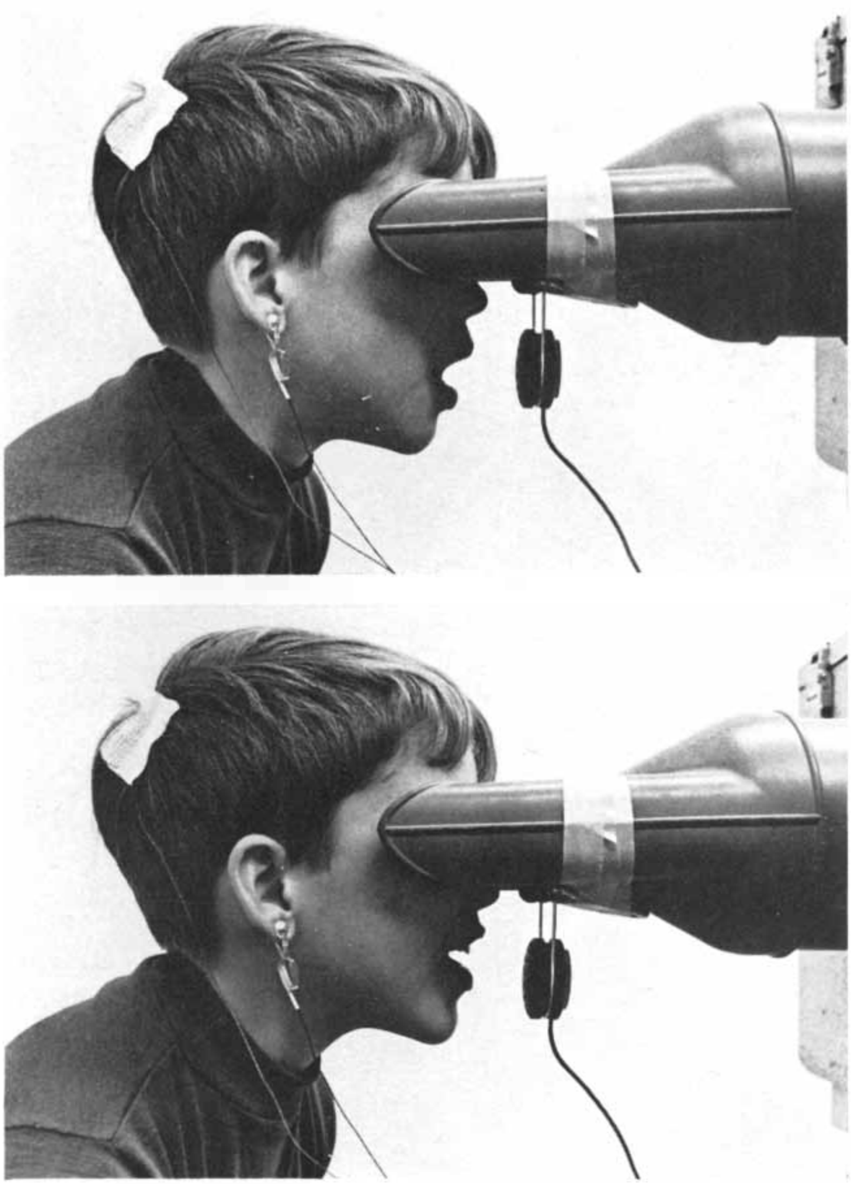
In contrast, the boys with low self-esteem presented a picture of discouragement and depression. They felt isolated, unlovable, incapable of expressing or defending themselves and too weak to confront or overcome their deficiencies. They were fearful of angering others and shrank from exposing themselves to notice in any way. In the presence of a social group, at school or elsewhere, they remained in the shadows, listening rather than participating, sensitive to criticism, self-conscious, preoccupied with inner problems. This dwelling on their own difficulties not only intensified their feelings of malaise but also isolated them from opportunities for the friendly relationships such persons need for support.

By examining our subjects' styles of expression, in drawings and other creative products, we obtained further insight into the effects of the various levels of self-esteem. The boys with high self-esteem were consistently freer and more original in creativity than those with lower levels of self-confidence [*see illustration on next page*]. Their drawings were characterized by activity, humor and sensitivity to details of costume, attitude and behavior. The drawings by boys of medium self-esteem were more restrained and static; for example, their pictures of the bearded figure (apparently a popular contemporary subject for youngsters) were less vigorous and less complex than those of the high-self-esteem group. The boys with low self-esteem clearly showed their lack of confidence by drawing small, constrained and distorted figures. In general the figures drawn by the three categories of subjects revealed distinct differences in their perceptions of themselves and other people.

Our exploration of the factors that lead to the development of high self-esteem produced a number of surprises, or at least contradictions of popular clichés. Let me first list the factors we found to have little or nothing to do with self-esteem in our sample of subjects. We found no consistent relation between self-esteem and physical attractiveness, height, the size of the boy's family, early trauma, breast- or bottle-feeding in infancy or the mother's principal occupation (that is, whether she spent her time at home as a housewife or went out to work). Even more surprising, our subjects' self-esteem depended only weakly, if at all, on family social position or income level. Studies by other investigators confirm that what we observed in our boys is also true of adults: the proportion of individuals with high self-esteem is almost as high in low social classes as it is in the higher classes. Our subjects tended to gauge their individual worth primarily by their achievements and treatment in their own interpersonal environment rather than by more general and abstract norms of success. It appears that we should reexamine the common definition of success: probably most persons define success for themselves not in terms of some external, abstract standard but in the more direct terms of their day-to-day personal relationships.

Looking into the backgrounds of the boys who possess high self-esteem, we were struck first and foremost by the close relationships that existed between these boys and their parents. The parents' love was not necessarily expressed in overt shows of affection or the amount of time they spent with their children; it was manifested by interest in the boys' welfare, concern about their companions, availability for discussion of the boys' problems and participation in congenial joint activities. The mother knew all or most of her son's friends, and the mother and father gave many other signs that they regarded the boy as a significant person who was inherently worthy of their deep interest. Basking in this appraisal, the boy came to regard himself in a similar, favorable light.

A second and more surprising finding was that the parents of the high-self-esteem children proved to be less permissive than those of children with lower self-esteem [*see lower illustration on page 106*]. They demanded high standards of behavior and were strict and consistent in enforcement of the rules. Yet their discipline was by no means harsh; indeed, these parents were less punitive than the parents of the boys whom we found to be lacking in self-esteem. They used rewards rather than corporal punishment or withdrawal of love as disciplinary techniques, and their sons praised their fairness. We found that the parents of the low-self-esteem



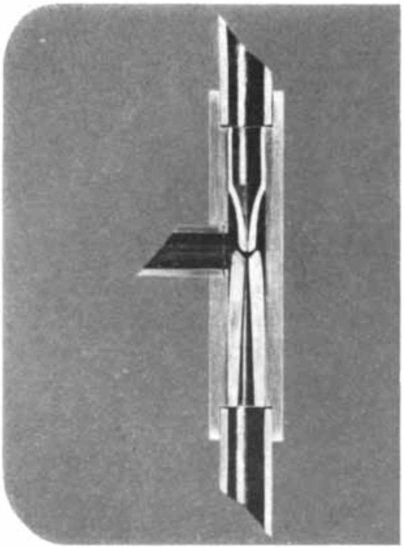
PROJECTOR was employed in tests timing a boy's recognition of words shown one by one. The words used were either neutral; threatening, such as "monster" (*top*), or pleasant, such as "ice cream" (*bottom*). To signify recognition the boy spoke into the microphone; his reaction was also recorded by the two electrodes. Boys whose self-appraisal was positive recognized threatening words quicker than boys whose self-appraisal was negative.

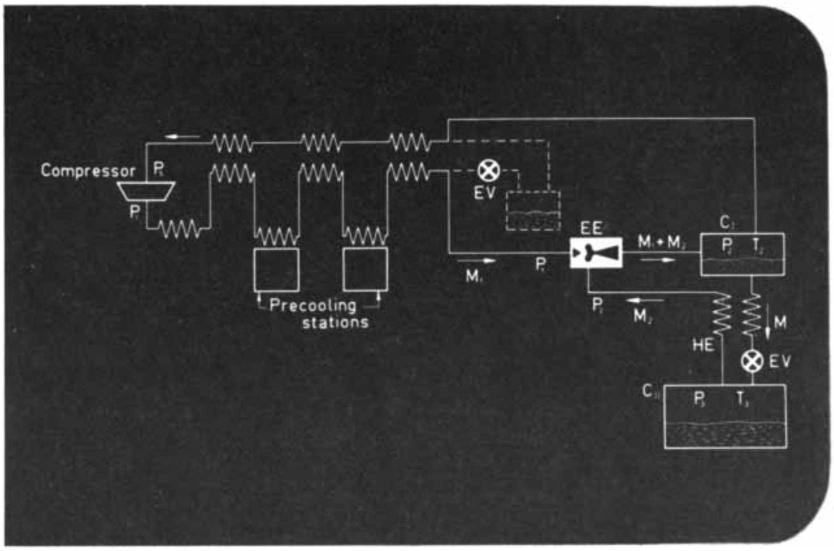
BOYS' DRAWINGS were made following instructions to "Draw a person and complete the drawing in 10 minutes." The first two figures are from the collection of drawings by boys judged to be low in self-esteem (*a*, *b*). The figures made by this group were constrained and distorted. Next are shown two drawings executed by subjects in the medium-self-esteem group (*c*, *d*). More originality, complexity and humor were displayed in the drawings made by boys with high self-esteem (*e*, *f*). Many of the men drawn had beards.

boys, on the other hand, tended to be extremely permissive but inflicted harsh punishment when the children gave them trouble. These boys considered their parents unfair, and they took the absence of definitely stated rules and limits for their behavior as a sign of lack of parental interest in them.

The family life of the high-self-esteem boys was marked not only by the existence of a well-defined constitution for behavior but also by a democratic spirit. The parents established the principles and defined the powers, privileges and responsibilities of the members, but they presided as benevolent despots: they were respectful toward dissent, open to persuasion and generally willing to allow the children a voice in the making of family plans. It seems safe to conclude that all these factors—deep interest in the children, the guidance provided by well-defined rules of expected behavior, nonpunitive treatment and respect for the children's views—contributed greatly to the development of the boys' high self-esteem.

Does the level of one's aspirations, or goals, play a part in one's achievement of self-esteem? This is a complex question. It might be supposed from abstract theory that anyone can attain success and consequent high self-esteem simply by setting his goals at a low enough level. Our findings, however, tend to refute that idea. We found that low aspirations do not promote self-esteem; on the contrary, they proved to be characteristic of boys who failed to develop high self-esteem. The boys with high self-esteem had significantly higher goals than those with only medium or low self-esteem did. In tests designed to indicate the level of goals they set for themselves the high-esteem boys had a mean score of 86.3; the medium-esteem group, 76.7; the low-esteem group, only 70.1. These tests measured the boys' actual hopes or expectations rather than a theoretical ideal. For example, one test involved skills at various levels of difficulty in tossing a beanbag. Boys at all levels of self-esteem agreed on the ideal skill they would have liked to strive for, but when they were asked which skill they expected to succeed in, the boys of





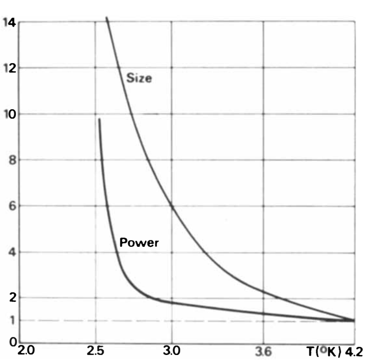
How To Use Your Losses Efficiently

If that statement reads like an offer of 'something for nothing', we apologize! Yet one of our recent cryogenic developments will allow users of super-cooled equipment to put the pressure potential normally wasted in the Joule-Thomson refrigeration cycle to very good use.

Dr. Rietdijk, a worker on cryogenic problems in the Philips Research Laboratories at Eindhoven (Netherlands), found a simple way to obtain a significant increase in cooling system efficiency, by using part of the kinetic energy which is wasted in the conventional Joule-Thomson valve. His findings promise a reduction in the compressor size required to reach a given temperature with practical liquid-helium super-cooling systems; alternatively, users will be able to produce lower temperatures without increasing compressor size.

In the conventional Joule-Thomson cycle, an expansion valve (see the diagram above) is used to expand compressed gas, which has already been cooled to below its 'inversion temperature' and passed through a heat exchanger. (Inversion temperature is the temperature below which isenthalpic gas expansion, produced by aperture 'throttling', causes a further temperature decrement). This classic system is 'irreversible': a great deal of pressure potential is wasted.

Since suction pressure P_s in the diagram must always be equal to, or lower than, vapour pressure P_v of the liquid in the evaporator, it is clear from the graph that, with a pressure loss $P_v - P_s$ of, say, 0.1 kg./cm², the required compressor size and power will increase very rapidly with successive temperature decrements below 3.5 degrees Kelvin.



Rietdijk replaced the classic Joule-Thomson expansion valve with a new device, which he called an 'expansion-ejector' (see photograph). In operation, the nozzle of the ejector converts most of the high pressure P_1 of the main flow M_1 into kinetic energy of a high velocity jet. The kinetic energy obtained is then used to compress a second mass flow M_2 from a low pressure level P_3 up to a higher level P_2, which is about the same as compressor suction pressure. This takes place in the ejector mixing zone and diffuser.

Referring to the diagram, the flow is then split again between M_1 and M_2 in C_I. Flow M_2 passes from C_I through the heat exchanger HE to be expanded in the valve EV. The resulting liquid is collected in the evaporator C_{II} where it can be evaporated (refrigeration) or removed from the cycle (liquefaction). Low temperature vapour P_3, T_3 then flows via HE to the ejector's suction side, where it is again compressed to P_2. So, the expansion-ejector behaves as a J-T valve between P_1 and P_2, and as a compressor between P_3 and P_2. Cold is therefore delivered at a temperature T_3 which is much lower than the temperature corresponding to compressor suction pressure (i.e. T_2).

Using the expansion-ejector, P_s can be considerably increased for a given temperature value T_3, and therefore compressor size can be reduced. Naturally, the compressor power consumption goes down as well. For example, experimental results with a helium liquefaction system, using Stirling machines for pre-cooling, show that, given an expansion-ejector efficiency of 30%, refrigeration can be carried out at 3.5 °K. with an efficiency significantly greater than that of the conventional system.

This story is unusual, in that it shows the successful combination of two well-known principles - the Joule-Thomson effect, known since 1852, and the gas ejector - to produce valuable results with a relatively simple device. Rietdijk, although working in cryogenics, happens to be an aerodynamicist; he brought his knowledge of flow and pressure problems to bear on the apparently unrelated problems of the Joule-Thomson cycle. The results of this unconventional approach may be applied, not only with helium, but also with other gases in cryogenics.

In the Research Laboratories of the Philips group of companies, scientists work together in many fields of science. Among these are: Acoustics, Cryogenics, Information Processing, Mechanics, Nuclear Physics, Perception, Solid State, Telecommunications, and Television.

Our research is an essential tool for maintaining the standards implied in the slogan:

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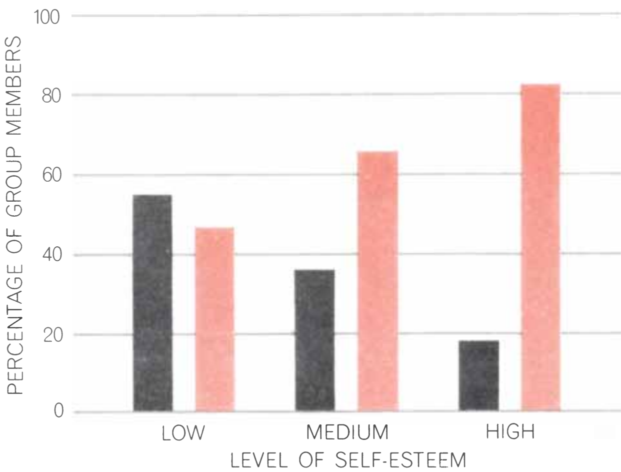
high self-esteem chose higher levels of skill than the others. Similarly, the subjects generally agreed on a list of desirable occupations they would like to enter, but the boys of high self-esteem expressed higher ambitions than the others as to the occupations they actually expected to enter.

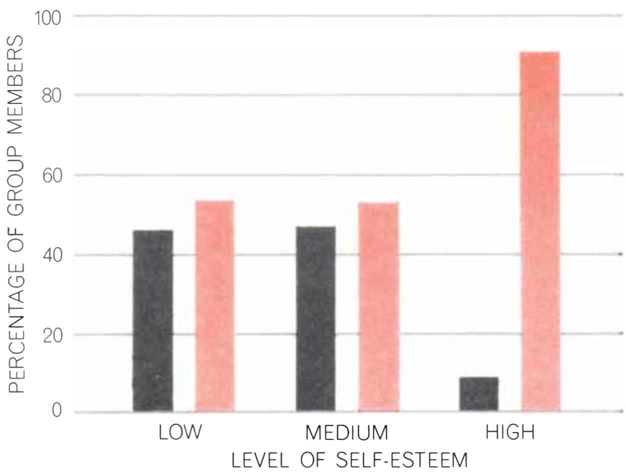
Not only did the subjects with high self-esteem have higher goals; they were also more successful in achieving their goals. Those lacking in self-esteem ran behind in performance as well as in ambition; they tended to fall shorter of attaining their lower goals.

The high expectations of the boys with high self-esteem clearly reflected the influence of their parents. The parents of these boys specifically indicated that they placed greater value on the achievement of standards of excellence by their children than on adjustment or accommodation to other persons. They set up definite standards of performance that enabled the child to know whether or not he had succeeded in a task, how far he had fallen short when he failed, and what efforts would be required in order to achieve success. That is to say, they presented the child with challenges to his capacities and thus led him to learn and appreciate the reach of his strengths.

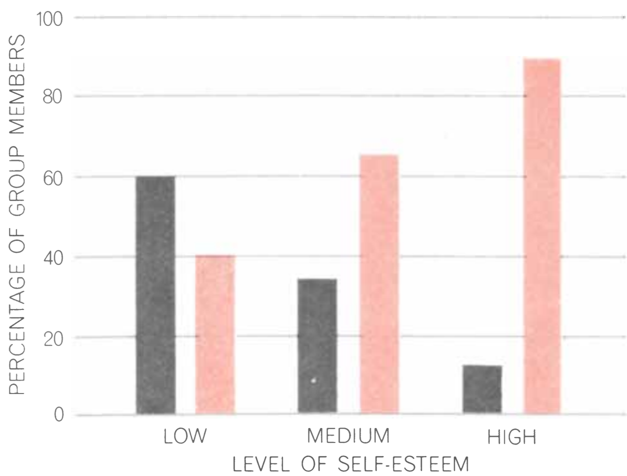
Is high self-esteem likely to result from outstanding competence or virtue in a particular field, such as athletic prowess or uncompromising honesty? Here again a careful examination of the facts raises questions about the common belief. Theoretically it can be supposed that the especially talented individual, placing a high value on the behavior at which he excels and deprecating those behaviors in which he is inferior, might develop a high degree of general self-confidence. In practice, however, one is subject to many social influences that affect self-evaluation. The home, the school, friends and other associations generally lead one to accept group norms and values. It is well known, for example, that children who do poorly in school nevertheless place as high a value on intelligence and good grades as able students do. Consequently, although an athlete or other person with special capacities obtains considerable gratification from his achievements, he is unlikely to accept this special competence alone as the principal basis for evaluating his



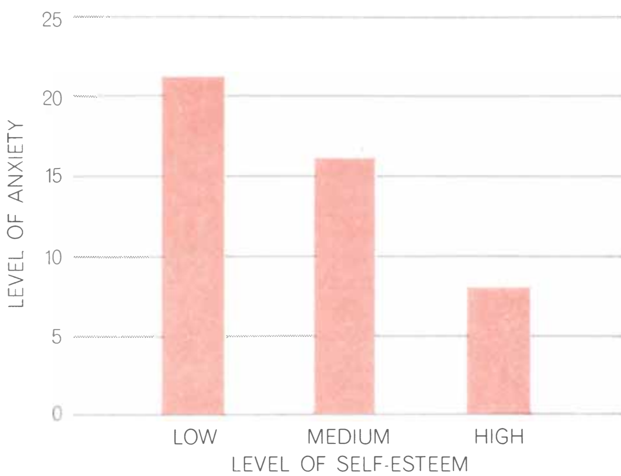
SENSITIVITY TO CRITICISM was high (*gray*) when self-evaluation was low. Except in the low-self-esteem group, most subjects were moderately or slightly sensitive to criticism (*color*). The findings are based on interviews during which the boys explained why they had or had not participated in the earlier group discussions.



