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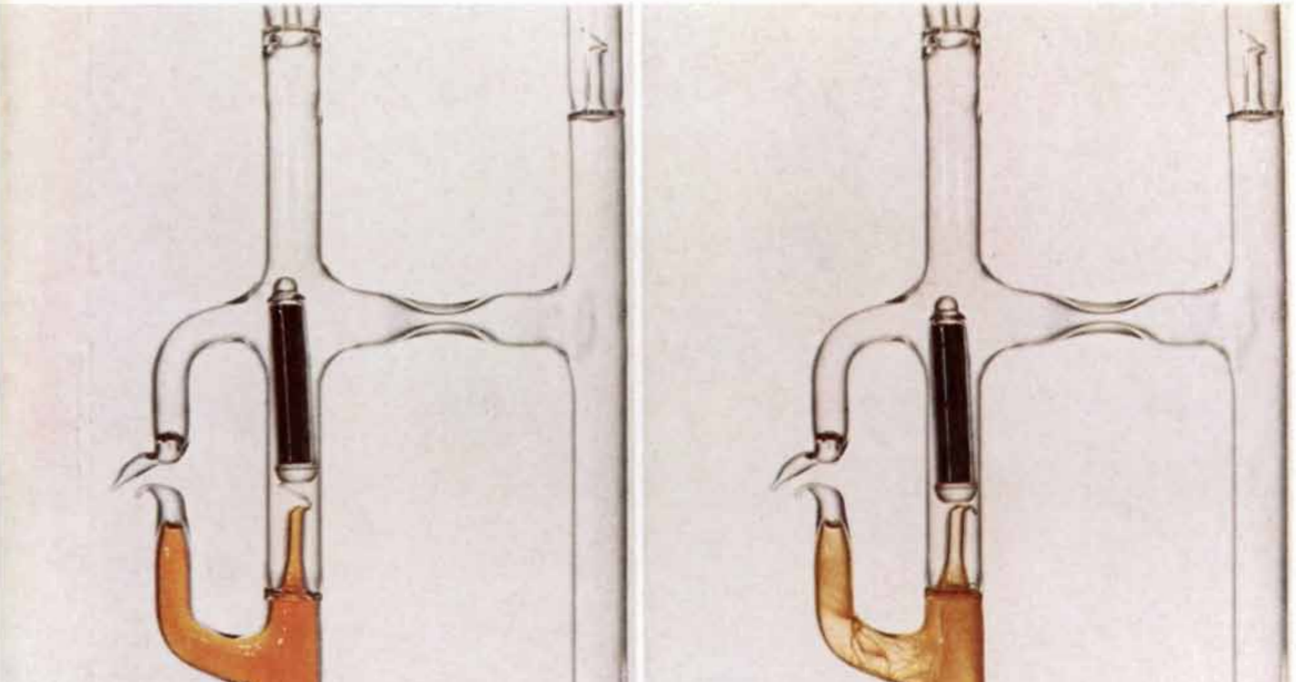
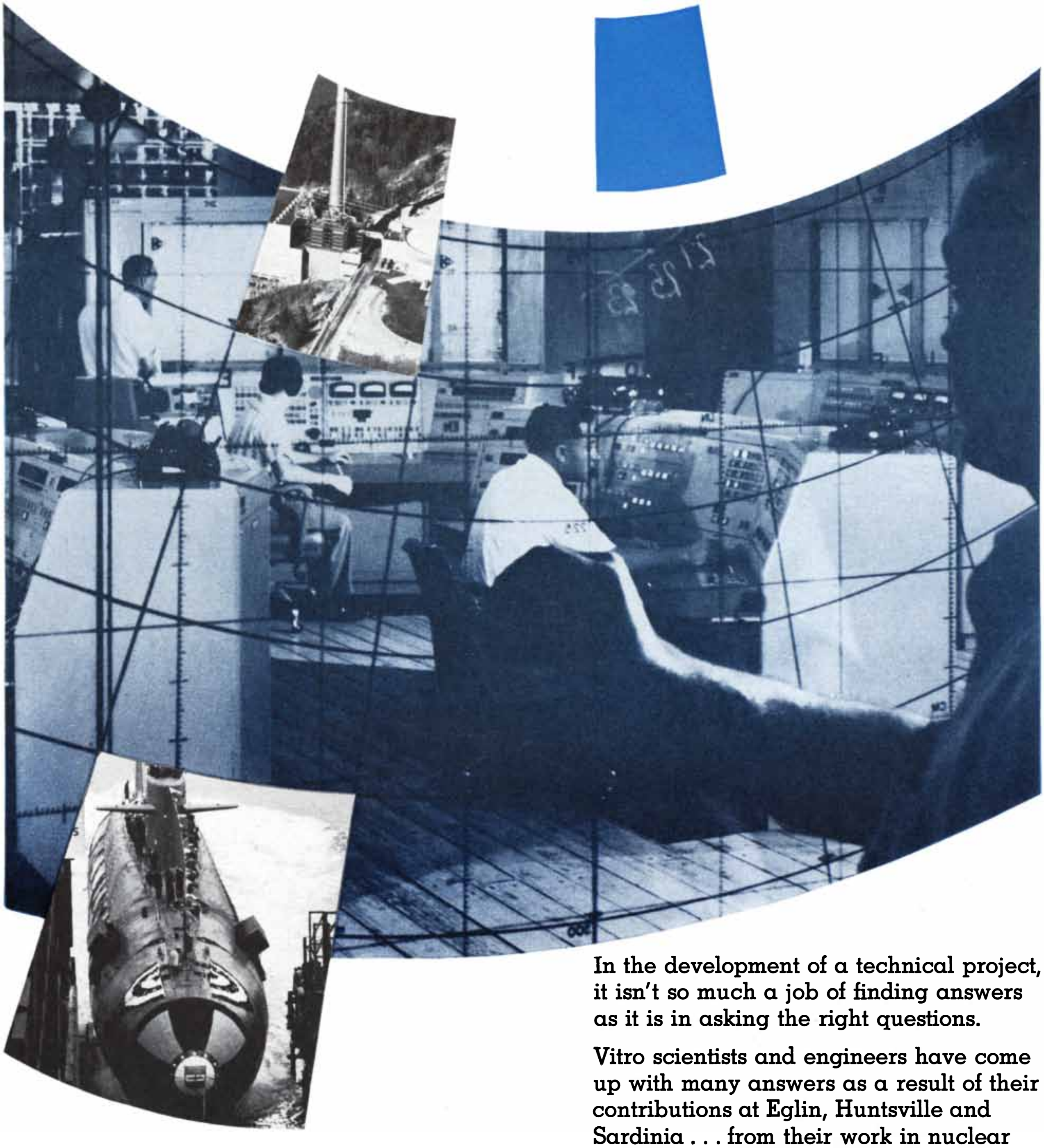


NOBLE-GAS CHEMISTRY

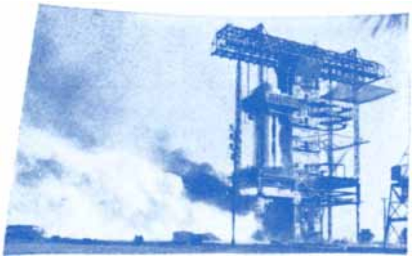
SIXTY CENTS

May 1964



In the development of a technical project, it isn't so much a job of finding answers as it is in asking the right questions.

Vitro scientists and engineers have come up with many answers as a result of their contributions at Eglin, Huntsville and Sardinia . . . from their work in nuclear power, on chemical plants, in electronic hardware and on such operational weapon systems as Polaris. But don't come to us just simply for answers; our future is in questions.



Vitro

VITRO CORPORATION OF AMERICA
261 MADISON AVE., NEW YORK, N.Y. 10016

Established 1845 **SCIENTIFIC AMERICAN** May 1964 Volume 210 Number 5

ARTICLES



DEPARTMENTS





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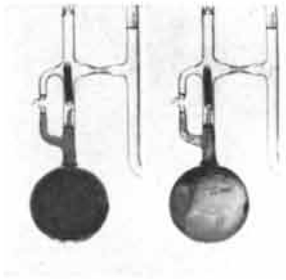

## THE COVER

The two photographs on the cover show the reaction between platinum hexafluoride and the "noble" gas xenon, which until two years ago was thought to be chemically inert (see "The Chemistry of the Noble Gases," page 66). The platinum hexafluoride is a reddish vapor in the lower part of the glass system in the photograph at left. The xenon, separated from the platinum hexafluoride by a glass "break-off tube," is a colorless gas in the upper part of the system. Resting atop the break-off tube is a cylindrical glass hammer weighted with iron. When the hammer is lifted with a magnet outside the glass and dropped on the break-off tube, the xenon rushes into the lower part of the system and combines with the platinum hexafluoride. The result is the yellowish crystals coating the lower part of the system in the photograph at right. This experiment, which was first performed by Neil Bartlett at the University of British Columbia in 1962, was photographed at the Argonne National Laboratory. Subsequent experiments indicate that many chemical reactions of xenon are even simpler.

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Cover photograph by Paul Weller

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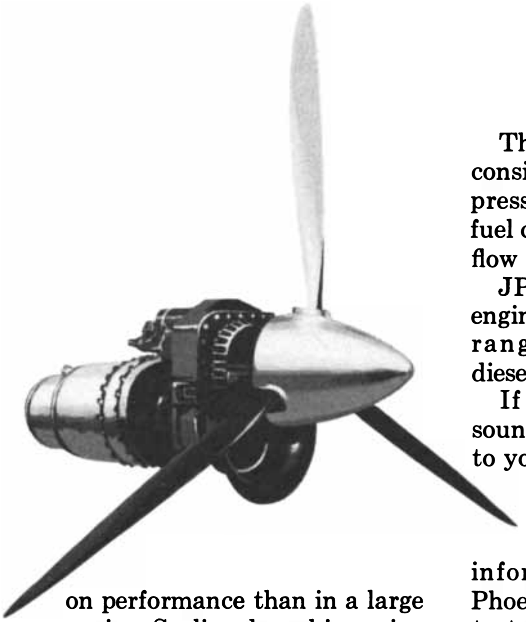
# Everything we learned from building 10,000 small gas turbine engines has been packed into this new 600-horsepower turboprop engine —and it shows!



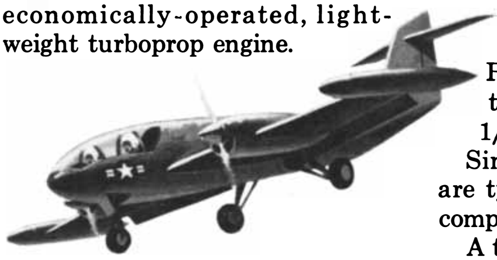
You'd probably expect the world's largest manufacturer of small gas turbine engines to turn out the world's finest small turboprop job.

And we have.

We call our new engine the TPE-331. (The military version is designated T-76.) It is a versatile turbine capable of powering many vehicles. Its 600-horsepower category makes it particularly suitable for the new generation of executive and military fixed-wing aircraft.

More specifically, our new prime propulsion engine is designed to fill the gap between reciprocating engines and larger turboprops.

And the reason we built it, is because both civil and military sources have asked for a simple, rugged, reliable, easy-to-maintain, economically-operated, lightweight turboprop engine.



The Garrett-AiResearch TPE-331 more than fills the bill.

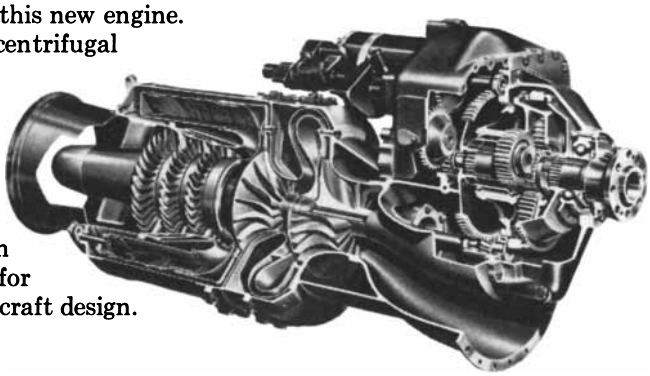
Obviously, building such an engine is a specialized art that demands experience, especially in miniaturization of controls, oil pumps, and starter motors.

Manufacturing tolerances are precise and have a greater effect on performance than in a large engine. Scaling down big engine techniques is not the answer.

The TPE-331 has a specific fuel consumption of .62 pound per shaft horsepower hour. Its weight to power ratio is .45 pound per horsepower. Response rate from flight idle to full power is approximately 1/3 of a second.

Single-casting turbine wheels are typical of the simple, rugged components of this new engine.

A two-stage centrifugal compressor is driven by a 3-stage axial turbine. Propeller drive is through a 2-step reduction gear box offset for flexibility of aircraft design.



The fuel system of the TPE-331 consists of a fuel filter, single high-pressure pump, speed-governing fuel control, manual shutoff valve, flow divider and fuel nozzles.

JP-5 is the normal fuel, but this engine will take all kinds of fuel, ranging from AV-gas to light diesel fuel.

If this new turboprop engine sounds like something very special to you, we've made our point.

The TPE-331 *is* an exceptional engine.

You can get further information by contacting our Phoenix Division. When it comes to turbine engines under 1000 horsepower...

**Garrett *is* experience**

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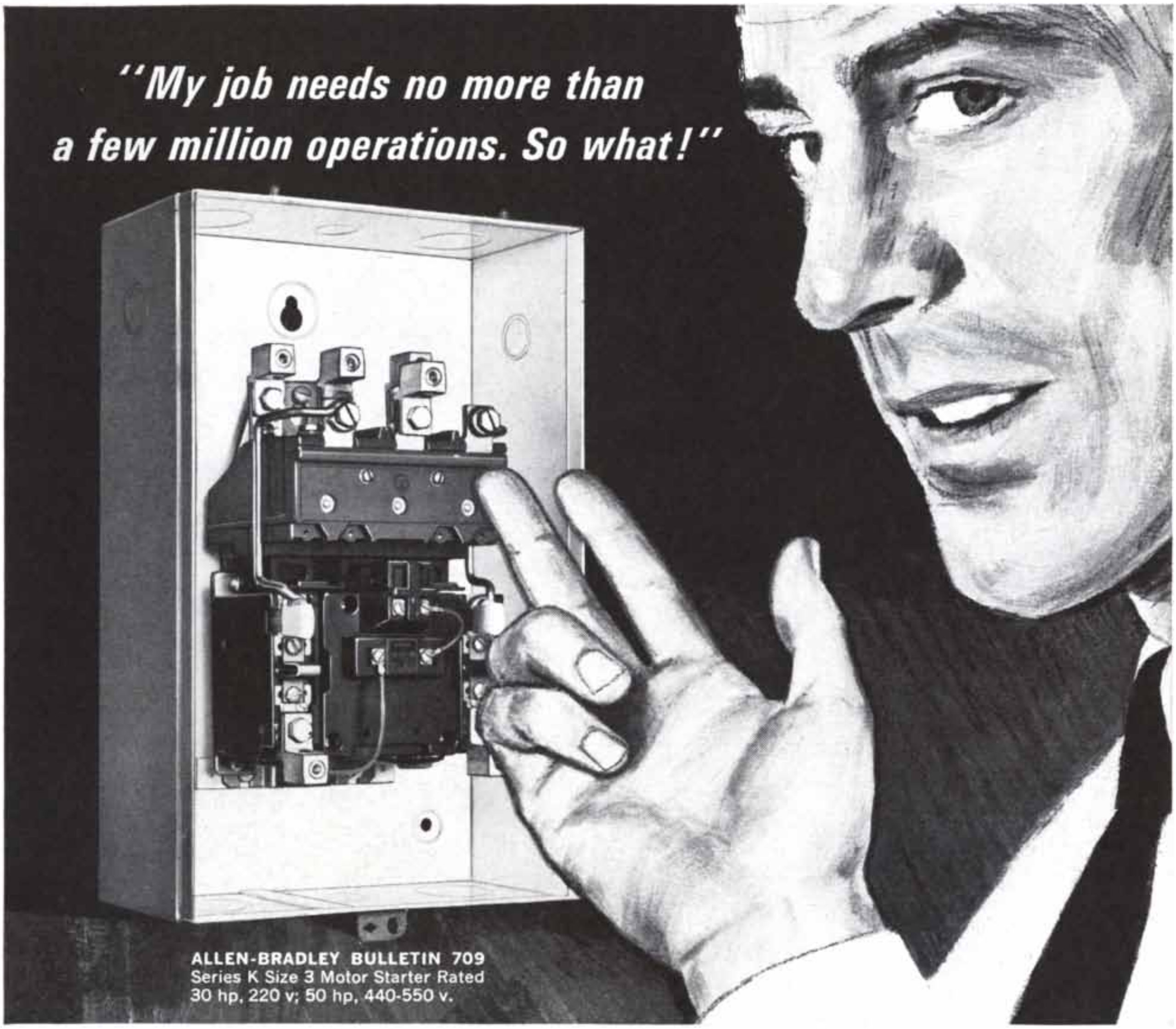


■ Well—have you ever thought of this? We know you must be interested in the uninterrupted operation of the machine controlled by the starter. Now then, if, because of the simplicity and rugged construction, the Allen-Bradley Series K starter has a proven life of many millions of operations, it stands to reason that, at only one million operations, life has just begun for this starter. Like a new automobile, it hasn't had time to have trouble.

Let's use this same example with some other starter, good for only two or three million operations. At the one million mark, ½ or ⅓ of the life of this starter is gone—and if you have not already experienced trouble, you won't have long to wait.

In other words, you *do* obtain extra value from the same dollar when you invest it in Allen-Bradley Series K starters—with all ratings (sizes) having extra millions of trouble free operations *built in!* And—when you have a really tough job, this same built-in life of the A-B Series K line of control is your assurance that no other starter can equal the trouble free performance that you have a right to expect from Allen-Bradley quality control.

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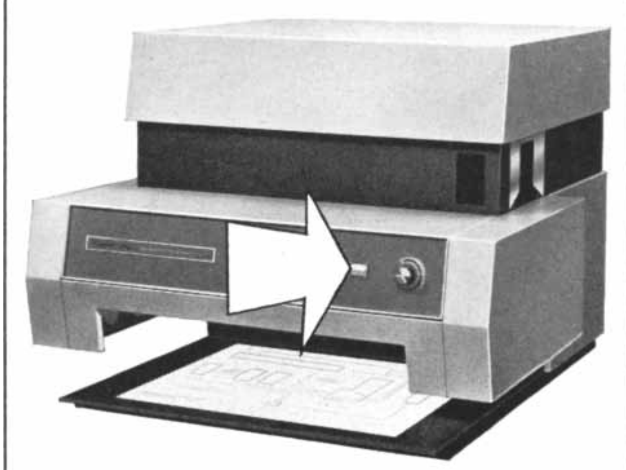
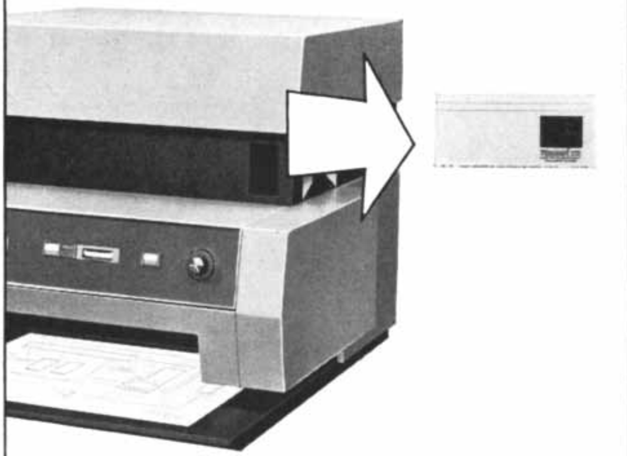
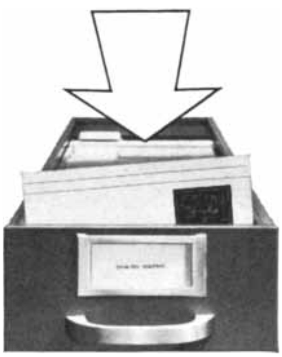


**Push a button.**



**Complete in 54 seconds.**



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# LETTERS

Sirs:

As an old acquaintance of frogs, I read with considerable interest the article by W. R. A. Muntz entitled "Vision in Frogs" [SCIENTIFIC AMERICAN, March]. Since there are about 2,200 known species of Salientia, or Anura, I was at somewhat of a loss as to which species was being referred to throughout the article as "the frog." These species are quite diverse in form, function and habitat, so that one wonders whether all species of frogs will in fact have visual systems identical with the one described.

But let us assume that they do, and that "the frog" is actually *Rana pipiens*. Dr. Muntz raises the question, "Why should a frog need to distinguish blue?" and answers, "I think it is quite possible that the function of the blue-sensitive system is to direct the jump of a frightened frog in such a way that it will leap into the water to avoid its predators."

At the last count I had frightened about 15,000 leopard frogs, omitting all that outwitted me. During this time several facts have become eminently clear. Approached from the land, it's true, leopard frogs will usually jump into the water. However, don a pair of boots and approach them from the water and they will take off over the boondocks, plunging into thickets and climbing 40-foot embankments, very definitely turning their backs on blue. Even more interesting, it is sometimes almost impossible to get a frog to jump into the water, even when approached from the land. This type of behavior seems to coincide with places and seasons when bass are likely to be lying a few feet offshore.

Finally, in Minnesota rather striking seasonal migrations occur. The frogs must travel to deep water from their summer haunts in order to survive the winter. One might expect the preference for blue to be related in some way to this migration, but most of the movement is at night. The spring migration, from the overwintering sites to the breeding ponds, occurs during the day to a greater extent, but this movement is toward the shore rather than the open sky. The mechanisms regulating migratory behavior in the leopard frog are unknown, but it seems probable that some of the cues are visual. If so, then one wonders if the frogs' response to blue might not shift with seasonal changes in its physiological condition.

There seems little reason to doubt that the preference for blue revealed by this very interesting work has adaptive significance. Its relation to adaptation, however, may be considerably more complex than was suggested.

DAVID J. MERRELL

Department of Zoology
University of Minnesota
Minneapolis, Minn.

Sirs:

I am in agreement with much of what Dr. Merrell has to say. The species of frog used should have been given, and I regret the oversight. Nevertheless, I do not feel that this can have been very misleading. Most people will deduce the correct species from the phrase "the frog," as indeed Dr. Merrell has himself, and five minutes in the library looking up the reference given in the bibliography would remove any residual uncertainty.

It is probable that different species of anuran would show different behavior in the situation used, as indeed I have shown to be the case for urodeles. If my interpretation of the adaptive significance of the blue discrimination has any truth at all, one would predict, for example, that burrowing toads would behave quite differently.

**Scientific American,** May, 1964; Vol. 210, No. 5. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

**Editorial correspondence** should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

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**Offprint correspondence** and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104.