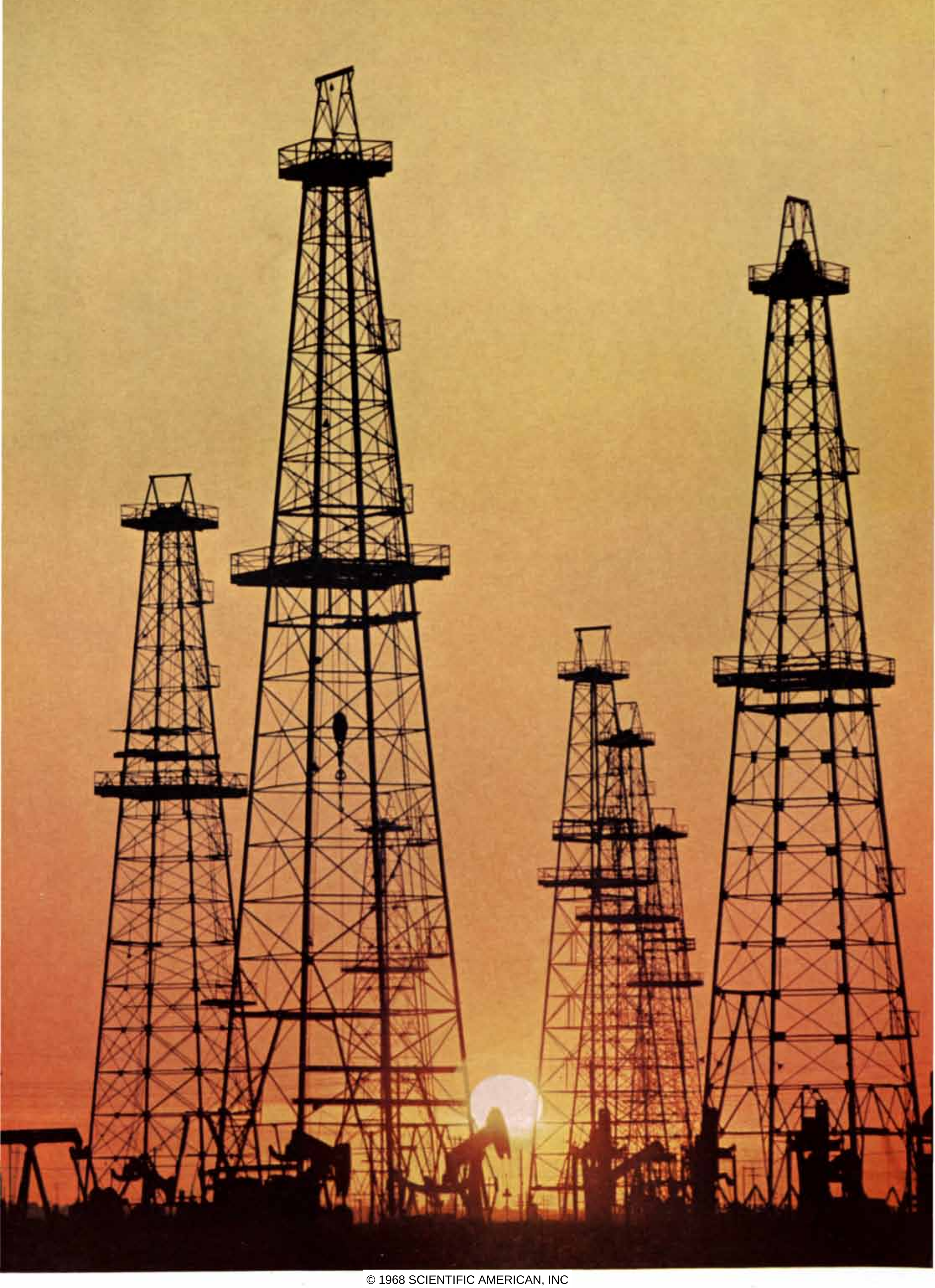
CONCERN WITH PUBLIC AFFAIRS (*color*) was evinced by boys with a higher level of self-esteem, in contrast to the other subjects, about half of whom expressed indifference (*gray*). During interviews a number of the boys who had been found lacking in self-regard expressed a wish to avoid involvement with other people.

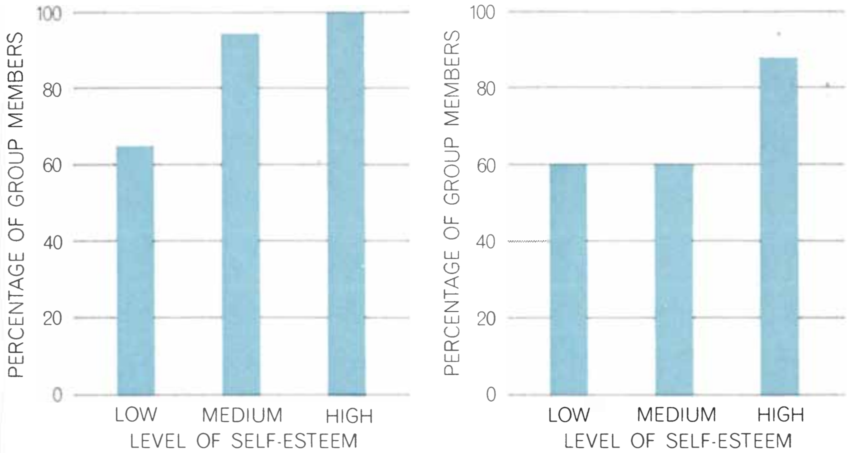


CHILDHOOD DESTRUCTIVENESS was considerable (*gray*) when self-esteem was low and little (*color*) when it was high. The ratings are based on mothers' reports of the boys' early behavior.

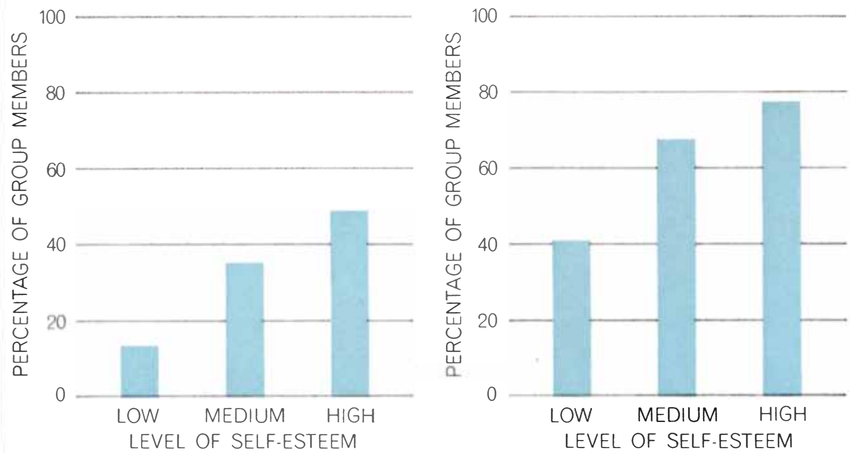


LEVEL OF ANXIETY in the three groups of subjects was rated on the basis of the frequency of feelings of distress reported by the subjects and of psychosomatic symptoms reported by their mothers.





CHILD REARING ATTITUDES of the subjects' mothers were revealed through interview and questionnaire. Mothers of the high-self-esteem boys displayed the most interest in and concern for the child. For example, they knew all or most of his friends (*left*). They also appeared to be more careful and consistent in enforcing limits on his behavior (*right*).



LESS PERMISSIVENESS but more respect for the child's rights were shown by mothers of boys with high self-esteem. Strict in enforcing rules, they used rewards rather than corporal punishment or withdrawal of love as disciplinary measures (*left*). Most mothers of boys in this group agreed that children should have a say in the making of family plans (*right*).

worth as a person. He may, indeed, tend to dwell on his deficiencies and be low in overall self-esteem.

The findings from these studies concerning the factors that contribute to the formation of high self-esteem suggest important implications for parents, educators and therapists. They indicate that children develop self-trust, venturesomeness and the ability to deal with adversity if they are treated with respect and are provided with well-defined standards of values, demands for competence and guidance toward solutions of problems. It appears that the development of independence and self-reliance is fostered by a well-structured, demanding environment rather than by largely unlimited permissiveness and freedom to explore in an unfocused way. From our studies of a sample of preadolescent boys in a typical American environment we have become convinced that learning at an early age to respond constructively to challenges and troublesome conditions is essential to becoming a self-respecting individual.

We are now studying other selected groups for further light on this process. Among the questions inviting further exploration are the nature of the rules and limits on behavior that can contribute most effectively to building youngsters' self-esteem and the appropriate ages for presenting particular demands and challenges to them. We are also exploring the therapeutic problem of finding ways to raise the self-esteem of persons who have already developed a low self-evaluation.

The Migration of Polar Bears

These large carnivores travel widely in pursuit of their prey. Exactly how widely is unknown, but steps are being taken to find out with the help of artificial satellites

by Vagn Flyger and Marjorie R. Townsend

The polar bear, the largest nonaquatic carnivore, has to roam widely over its Arctic habitat in quest of its principal food, which is seal meat. Few human investigators are inclined to spend much time following polar bears in such a forbidding environment. Even if they were, their presence in an otherwise virtually barren landscape would be likely to disturb the bears and alter their normal pattern of behavior.

As a result remarkably little is known about these lumberingly graceful animals. Eskimos have provided some information, which is partly fact and partly folklore. Scattered accounts have come from hunters and members of Arctic expeditions. By tracking and other means it has been ascertained that an individual bear may move hundreds of miles, but this kind of information reveals little about the activities of the animal during the journey.

Now, however, a technique is at hand that promises to fill some of the gaps in our knowledge of what kind of life the polar bear leads. The technique involves following a number of bears over an extended period by means of an artificial satellite in a polar orbit. If present plans are realized, a program of tracking polar bears will be incorporated in one of the Nimbus satellites to be launched by the National Aeronautics and Space Administration within the next two years.

The information that the satellites can be expected to yield will be of both scientific and economic value. Polar bears, which apparently have evolved from the brown bears of the Temperate Zone forests, represent a remarkable instance of adaptation to a singular environment. They also represent a significant element in the subsistence economy of Arctic regions, not only as a source of meat and skins for Eskimos but also as an attraction to hunters, who pay substantial amounts of money for guide fees and air travel in pursuit of the bear. The U.S. Department of the Interior has estimated that "each polar bear harvested in Alaska at the present time contributes at least $1,500 to the economy of the state in one way or another," so that the harvest of about 300 bears in Alaska in 1965 meant an income of about $450,000, much of which was "expended in relatively small Arctic villages."

A harvested polar bear is of course a dead one. No one knows with certainty how many of the bears are killed by hunters from various nations, but in the light of increasingly efficient techniques for hunting bears there is concern about the survival of the species. The hunting techniques include the use of small, ski-equipped airplanes that fly out over the ice in pairs. In Norway hunters can charter a yacht and travel along the edge of the ice pack near the Svalbard Islands shooting bears from the deck of the ship. As a result of pressures of this kind the International Union for the Conservation of Nature and Natural Resources has put polar bears on its list of animals in danger of extinction.

For both economic and scientific reasons, therefore, it is important to establish the trend of population among polar bears. Present estimates of the bear population range from 5,000 to 20,000 (another indication of the state of knowledge about the bears). Satellites will not count bears, but by providing accurate data about their migratory habits they will make counts more meaningful.

A vivid description of the environment to which polar bears have adapted was provided in 1856 by one of the early Arctic explorers, Elisha Kent Kane of the U.S. He wrote of a scene during the long polar night: "Intense moonlight, glittering on every crag and spire, tracing the outline of the background with contrasted brightness, and printing its fantastic profiles on the snowfields. It is a landscape such as Milton or Dante might imagine—inorganic, desolate, mysterious. I have come down from deck with the feelings of a man who has looked upon a world unfinished by the hand of its creator."

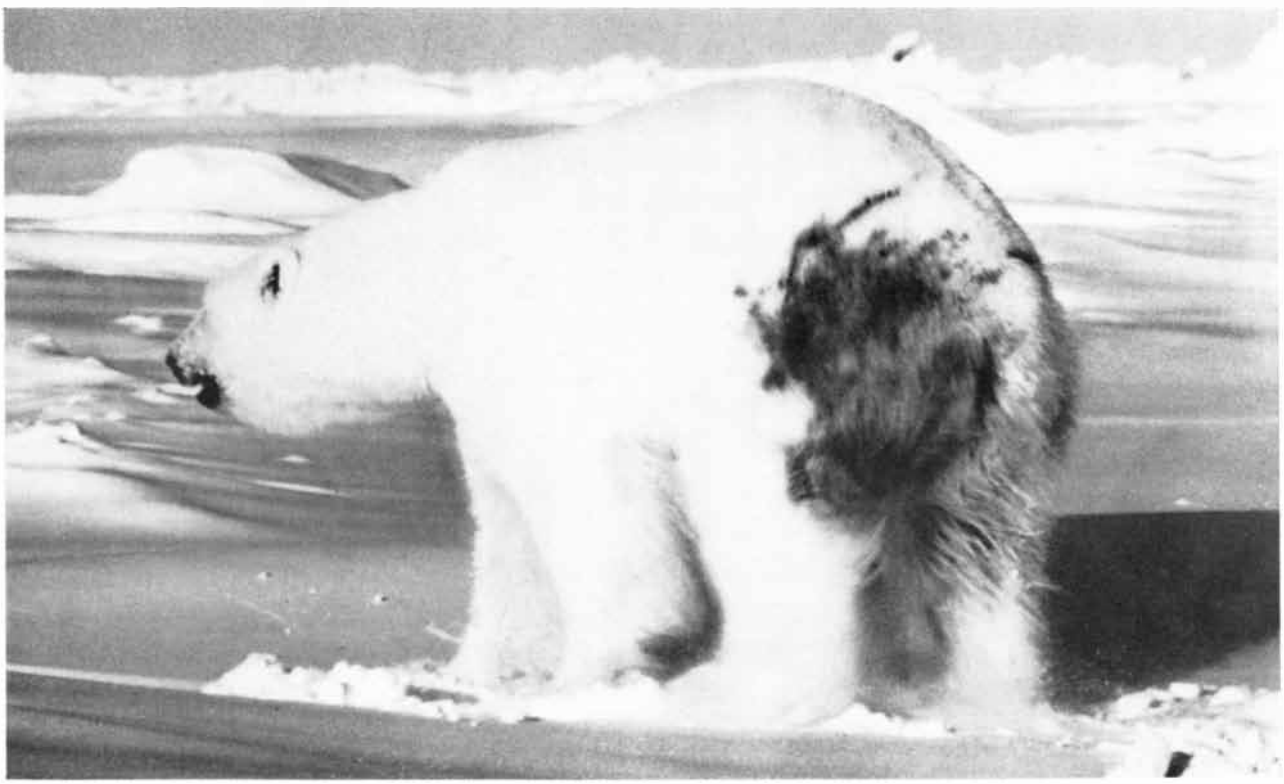
Polar bears are abroad in this formidable environment during the entire year—even in the dead of winter, when the temperature can drop as low as 65 degrees below zero Fahrenheit. Unlike other mammals, the polar bear appears to have no home territory. The apparent reason is that the bear does not find its food in one place for very long.

The bears do occasionally seek shelter. Females in particular excavate dens in the snow to give birth and rear their young. A female and her cubs (usually two) will stay in the den for as long as five months. The cubs survive by nursing, and the female lives off her reserve of fat.

Emerging from the den in March or April, the mother leads her cubs down to the sea ice. During the journey the cubs play constantly, tumbling, wrestling with one another and sliding on the ice. C. R. Harington of the National Museum of Canada has described what he has seen such a group do after it reaches the sea ice:

"If we watch the group closely for a few hours during early April, we will observe the mother prowling, head down, along the drifted leeward margin of some hummocky ice. Catching the scent of a snow-covered seal den, she crouches motionless before it—the cubs behind following her example. With lightning-

IMMOBILIZED POLAR BEAR is marked by one of the authors (Flyger) with a long-lasting dye. The dye helps in the identification of the bear when the animal is seen in subsequent months and so provides an indication of the extent of the animal's migration. The bear was on the Arctic ice cap north of Point Barrow, Alaska. Flyger and his colleagues immobilized the animal by shooting it with a syringe filled with succinylcholine chloride, a drug that acts quickly on the voluntary muscles and wears off in about 30 minutes.



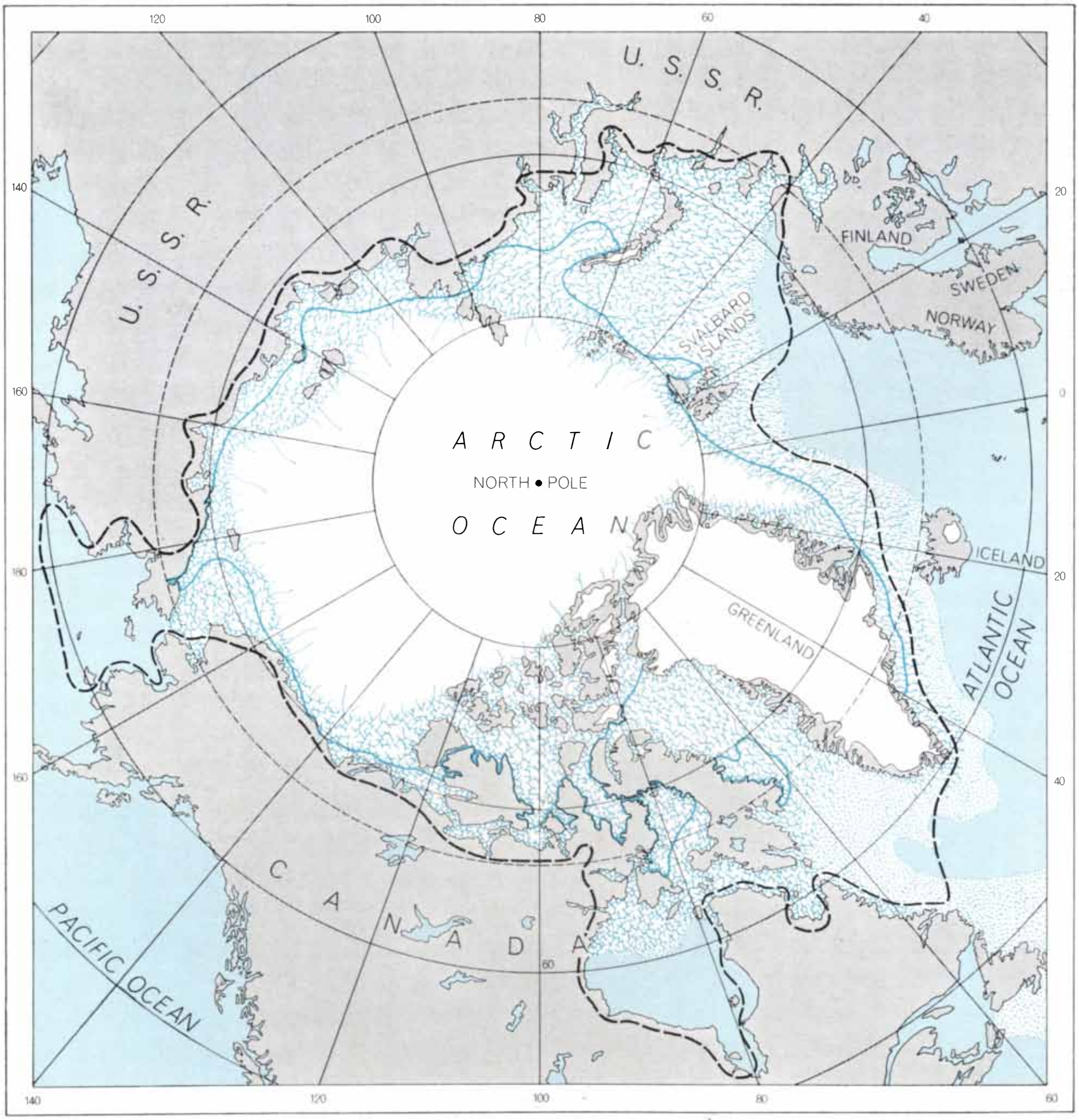
RECOVERY OF BEAR shown in the top illustration on this page took place approximately 30 minutes after the immobilizing drug had taken effect. The bear was marked not only with the dye but also with a tag on its left ear. Drug appears to leave no aftereffects.

like blows of her paws she shatters the hard upper layer of snow, rises on her hind legs and drives both forelegs down with the entire weight of her body. The den collapses and the breathing hole is stopped with snow. She scoops out the young 'whitecoat' seal within—almost simultaneously dispatching it."