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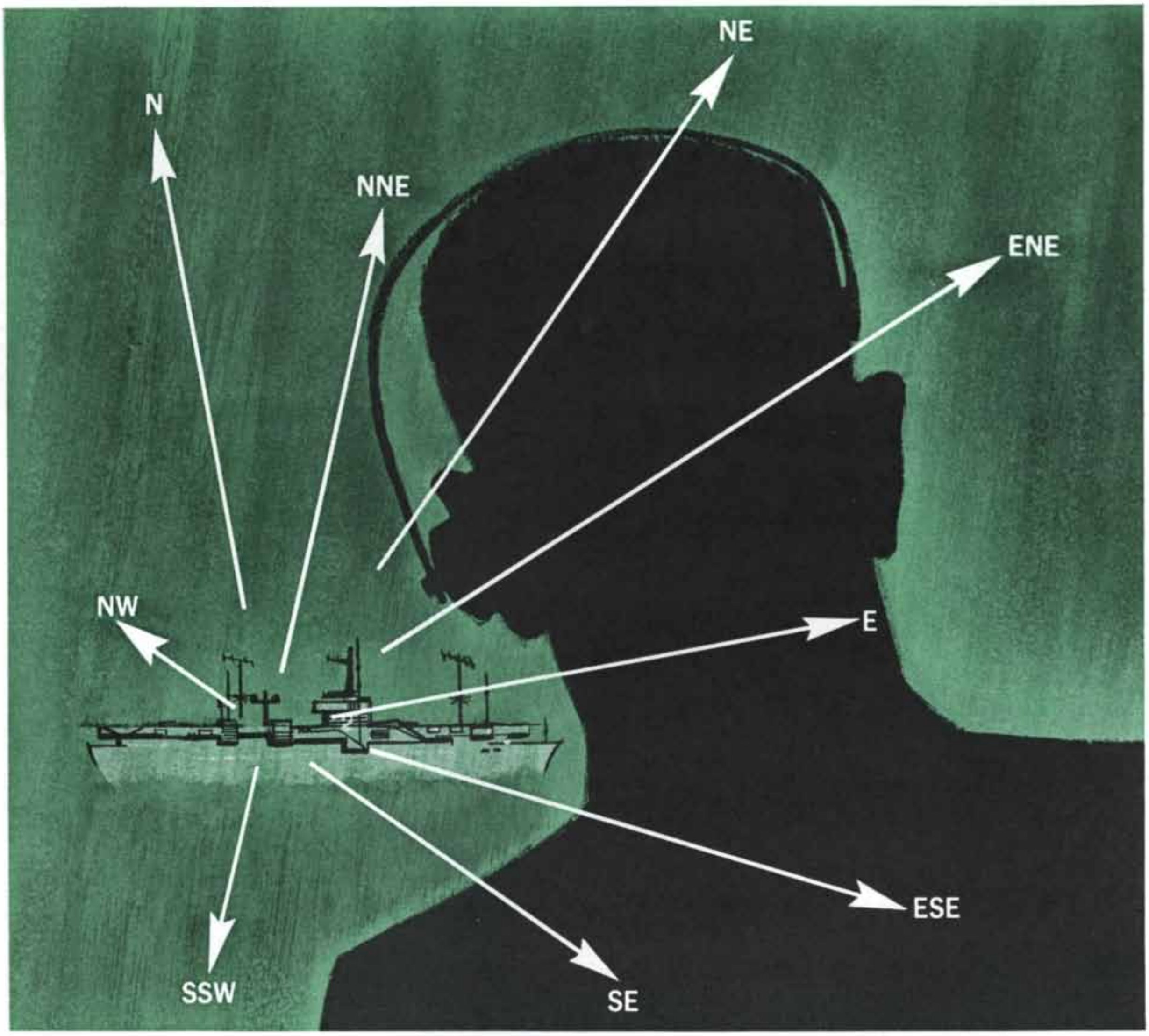


Building a system is only part of our job. Through PSO (Product Support Organization), our Sylvania subsidiary can *stay with* the system through every stage of its creation and operation.

For example, PSO helped Navy engineers redesign the aircraft carrier USS WRIGHT into a command ship with the largest, most powerful transmitting antennas ever installed on a naval vessel. This "Voice of Command" can be heard anywhere in the world. But redesign was only the beginning. PSO engineers also helped to install, test and maintain the equipment, and remained on board until these functions were transferred to naval personnel.

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Of the eight or so species of anuran so far tested by various workers, however, all have shown phototactic behavior very similar to that shown by "the frog."

This brings us to Dr. Merrell's criticism of my hypothesis about the adaptive significance of the mechanism. I am entirely in agreement that the hypothesis is an oversimplification. Many other factors are probably involved, and one of these may well be a tendency to jump away from large moving objects, such as zoologists. Several people are at present collaborating with me in an attempt to find out more about what these may be. Nevertheless, I still believe that the mechanism must be one of the factors controlling the direction of the jump. Although Dr. Merrell's experimental sample of 15,000 is large, I am not sure that his experimental design is valid: a better procedure would be to walk along the bank with one foot in the water and one on the land and then see which way the animals jump.

The suggestion that the mechanism may be involved in migration is an interesting one. We have, however, tested frogs during most seasons of the year without showing up any differences, and so I feel that there is no evidence to support this conjecture as yet.

W. R. A. MUNTZ

Institute of Experimental Psychology
University of Oxford
Oxford, England

Sirs:

I was most interested in the article by Eugene S. Ferguson entitled "The Origins of the Steam Engine" [SCIENTIFIC AMERICAN, January].

I was surprised, however, that although there was a picture of a working pump of Newcomen design at a colliery in England, a pump that was subsequently taken down and re-erected at the Science Museum in London, there was no reference to the Newcomen engine acquired in 1929 by Henry Ford in England and re-erected in Dearborn, Mich. This engine, known as "Fairbottom Bobs," was installed about 1750 at the Cannell Collieries in Ashton-under-Lyne, England. . . .

JAMES A. FOWLER

Director of Education
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and Greenfield Village
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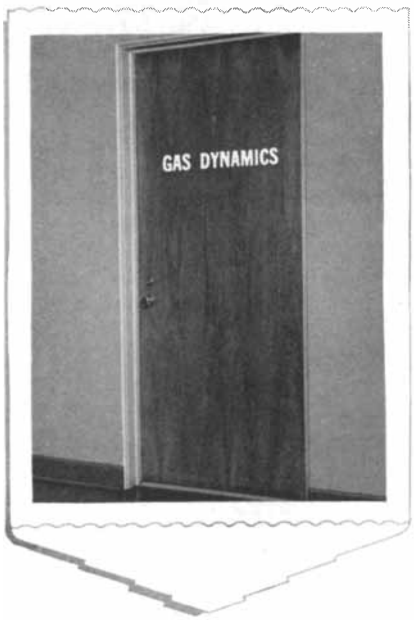


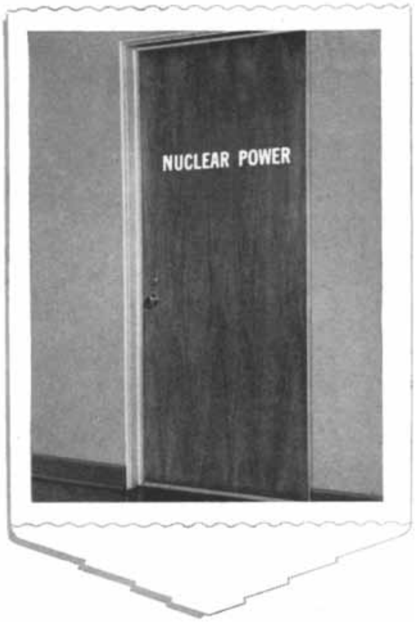



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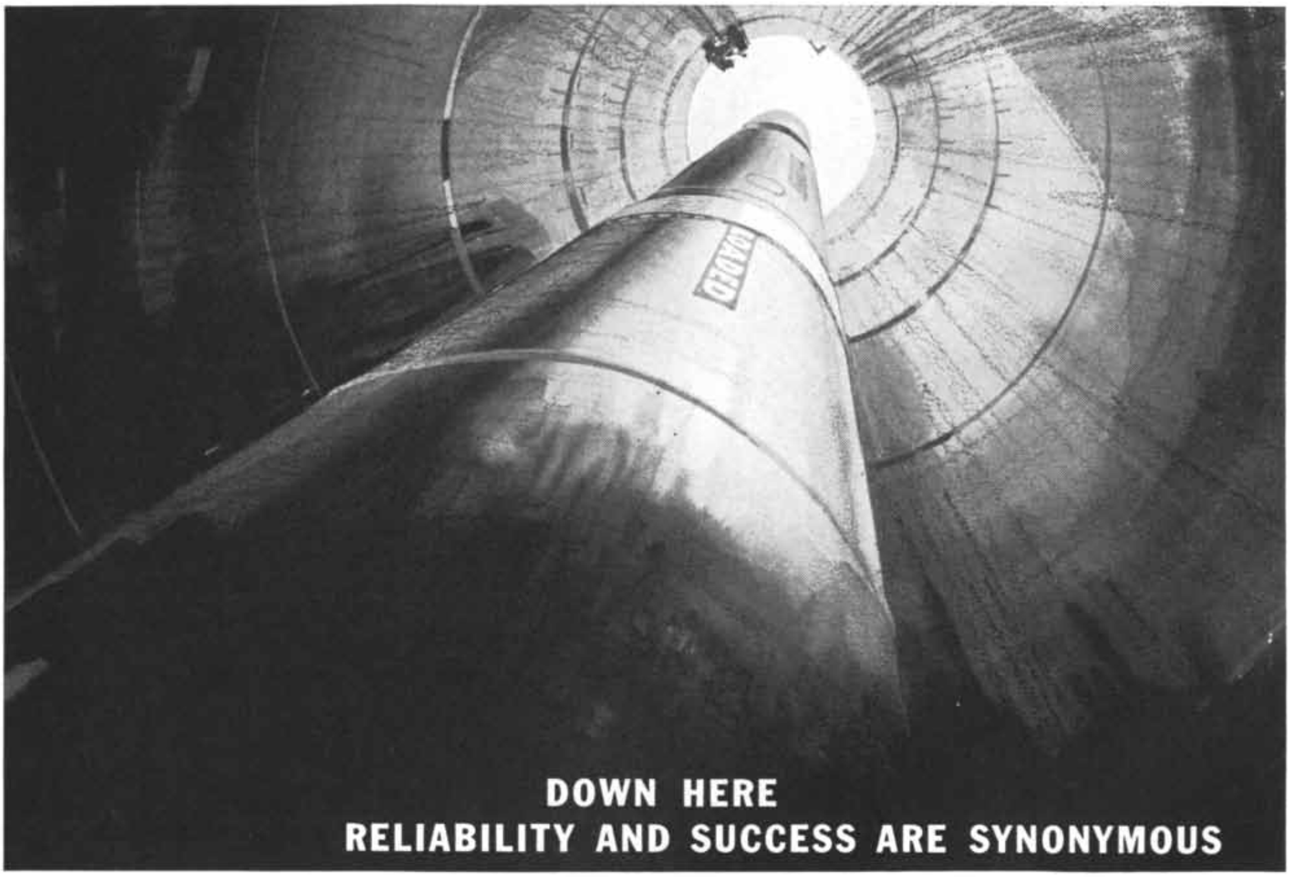


**To us this means a requirement for: A diesel electric set for the Environmental Control System of a missile launch control facility, delivering continuous KW for 2500 operational hours—in a three-year period—without service attention of any kind!**

This missile assignment meant refining our commercial reliability program, so we could give a specific mathematical probability that a special engine package would perform its mission.

Our research group directed its effort to meet these military requirements by the utilization of data compiled in conjunction with our commercial programs.

### Diesel Power and the Bathtub Curve

Prior work included examination of published studies of pre-wearout failures in compound machines. Dr. Morris, of Imperial Chemical Industries, Ltd., had identified two types of failure faults, Stage I and Stage II.

Initially we plotted failure fault curves. These were established by detailed studies of field service reports of engine failures and basic engine test programs charting failure events as they occurred.

Analysis and comparison of these curves with the Bathtub Curve, familiar to reliability people, revealed a mathematical relationship. We then established the bathtub, or failure rate, curve for Caterpillar Engines.

### A Predictable Pattern

In our test and study program we found, right at the start, the Stage I faults—the few with high probability of occurrence—did happen as predicted. These were often traced to human error. Some components were predisposed to fail in Stage I. In diesel generator sets, for example, special relays and diodes of 50% more capacity were added to the control circuit. Hose clamps were replaced by sealed flange joints. Gauges were removed completely. Instead, engine inspection kits include a full set of test gauges.

### New Designs Required

Ultimately, analysis of potential failure points revealed the need for designing additional capacity oil and air filter systems and an entirely new cooling system. These changes, with attention to detail, were, in terms of the reliability objective, highly rewarding.

With .90 reliability for a 2500-hour mission achieved, Cat Diesel Electric Sets are ready for missile duty.

From this reliability program have come significant benefits to the research for a new VHO engine family for tactical and logistical vehicles. The battlefield reliability standard for these engines was set at .95 for 500 hours—without major breakdown. This Research project for ATAC is already in the building stage.

If you have a vehicle or power problem with a high reliability factor, why not bring it to the people who were successful with the first full-scale reliability effort in the diesel industry? Write or call Defense Products Department, Caterpillar Tractor Co.

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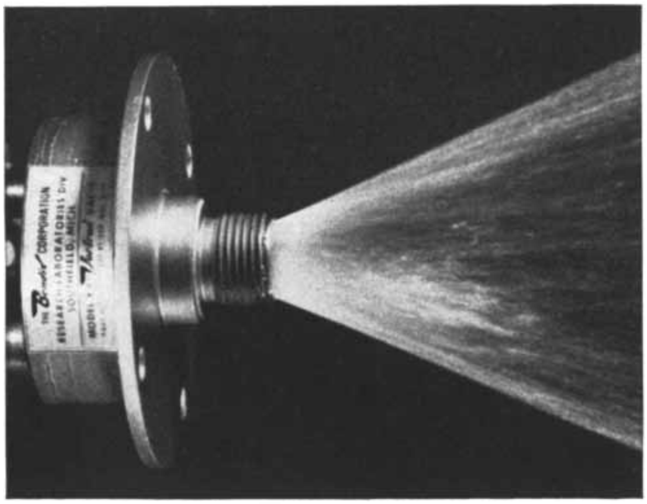


Vortex Valve for operation at 2000°F.

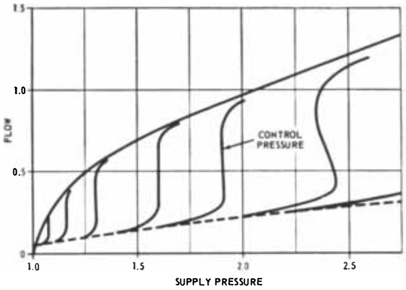
# Fluid Phenomena:

## New Technique For Sensing, Computing, And Control

Advances in all-fluid signal generation and amplification (the use of a flowing liquid or gas without moving parts) have opened a new field of research and development and have made available a new family of techniques for sensing, computing, and control. These methods offer many potential advantages in the extreme temperature, radiation, and acceleration environments of advanced aircraft, missile, and space applications, and in less exotic applications where rugged, inexpensive, and reliable equipment is required.

The all-fluid program at Bendix includes research in jet, boundary-layer, and vortex phenomena, and the application of these phenomena to both all-fluid devices and complete subsystems. Sensors, amplifiers, oscillators, logic elements, control valves, and regulators are among the components under development. Control systems for gas turbine engines, nuclear reactors, and flight vehicles are typical of the subsystems being studied.

The vortex valve is one of the most versatile of the all-fluid components. Fundamentally a flow control device, it varies flow rate through the action of a controlled vortex sheet on the main fluid stream. It can be used as a power amplifier and, with appropriate configurations, as an oscillator, or as a variety of sensors.




Normalized flow curves for vortex valve.

Because of the potential of the vortex valve, Bendix has undertaken fundamental studies of vortex phenomena related to this valving principle. A normalized analysis of the vortex valve has been established which can be used to predict the performance characteristics of the valve over a wide range of operating parameters. By appropriate design, vortex valves have been made to have extremely high gain. In fact, near mid-range they have been made to have negative resistance characteristics as shown in the curves. Negative resistance oscillators have been operated using vortex valves in conjunction with appropriate tuned flow networks.

Bendix Research embraces a wide range of technology including acoustics, nuclear, solid state physics, quantum electronics, mass spectrometry, photoelectronics, electron beam and tube technology, measurement science, applied mechanics, energy conversion systems, dynamic controls, systems analysis and computation, navigation and guidance, microwaves, digital techniques, data processing and control systems. Motivation: to develop new techniques and hardware for The Bendix Corporation to produce new and better products and complete, integrated, advanced systems for aerospace, defense, industrial, aviation, and automotive applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

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# 50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1914: "The latest of Mr. Wells's books (*The World Set Free,* by H. G. Wells) is a curious combination of his earliest and latest methods, for it is at once one of those magnificent flights of imagination which gave us *The Time Machine* and *The War of the Worlds* and the keen sociological perception which gave us *The New Machiavelli* and its successors. How the great world war started, how it was fought with the aid of aeroplanes and atomic bombs, how it became so terrible that the utter folly of fighting was driven home with telling horror, Mr. Wells sets forth with a vividness that stamps him as a literary artist of the first rank. The most interesting feature of the book is the method in which the discoveries in radio-activity are given artistic treatment, a method which shows that in the hands of a master science offers possibilities that can hardly be overrated. The atomic bomb which plays so great a part in this story, although a creation of Mr. Wells's, may be regarded as inspired by Soddy's *Interpretation of Radium.* Wells argues that inasmuch as radio-active substances are constantly decaying and giving off energy as they do so, tremendous results could be obtained if the decay could occur with explosive rapidity. He presents his atomic bomb with an air of definiteness and conclusiveness that almost convinces one it exists."

"Two French engineers, A. Papin and D. Pouilly, are responsible for a new departure in aeronautics—a departure that has not yet departed from the solid earth. They explain that in designing their machine they had before them mainly three purposes: to provide a device which could rise from the ground without preliminary 'run' and which could similarly alight on a selected spot; to furnish a machine that could at will either advance through the air or be held stationary; to provide for a slow descent in case of failure of the motor. The new 'flying machine' constitutes a huge single-blade screw propeller with a spread of 178 feet. The blade and the central body are hollow and through them a stream of air is blown by a fan, which is driven by a motor. The motor is an 80-horse-power, nine-cylinder gasoline engine and is manipulated by compressed-air controls from the car, which is mounted on ball-bearings and does not participate in the rotation of the rest of the machine. The blast of air escaping from the curved tip of the propeller causes it to revolve by impulse reaction."

"Since Wöhler's first synthesis of a natural organic compound, the chemist has succeeded in building up nearly all the natural compounds from their constituent elements in his laboratory; indeed, the synthesis of the sugars, the polypeptides, the alkaloids, uric acid and its derivatives are some of the greatest triumphs of the chemist. Much of the success in this field is due to the genius of Emil Fischer, and although he has celebrated his 60th birthday he shows no signs of relaxing his labors, being now responsible for another great achievement. The importance of the nucleus of the living cell needs no emphasis, and therefore the value of the recent work, more particularly that of Levene and his collaborators in the U.S., on its chemical composition has been widely recognized. In brief, the nucleic acids are composed of glucosidic compounds of purine derivatives combined with carbohydrates to which phosphoric acid is coupled. The synthesis of such a glucosidic compound of sugar and purine has long been essayed, but it is only now brought to a successful conclusion. Once the principle of the method of synthesizing them has been made clear, all kinds of purine derivatives can be coupled with the carbohydrates, and when phosphoric acid has been introduced into the molecule, the complete synthesis of the nucleic acids will have been achieved."

"A very ingenious German once wrote a bitter book called *A History of Human Stupidity.* In it he chronicles many delectable examples of medieval superstition, which retarded the progress of the world by centuries, as well as numerous examples of modern asininity. Someday that history of stupidity will be amplified. Its most distressing new chapter will be devoted to the antivivisection mania which threatens to strangle scientific research, of whose inestimable benefit to humanity there cannot be the slightest question. In this campaign

which ignorance, fanaticism and sentimentality have waged against humanity, surely the pinnacle of absurdity was reached when the bill to permit the Rockefeller Institute to establish a research laboratory in the State of New Jersey for the study of animal diseases and their cure was vetoed by Governor Fielder."

Scientific American.

MAY, 1864: "For some years past M. Pasteur, a distinguished French chemist, has been engaged in investigating the phenomena of fermentation and putrefaction and the results attained to by him constitute some of the most important contributions made to chemical science during the past few years. In the report of researches heretofore published, M. Pasteur claims to have proved that the effects hitherto attributed to the atmosphere of oxidizing and thus consuming dead organic matter are really dependent on the growth of infusorial animalculæ."

"At a recent meeting of the Manchester Philosophical Society, Dr. Joule exhibited an exquisitely sensitive air thermometer, capable of being affected by the one-thousandth of a centigrade degree of heat. A proof of the extreme sensibility of the instrument is obtained from the fact that it is able to detect the heat radiated by the moon."

"A clergyman writes from the Army of the Potomac of an interview with Lieutenant-General Grant, whom he met sitting in a once elegant mansion with a New York paper in his hand, quietly enjoying his cigar:—'Like every one else who meets him, we were charmed with his quiet, modest simplicity and manly bearing. He is a low-voiced, diffident man, with fair skin and brown hair—looks younger even than Frémont and talks slowly, like one used to keeping his own secrets. He says he "never had even a headache." God grant he may have no heartache during the coming eventful month! When I rallied him pleasantly about the traditional cigar, which he used as Napoleon did the snuff-box, he smilingly replied, "When the war is over, I am going to give it up." He has the most unbounded confidence of the troops; in every tent we hear the same spontaneous testimony.' "

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In fact, this timepiece only has 12 moving parts—and the only thing you ever have to replace is the battery. (And the battery lasts at least a year.)

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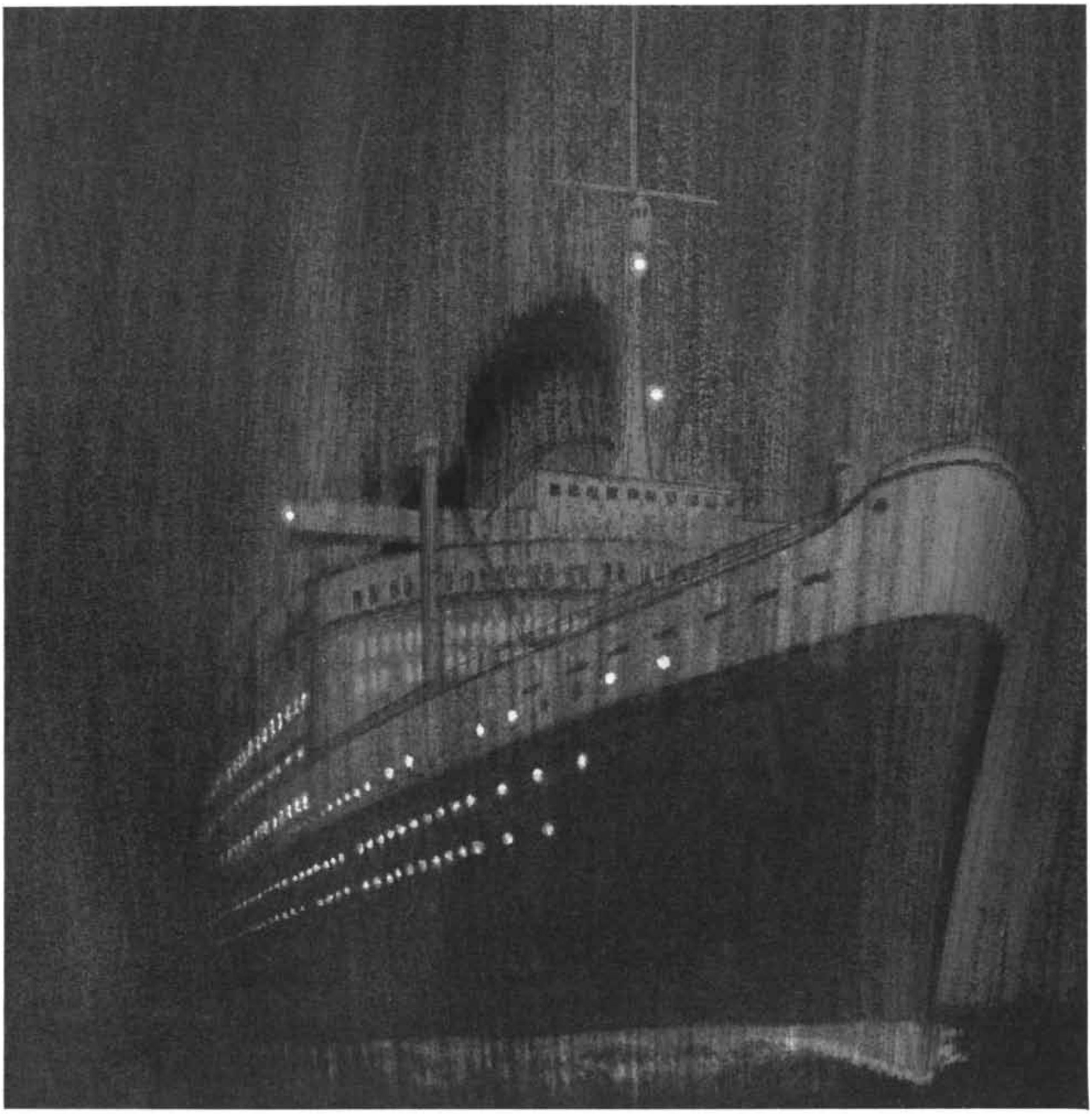
*Your Accutron jeweler will adjust time to this tolerance, if necessary. Guarantee is for one full year.