Except when a mother is traveling with her young and during the mating season, the polar bear is a solitary animal, seldom seen in the company of other bears unless a large supply of food is available. In such a case a number of bears may appear; once as many as 42 were counted in the vicinity of a dead whale. Bears that are really hungry—and it is sometimes a long while between meals—have been known to kill and eat other bears, which is perhaps one reason the bears tend to avoid one another's company.

A mature male polar bear is likely to be from eight to nine feet long and to weigh between 800 and 1,000 pounds. Bigger bears have been reported, not always reliably. A mature female will be perhaps six feet long and will weigh about 700 pounds. The normal color of a mature bear is a creamy or yellowish white; in some kinds of light the bear looks more yellow than white.

The normal gait of a polar bear is a somewhat ponderous shuffle that covers ground much more rapidly than one might expect. When pressed, a bear will break into a lope or a gallop; at top speed the animal can travel over rough ice at a speed estimated as 20 to 25 miles



HABITAT OF POLAR BEARS is the large ice cap surrounding the Arctic pole. The map shows the extent of the winter ice pack and, with a colored line, the normal limits of the summer ice. The broken line shows the approximate maximum range of polar bears.

an hour. The bear also spends a considerable amount of time swimming, particularly in summer when the ice is broken over wide areas. A bear moving from ice into water seems hardly to break its stride, entering the water with a great belly flop and moving off rapidly with a strong swimming stroke. It became known only recently, through underwater photographs made under the supervision of Martin W. Schein of Pennsylvania State University, that a swimming bear normally uses only its front legs for propulsion; the hind legs appear to serve as rudders [*see illustration on page 113*].

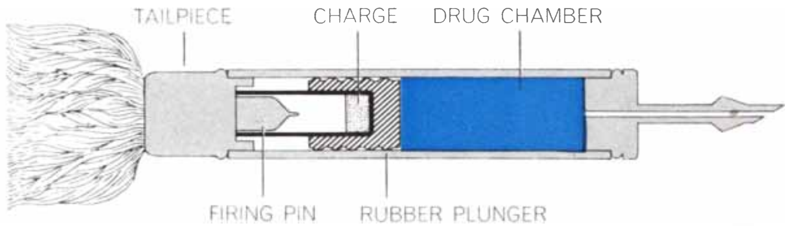
Such is the kind of information about polar bears that has been accumulated through occasional (and seldom very lengthy) observations. If, as is now proposed, some bears are to be followed more systematically by satellite, the first task to be mastered is equipping bears so that the satellite can communicate with them. The task requires immobilizing a bear long enough so that a unit for receiving and transmitting radio signals can be fastened to its neck. This must be done in such a way that the bear recovers quickly and is able to continue its normal activities while it is being followed by the satellite.

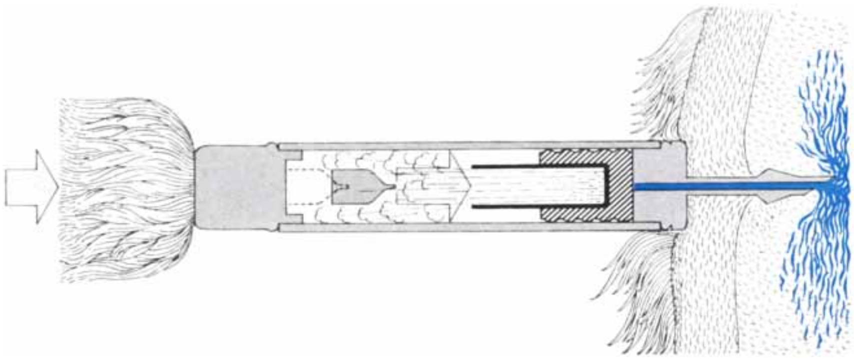
One of us (Flyger) has been experimenting with techniques for immobilizing polar bears with drugs. The drug is injected by means of a syringe that is shot from close range. When the syringe strikes the bear, the inertia of the projectile activates a firing mechanism that injects the drug into the animal [*see illustration on this page*]. The work presents several problems, not the least of which are the hostility of the environment and the potential hostility of the bear.

The kind of drug used to immobilize a bear must have several characteristics besides those of taking effect rapidly and wearing off within a matter of hours. First, there must be a wide margin of safety between the effective dose and the lethal dose. Second, the drug must be so potent that it can be contained in no more than 10 milliliters of fluid; 10 milliliters is the capacity of the largest projectile syringe. Third, the drug must produce no serious aftereffects. Fourth, the drug should be one for which an antidote can be given if necessary.

Few drugs have these characteristics. The ones most commonly used for immobilizing various animals have been nicotine alkaloid, succinylcholine chloride, phencyclidine and the synthetic opiate M. 99. Nicotine alkaloid acts on nerve ganglia and causes immobilization lasting from 10 minutes to an hour. During that time the animal is completely anesthetized.

Succinylcholine chloride causes immobilization by depolarizing voluntary muscles so that they are unable to function. The animal is immobile for between five and 30 minutes but retains such faculties as hearing, sight and smell. Phencyclidine affects the ganglia and the central nervous system, immobilizing an animal for periods of one to 12 hours. M. 99 takes effect slowly, sometimes requiring 20 minutes to immobilize an animal, but then the animal is completely anesthetized and immobile for as long as eight hours.





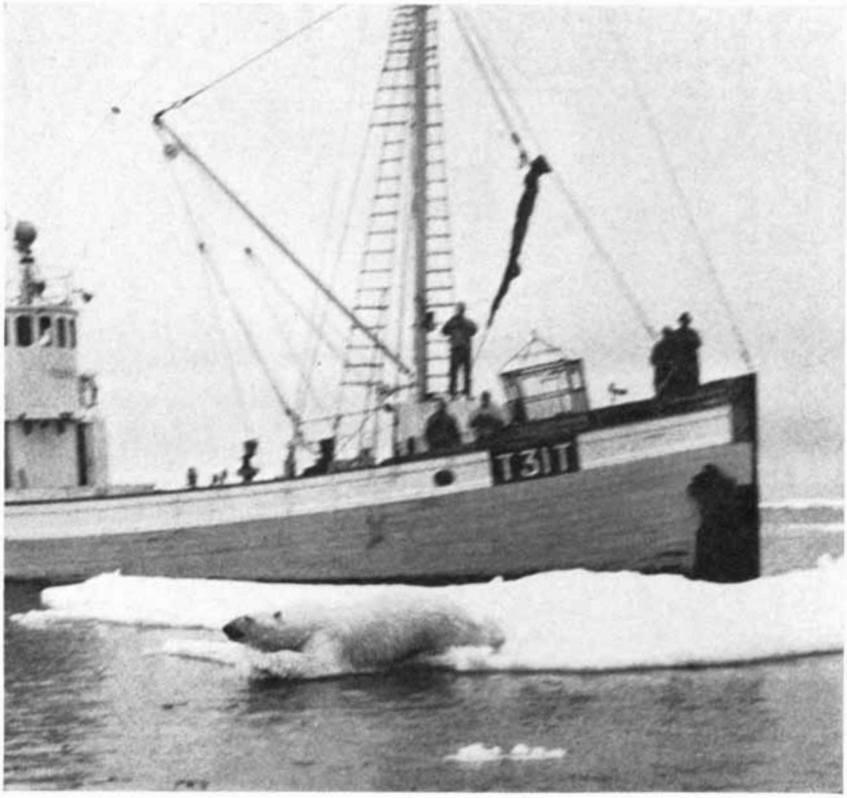
EXPLOSIVE SYRINGE is used to immobilize bears. At top the syringe appears as it looks before it is fired from a special rifle. At bottom the syringe has struck a bear. The resulting inertia drives the firing pin forward into the charge, which explodes and forces the drug into the bear. The amount of drug that is used depends on the size of the bear, so that an appropriately loaded syringe cannot be put into a rifle until a bear has been spotted.

In March, 1966, Schein and one of us (Flyger) went to Point Barrow, Alaska, to develop methods of capturing and marking polar bears. The Arctic Research Laboratory of the University of Alaska put its facilities, including two aircraft, at our disposal, and on days when the weather permitted we flew over the polar ice cap searching for bears. One plane flew at an altitude of 100 feet, looking for polar-bear tracks. We were in the other plane, flying at an altitude of 500 feet and slightly behind the lower plane so that it could maneuver freely.

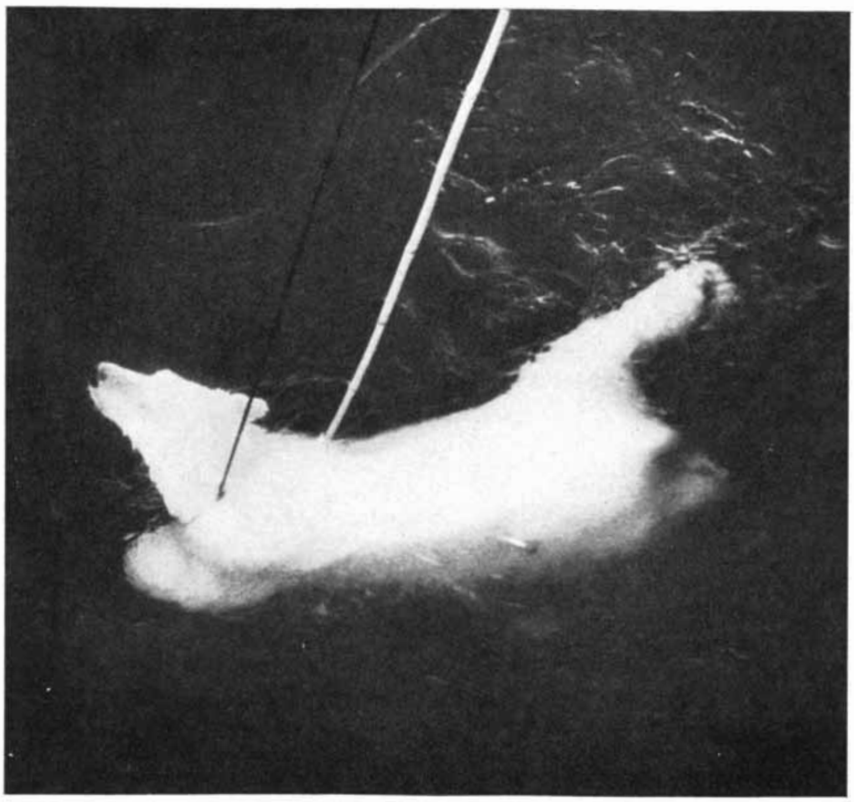
When we found tracks, we followed them to the bear. Our plane then flew on ahead in the direction of the bear's travel while the pilot of the other plane attempted to judge the size of the bear and notified us of it by radio so that we could load the appropriate charge into the syringe. Our plane landed about two miles beyond the bear. We got out and walked to a ridge of ice while our plane took off again and joined the other plane in herding the bear toward us. When the animal was within range, we shot it in the hip or shoulder with the syringe.

The next minute or so always gave us some concern. Our syringe guns, which we had expected to have a range of about 70 yards, actually had a maximum range of about 40 yards, apparently because the intense cold had congealed the lubricant in the gun barrel. We had several narrow escapes from charging bears. Although both of us carried rifles, the man who had fired the syringe gun had very little time to unlimber his rifle against the charging bear, and the other man often could not shoot without endangering his companion.

We were using succinylcholine chlo-



SWIMMING ABILITY of polar bears is exhibited by a bear diving from an ice floe as a research vessel draws near in Diskobukta Bay of the Svalbard Islands of Norway. The vessel was used as a base for temporarily immobilizing bears with drugs and marking them.



YOUNG BEAR is almost immobilized after being injected with a drug from the syringe visible in the bear's left flank. The rope is to keep the bear from drowning while drugged.

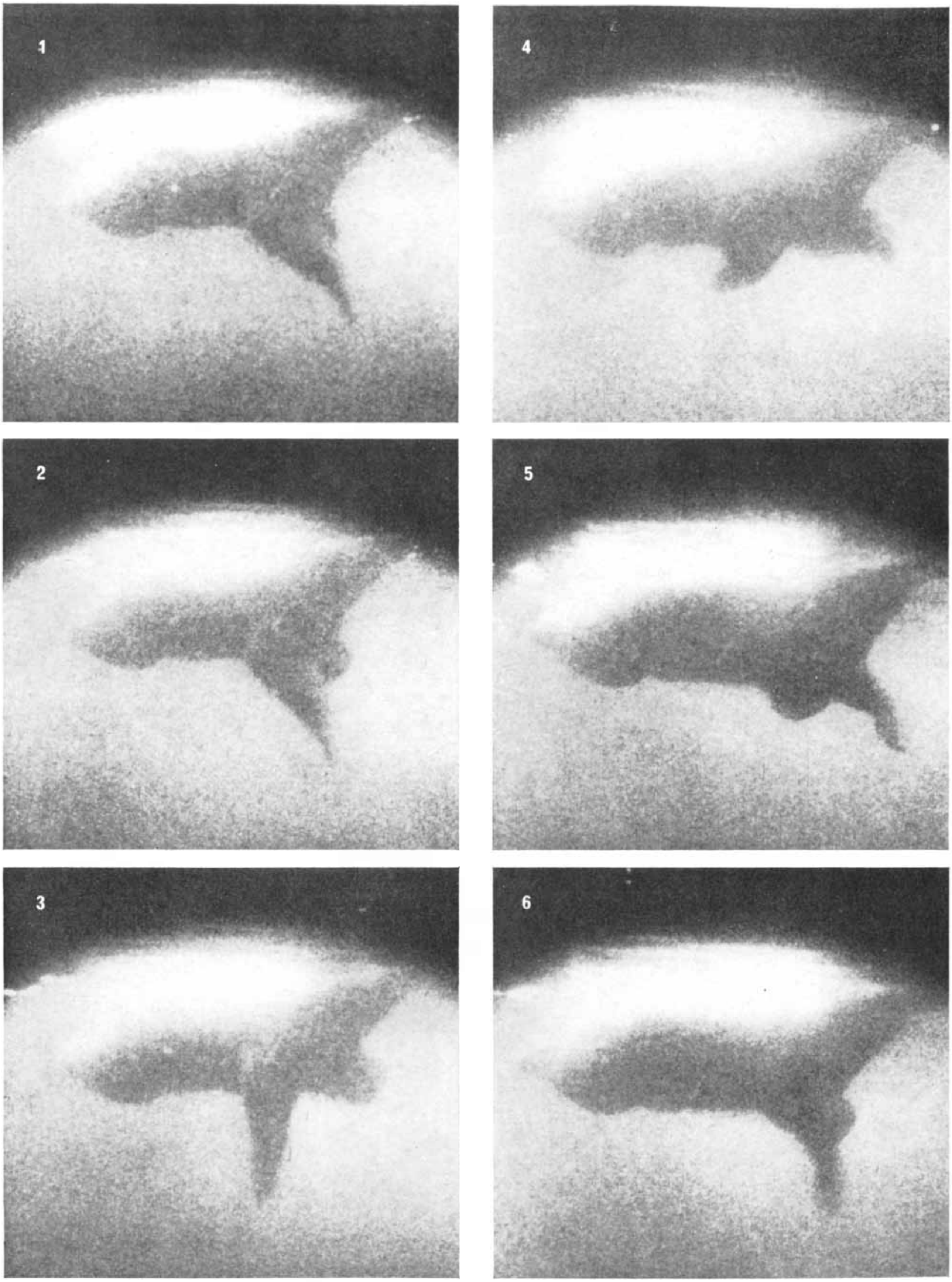
ride, and the results were disappointing. Some bears were unaffected. Others died, apparently from a combination of factors. One factor was that it is difficult to estimate the size of a bear in the absence of reference points on the ice, so that we often had an overcharge of the drug. Another factor was that the bears, having been chased for some distance, were rather out of breath when we shot them. As a result the drug seemed to have an exaggerated effect on their respiratory muscles, causing death from suffocation.

The difficulties we encountered both in hunting the bears and in immobilizing them led us to the conclusion that the ideal platform from which to shoot the syringe would be a helicopter. A helicopter could hover over a bear long enough for the hunters to make an accurate estimate of the bear's size, so that they could load the syringe with the proper dose. Helicopters would make it unnecessary to drive the bears, with the result that they would not become winded. The helicopter would also have the obvious advantage of keeping the men out of the bear's reach until the animal was immobilized.

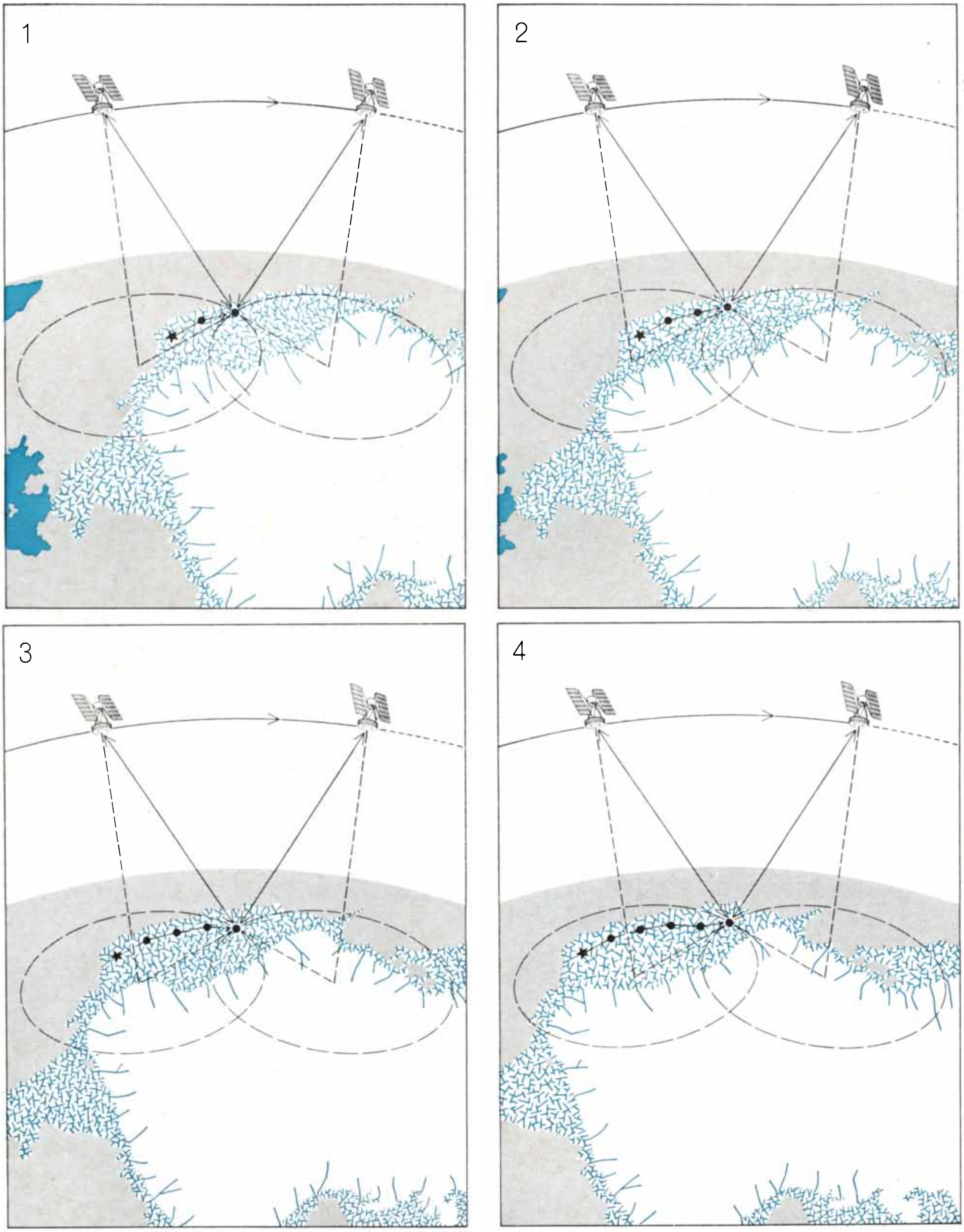
Our experience in Alaska was by no means a total failure. We did manage to capture, mark and release some bears. We learned that the bears can be successfully marked with ear tags and long-lasting dyes. We also established that a collar can be attached firmly to a polar bear, which is a prerequisite to equipping the animal with a radio transmitter. The point had been in doubt because of the bear's tapering neck, which might have meant that the bear could slip out of a collar in a short time.