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# THE AUTHORS

BERNARD BERELSON and RONALD FREEDMAN ("A Study in Fertility Control") worked together on the Taiwan population study discussed in this article. Berelson is vice-president of the Population Council. A graduate of Whitman College, he received a B.S. and an M.A. from the University of Washington in 1936 and 1937 respectively and a Ph.D. from the University of Chicago in 1941. He was a special analyst for the Foreign Broadcast Intelligence Service of the Federal Communications Commission from 1941 to 1944, when he became research director of the Columbia University Bureau of Applied Social Research. He joined the faculty of the University of Chicago in 1946 and subsequently served as professor of library science, dean of the Graduate Library School and chairman of the Committee on Communication. In 1951 he was appointed director of the behavioral sciences program of the Ford Foundation. He returned to the University of Chicago in 1957 as professor of the behavioral sciences and director of the Study of Graduate Education. From 1960 to 1961 he served as professor of sociology and director of the Bureau of Applied Social Research at Columbia. Freedman is professor of sociology and director of the Population Studies Center at the University of Michigan. He is also president-elect of the Population Association of America. A native of Winnipeg, Canada, he was graduated from the University of Michigan in 1939 and obtained a Ph.D. from the University of Chicago in 1947. He has been a member of the Michigan faculty since 1946. The authors wish to acknowledge the valuable contributions of their colleagues on the Taiwan project: S. C. Hsu of the Joint Commission on Rural Reconstruction in Taiwan; T. C. Hsu, Commissioner of Health; C. L. Chen and J. Y. Peng of the Maternal and Child Health Institute, and John Takeshita of the University of Michigan.

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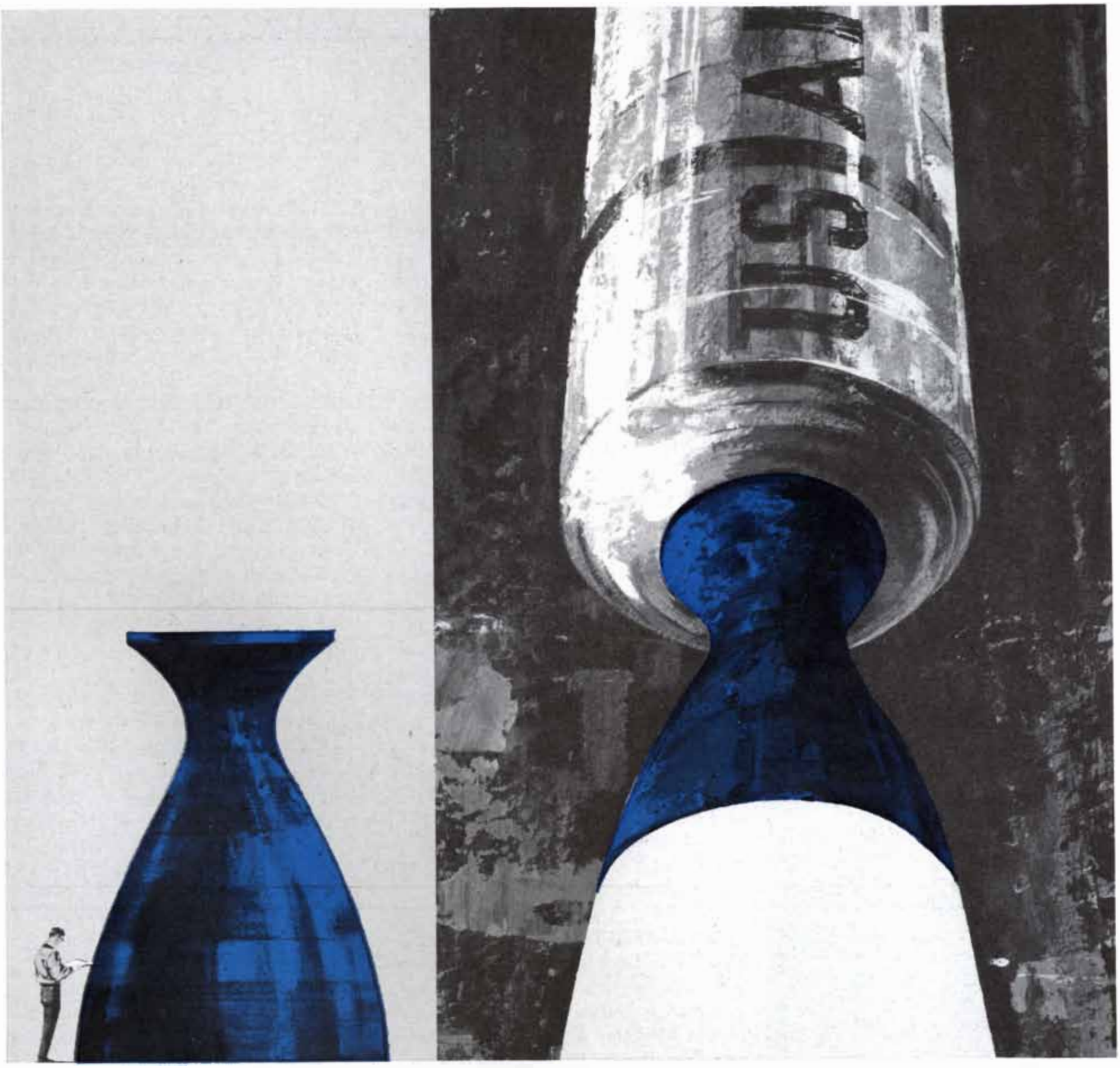
S. SPIEGELMAN ("Hybrid Nucleic Acids") is professor of microbiology at the University of Illinois. He acquired a B.S. in mathematics and physics from the College of the City of New York in 1938 and a Ph.D. in cellular physiology from Washington University in 1944. From 1942 to 1945 he was lecturer in physics and mathematics at Washington University and from 1946 to 1948 he was assistant professor of microbiology at that university's College of Medicine. He did research as a special fellow of the U.S. Public Health Service at the University of Minnesota's Medical School from 1948 to 1949, when he was appointed to his present post.

HENRY SELIG, JOHN G. MALM and HOWARD H. CLAASSEN ("The Chemistry of the Noble Gases") are members of the experimental team at the Argonne National Laboratory that prepared the first simple chemical compounds of an inert gas (the xenon fluorides) less than two years ago. Selig does research in the fluoride chemistry group at Argonne. He acquired an M.S. from the University of Chicago in 1950 and a Ph.D. in chemistry from the Carnegie Institute of Technology in 1953. He joined the Argonne Laboratory in 1953 and has been there ever since, with the exception of a year spent in the department of inorganic and analytical chemistry of the Hebrew University at Jerusalem as a fellow of the Israel Atomic Energy Commission. Malm has been doing research in the fluoride chemistry group at Argonne since its inception in 1954. He received a B.S. in chemistry from the University of Wisconsin in 1944 and that same year joined the Metallurgical Laboratory of the Uni-



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versity of Chicago as a research assistant. At the Metallurgical Laboratory he participated in the development of the plutonium-separation process. After the war he continued to work at the Argonne Laboratory, successor to the Metallurgical Laboratory. Claassen is professor of physics at Wheaton College in Illinois and a consultant to the Chemistry Division at Argonne. He was graduated from Bethel College in Kansas and obtained an M.S. and a Ph.D. from the University of Oklahoma, where he taught for two years before joining the Wheaton faculty.

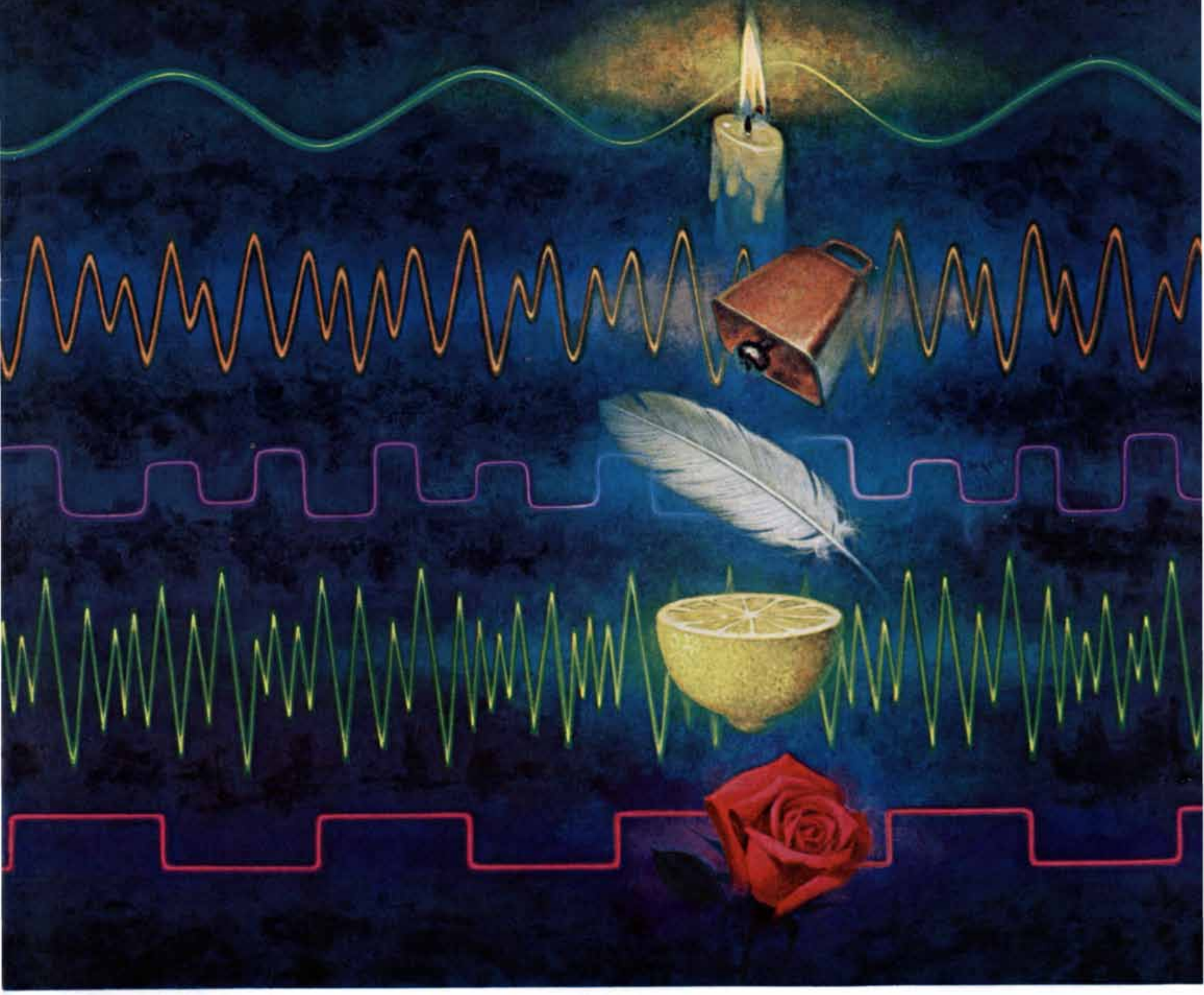
PAUL W. HODGE ("Dwarf Galaxies") is assistant professor of astronomy at the University of California at Berkeley. A graduate of Yale University, Hodge received a Ph.D. in astronomy from Harvard University in 1959. He began work on the structure of the Sculptor and Fornax dwarf galaxies while still at Harvard and spent six months in 1958 studying these objects at the Harvard College Observatory's Boyden Station in South Africa. During 1960 and 1961 he investigated the dwarf galaxies of the local group while at the Mount Wilson and Palomar Observatories. He went to Berkeley in 1961. Last year he spent three months at the Mount Stromlo Observatory of the Australian National University, measuring the light from the southern dwarf galaxies in the local group.

EMIL FREI III and EMIL J. FREIREICH ("Leukemia") are physicians who do research at the National Cancer Institute in Bethesda, Md. Frei is chief of the Medicine Branch and associate scientific director for experimental therapeutics at the Institute. A graduate of Colgate University, he obtained an M.D. from the Yale University School of Medicine in 1948. After interning at the St. Louis University Hospital, he served as resident in pathology at Barnes Hospital in St. Louis and as resident in internal medicine at the St. Louis University Hospital. He joined the National Cancer Institute in 1955. Freireich is a senior investigator at the Institute. He received a B.S. and an M.D. from the University of Illinois College of Medicine in 1947 and 1949 respectively, interned at Cook County Hospital in Chicago and served his residency in internal medicine at Presbyterian Hospital in Chicago. After two years as a research associate in hematology at the Massachusetts Memorial Hospital in Boston, Freireich joined Frei at the National Cancer Institute in 1955. The remarkable similarity of their names is purely coincidental.

CHARLES B. FERSTER ("Arithmetic Behavior in Chimpanzees") is associate director of the Institute for Behavioral Research in Silver Spring, Md. He is also adjunct professor of psychology at Southern Illinois University and research professor at Arizona State University. Ferster obtained a B.S. from Rutgers University in 1947 and an M.A. and a Ph.D. in experimental psychology from Columbia University in 1948 and 1950 respectively. He taught and did research with B. F. Skinner at Harvard University from 1950 to 1955, when he joined the Yerkes Laboratory of Primate Biology in Orange Park, Fla. From 1957 to 1962 he was a member of the faculty of the Institute of Psychiatric Research of the Indiana University School of Medicine. He took up his present post in 1963, after spending a year as associate professor of psychology at the University of Maryland.

A. C. CROMBIE ("Early Concepts of the Senses and the Mind") lectures on the history and philosophy of science at the University of Oxford. A native of Australia, he was graduated from the universities of Melbourne and Cambridge. He taught and did research in biology at Cambridge until 1946, when he took up his present post. Crombie is the author of two books: *Augustine to Galileo* (reissued in a two-volume revised and expanded edition in 1959 under the title *Medieval and Early Modern Science)* and *Robert Grosseteste and the Origins of Experimental Science: 1100–1700.* The author of numerous articles, he was also the original editor of the *British Journal for the Philosophy of Science,* an annual review of literature and research. He has been visiting professor of philosophy at the University of Washington and Shreve Fellow at Princeton University. In 1961 he directed the Oxford Symposium on the History of Science, the proceedings of which were published last year under the title *Scientific Change.* This is his third article for SCIENTIFIC AMERICAN.

MARSHALL D. SAHLINS, who in this issue reviews Jules Henry's *Culture against Man,* is associate professor of anthropology at the University of Michigan. He is currently on leave from Michigan and a fellow at the Center for Advanced Study in the Behavioral Sciences in Stanford, Calif.



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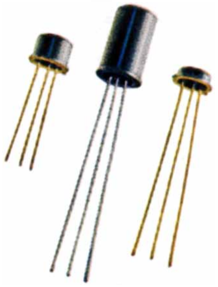

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**A.** From our solid state physics lab (*Two grains of iron thermally transformed from an iron single crystal*) **B.** From our solid state physics lab (*Thin oxide film on a single crystal iron whisker*) **C.** From our semiconductor lab (*Etch pit in a cadmium sulfide single crystal*) **D.** From our fluid mechanics lab (*Cavitation in a thin oil film*) **E.** From our chemical separations lab (*Crystalline organic nitrogen compound from vehicle exhaust gas*)

Established 1845 SCIENTIFIC AMERICAN May 1964 Volume 210 Number 5

# A Study in Fertility Control

*Can modern concepts of family planning have a significant impact in the underdeveloped countries? A study in Taiwan suggests that fertility can indeed be changed substantially by a planned program*

by Bernard Berelson and Ronald Freedman

It is widely recognized that in many parts of the world there is a "population problem": the high rate of increase in population makes social and economic development difficult if not impossible. Can anything be done about the problem? Practical means of fertility control are available to individual couples, but can the control of fertility actually be implemented on a large scale in the developing areas? This article will describe an experiment designed to find out what can be done in one of the world's most densely populated places: the island of Taiwan off the coast of mainland China.

Large-scale efforts to control fertility are, to be sure, not unknown. A number of governments have assumed the responsibility of providing their people with information and services on family planning, and some countries have organized major national programs. Lowering a birthrate is a novel objective for a government, however, and no country has yet managed to achieve widespread family limitation through a planned social effort. Current programs are therefore handicapped by a lack of information on attitudes toward fertility control and by a lack of experience with programs to implement family planning.

Since any change in birthrate depends on individual decisions by large numbers of husbands and wives, it is essential to know first of all how the people concerned feel about family size and limitation. Do they need to be motivated toward family planning? If they are so motivated, how can they best be helped to accomplish their aim? To investigate these questions the Taiwan study was inaugurated a year and a half ago under the sponsorship of the provincial health department of Taiwan with the support of the Population Council, a U.S. foundation that advances scientific training and study in population matters. The most significant preliminary finding is that the people do not need to be motivated. They want to plan their families, but they need to know how. Teaching them how—implementing a family-planning program—has proved to be feasible.

Taiwan has a population of about 12 million in an area of 14,000 square miles, and its population is increasing rapidly. In recent years mortality has fallen almost to Western levels: life expectancy is more than 60 years and the death rate is less than eight per 1,000 of population per year. The birthrate is about 37 per 1,000, so the rate of increase is almost 3 per cent per year, or enough to double the population in 25 years. Nevertheless, compared with other parts of Asia, Taiwan provides a favorable situation for the diffusion of family planning. The island is relatively urbanized and industrialized, the farmers are oriented toward a market economy, literacy and popular education are fairly widespread, there is a good transportation and communication system and a solid network of medical facilities. The standard of living is high for a population of this size in Asia outside of Japan. The society is highly organized. Women are not sharply subordinated and there are few religious or ideological objections to contraception.

The birthrate in Taiwan has been falling slowly since 1958. When fertility rates are analyzed by age group [*see lower illustration on page* 33], it becomes apparent that they have decreased first and most for the older women of the childbearing population. This is exactly what one would expect if many women wanted to have a moderate number of children, had them with low mortality by the age of 30 and then tried to limit the size of their families in some way. The same pattern was observed earlier in a number of Western countries at the beginning of the declines in fertility that have tended to follow declines in mortality.

Although the situation in Taiwan was quite favorable for family planning and the birthrate trend had been downward, this was not to say that it would be a simple matter to accelerate the decline in fertility. As a first step in that effort the Population Studies centers in Taiwan and at the University of Michigan undertook a survey that would serve as a base line and also as a guide for a program of action. Between October, 1962, and January, 1963, public health nurses interviewed nearly 2,500

TAICHUNG STREET SCENE is in a typical *lin*, or neighborhood, in the central part of the city. Taichung, the city chosen for the population study reported in this article, has a population of about 300,000 and has rural as well as urban sections.

FIELDWORKER makes a home visit, the key element in the Taichung action program. She is interviewing the wife of a teacher.

AT HEALTH STATION, of which there are nine in the city, a worker explains a contraceptive technique to a Taichung woman.

married women of the city of Taichung in the prime reproductive age group (ages 20 to 39) as to their attitudes toward family planning, their information about it and what they did about it. The survey made it clear that these women as a group wanted to have a moderate number of children, were having more children than they wanted, approved of the idea of family limitation and were trying—ineffectively—to limit the size of their families.

The number of children most of the women wanted was four, and women who had already borne more than that number acknowledged that they would have preferred fewer children [*see top illustration on page 34*]. More than 90 per cent of Taichung's wives (and their husbands too, according to the wives) were favorably inclined toward limiting family size. They had few objections in principle, they saw the value of such limitation for the economic welfare of their families and they did not believe that the number of children should be left to "fate" or "providence." In this regard (and the same has been found to be true in other countries) their attitudes are more advanced than some officials believe them to be.

The women were in general poorly informed about family-planning methods and indeed about the physiology of reproduction. About a fourth of them had employed some means of contraception, but in most cases only after four or five pregnancies and in many cases without success. The women expressed strong interest in learning and adopting better methods. And in their own minds family planning did not conflict with their traditional feelings about the Chinese family or its central role in their lives.

Experience with contraception or other methods of limiting family size was naturally most common in the "modernized" sectors of the population: the best-educated women, the most literate and those with an urban background. The women's actual and desired fertility were also related to these characteristics [*see middle illustration on page 34*], but we found that on every educational level the average woman between 35 and 39, when childbearing is not yet over, had borne more children than she wanted. This was true even of groups in which substantial numbers of women had tried to limit the size of their families: contraception had arrived on the scene too late and was too ineffective to enable such women to attain their goals.

The survey data made it clear that the women had become aware of the decline of infant mortality in their community. This is an important perception, and one that does not follow automatically on the event. (Other surveys have shown that women sometimes perceive a decrease in infant mortality as an increase in births.) Because they recognized that more children were surviving, the women appreciated that, unlike their parents, they did not need to have five to seven children in order to see three or four survive to adulthood.

The salient message of the survey was that in Taichung people have more children than they want. There are indications that the same thing is true in many similar societies. It seems clear that if throughout the world unwanted children were not conceived, a large part of the "population problem" would disappear.

The next task was to facilitate the matching of behavior to attitude—to implement family planning. Several things were required beyond the mere wish to limit the number of children: information and knowledge, supplies and services, public acceptance and social support. To study how best to en-


**POSTERS were used widely in an educational campaign throughout Taichung. The caption reads: "A wise grandmother says: 'Look! My son and his wife have only three children. How healthy and happy they are!' If you have any question, go to the nearest health station."**



**POPULATION GROWTH in eastern Asia is mapped at left. The three shades indicate average yearly per cent increases, many of them rough estimates, from 1958 to 1961. Map at right shows population density in Taiwan in number of people per square kilometer.**

able the people of Taiwan to do what they themselves said they wanted to do, the provincial health authorities undertook to develop a program of action to make the practice of family planning more readily available in the city of Taichung. This effort, we think, is one of the most extensive and elaborate social science experiments ever carried out in a natural setting.