Later in 1966 one of us (Flyger) accompanied Albert W. Erickson of the University of Minnesota and Thor Larsen of the University of Oslo on an expedition to capture bears in the Svalbard Islands. This time we operated under summer conditions, working from a ship in the pack ice. With the drug M. 99 we immobilized, marked, measured and released four bears. The drug did leave the bears sleepy for a long time, but that is not a serious handicap for the animal in the summer.

In various expeditions by various investigators, about 100 bears have thus been captured, marked and released. The work seems to establish that it will be feasible to put a radio transmitter on a bear. Indeed, it has already been done with grizzly bears and other Temperate Zone animals, which have then



SWIMMING MOTION of a polar bear normally involves only the front legs, as seen in this series of photographs from a motion-picture film made underwater in the Svalbard Islands region. The photographer was in a cage that was lowered over the side of a ship. The rear legs of a swimming bear apparently function as rudders. In these photographs only the bear's head is above water.



LOCATION OF A BEAR by means of a satellite involves an exchange of radio signals between the satellite and the bear. The position of the satellite is known and the distance between the satellite and the bear is established by the time required for the exchange of radio signals. Thus two sides of a right triangle are known and the third side, which forms the radius of an imaginary circle, can be calculated (*1*). The bear is on the circumference of the circle. Another exchange of signals a few minutes later establishes another circle. Bear is at one of the two intersections of the circles. Since one knows where it was when caught (*star*) or last reached by the satellite (*dots*), the proper intersection can be identified. The bear can thus be followed for many days (*2–4*).

been followed by ground-based radio receivers [*see illustration on next page*].

No polar bear has actually been fitted with a transmitter, however, because some technological problems remain to be overcome. Most electric batteries cannot produce enough current to operate a transmitter at the low temperatures of the polar bear's environment. Moreover, the equipment must be able to withstand frequent immersion as the bear goes in and out of the water. It nonetheless seems probable that these difficulties will be overcome before long, so that polar bears can be equipped to communicate with a satellite.

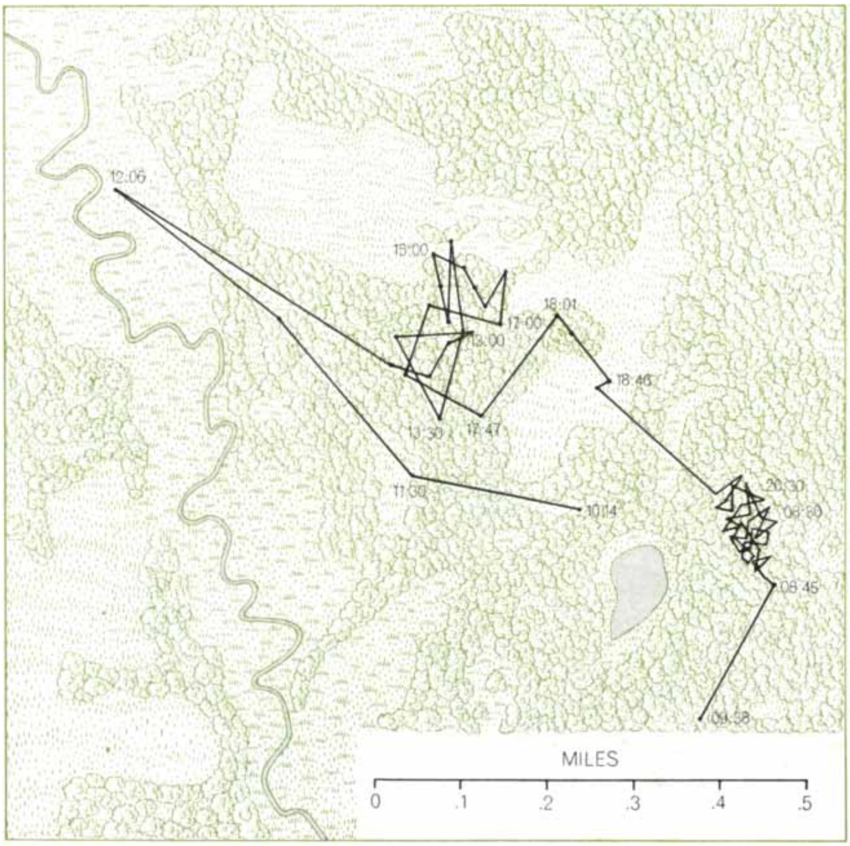
The Nimbus satellite, which will be used primarily for oceanography and meteorology, is being designed to orbit the earth from pole to pole at an altitude of about 600 miles. During a single 24-hour rotation of the earth the satellite will pass over every point on the earth twice—once as it moves from south to north and again, 12 hours later, as it moves from north to south and the point has rotated to that side of the orbit. At the higher latitudes the satellite will actually be within radio range of a given point on several sequential orbits. As a result the satellite could provide the location of a polar bear every two hours for half a day. For the other half the bear would be out of communication.

The system being developed by NASA to follow bears and other moving objects is called the Interrogation, Recording and Location System. In its ultimate form it will enable the satellite to interrogate some 32,000 "platforms" (bears, ocean buoys, balloons and a variety of other units), accurately fixing their position at least twice a day and recording other data they transmit.

Let us consider the case of a single polar bear that has been instrumented to communicate with a satellite. At a specified time, when the satellite is expected to be over the bear, the satellite broadcasts a signal that will turn on the bear's transmitter if the animal is within the signal beam. Once the transmitter is on, it returns a signal to the satellite. Because the position of the satellite is known at all times, and the distance between the satellite and the bear can be computed from the length of time it takes the radio signals to travel between them, it is possible to calculate the position of the bear by triangulation after two communications with the animal about three minutes apart. The location data and any other information the bear's communication system has been programmed to

DUMMY RADIO is fastened to a collar on an immobilized bear in Alaska. The dummy matches size and weight of a radio that could be used for communication between a bear and a satellite. Experiment helped to show that a collar will stay on a bear's tapering neck.

MATERNITY DEN of a polar bear was photographed at Southampton Island of Canada's Northwest Territories by C. R. Harington of the National Museum of Canada. The bear that excavated the den in snow used it to give birth and to rear her cubs during their first winter.



TRACKING OF DEER and other animals has been accomplished by means of radio communication between the animals and ground-based receivers, indicating the feasibility of following polar bears with a satellite. The map, which is based on the work of John R. Tester of the University of Minnesota and Keith L. Heezen of the Michigan Conservation Department, shows the movements of a single deer in the Cedar Creek Natural History Area of Minnesota from 10:14 A.M. on a January day to 9:38 A.M. the following day.

provide are stored in the satellite and periodically sent by it to ground stations, from which they are transmitted to a computer for processing.

Step by step the sequence proceeds as follows. The set of interrogations that the satellite will conduct on a given orbit is worked out by the computer, and a punched tape is prepared so that the entire set can be transmitted to the satellite when it passes over its command station. A command for a single interrogation has two parts: (1) the address, or radio code, that has been assigned to the platform (in this case a bear) and (2) the exact orbital time at which the interrogation is to be conducted.

At the stipulated time the satellite begins transmitting the address. If the bear is within the range of the signal, the radio unit on the bear receives the signal, decodes it for comparison with the address assigned to the bear and, if the signal corresponds to the address, verifies the platform's identity to the satellite. The satellite then signals the platform to begin transmitting whatever data it is programmed to provide. In the case of a bear the data would presumably be physiological. The entire exchange takes about three seconds.

The results of all the interrogations are stored in the satellite. On completion of an orbit the ground station commands the satellite to transmit the data it has stored. When the satellite has sent all the data, it automatically signals the ground station to that effect. The satellite is then ready to accept a new set of interrogations.

The data received at the ground station are given some further processing there and then transmitted to a central data-processing unit at NASA's Goddard Space Flight Center in Maryland. There the location of each platform is computed and the information obtained from the platform is distributed to the people who want it. The Goddard computer also generates the next set of interrogations for the satellite.

So much for the interrogation and recording functions of the Nimbus system. The location function is predicated on the fact that the location of the satellite is precisely known at all times. Hence the distance from the satellite to the point on the ground directly below the satellite is known at any instant. That distance represents one side of a right triangle.

The hypotenuse of the triangle is the line from the satellite to the platform. Its length can be computed from the time required for the special signal generated in the satellite to reach the platform, be regenerated and return to the satellite—traveling at the speed of light. With the length of two sides of the right triangle known, the length of the third side can be calculated. The third side is the hypothetical line on the ground from the platform to the point directly below the satellite. That line constitutes the radius of a circle. The complete calculation establishes that the bear is somewhere on the circumference of the circle [*see illustration on page 114*].

In order to establish exactly where the animal is, another exchange of signals between the satellite and the bear is required. It takes place about three minutes after the first exchange. By means of the second exchange another imaginary circle, with the bear on the circumference, is described on the ground. The two circles intersect at two places. The bear is at one of these places. Since one knows where the bear was during the satellite's previous orbit (or where the animal was captured, in the case of the first orbit in which its location was determined), it is not hard to decide which intersection represents the location of the bear; the two intersections are normally hundreds of miles apart. The precision of the technique is sufficient to determine the location of the bear to within about a mile.

It will be well within the capacity of a satellite system to provide information not only about the migration of polar bears but also on such matters as their respiration and heart action under various circumstances. With such data it would be possible to relate the activity of polar bears to weather conditions on the polar ice cap and thus to come to a better understanding of how an animal can survive in the harsh conditions regularly encountered by the polar bear. Perhaps some of this information will be useful to men who are obliged to adapt themselves to living under Arctic conditions.

MATHEMATICAL GAMES

Combinatorial problems involving "tree" graphs and forests of trees

by Martin Gardner

A "connected graph" is a set of points (vertices) joined by line segments (edges) in such a way that a path can be found from any point to any other point. If there are no circuits, or paths leading from a point back to the same point, a connected graph is called a "tree." In nature the tree itself is of course a splendid three-dimensional model, and there are also crystals that grow in a similar manner. Rivers and their tributaries sprawl over the earth's surface in gigantic tree diagrams. Certain brittle solids crack in such a way that the break, examined under a microscope, shows a beautiful treelike pattern. Electric discharges sometimes branch like trees.

The simplest tree graph is a line connecting two points. Three points also join in only one way to form a tree, but four points can be connected in two topologically distinct trees. Five points yield a "forest," or set, of three trees and six points can be connected in six trees [*see illustration on opposite page*]. The placing of the points and the shapes of the edges are irrelevant because only topological properties are used here as distinguishing features; think of the diagrams as being formed of identical balls joined by elastic bands. These are called "free trees" to distinguish them from "rooted trees," in which one point is distinguished from all others, or "labeled trees," in which all points are distinguished.

There are still other types of trees for which there is as yet no standard nomenclature. The problem of calculating the number of distinct n-point trees of a given type gets into complex combinatorial theory. There are 11 free trees with seven points, and then the series continues 23, 47, 106, 235, 551,.... A dozen seven-pointers are shown on page 120 but two are duplicates. Can you find the twins? As a further exercise the reader can see if he can draw the 23 eight-pointers.

It is obvious that every tree of n points has $n - 1$ edges, and a forest of n points and k trees has $n - k$ edges. Another obvious theorem is amusingly illustrated by a scene in L. Frank Baum's fantasy *The Magical Monarch of Mo and His People*. An apple on a high branch cannot be reached by climbing the tree because someone has sawed off part of the trunk, near the branch, to use for kindling. The theorem: Removal of any edge from a tree graph disconnects the graph. Even a terminal edge, if it is removed, leaves its terminal point stranded.

Investigations of the properties of tree graphs did not get under way until the late 19th century, but of course the diagram was in use in ancient times. It is a handy way to show all kinds of relations—genealogical ones, for instance—and for dividing a subject matter into hierarchic categories. One of the most ubiquitous tree graphs in medieval metaphysics was proposed in a commentary on Aristotle by Porphyry, a third-century Roman philosopher and opponent of Christianity. In essence the Tree of Porphyry is what is now called a "binary tree." Categories are split into two mutually exclusive and exhaustive parts on the basis of a property possessed by one part but not the other. Substance, the *summum genus,* divides into the corporeal and the incorporeal, the corporeal into the living and the nonliving. The living divides into the sensible (animals) and the insensible (plants). Animals divide into the rational (man) and the nonrational; the rational in turn splits into individual persons, the *infama species* of the tree. After the invention of engraving Renaissance philosophers liked to publish fantastically branched and elaborately decorated diagrams of the Porphyrian tree.

Petrus Ramus, the French Protestant logician killed in 1572 in the Massacre of St. Bartholomew, was obsessed by this kind of exhaustive division and applied the binary tree to so many topics that it was thereafter known as the Tree of Ramus. Jeremy Bentham, in the early 19th century, was perhaps the last important philosopher to take the binary tree quite so seriously. Although he realized that a complete Ramean tree was unwieldy in many areas (for example botany!) and that, like an apple, a category can often be halved in thousands of different ways, he was convinced that dichotomous division was one of the great tools of analysis. He wrote of the "matchless beauty of the Ramean tree," and headed a section of one essay "How to plant a Ramean encyclopedical tree on any given part of the field of art and science."

Philosophers today have little use for tree diagrams, but mathematicians and scientists have found applications for them in such diverse fields as chemical structure, electrical networks, probability theory, biological evolution, operations research, game strategy and all kinds of combinatorial problems. The most striking example I know of the unexpected applicability of tree diagrams to a combinatorial problem (in this case a game of card solitaire) is given in a discussion of tree theory in *Fundamental Algorithms,* just published by Addison-Wesley as the first volume of a projected seven-volume series titled *The Art of Computer Programming*. The author is Donald E. Knuth, a mathematician at the California Institute of Technology.

The solitaire game is best known as "clock," although it also goes by such names as "travelers," "hidden cards" and "four of a kind." The pack is dealt into 13 face-down piles of four cards each, the piles arranged as shown in the illustration at the left at the bottom of page 120 to correspond to the numbers on a clock face. The 13th (king) pile goes in the center. Turn over the top card of the king pile, then slide it face up under whichever pile corresponds to the card's value. For example, if it is a four, put it under the four o'clock pile; if a jack, under the 11 o'clock pile, and so on. Now turn up the top card of the pile under which you just placed the card and do the same thing with the new card. The play continues in this way. If you turn a card that matches the pile it is in, slide it face up under that pile and turn the next top card. If you place a card under a pile and there is no face-down card on it (the pile consisting of four face-up cards of the same value), then move to the next-higher pile clockwise. The game is won if you get all 52 cards face up. If you turn a fourth king before this happens, the play is blocked and the game lost.

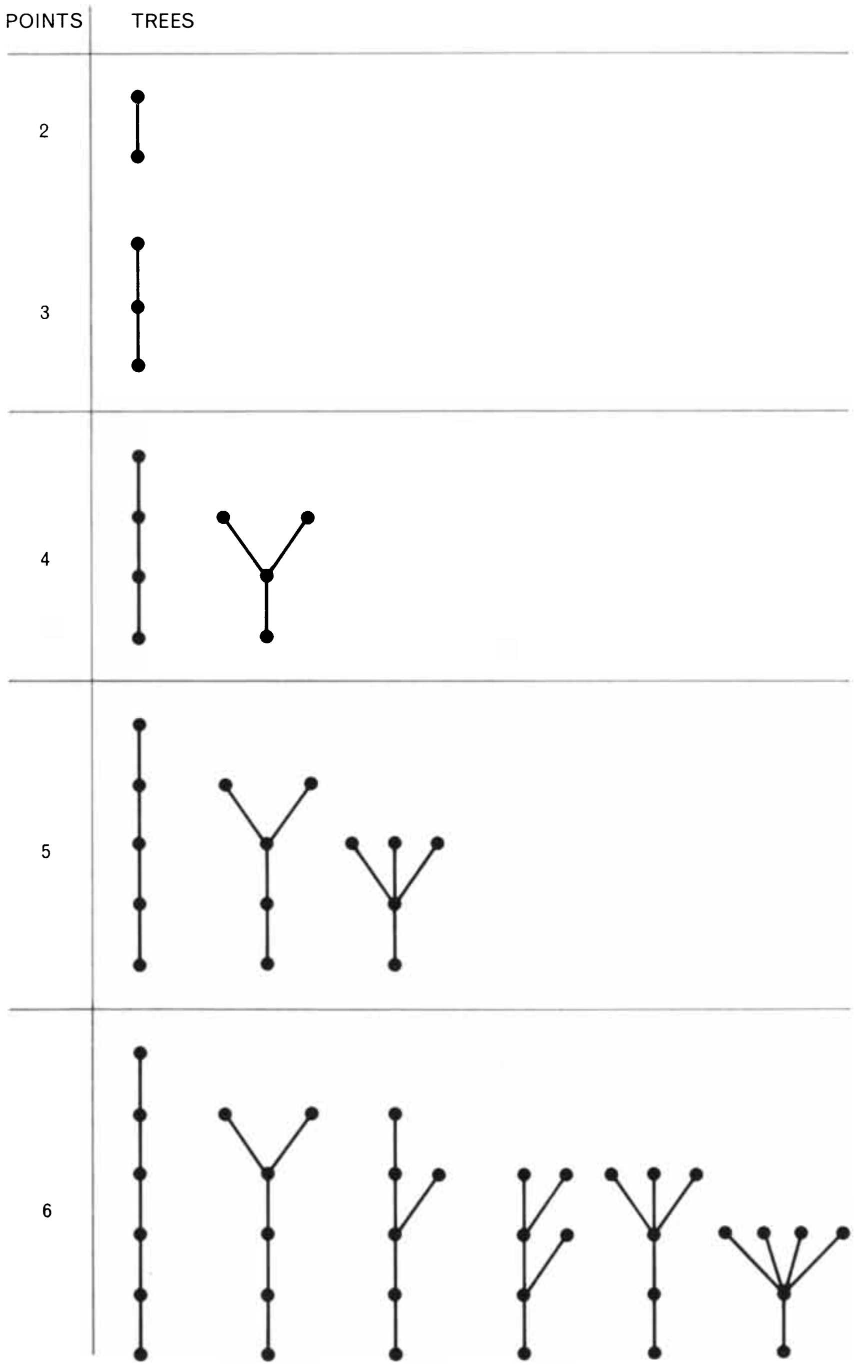
Playing clock is purely mechanical, demanding no skill. Knuth proves in his book that the chances of winning are exactly 1/13 and that in the long run the average number of cards turned up per game is 42.4. Even more astonishing is Knuth's delightful discovery of a simple way to know in advance, merely by checking the bottom card of each pile, whether the game will be won or lost. Draw another clock-face diagram, but this time indicate on each pile the value of the bottom card of that pile—except for the center, or king, pile, the bottom card of which remains unknown. Now draw a line from each of the 12 bottom-card values to the pile with the corresponding number [*see illustration at right at bottom of next page*]. (No line is drawn if the card's value matches its own pile.) Redraw the resulting graph to reveal its tree structure [*see top illustration on page 121*]. If and only if the graph is a tree that includes all 13 piles will the game be won. The arrangement of the 40 unknown cards is immaterial!

The illustrated game, as the tree graph reveals, will be won. The reader is invited to draw a similar diagram for another starting position [*see bottom illustration on page 121*] to determine whether it is a win or a loss, and then to check the result by actually playing the game. A proof that the tree test always works will be found in Knuth's fascinating and charmingly written 634-page book. In addition to being the introductory volume of what will surely be a monumental survey of computer science, it is crammed with fresh material that is of great interest to recreational mathematicians.