Taichung has a population of about 300,000, including about 36,000 married women from 20 to 39 years old, of whom 60 per cent have had three or more children. Most of the people live in a central region of shops, offices and residences, but there are also rural areas within the city's administrative limits. A number of government health stations and hospital clinics provide focal points for the action program.

The city as a whole was exposed to only two aspects of the program: a general distribution of posters pointing out the advantages of family planning and a series of meetings with community leaders to inform them about the program, get their advice and enlist their support. That was the extent of the community-wide effort; the remainder of the program was designed as a differentiated experiment involving various kinds and degrees of effort. The objective was to learn how much family planning could be achieved at how much cost in money, personnel and time. To this end the local health authorities and a cooperating team from the U.S. devised four different "treatments," and applied one of them to each of the 2,389 *lin*'s, or neighborhoods of 20 to 30 families, into which Taichung is divided. In order of increasing effort, the treatments were designated "Nothing," "Mail," "Everything (wives only)" and "Everything (wives and husbands)."

In the "Nothing" *lin*'s there was no activity beyond the distribution of posters and the meetings with leaders. In the "Mail" *lin*'s there was a direct-mail campaign addressed to two groups: newlywed couples and parents with two or more children. It was in the "Everything" neighborhoods that the major effort was made to increase family planning. The primary procedure was a personal visit to the home of every married woman from 20 to 39 years old by a specially trained staff of nurse-midwives. The fieldworkers made appointments for people at the health stations, provided contraceptive supplies, answered questions and did whatever else was necessary to satisfy a couple's desire for family-planning guidance. In half of the "Everything" *lin*'s the visits were made to wives only; in the other half the visits were extended to both husbands and wives, who were seen either separately or together.

Rather than apply each of these treatments to a different part of the city, the investigators decided to arrange matters so as to test a central economic issue: How much "circulation effect" can one expect in a program of this kind? To what extent can one depend on the population itself to spread the desired innovation, and how large an initial effort is required to prime the process? There has been substantial testimony that word-of-mouth diffusion played a large role in spreading ideas about family planning in the West and Japan; any such effect would clearly be of major importance to national efforts in the underdeveloped countries, which must influence large numbers of people and do so with limited resources.

In order to investigate this question of "spread" it seemed advisable to apply the four treatments in different concentrations in different parts of the city.

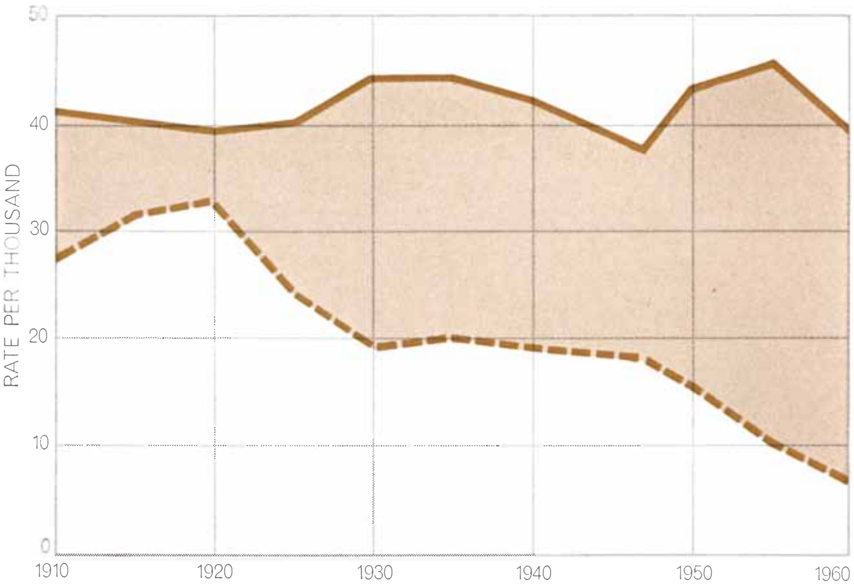
Taichung was divided into three sectors roughly equivalent in urban-rural distribution, socioeconomic status and fertility, and designated as areas of heavy, medium and light "density." In the heavy-density sector the two "Everything" treatments were administered to half of the *lin*'s, in the medium sector to a third of them and in the light sector to a fifth. In each sector the remaining *lin*'s were assigned equally to the "Nothing" and the "Mail" treatment groups [*see bottom illustration on next page*]. The *lin*'s were assigned at random, although always in the proper proportion, and those designated for a particular treatment received exactly the same program regardless of their location in the city. They differed only in their environment; in the heavy-density sector, for example, "Nothing" *lin*'s were much more closely surrounded by "Everything" *lin*'s than were the "Nothing" neighborhoods in the two lighter-density sectors [*see top illustration on page 35*].

The program got under way in mid-February of 1963: the posters went up, meetings were held, 18 fieldworkers fanned out through the "Everything" *lin*'s and the health stations prepared to receive inquiries. A set of educational materials was prepared for group and individual discussion, primarily visual aids dealing with the elementary facts about the physiology of reproduction, the reasons for practicing family planning and the major methods of contraception. The fieldworkers offered a wide choice of methods, encouraging couples to select whichever seemed most suitable: jelly, foam tablet, diaphragm, condom, rhythm, withdrawal, the oral pill and the new intra-uterine device. (The last is a recent development that holds great promise for mass programs to reduce fertility because it does not require continued supply, sustained motivation or repeated actions on the part of the user. A plastic ring or coil is inserted in the uterus by a physician and remains there; it is extremely effective as a contraceptive, although its mode of action is still unclear.) Contraceptive supplies were provided at or below cost, or free if necessary; the pills sold for the equivalent of 75 cents for a cycle of 20. The same charge was made for the insertion of an intra-uterine device.

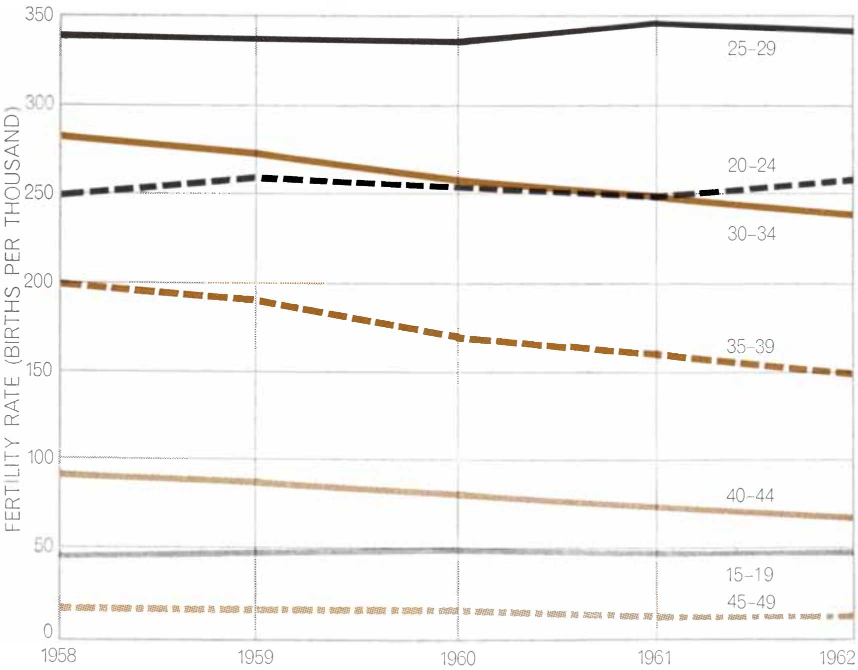
By the end of June fieldworkers had visited each of the nearly 12,000 designated homes at least once and more than 500 neighborhood meetings had been held. Between then and the middle of October follow-up visits were made to women or couples who had indicated interest and to women who had been pregnant or had been nursing infants earlier in the year. A final phase began in late October and is still continuing; direct action has been terminated, but services and supplies are still available at the health stations, and the momentum of the program is continuing to have effect as of this writing.

There are three ways in which the effectiveness of the whole program will be measured. One is through case records kept for all couples who were visited in their homes or came to clinics as a result of the action program. The second is a before-and-after survey of a random sample of 2,432 women of childbearing age. The final story will be told in fertility statistics to be compiled eventually from the official register.

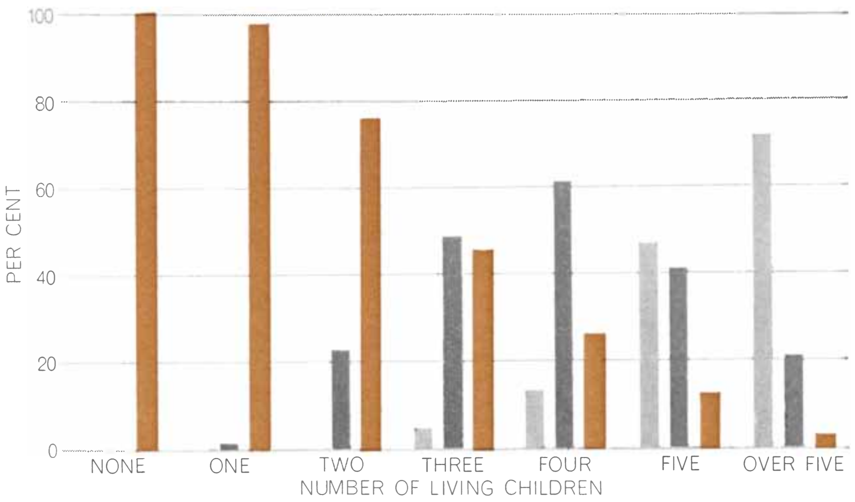
So far one result has emerged from the before-and-after survey, and it is a key measure of the outcome: at the end of 1962, 14.2 per cent of the wom-



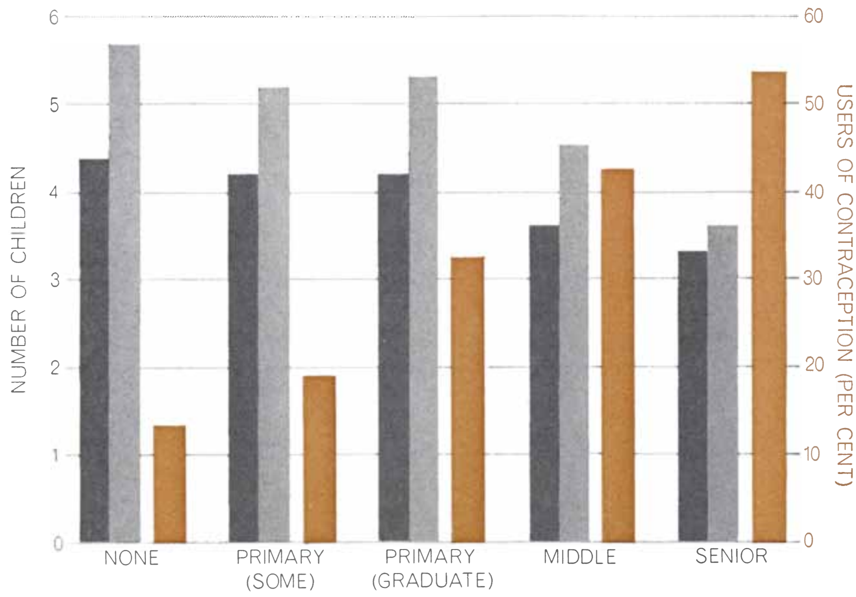

**RATE OF INCREASE in Taiwan's population (*colored area*) has grown because the birthrate (*solid colored line*) has remained high while the death rate (*broken line*) has fallen.**




**FERTILITY RATES, shown here for Taiwan women in seven age groups (*figures at right*), have fallen since 1958 in the case of the older women, presumably because they are trying to limit their families. The rates are birthrates per 1,000 women of the relevant age groups.**




**FAMILY-SIZE PREFERENCES** are charted for Taichung wives according to the number of children they have. The chart shows the per cent of wives in each group who said they would have preferred fewer children (*light gray bars*) or more children (*colored bars*) than they had or were satisfied with the number of children they had (*dark gray bars*).