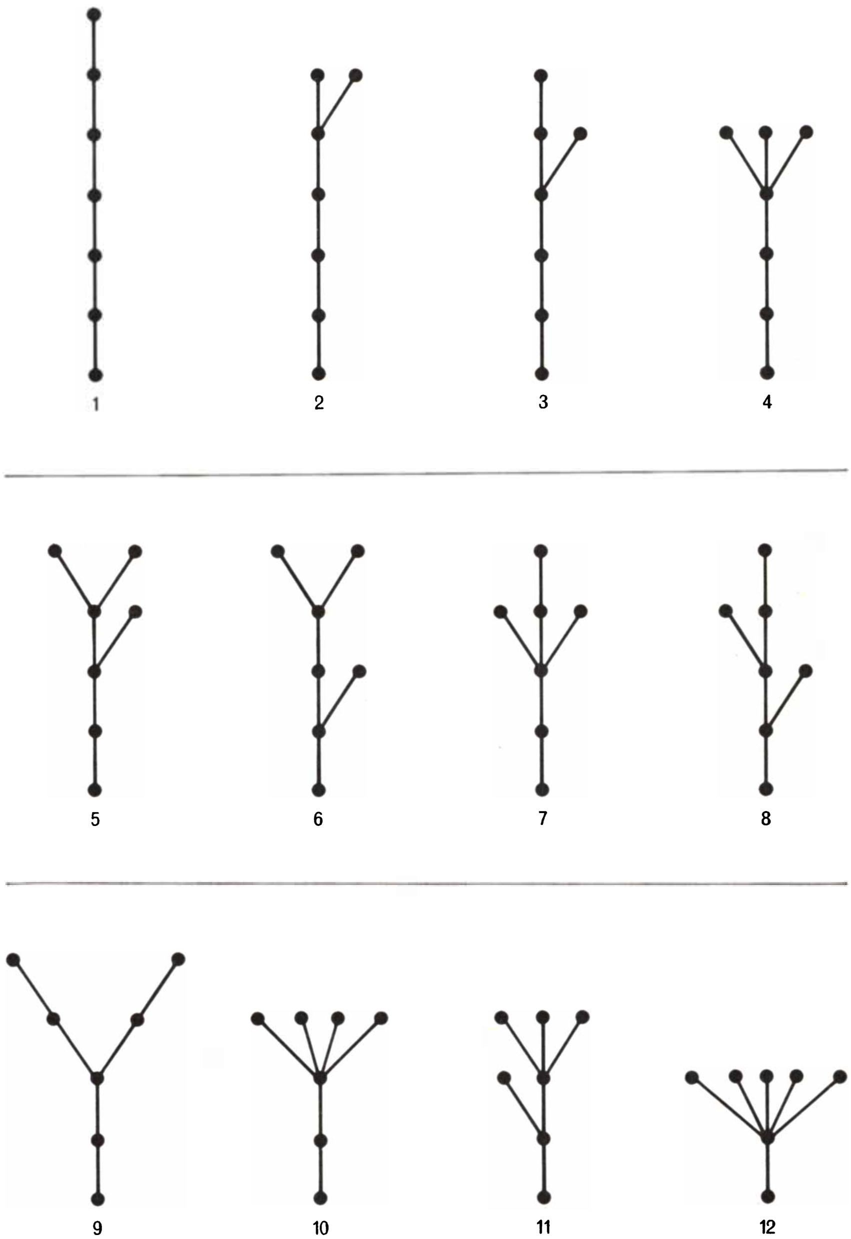
A tree that catches all of a set of points is said to be a "spanning tree" for those points. One of the earliest theorems in tree theory was the discovery, by the 19th-century Cambridge mathematician Arthur Cayley, that the number of different spanning trees for n labeled points is n raised to the power of $n - 2$. (Cayley was one of the founders of tree theory, which he developed in 1875 as a method of calculating the number of different hydrocarbon isomers.) Suppose there are four towns, *A, B, C* and *D*. If we join them with a spanning tree, in how many different ways can it be done? Cayley's formula gives 4^2, or 16 [*see top illustration on page 122*]. There are topological duplications, but because the vertices (towns) are distinguished we count each as being different. Where crossings occur one edge is shown going under the other to make it clear that the crossing is not another vertex; otherwise the tree would be a five-point tree.

Suppose n towns are to be joined by a railroad network consisting of track segments connecting pairs of towns. Tracks may cross, but if so the crossings must not be taken as new vertices; that is, they are not points at which a traveler can transfer from one track to another. By what procedure can you find a spanning graph that has the smallest total length?

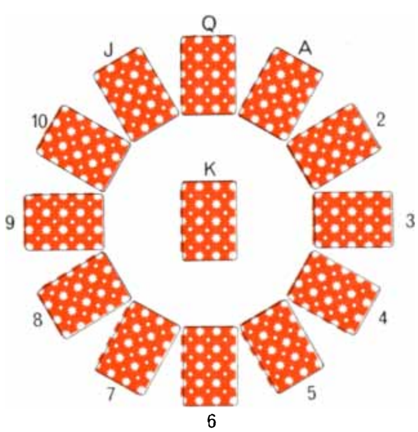
It is easy to see that the minimum graph is a tree. Otherwise it would contain a circuit, in which case the graph's length could be made shorter by the removal of one edge, breaking the circuit but leaving all towns still connected. Since any circuit can be eliminated, shortening the graph, the minimum graph will be a tree. There are several simple algorithms (procedures) for finding a minimum-length tree. The following is given by Hugo Steinhaus in



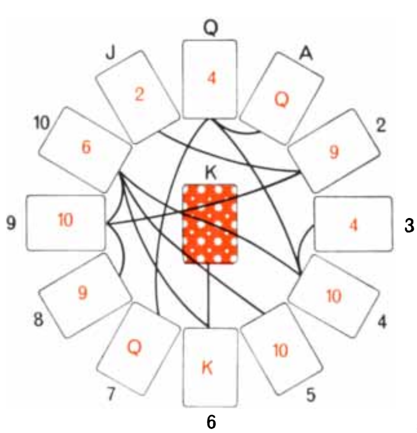
Topologically distinct trees of two to six points



Twelve seven-point trees, two of which are twins



Starting position for clock solitaire



Bottom cards and their tree connections

the revised edition of his *Mathematical Snapshots* (Oxford, 1960). Pick any town and join it to its nearest neighbor with a straight line. Do the same with each of the other towns. If this connects all the towns, you have completed an "economy tree" and solved the problem. If it produces a disconnected forest, pick one of the trees and draw the shortest line that will connect a town of that tree to a town of another tree. Repeat with the other trees. If this also fails to connect all the towns, continue the same procedure with the new forest. Eventually you will complete an economy tree. It will be of minimal length and there will be no intersections of edges. If at any stage you have a choice of two or more edges of the same minimum length, it does not matter which you choose. Where there are such choices there will of course be more than one economy tree.

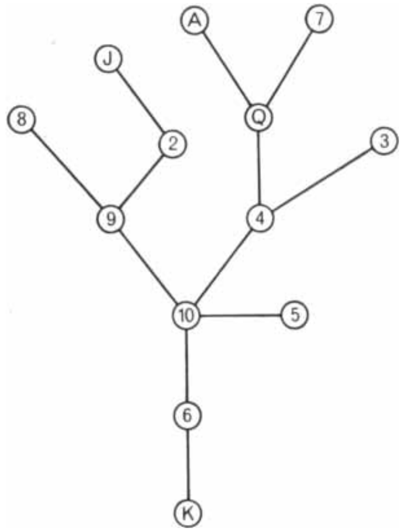
The economy tree problem should not be confused with the "traveling salesman problem," a famous unsolved problem of graph theory. In that problem one seeks the shortest circuit enabling a salesman to visit every town once and only once and return to his starting town. There are good computer algorithms for finding close approximations to the shortest circuit when the number of towns is large, but there is no absolutely accurate general procedure except the tedious testing of all possible routes.

If one is allowed to join towns by trees that contain new vertices, then the economy tree structure is quite different. This is brought out neatly by a classic problem: What is the shortest railroad connecting four towns at the corners of a square? Assume that the square's side is one mile. Remember, the minimal spanning tree in this case may contain one or more additional vertices; it need not be a four-point tree. If the reader succeeds in finding this tree, he can try the more difficult problem of determining the minimal-length tree joining the five corners of a regular pentagon. Answers to all these questions will appear next month.

Last month's problems about square numbers are answered as follows:

After 1,444 the next-smallest square ending in 444 is 462^2, or 213,444. The formula $500x \pm 38$, where x is any integer including 0, generates all numbers whose squares end in three 4's.

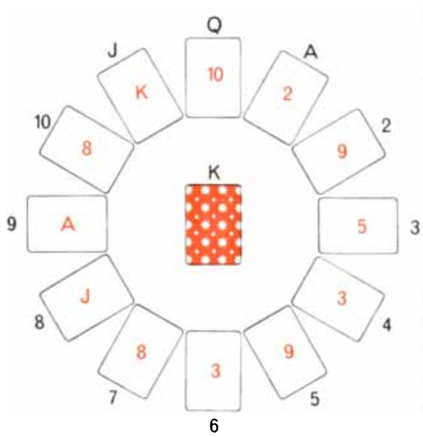
To prove that no square can have all odd digits, we show that every square ending in an odd digit must have an even digit second from the end. If a square ends in an odd digit, so must its square



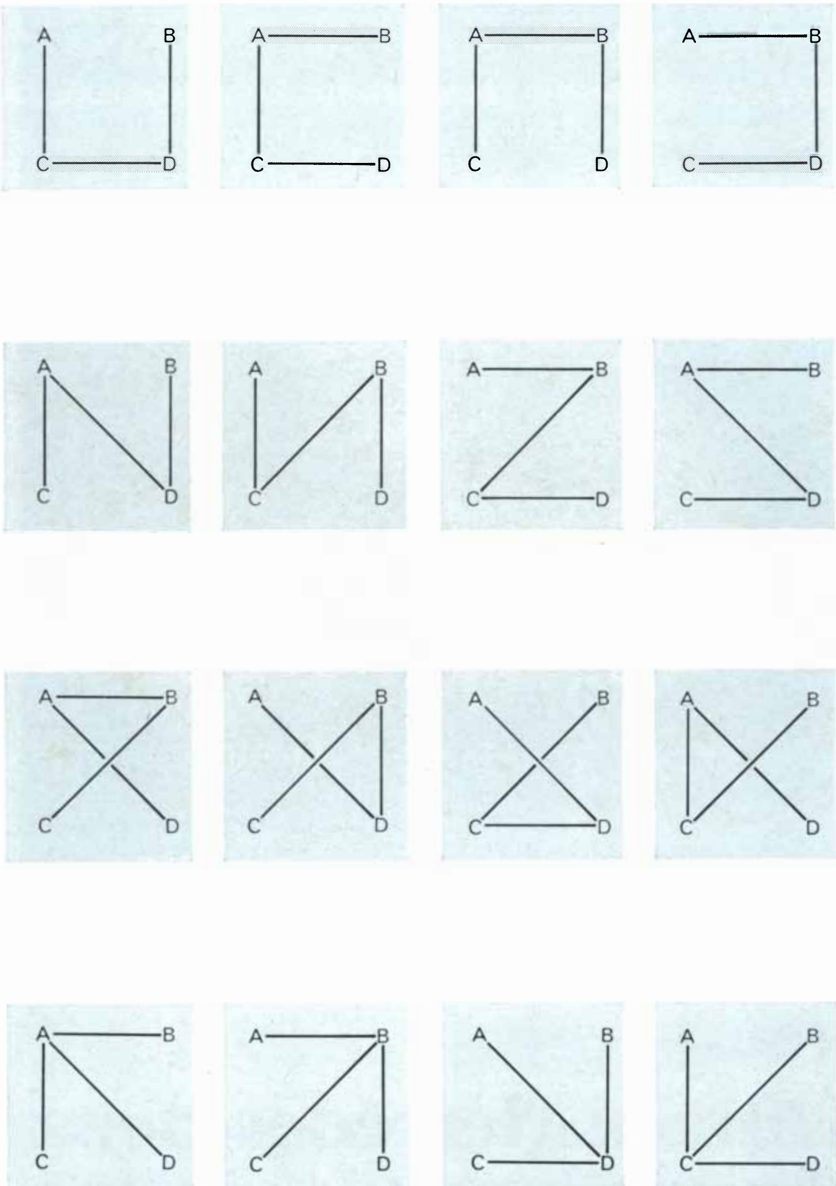
Card connections as a tree diagram

root, therefore we have two situations to consider: a square root ending in odd-odd digits and one ending in even-odd digits. The squarings of both numbers are shown schematically in the bottom illustration on the next page, with *E* for even and *O* for odd. The dots indicate that each line of numbers may extend any length to the left.

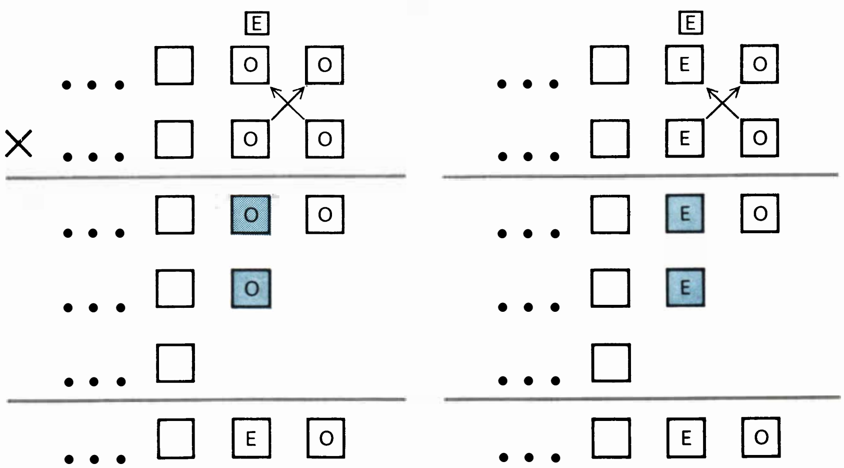
In both cases, when the odd end digits of the square roots are multiplied, the amount carried must be 0, 2, 4 or 8. Since these are all even we place an *E* inside the two smaller squares to show that the carried amount is even. On the left, each cross multiplication indicated by an arrow gives an odd product that remains odd after the carried amount is added to it. The two shaded digits therefore will be odd, and since the sum of two odd numbers is even, the second digit from the end of the bottom line must be even. The situation on the right is similar, only now the cross multiplications give even products that remain



Bottom cards to be treed



The 16 labeled trees that span four points



Proof of the odd-digit square problem

even after the carried amount is added. The two shaded digits therefore will be even. Since their sum is even, the second digit from the end of the bottom line again must be even. Interested readers can go on to prove a stronger theorem, which states that the second digit from the end is odd if and only if the end digit is 6.

Number 12 and its reversal have the same curious properties as 13 and 31. Square 12, reverse the digits, extract the square root and you get 21, the reverse of 12. The digits of either square sum to 9, the square of 3, which is the sum of the digits of 12 or 21. Fred S. Parmenter of Troy, N.Y., read about these numbers in the last chapter of Leonard Eugene Dickson's *History of the Theory of Numbers, Volume I: Divisibility and Primality* and recently set about the task of searching for all pairs of numbers with the same properties. Let us call such a number a par number. Parmenter proved to his surprise that no par number can contain digits other than 0, 1, 2, 3, and that a number n is par if and only if the sum of its digits is the square root of the sum of the digits of n^2. Since numbers in the series 12, 102, 1002, 10002, ... are all pars, the set of pars is infinite. If we define a fundamental par as one with no zeros, and include palindromic pars, the set has 55 members, the smallest 1, the largest 111111111. Eliminating the trivial palindromes, the fundamental pars are the following 20 numbers and their reversals: 12, 13, 112, 113, 122, 1112, 1113, 1121, 1122, 1212, 11112, 11113, 11121, 11122, 111112, 111121, 111211, 1111112, 1111121, 1111211.

The two two-digit automorphic numbers in base-6 arithmetic are 13 and 44. Extended leftward to seven digits, 1350213 and 4205344 are base-6 automorphs. The second 100-digit base-10 automorph, the companion to the automorph given last month, is shown on the opposite page.

All pairs of automorphic numbers of the same length, in any number system, have a sum of the form 11, 101, 1001, 10001 and so on. In the decimal system, therefore, given one of such a pair, its mate is found by subtracting the last digit from 11 and all other digits from 9. In the base-6 system the last digit is taken from 7, all others from 5.

The ambiguity in the fourth and ninth cross-lights of Lewis Carroll's double acrostic ballad in the September issue brought a large number of interesting letters. Martin Burkenroad noticed that the poem contained two phrases from

6	0	4	6	9	9	2	6	8	0
8	9	1	8	3	0	1	9	7	0
6	1	4	9	0	1	0	9	9	3
7	8	3	3	4	9	0	4	1	9
1	3	6	1	8	8	9	9	9	4
4	2	5	7	6	5	7	6	7	6
9	1	0	3	8	9	0	9	9	5
8	9	3	3	8	0	0	2	2	6
0	7	7	4	3	7	4	0	0	8
1	7	8	7	1	0	9	3	7	6

Hundred-digit automorph

Coleridge's *Kubla Khan,* "river ran" and "mazy motion" as well as the capitalized word "Vision" and the cross-light "ice," but these allusions were of no help in clearing up the two ambiguous cross-lights.

I cannot list all who wrote or give their arguments, but I shall cite some of the words that were suggested. Most readers agreed that "stream" was the best choice for the fourth cross-light, referring to the divided river of men in black cloth and girls in muslin dresses. Four readers preferred "swarm," four "stoicism" ("swallowed down her wrath") and three "schism." Other proposals were "seam," "spasm" and "scrum" (a rugby formation).

The ninth cross-light, for which "arena," "aurora" and "abracadabra" had been suggested, prompted four readers to propose "America" and four "asea." Three preferred "aphasia," three "agora." Others suggested "alfalfa," "ataxia," "arista," "arcadia," "avena" and "anarrhoea" (Greek for the flowing back of a tide after the ebb).

E. Robinson Rowe concluded, after a long and good analysis, that correct solutions for cross-lights 4 and 9 and possibly for others may have hinged on allusions to contemporary history or fiction or to local Oxford customs; the student for whom Carroll wrote his puzzle poem (he is the "Uncle" of stanzas 12 and 13) may have had much less difficulty with the answers than we do today. Incidentally, the name of the student's niece, Miss Keyser, was incorrectly spelled Kyser. Her first name remains unknown. If it began with *K,* her initials K. K. might explain the allusions to *Kubla Khan.*

Next month I shall report some unusual new discoveries made by readers in connection with the short problems presented in November.

THE AMATEUR SCIENTIST

Building a sensitive magnetometer and an accurate solid-state timer

Conducted by C. L. Stong

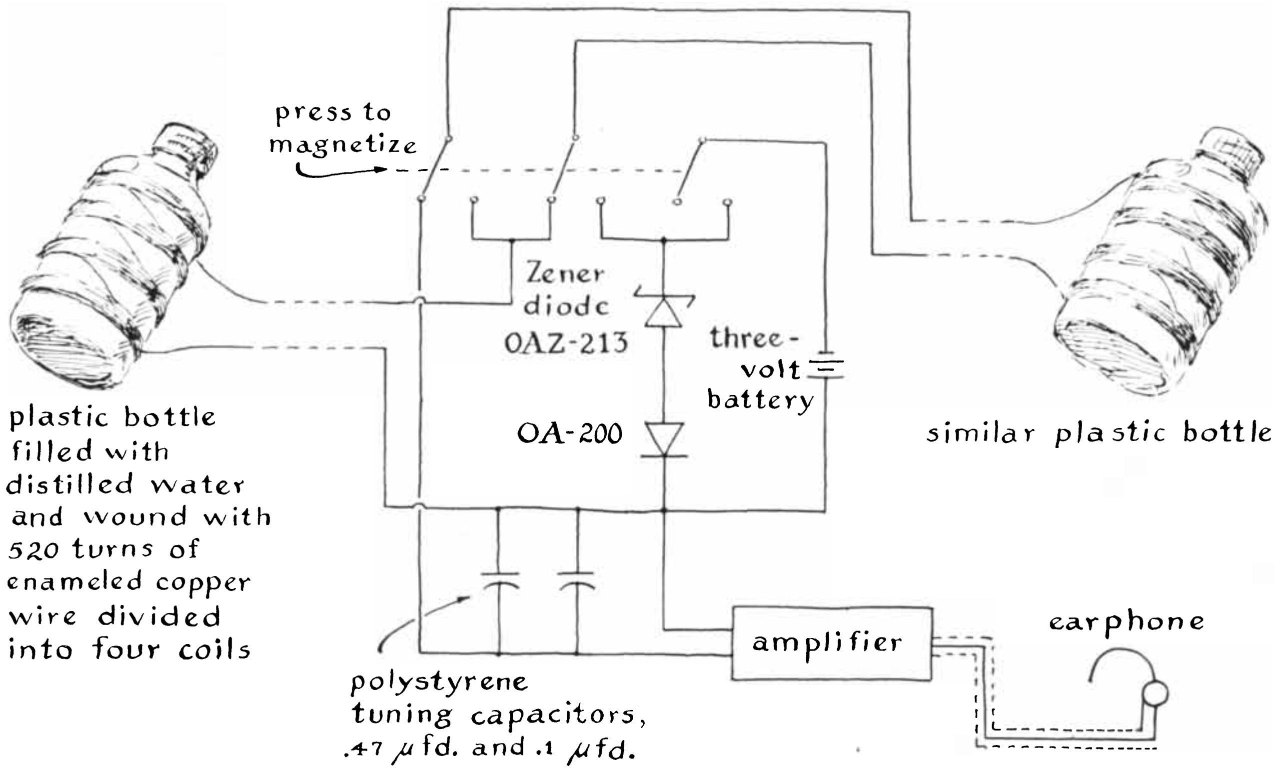
Anyone making field studies of wild plants might want to mark out areas so that he could observe the spread or retreat of certain species over a period of several years. The area can be marked by stakes, of course, but if the stakes are large enough to be found easily among tall plants in summer, they run the risk of being accidentally knocked down or being pulled out by someone who does not know what they are for. Even short stakes become conspicuous in winter and invite destruction. Inoffensive bench marks can be installed close to the surface along fence rows or natural boundaries for locating points of interest by triangulation, but this expedient is both troublesome and time-consuming.

A novel method of marking that appears to overcome such drawbacks has been devised by Nicholas Wadsworth, an amateur plant ecologist of Farnborough in England. Wadsworth buries small bar magnets at various points in the fields. Later he locates them to within a few feet using a proton free-precession magnetometer that he designed and built at home. He then uses a pocket compass to zero in on the exact location of the magnets. Wadsworth writes:

"My magnetometer is based on the effect a magnetic field exerts on protons in the nuclei of atoms of water. According to theory, most elementary particles—including the protons in water—spin on their axes like tops. They are also magnetized. In the presence of a magnetic field, such as the earth's, the spinning protons precess around the direction of the field in the same way that a spinning top standing on its point at an angle precesses around the direction of the earth's gravitational field. The rate of precession is proportional to the strength of the magnetic field.

"Normally the protons are out of step with one another, so that their effects cancel and the precession cannot be detected. If, however, all the protons could be made to point in the same direction at right angles to the earth's field and were then released together, they would all precess together. The effect of all would add, and the precession would be easily detectable for a few seconds until the protons got out of step again.

"Unfortunately a magnetic field of more than a billion oersteds would be needed to line up all the protons at room temperature. This is much larger than



Plan of Nicholas Wadsworth's magnetometer the largest magnetic field ever produced. However, much smaller fields, which can be produced easily by a dry battery and a coil of wire, can cause slightly more protons to point one way than the other. The difference is sufficient to produce a detectable signal in the coil when they are released. The precession frequency, and hence the frequency of the signal induced in the coil, is about 2,025 cycles per second. After amplification it can be heard in an earphone as a musical tone about three octaves above middle *C*.

"(This is, of course, a 'classical' description of the process. The quantum-mechanical description involves the emission of quanta as the protons 'flip' from one quantized state to another in the presence of the magnetic field. The description is different but the end result is the same.)

"The heart of the instrument is two plastic bottles wrapped with insulated copper wire and filled with distilled water. A switch of the push-button type enables me to connect the coils to either a three-volt dry battery or the input terminals of an amplifier. The bottles are mounted on the ends of a nine-foot pole at right angles to the pole, which supports in the middle the switch, battery and amplifier. Usually the coils are connected to the input of the amplifier. Pressing the switch transfers the connections to the battery. When the switch is released, the battery circuit opens first and other contacts transfer the coil leads to the amplifier [*see illustration on opposite page*].

"At a potential of three volts the current in the coils develops a magnetizing force in the water of about 30 oersteds. When the field is turned off, the protons precess around the earth's field for about three seconds and induce an alternating voltage in the windings of the bottles. The windings are connected in reverse polarity. For this reason the induced voltages cancel if the earth's field is uniform in strength and direction at both bottles. Nothing is heard in the earphone except the residual noise of the amplifier.

"On the other hand, if the magnetic field differs at the two bottles, the induced frequencies also differ and a net difference in voltage appears at the terminals of the amplifier. Such differences are observed when one bottle is closer than the other to a buried magnet, a piece of iron or inhomogeneities of the soil. Beats or wavers then appear in the signal. They reflect the difference frequency of the current in the two sets of coils. The 2,025-cycle note from the earphone gets alternately louder and softer.

"The magnetometer can detect a minimum difference in field strength of about 3×10^{-5} oersted, but where I live the earth's field is disturbed more than this by differences in soil composition. The smallest difference that I can definitely identify as arising from a buried magnet is about 2×10^{-4} oersted, which gives about one beat per second. I bury permanent bar magnets that are three inches long and 3/8 inch by 5/8 inch in cross section.

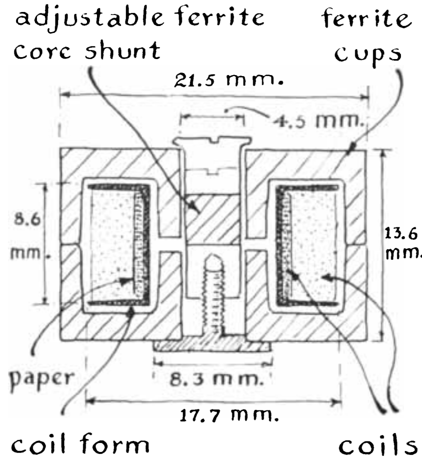
"When searching for magnets, I hold the pole horizontally at right angles to my path. If I am moving east, the pole points north and south and the bottles point east and west. I press the switch for about three seconds and release it. If I hear either no beats or one that persists for more than a second, I conclude that no magnet is in the vicinity. Then I press the switch while taking three slow paces forward, stop and listen again. In this way I search a strip about 12 feet wide. If I find no magnet, I similarly scan parallel strips. Thus I can quickly search a large area, listening at points nine feet apart in a series of 12-foot strips.

"When I hear two or more beats per second, I know that I am near a magnet or some other object that exerts a strong influence on the earth's field. I then spoil the signal from one coil by placing a small piece of iron near it. The field at that bottle becomes so inhomogeneous that the signal fades abruptly. Then I hear only the steady signal from the second bottle. This signal also disappears when the second bottle is moved close to the buried magnet. By this procedure I locate the magnet to within a foot or two. It can then be found easily with a pocket compass.

"The magnetometer is inexpensive and easy to build. At a variety store I bought thin-walled polyethylene bottles 1⅜ inches in diameter and 2⅛ inches long with plastic tops. I filled the bottles with distilled water. Each bottle was wound with 520 turns of No. 24 Standard Wire Gauge enameled copper wire. (The diameter of the wire is .022 inch, equivalent to No. 23 American Wire Gauge.) Each winding is divided into four sections of 130 turns each. The sections are spaced uniformly along the bottle to minimize capacitance in the coils.

"The terminals connect directly to the push-button switch. The switch consists of the contact assemblies of three microswitches. The assemblies are mounted so that one plunger actuates all three assemblies. When the plunger is released, the battery circuit is broken and then the coils are reconnected to the amplifier.

"The signal from the coils amounts to only about 10^{-16} watt, equivalent to the radiant energy that enters the eye from a candle 16 miles away. The amplifier must therefore be of the type that develops high gain and little noise at the desired frequency of 2,025 cycles. It should also be compact and light, and it should impose a minimum load on the battery.



Cross section of the pot core

"My amplifier was designed around inexpensive germanium transistors. The first transistor of the string develops only about as much noise as is generated by the random motions of electrons in the copper coils. Noise is suppressed further by the insertion of a tuned transformer between the third and the fourth transistor of the string. The magnetic core of the transformer is of the 'pot' type: it has roughly the shape of a hollow doughnut equipped with a movable plug in the central hole. The torus contains two coils of wire, which are the primary and the secondary winding of the transformer.

"The unit passes only the narrow band of frequencies determined by the position of the movable plug and the tuning capacitor. The position of the plug is set by a screw adjustment to pass the desired 2,025-cycle tone generated by the protons. I use the Mullard Type LA2416 pot core, which I bought (together with the transistors) from Mullard Ltd., Mullard House, Torrington Place, London WC 1. Mullard is a branch of Philips' Gloeilampenfabrieken of Eindhoven in the Netherlands.

"The design of the tuned transformer is fairly critical. In particular the *Q* of the completed transformer—the ratio of the average energy stored in the transformer to the energy that is dissipated per 1/3.14 cycle—must be at least 160. Any pot core that, when wound, will yield this *Q* can be substituted for the Mullard Type LA2416.

"The primary winding of the transformer consists of 120 turns of No. 42 S.W.G. enameled copper wire; the diameter is .004 inch, equivalent to No. 38 A.W.G. The coil is wound first on an insulating form and covered by a thin layer of paper insulation. The secondary coil of 1,170 turns of No. 40 S.W.G. enameled copper wire, tapped 30 turns from the inner end, is then wound over the primary. (The diameter of the wire is .0048 inch, approximately equivalent to No. 36 A.W.G.) The secondary winding, when it is in place within the pot core, has an inductance of one henry and is tuned to the resonant frequency of 2,025 cycles per second by a capacitor of .006 microfarad. I used a capacitor that was made with polystyrene insulation to minimize the loss of energy and thereby minimize the width of the band of frequencies transmitted by the resonant circuit.

"A signal of 10^{-18} watt can just be heard above the noise of the coils and amplifier. The gain in voltage is about two million, so that certain parts must be shielded to prevent the amplified signal from feeding back into the low-energy parts of the circuit. I installed the amplifier and its nine-volt dry battery in a tobacco tin. The tuned circuit was isolated from the remaining parts by metal partitions that divided the housing into three compartments and thus shielded the input and output portions of the circuit from each other. The internal layout of the parts is not critical.

"The assembly is completed by tuning the pot-core transformer. This adjustment is determined by the local strength of the earth's magnetic field. The operation must be performed away from buildings and pieces of iron. The magnetic field inside the average dwelling is so inhomogeneous that the signal quickly dies away.

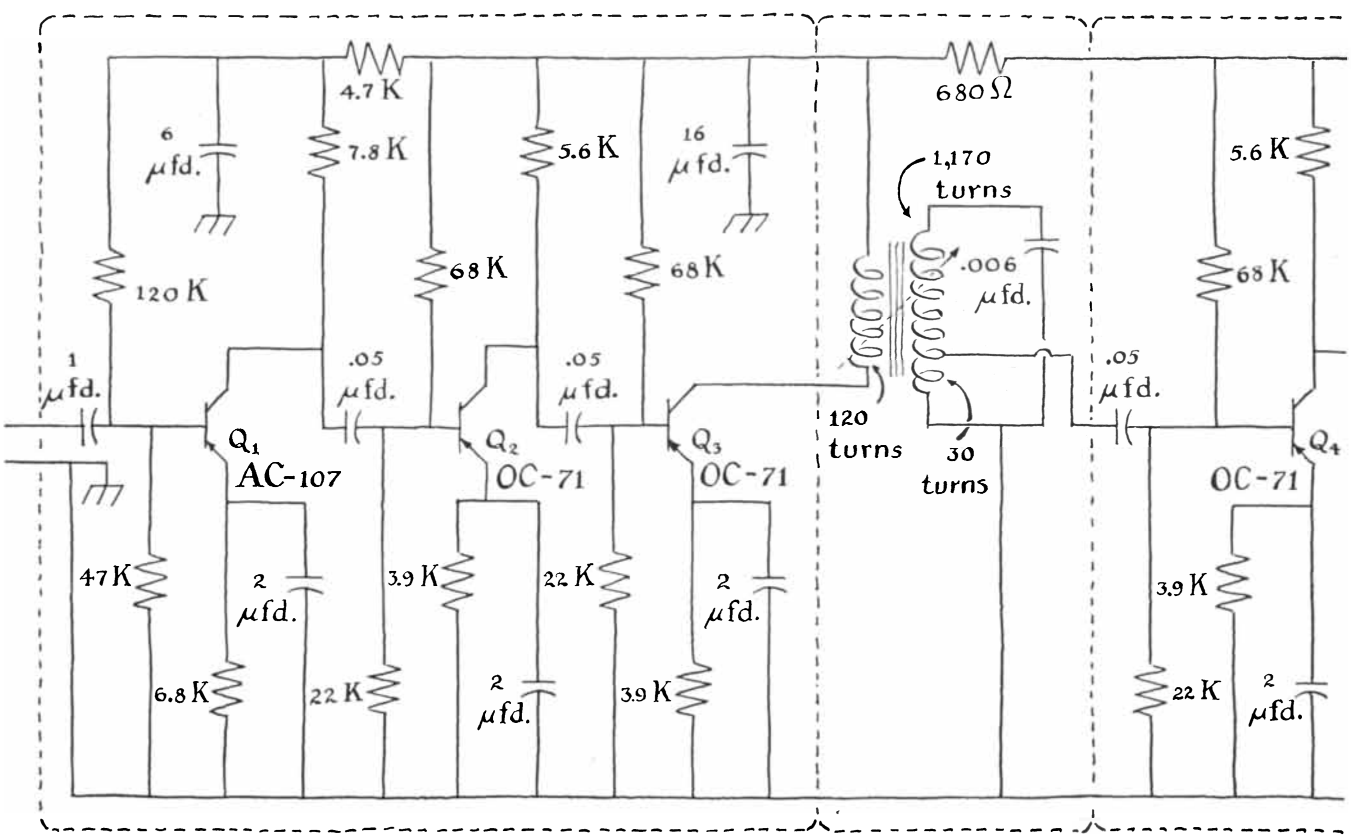
"Any germanium transistors that have a current gain of about 40 at .5 milliampere can be substituted for those specified by my circuit [*see illustration below*]. The transistors designated in the illustration are of British manufacture and have no exact U.S. equivalent. The first transistor in the string, Q_1, must have a low noise figure—about three decibels when connected to a 1,500-ohm resistor, which is a source of noise.

"A diode of the Zener type connected in series with a conventional diode is bridged across the switch contacts of the three-volt battery. These diodes minimize sparking at the switch contacts and speed up the collapse of the magnetic field when the circuit is opened. The rating of the Zener diode should lie between 10 and 20 volts. The unit must be capable of transmitting 300 milliamperes for a maximum of 500 microseconds. Any diode of the silicon-junction type can be connected in series with the Zener diode.

"The current drawn from the nine-volt battery by the amplifier amounts to only 2.5 milliamperes, so that the battery should have a long life. In contrast, the coils draw about one watt when they are magnetized by the three-volt battery. I use a heavy-duty dry battery for energizing the coils. The life of the three-volt battery is about 24 hours if it is used intermittently."

An essential apparatus for making experiments of many kinds is a reasonably accurate clock that can operate a switch automatically at regular and predetermined intervals, make a periodic sound, register the passage of time in discrete units and so on. A clock of this kind is described by Eric Newman, a high school student in New York. He built the unit primarily as an introductory exercise in the use of two solid-state devices of recent origin: the unijunction transistor and the silicon-controlled rectifier.

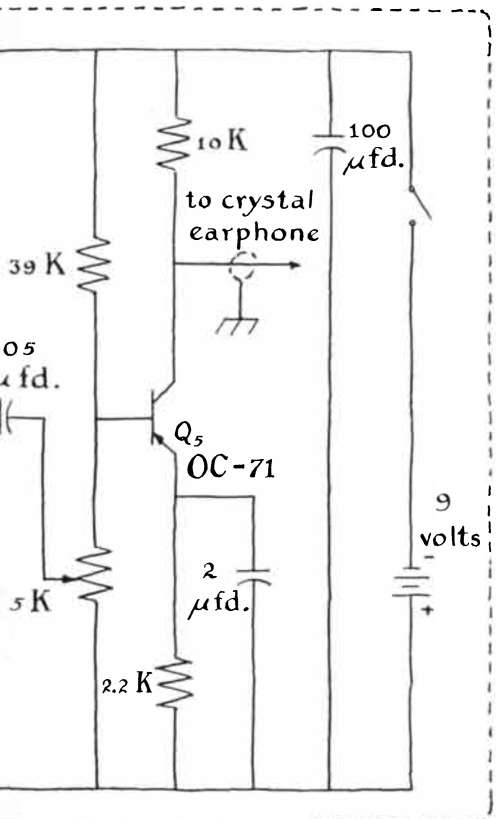
Like the vacuum tube and the tran-

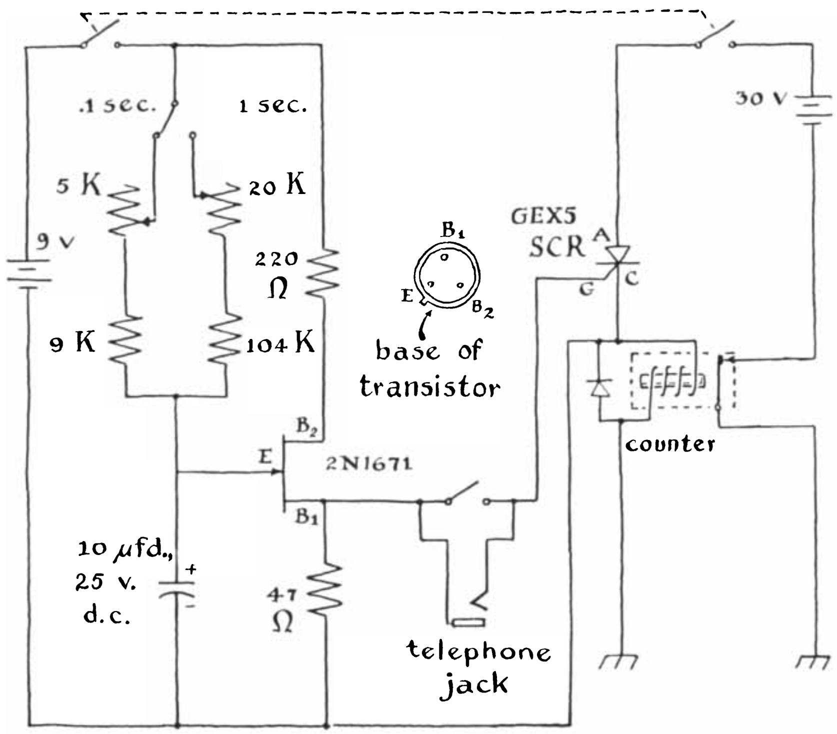


Circuitry of the amplifier

sistor, these devices are equipped with three terminals. The devices will conduct electric current in only one direction between two of the terminals when an appropriately smaller current is applied to the third terminal. In effect, the devices function as switches that can be opened or closed thousands of times per second by a signal that can be transmitted from a distant location. Both devices are made essentially of semiconducting materials.

The unijunction transistor consists of two minute rods of silicon joined in a structure that resembles a *T* crossed somewhat off center. Normally the electrical resistance of the crossarm of the *T* is quite high—5,000 ohms or more. Positive potential is usually applied to the end of the shorter portion of the crossarm and negative potential to the longer portion [*see illustration on next page*]. The shorter portion goes by the name of "base two" and is designated B_2 in the illustration; the longer portion is called "base one" and is shown as B_1 in the illustration. The leg of the *T* is called the emitter. The emitter will conduct current into the base region but not in the reverse direction. Normally the path between the emitter *E* and B_1 behaves like an open circuit. When one applies to the emitter





Circuitry of Eric Newman's solid-state timer

a positive potential that is equal to about 60 percent of the potential between B_1 and B_2, however, the resistance between the emitter and B_1 drops abruptly to a low value.

Devices that exhibit this characteristic can be made to generate electrical oscillations: to convert direct current into alternating current. The unijunction transistor makes an ideal oscillator for generating pulses of short duration, waves in the shape of sawteeth and other forms that—before the advent of this small and inexpensive device—could be generated only by complex apparatus. Unijunction oscillators nearly always work the first time you try them. For this reason experiments that are based on them can serve as a pleasant introduction to the technology of solid-state devices in general.

The maximum average current that can be switched by the unijunction transistor amounts to only a few thousandths of an ampere. In contrast, the silicon-controlled rectifier (SCR) is a high-current device. The largest SCR can carry hundreds of amperes and control loads of many kilowatts.

The terminals of the device include an anode, a cathode and a control electrode called the gate. The SCR will conduct current from the anode to the cathode when a pulse of positive current is applied to the gate. Once the device has been triggered it continues to conduct until the current is interrupted by some external device. The unijunction transistor makes an ideal triggering companion for the SCR.

"My solid-state timer," writes Newman, "includes two basic circuits: an oscillator that consists of a unijunction transistor and an associated timing circuit that generates a series of extremely short periodic pulses of current, and a silicon-controlled rectifier that is actuated by the timed pulses. An electromechanical counter, powered by the SCR, registers the accumulated intervals of time.

"The timing circuit consists of two adjustable resistors that can be connected alternately by a switch to the positive terminal of a nine-volt dry battery that applies potential to a capacitor. The negative terminal of the battery is connected to the second terminal of the capacitor. The rate at which the capacitor accumulates charge varies inversely with the size of the resistors.

"The junction between the capacitor and the resistors is connected to the emitter of the unijunction transistor. B_2 of the transistor is connected to the positive terminal of the battery through a resistor that limits the current to a safe value. B_1 is similarly connected to the negative terminal through a resistor that serves as a load. A potential difference appears across the load resistor when the transistor conducts current.

"When power is applied to the apparatus, charge accumulates in the capacitor. Voltage simultaneously rises across the terminals of the capacitor and across the emitter and B_1 of the transistor. When the potential has increased to about 60 percent of the potential across the battery, the emitter abruptly conducts and the resistance vanishes between the emitter and B_1. The capacitor discharges almost instantly through the transistor. During the discharge a voltage pulse appears across the terminals of the load resistor. The cycle continues as long as power is applied.

"One resistor of my instrument is adjusted to generate pulses at the rate of one pulse per second and the other at the rate of 10 pulses per second. The rate of pulsing, in seconds, is roughly equal to the product of the capacitance in microfarads multiplied by the resistance in megohms. I refined the calibration by accumulating the total count, as indicated by the electromechanical counter, for a series of 15-minute intervals, as indicated by an accurate clock, and then adjusted the resistors as required.

"Pulses from the timing circuit are applied to the gate of the SCR. The anode-cathode circuit of the SCR includes the electromechanical counter, a 30-volt battery and a set of relay contacts that are operated by the armature of the counter. The SCR, when it is triggered into the conducting state, remains conductive until the power is interrupted. The relay contacts perform this function.

"The SCR, when it is triggered, also applies power to the solenoid of the counter. The solenoid then magnetically attracts a movable armature, which operates a ratchet that advances the counting wheels one unit. The armature also opens the contacts at the inner limit of its excursion (after it has actuated the ratchet).

"Contacts must be added to the counter. I salvaged a contact-spring assembly from an old relay. The assembly consists of a pair of flat, narrow springs joined at one end with an insulating spacer. The contacts, which are welded to the opposite end of the springs, are usually closed.

"The insulated end of the assembly was mounted on the frame of the counter with epoxy cement. A short rod was cemented to the armature to depress the innermost spring—and thus open the contacts—at the inner extreme of the armature's excursion. When the contacts open, the SCR returns to the nonconducting state. In this state it is prepared to accept the succeeding count."

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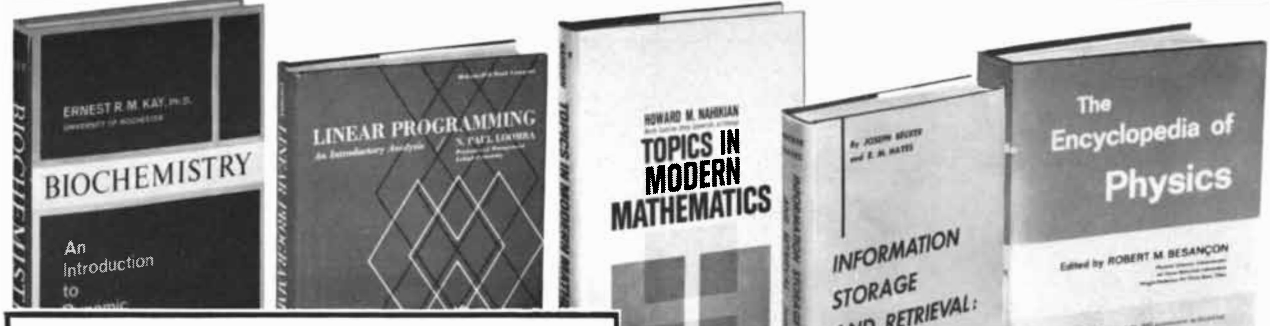

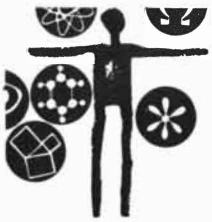

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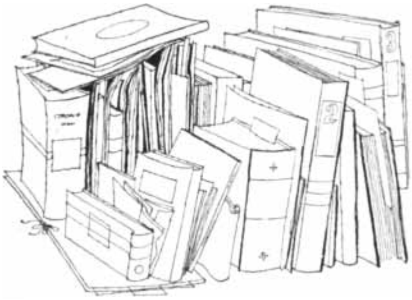

BOOKS

What are the goals of man's evolution?

by H. Bentley Glass

THE BIOLOGY OF ULTIMATE CONCERN, by Theodosius Dobzhansky. The New American Library ($5).

A book devoted to the *Weltanschauung* of a biologist is quite unusual, yet it is timely in an era when the discoveries of biology threaten us with quandaries more numerous and more severe than any issues we have yet resolved. What will man do with the power to control the course of the future evolution of every living species, including his own? This power he already possesses, but the goals are not chosen. Who will establish them, and how? It is not enough to say: Let us avoid intervention in the natural course of evolution—let it take its own course. It is plain that we are already committed to many practices that clearly modify, usually in a detrimental way, the genetic structure of populations of plants and animals, microorganisms and men. We have already intervened in the evolutionary process, although mostly in blind ignorance of the consequences of what we do. There remains time, not much but perhaps enough, to guide the process toward a more agreeable outcome, if the power of decision-making is strengthened and focused on the matter. Today many students of evolutionary processes see that these issues face mankind with disastrous possibilities, yet few are willing to forsake the pursuit of scientific knowledge for the difficult battle between conflicting human desires and values.

It is thus doubly fortunate to have a consideration of human problems by an acknowledged leader in the field of evolution. Professor Dobzhansky, of Rockefeller University, speaks with the knowledge and authority of one whose book *Genetics and the Origin of Species* in 1937 established with a fresh and vigorous grasp the modern view of Darwinian theory and began the experimental analysis and testing of evolutionary hypotheses. His own researches and those of his numerous students have contributed a major portion of our present understanding of the evolving genetic structure of populations. The reader will therefore turn with special interest to these pages, which portray a scientist's very personal quest for the meaning of life, his own effort to harmonize spirit and animality, his effort to press beyond the synthesis of science.

The book has six major chapters, the first five of which are in fact introductory to the author's statement of belief in the last one. First Dobzhansky considers the familiar, timeworn effort to supply divinity within the gaps of present knowledge. He rejects the "gods of the gaps" out of hand. As so often in the past, so too in the future the increase of scientific knowledge will narrow the gaps, fill the vacant spaces with once-missing links, and reduce the freedom of action of the gods who have been invented to account for action not understood. "The historical odds," Dobzhansky says, "are all against the 'God of the gaps' being able to retain these shelters in perpetuity."

In biology vitalism, in spite of a few recent efforts to revive it, is dead. Nevertheless, the kind of simple reductionism that treats the living organism as a physical and chemical machine is not an adequate view of the nature of life either. We must seek to find out how organisms became what they are. Every living being is a direct lineal descendant of primordial life. The new living machines are not exact replicas of the old ones. Natural selection acting on the effects produced by mutations generates adaptations. There is thus a feedback from the challenges of the environment to the genetic nature of the species. The nature of the organism, down to every minute feature of its development, is a product of its past evolutionary history. Dobzhansky therefore searches for some emergent quality (perhaps rooted in panpsychism, as various other biologists have believed) to account for the novelties in the origin of life and the origin of man and mind.

Considering the problem of transcendence in an evolutionary context, Dobzhansky notes that "Christianity is, among the great religions, most explicitly history-conscious, and in this sense evolutionistic." On the foundation of the Judeo-Christian background the idea of progress has dominated Western thought. A belief in evolution—cosmic, biological, human—was a natural sequel. The pertinent question is whether these are three unrelated processes, or "parts, perhaps chapters or stages, of a single universal evolution." Dobzhansky would knit them together through evolutionary transcendence. "Cosmic evolution transcended itself when it produced life. . . . In the same sense, biological evolution transcended itself when it gave rise to man." Natural selection offers an adequate basis for this evolutionary transcendence. It may well have operated, as the Russian biologist A. I. Oparin and others have suggested, prior to the advent on earth of living organisms, in the competition for survival of complex chemical systems differing in their individual capacity to grow, to remain stable and to replicate themselves. Particularly evident in the later stages of competition among biological organisms is the lack of any perfect or ideal fitness. "The fitness that is selected," Dobzhansky says, "is the overall fitness of the organism to survive and to reproduce, not the excellence of different organs, processes, and abilities taken separately. A consequence is that, especially in radical evolutionary reconstructions, the emerging product is an appalling mixture of excellence and weakness." Nonetheless, although it is a process embodying chance and imperfection, natural selection is truly creative, since it brings into existence constellations of genes characterizing species that have never been before.

The transcendent qualities of man are to be found in his mind—in his self-awareness and his death-awareness, his consciousness of individual identity and his foresight of its loss. It is a point to be kept in mind that the individual consciousness of identity is not a mere expression of the uniqueness of the genotype. It may well start with that. Yet we must recognize that identical twins do not regard themselves as the same person in spite of their identical genotypes. Hence the entire course of personal history, starting from the first exposure of initially identical embryos to different circumstances, leads to different characteristics, different experiences and different memories. The sense of distinct individuality is formed with the dawn of consciousness itself. Dobzhansky provides an interesting line of reasoning to support the view that both self-awareness and death-awareness can be advantageous in the course of natural selection. To the existence of death-awareness he attributes in prime degree man's "ultimate concern," his search for the meaning of his own life and the lives of others, his long quest for the meaning of the cosmos.

In a chapter entitled "Search for Meaning" Dobzhansky reasons that man's (and woman's) sexuality, the prolonged helplessness of infants, the family as the social outgrowth of the parent-child relation, the evolving tendency of man to "ethicize" and man's death-awareness all play roles of importance in natural selection and culminate in the quest for meaning. Magic and religion—the latter defined as "what man does with his ultimate concern"—are the natural products. One might say that "the human species has developed a capacity, in fact a need, to have a religion." On the other hand, human ability—predicated on one's self-awareness—to identify oneself with groups, movements and institutions produces the social cohesion without which human history could not have been. It follows from the foregoing line of reasoning that science, particularly biology, is "relevant to man's ultimate concern." The growing alienation of the individual man and the widespread sense of the meaninglessness of life thus acquire a new illumination. One may ask: Would a recognition by the individual of the existence and nature of the evolutionary process of which he is part and product actually create in him the necessary sense of involvement and of participation in a process the ends of which none can see but whose capacity to transcend current levels of being is clear enough? Can education, specifically in biology, strongly promote the understanding of the ultimate concern?

In his final chapter Dobzhansky attempts to answer this question. A true and satisfying synthesis of knowledge and wisdom must be, he affirms, an evolutionary synthesis. It cannot, like some religions, rest on static concepts, either of what exists or of what is right or best. The author himself finds such a synthesis in the writings of Pierre Teilhard de Chardin, who is characterized as a "Christian mystic, who happened also to be a scientist, and who had in addition a gift of poetic imagery." One should discard the notion, says Dobzhansky, that Teilhard really wrote science. "It would . . . be nearer the truth to say that Teilhard saw science illuminated by his mystical insights." Since not a few scientists (George Gaylord Simpson, for example) have dismissed Teilhard in sharp or cavalier fashion, it is most interesting to see just what Dobzhansky makes of Teilhard's synthesis. Granting that "every generation will face the task of revising and renewing the synthesis," Dobzhansky picks out as the cardinal postulate of Teilhard the following statement: "Men's minds are reluctant to recognize that evolution has a precise *orientation* and a privileged *axis*." Man's ultimate concern, then, is with his own individual part of this evolution of the whole universe, marked by progress and directionality. Teilhard describes evolution as "groping," a term that Dobzhansky finds apposite, although he challenges Teilhard's view that evolution "tries everything." The evidence is clear to the biologist that innumerable possible modes of evolutionary development have never been tried at all, and that the initial chance that life today would be exactly what it actually is, is comparable to the choice of one atom among all those in the universe. Yet here we are, a part of that totality of living beings on the earth which Teilhard has regarded as a supra-organism, and specifically that part in which the emergent qualities of mind and consciousness have transcended simple biological evolution. I take Dobzhansky's own ultimate statement to be the following:

". . . in progressive evolution we find a competition for cooperativeness. There is also an evolution of love; love ascends from sexual love, to brotherly love, to love of mankind, to love of God. Love unites without casting off the diversity. On the human level it is the means whereby a person as well as the species achieves self-transcendence. The mega-synthesis is 'a gigantic psycho-biological operation' in which love is the main agent, and which leads to the unity in diversity."

And what is God? Dobzhansky is satisfied with the vision of Teilhard: the eventual consummation of all evolution is a convergence in the Omega. In the Book of Revelation (22:13) is the Christian statement in symbolic form: "I am the Alpha and the Omega, the first and the last, the beginning and the end."

What can another scientist say of Dobzhansky's credo, particularly one who is himself a biologist, a student of evolution and a humanist? There will be many scientists who will reject this book because it ventures beyond the facts and hypotheses of science. They are those who have not found a need for the "ultimate concern." There will also be many readers who will acclaim the work because it fits well their own philosophy of life, without knowing whether Dobzhansky's underpinning of scientific interpretation is sounder than that of Teilhard de Chardin or not. I can assure them that it is, that it accords well with all that is known today of the nature of the evolutionary process; but the assurance is unnecessary since they would have grasped at the hope anyway. There are others, perhaps, who will examine the author's venture into metaphysical and religious thinking with a critical yet sympathetic spirit. It is not necessary for Dobzhansky to be right on every point. Maybe he is not. In any case, as he says himself, "every generation will face the task of revising and renewing the synthesis." The reason we owe so much to Dobzhansky—and to Teilhard before him—is that *someone* must venture to attain a higher synthesis of knowledge and meaning, someone must grapple with man's "ultimate concern." For too long this task has been left to the philosopher untrained in science or to the spokesman of religion. As a consequence a disheartening paralysis has prevailed. On the one hand, how many scientists engage ever more exhaustively in an analysis of phenomena while neglecting the equally important synthesis of ideas about the cosmos, about life, about man! On the other, how many philosophers content themselves with mathematical logic or existentialism and deny the relevance of the scientific advances of our time for the appropriate reconstruction of our systems of thought.

If the ultimate concern of man is so inherently biological and evolutionary as Teilhard and Dobzhansky have insisted it is, then the neglect of such matters in our schools, colleges and universities is appalling. The social resistance to such a view can be measured by the fact that more than a century after Darwin no high school biology textbook in the U.S. provided a forthright discussion of either the evidence for evolution or the theory of natural selection. Most of them even refused to use the word "evolution" and referred ambiguously to some theory of organic "development" still on supposedly shaky scientific grounds. This, more

than 30 years after the discovery of how to produce mutations artificially and to study the processes of evolution experimentally! If the Biological Sciences Curriculum Study had done nothing more in the past eight years than to break this social reluctance to examine, discuss and evaluate the evidence and the theory, American education would owe it a lasting debt of gratitude. Nevertheless, as I reflect on my own experiences in this area during the past decade, I remain deeply troubled that so few biologists have voiced their concern or volunteered their personal services in taking the first steps toward seeing that all Americans in the next generation will be provided with the particular educational experience essential to the understanding of our "ultimate concern." Is it that we are so materialistic that we have no ultimate concern? Or so shortsighted that we are concerned only with discovery and not with the uses made of discovery?

Dobzhansky's vision is both human and all-embracing. I fear that its reception may be cool and narrow. Will there be even one biologist in the younger generations who does not say, "This is not science"? Will there be even one philosopher who does not say, "This is too much science for me—I shall stick to straight philosophy"? The trouble is that Dobzhansky, in the true 18th-century meaning, is a natural philosopher, a species now extinct or nearly so. Yet the alienation of so many persons in our society today is proof enough that what we need is more enlightened education that will relate the natural sciences to human life and human problems, and especially to man's ultimate concern.

Short Reviews

THE GREENLAND ICE CAP, by Børge Fristrup. University of Washington Press ($20). If you live in the northern half of the U.S. and far enough from Puget Sound, you are likely as you read these lines to be in that third of the earth which is at any time temporarily covered with snow. The ice caps of the Antarctic and Greenland are relics of the age when a third of the earth was always locked in ice. Of these two the Greenland ice sheet, smaller and lying much closer to the center of human population, is the better known. *The Greenland Ice Cap* is a beautifully illustrated book, translated (by David Stoner) from the Danish text of an expert who seeks to make the history and nature of what we know about the Greenland ice available to the nonspecialist. It is two centuries since men first went for more than a brief walk onto the ice sheet; the trader Lars Dalager and five Greenlanders, equipped as hunters, made a hard week's foray into the intense cold and sterile beauty of the ice. Since about 1950 the airplane and the tractor, the spearheads of large-scale organizations (mainly but not exclusively military), have occupied stations on the cap, for study, for radar and for air rescue—stations where now "the ice sheet is invaded by men in lounge suits, collars, and ties, carrying briefcases." This is the story of that remarkable transient conquest, still only spotty, since "a mile or two from [the stations] living conditions are . . . as they have always been." There is a brave tradition of science on the ice too; the geophysicist Alfred Wegener, originator of the idea of continental drift, died somehow on the high ice in 1930, probably of a heart attack in his tent, and was buried there by a companion who himself was never found.

Nowadays the big camps humming with diesel or atomic power lie tunneled into the ice under Quonset roofs and thick layers of snow, or sit high above the unstable snow surface on stilts with hydraulic jacks. Tractor trains, aircraft and helicopters nourish the stations, bringing fuel, food and film. Radio altimetry and the more difficult seismic sounding have shown that the ice is about a mile deep, lying above a rocky terrain more or less like that around Hudson Bay. The crevasses are still a peril but a manageable one. The weather is cold, although surprisingly stable; the ice sheet cools the air at the ground, so that there is a permanent inversion, with light winds steadily falling into the sea on all sides. Weather, then, is not much made on the ice cap. Icebergs are; there break off from the edges and float away each year a couple of hundred cubic kilometers of ice, about the volume of the Green Mountains of Vermont. This ice seems to flow across the top of the sheet; the mile-thick layer is mainly stagnant. Greenland has certainly been warming, and the ice retreating, over the first half of this century, but for the past decade or so the trend appears to have been reversed. We do not know what will happen in the long run. The lavish volume ends with a fine tipped-in photograph showing sky brilliant blue above blued ice, and a double track stretching far toward the empty horizon. "These tracks will remain for a long time and will often be found again in the years to come."

FAMINE ON THE WIND: MAN'S BATTLE AGAINST PLANT DISEASE, by G. L. Carefoot and E. R. Sprott. Rand McNally & Company ($5.95). Readers of a certain age are sure to recall the marvelous romances of Paul de Kruif, who managed a generation ago to recount in a series of distinct narrative chapters the heroic stories of the pioneers of medical bacteriology, the men who isolated, controlled or immunized against the scourges of mankind—malaria, yellow fever, rabies and the rest. What men and what times they were! Working in plague-stricken cities, or watching on their own wrist the infected mosquito biting, these scientists before antibiotics were adventurers not only of the mind. The two Canadian authors of this agreeable book follow the pattern of De Kruif, but with two differences. The diseases are the diseases not mainly of men but of their crops, and the heroes are somehow subdued, a little by the point of view but largely because plant pathology is a large-scale, corporate kind of effort in which great men do not stand much above the plateau. Still, there are heroes.

Consider Dr. Thuillier, a French country physician in the year 1670, who saw his patients suffer and die with the Holy Fire, proceeding through convulsions and madness to certain death. He noticed three things. The disease was not infectious; often family members survived. It was a disease of the countryside and not of the city, and of the poor but not of the rich. He found the cause: it was the purple spurs of ergot, the fungus parasite of the heads of the rye grain, that brought the Holy Fire. City people ate white bread. In those years when the fungus *Claviceps purpura* visibly dotted the rye fields, the Fire took its dreadful tithe. Rye still harbors ergot, and today we are protected only statistically, by regulations on the content of ergot that salable rye can have. Indeed, in 1951 a few dozen persons died or went insane in Provence from ergot allowed to enter bread flour by three hardfisted Auvergnats who knowingly sold their poisonous product far away. LSD is only one of many pharmacologically potent substances now derived from ergot.

Another hero is Pierre Millardet, who recognized in 1882 that roadside grapes splashed with a mixture of lime and copper sulfate, to discourage passersby who scrounged the ripe ones, were untouched by the mildew. Out of this keenness of eye and mind came Bordeaux mixture, a prince among plant fungicides and still a major defender of the vine against mildew, of the potato against late blight and of the plantation banana against leaf spot.

There is a humane if restrained account of the terrible enslavement of the

Congo peoples for rubber latex at the turn of the century—one life expended for each eight pounds of rubber! The success of plantation rubber depends on freedom from the leaf blight, which is endemic in the New World and has so far made *Hevea* rubber a monopoly of Indonesia and Malaya. Chestnut, elm and now oak among our American hardwoods are falling before imported diseases; the oak wilt may yet be checked. This book tells the whole tale briefly for a dozen crops of man; it should become a standard, almost in the classic mode of *Microbe Hunters*. The bibliography too is rich and inviting.

Çatal Hüyük: A Neolithic Town in Anatolia, by James Mellaart. McGraw-Hill Book Company ($9.95). There is something golden about our best archaeologists today. They inherit so strong a method and tradition, they find such remarkable objects, they write so brilliantly of such fascinating problems, they bring out so many books so well illustrated with photographs and reconstruction drawings, so personal and yet so clear in argument and so sound in substance, that other scientists cannot rival them. Here is such a book.

Three or four years of digging into the high 30-acre mound on the open wheatlands of the dry Anatolian plateau, carried out by an expedition from the University of London under the author's leadership, are the source of this work. The mound is an ancient town site, already 3,000 or 4,000 years old, by secure radiocarbon dating, when Ur of the Chaldees was founded. The people lived not only by the cultivation of wheat and barley but also by the taking of big game, the red deer and the aurochs with its great spreading horns. They knew pottery and weaving, even in the oldest levels yet reached; they smelted beads and trinkets of lead and perhaps of copper; they worked and polished stone and bone with high art; they maintained a complex terraced pattern of mud brick and frame construction, which remained stable sometimes over a millennium. They had no writing or accounts.

Only a small part of the town has been uncovered. Of the 139 rooms found, perhaps 40 were decorated with wall paintings, plaster reliefs, human skulls and horns of the great wild ox set in rows along walls or benches. Mellaart feels he has opened the religious quarter of the town and that most of these large and splendid rooms were devoted to a cult. What a cult! There are painted on the wall great black vultures attacking tiny headless humans. There are plaster heads of bulls, surmounted with real horn cores, in rows and sets, defining courtyards surmounted by the modeled figure of a goddess, flanked by still more bulls, who is giving birth to a ram. The surfaces are painted, whitened, repainted and replastered, with scores of layers of painting. The ritual function had to be stopped and restarted many times. There are a few human skulls, and in one pit the bones of a premature infant, offered to the goddess. The dead were exposed to vultures, their bones stripped of the flesh and the skeletons buried in the platforms of houses and shrines.

We are offered a brilliant conjecture on the nature of this awesome and barbaric ancient religion; the argument is based on the absence of any overt reference to sexuality in the symbolism. Sexual organs are never shown; breasts and pregnancy, horns and horned heads take their place. Mellaart believes this shows that the religion was the creation of the women, who became associated with the fertility of fields and of flocks, with the idea of increase itself, "as the only source of life." Man appears "as boy and as paramour," but the heads of the cult, its great deities and their devotees, were women.

There is a decade of work ahead at this site. It shows man changing from gatherer to farmer in that time of the greatest change men have yet survived. One can only wait with fascinated expectation for what will be found in the rest of that strange old town in sight of the snow-capped volcanoes of eastern Anatolia.

U. S. Philanthropic Foundations: Their History, Structure, Management, and Record, by Warren Weaver, with contributions by 19 others. Harper & Row, Publishers, Inc. ($7.95). The author was a mathematical physicist 35 years ago when he became a philanthropoid of the Rockefeller Foundation. This is his look back at what he has been doing, a study of the whole institution, fortified with essays by a cluster of savants, each one appraising the foundation impact on a particular field, from molecular biology to modern dance. The foundations are traced back to antiquity, when under Marcus Aurelius they became artificial persons able to receive bequests and spend for the public good. The big American foundations today spend (by law they may not accumulate!) the gain from oil, automobiles, steel, breakfast food and tobacco on the public welfare, mainly at the level of investigation and prototype rather than on charitable operations themselves. The 10 big general-purpose funds together have assets about eight times those of Harvard but only half of what A.T.&T. holds. There are thousands of others, but they add up to less than the first 10. About $1 in $30 of all the money spent on higher education and university research now comes from private foundations; 50 years ago it was $6.

The foundations have done well by science. The Palomar telescope, the first cyclotron, the main research on fruit fly, *Neurospora* and bacteriophage genetics, on DNA, on the growth of national income and on input-output analysis—all were foundation-financed. The international control over death by yellow fever and by malaria owes a great deal to the foundations, and control over birth is now gaining the same attention. Food, too, was aided by foundations: the new richness of Mexican wheat and Indian maize are theirs. War and the disease of racism are scourges for which foundation research has plainly done little, although such work as that of Gunnar Myrdal and of many Southern colleges shows their earnest presence.

The book is filled with praise. There are troubles. The mark of the C.I.A. is a recent one, and the economist George Stigler's essay takes a rather wry look at the stimulation of fashions, although possibly of valuable ones. The entire work is doubtless to be the standard study of the American foundation, but although it is disarmingly candid (Ford's founding "did unquestionably accomplish the unimpaired continuation of the company"), there is a rather repetitive note of satisfaction. Natural enough, but what comes next? Weaver does not really try to say.

Contact and Frictional Electrification, by W. R. Harper. Oxford University Press ($11.20). Here is a remarkably fresh research monograph that recounts painstaking and ingenious experiments and merges order-of-magnitude estimates with a clear, brief version of the quantum theory of solids to come a good way toward the solution of a problem as old as amber. How do objects become electrically charged on contact and rubbing? The question is difficult, because this is the physics of two dimensions, only an atom deep. Moreover, it is the study of that surface skin by means so sensitive that impurities present only as parts in 10^{15} or so of the bulk cause major effects. How does a good insulator, such as polyethylene or amber itself, charge up? Harper proves that in fact it hardly does; these water-hating amorphous substances have no free bonds at the surface, nor can they admit electrons into interior traps. They collect less charge by two or three powers of 10 than glass or quartz does. That nonetheless amber and its like (electrum, the very namesake of electricity) show strong charge effects is the result of their excellent resistance: what they get they hold. In practice they gain a small charge because they sometimes harbor contaminating ions on the surface, or because they heat locally under vigorous rubbing. A surface charge of an odd ion or two—free electrons play no role—for every 100,000 typical lattice squares is about as much as one will find. It is plenty to cause the sparking and the obstinate stickiness of films, cloth and fibers.

Harper cannot quite rationalize all the strange effects seen, say, with the cat's fur of the lecture table, but he makes the subject at last become a part of physics. Ice is an unusually good ionic semiconductor, and its charging by contact and by thermal gradients lies behind the thunderbolt. The book can be enjoyed in part by anyone interested in physics. As a whole, however, it is for the professional. The literature is presented as deeply as the author's own considerable work; only the indexing and other bookish apparatus are not as good as the substance of this engrossing inquiry merits.

The Way Things Work: An Illustrated Encyclopedia of Technology. Simon and Schuster ($8.95). This thick book presents on nearly every pair of facing pages a one-page prose account and a page of related diagrams giving an explanation of how some device operates. It was originated in Germany, translated in Britain and retains a continental flavor, with some German notation left in and a number of Anglicisms. The depth of explanation is somehow random. The page that explains the cylinder lock, for instance, really convinces; in three big drawings you can see the tumblers raised by the key. But a device such as the zipper, shown much larger than life, somehow fails to become quite clear; one could never repair a zipper after the most careful study of this page with its "at exactly the correct angle" and its "so designed that." The differential gear is more successful; no one could expect to design a gear train on such a basis, yet the pages do make clear what the goal is and the means by which the four pinions and the big gears do the job. But what is one to make of radioactivity, lasers, cesium clocks? Photography, textiles, radio and television are each given many pages, in-

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cluding, for instance, the classical lens diagrams, plus accounts of electronic flash gear, Polaroid film principles and wide-screen movie optics. The Wankel engine is presented here in a dozen small drawings to show the stages of its cycle, and an enigmatic close-up of the all-important edge-sealing system. The pages all add up to an interesting and spottily useful book, a compendium of largely clear drawings and a less transparent text, but it isn't really the way things work. It is a kind of technological unabridged dictionary, giving some of its words real meaning and at most helping others to roll off the tongue with a pleasant but shallow familiarity.

MADE OF IRON, by the Art Department, University of St. Thomas, Houston, Tex. ($6). Bound in a striking paper jacket, which is a full-scale reproduction of chain mail, this catalogue of a rich and remarkable art exhibition held at the end of 1966 represents a new genre: the self-conscious extension of the appreciation of objects of craftsmanship and beauty to include the principles of the rational and empirical technology that made possible their creation. A brief initial essay on the nature of iron by Cyril Stanley Smith presents, for example, a diagram of the phase fields of the carbon-iron alloy system. Most of the captions under the photographs of the many striking works displayed do not yet make contact with science and technology, still restricting themselves to provenance, use or typology, but the intent of the show goes beyond these. The objects are strong and often beautiful. There are damascened plaques from the high Renaissance as well as door bolts with a man's head forged by some country smith. A gaunt and angular figure 15 inches high in blacksmith's iron was found at a Virginia site, once slaves' quarters, a visible link between 18th-century America and the great tradition of African sculpture. There is a suite of elegant Japanese forged steel arrowheads, shot into the air as a kind of offering at the battle's beginning. There are contemporary American sculptures, some very fine, and a foot-high allegorical figure chiseled directly out of a steel ingot, without drawing or model, in 1913 by an American artist, Frank Koralewsky. Quite overlooked, however, are the high bridges and towers and the lithe ships that are surely the greatest works of our Age of Iron.

GENERAL PALEONTOLOGY, by A. Brouwer, translated by R. H. Kaye. The University of Chicago Press ($7.50).

Unriddling the rocks is of course one of the major supports of the modern view of life on our earth. Most texts on this subject are devoted less to the evidence and its problems than to a kind of narrative history of life. This work, aimed in its Dutch original at geology undergraduates, is a clear and thoughtful essay in quite the opposite vein. It seeks to tell how fossils are made, and then to consider what one must ask about the environment, the age, the geographical position and the statistics of one's samples if one is to learn about ancient life. The text is not abstract, although it is deliberately and refreshingly general in interest in a science where there work the most recondite of specialists. It relies on examples. Do reconstructions always tell the truth? You can see a page of drawings of the mammoth, one of a genuine skeleton and six reconstructions by learned paleontologists. A seventh was done from memory of the living beast by a painter working in the ancient Dordogne. The modern artists are at least not ridiculously off the mark, although their beasts lack the necessary hump. Fossil groupings are formed not in life but rather in death. Here is sketched a horseshoe crab that was fossilized at the end of its final track, made in the limestone lagoon it entered only to die, a stranger. The problems of why there are so few transition forms, "missing links" such as the feathered reptile, of why some forms change slowly and others rapidly, of whether there were ages or places of great change are the principal ones discussed in these pages. The book owes a great deal to evolutionists of a more genetic and less geological bent, such as Sewall Wright and George Gaylord Simpson; this is essentially another reading of the same great layered record. That the fractional rate of producing new genera in invertebrates hit a peak in the Triassic is ascribed to the earlier regression of the shallow seas, which on returning opened a habitat freed from many competitors. There is the beginning of a quantitative science here, but it is no more than that. The current output of systematic handbooks may at last provide the data we are promised.

PLANTS, MAN AND LIFE, by Edgar Anderson. University of California Press ($1.95). A paperback reprint of the hardcover issue of 1952, with a three-page preface added by the modest and learned author, the book remains all but unique as a botanist's study of the origin of men's crop plants. It is as relevant as your next meal, full of wit and insight.

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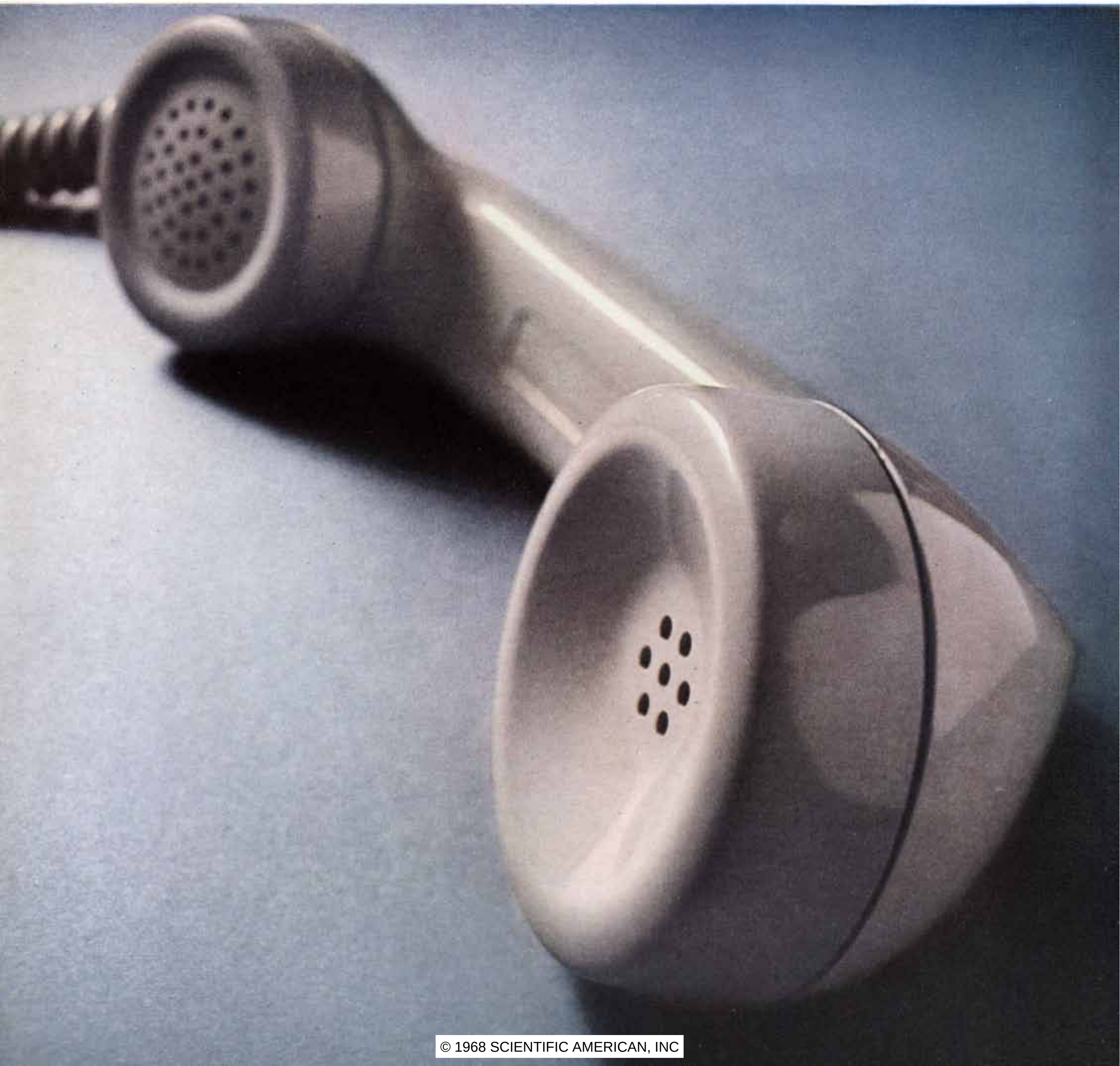

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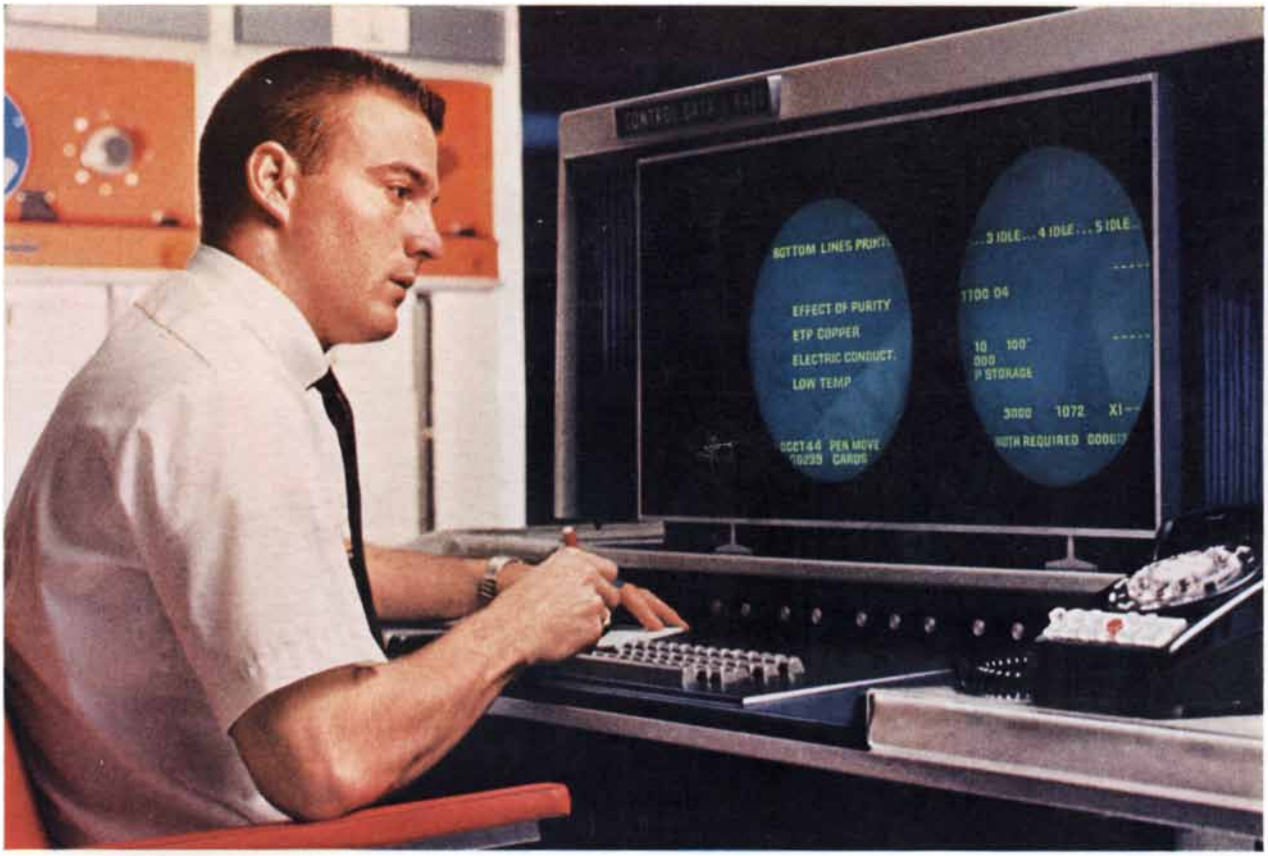

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