**EDUCATION** affects family size and the use of contraceptives. The chart groups women 35 to 39 years old according to the level of schooling they had reached. The bars show the average number of children they said they had wanted (*dark gray*) and the number they had borne (*light gray*), and the per cent of each group practicing contraception (*colored bars*).

| TREATMENT | HEAVY (13,908) | MEDIUM (11,154) | LIGHT (11,326) | TOTAL (36,388) |
|---|---|---|---|---|
| NOTHING | 232 | 243 | 292 | 767 |
| MAIL | 232 | 244 | 292 | 768 |
| EVERYTHING (WIVES ONLY) | 232 | 122 | 73 | 427 |
| (WIVES AND HUSBANDS) | 232 | 122 | 73 | 427 |
| TOTAL *LIN*'S | 928 | 731 | 730 | 2,389 |

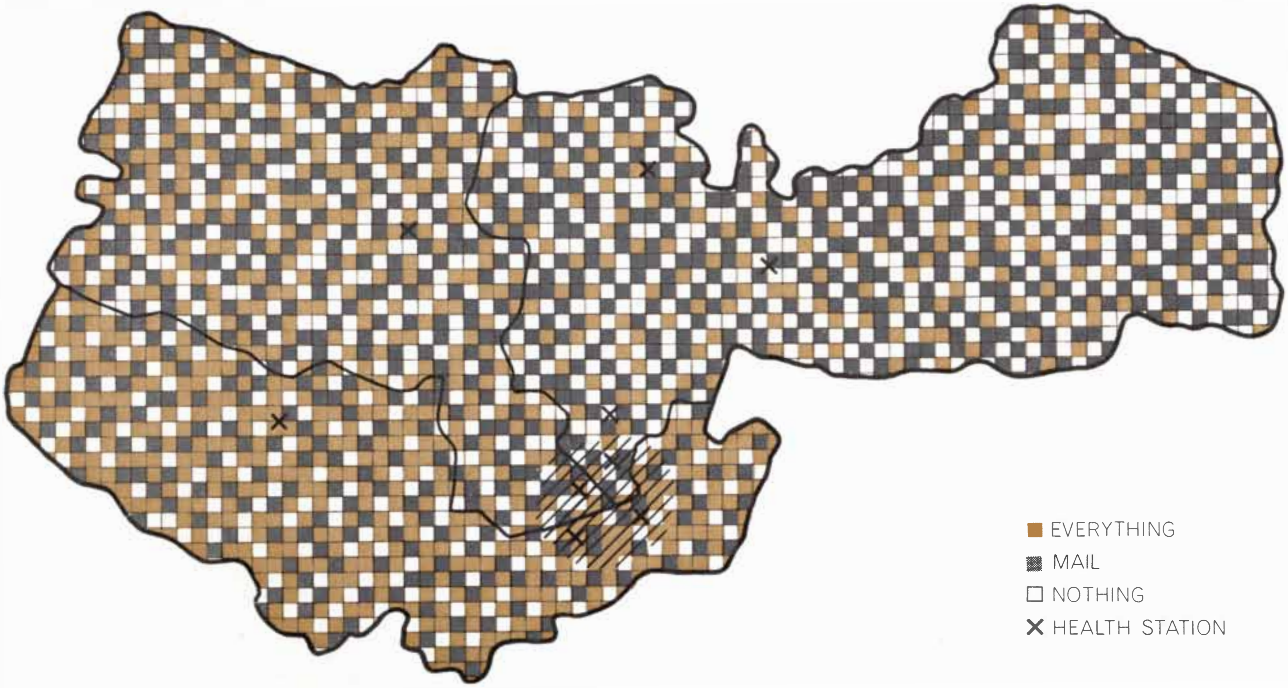
**MATRIX** shows the allocation of various "treatments" among the *lin*'s in the three density sectors. The figures in parentheses give the total number of women 20 to 39 years old.

en in the sample were pregnant, and at the end of 1963, 11.4 per cent were pregnant, a decline of about a fifth.

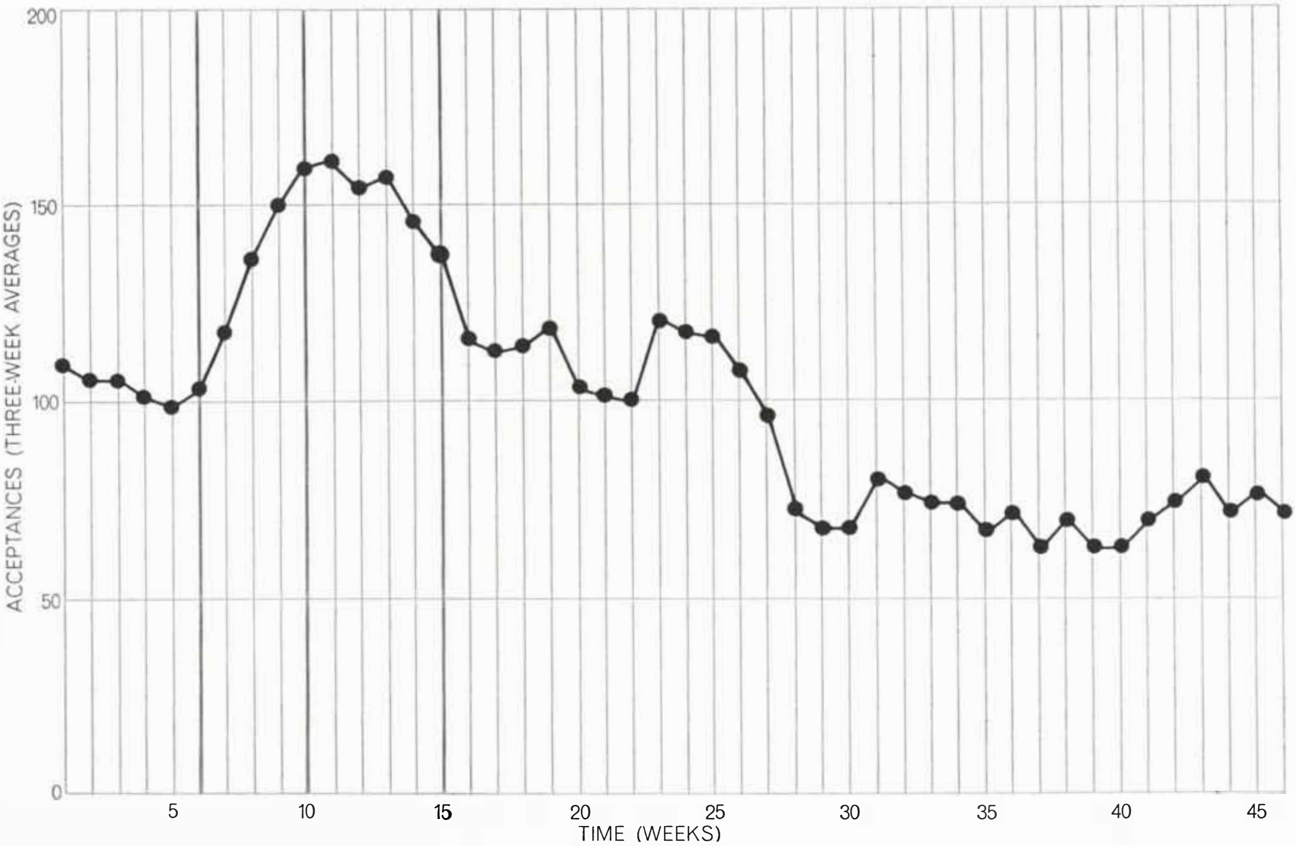
Aside from this one statistic, only the case records are available. Even for the people directly involved it is too early to measure the effect of the program on fertility; an immediate effect would take at least nine months to begin to show up! A presumptive effect, however, can be gauged from the record of "acceptances," defined as the insertion of an intra-uterine device or the receipt of instructions and the purchase of supplies for other methods, together with expressed intent to practice contraception. In the 13 months ending in mid-March of this year the action program was responsible for a total of 5,297 acceptances of family planning, 4,007 of which were from women living within Taichung proper. (The remainder came from outside the city even though no direct action was carried on there.)

How good is that record? There are different ways to appraise the figure of 4,000-odd acceptances within the city. First, the accepters constitute 11 per cent of the married women from 20 to 39. Not all the women in that age group, however, were "eligible" to accept family planning as a result of this program. About 16 per cent were already practicing contraception to their own satisfaction. Another 16 per cent had been sterilized or were believed to be sterile. Nine per cent were pregnant, 3 per cent lactating and 1 per cent experiencing menstrual irregularities of one kind or another. If these women are eliminated, only about 55 per cent of the 36,000 in the age group were "eligible." Of these 20,000 or so women, the program secured about 20 per cent as family planners. Included in that definition of eligibility, however, are women who actively want another child—young wives who have not completed their families or those who want a son. If they are considered not really eligible for contraception at this time, the "currently eligible" category is reduced to some 10,000 women, and those who have taken up contraception in the first 13 months come to about 40 per cent of this truly eligible population.

This arithmetic helps to define a "success" in the spread of family planning in the underdeveloped countries. At any given time somewhere between half and three-fourths of the target population is simply out of bounds for the purpose. If a program can get as



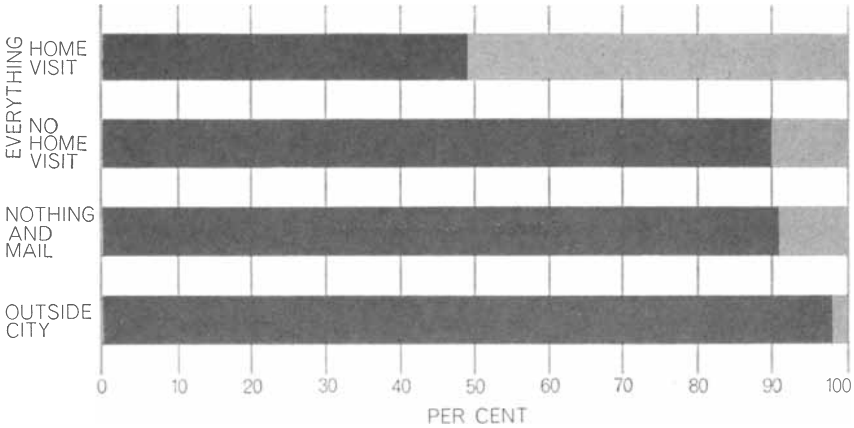

**CONCENTRATION OF EFFORT** in Taichung is mapped schematically. Each square represents a *lin* (although the correct number of *lin*'s is not shown). The city was divided into three sectors. The intensive "Everything" treatment was applied to half of the *lin*'s in the heavy-density sector (*lower left*), to a third of them in the medium-density sector (*upper left*) and to a fifth of the *lin*'s in the light-density sector (*right*). The remaining *lin*'s in each sector were divided equally between the "Mail" and "Nothing" treatments.




**PROGRESS OF ACTION PROGRAM** is traced by a curve showing the trend of "acceptances" of contraception in Taichung each week from the end of February, 1963, to mid-January, 1964. The three heavy vertical grid lines show (*left to right*) the points at which 40 per cent, 62 per cent and 85 per cent of the home visits had been completed. The program reached a peak, then leveled off.

| TREATMENT | HEAVY | MEDIUM | LIGHT | TOTAL |
|---|---|---|---|---|
| NOTHING | 7 | 5 | 5 | 5 |
| MAIL | 7 | 5 | 6 | 6 |
| EVERYTHING | | | | |
| (WIVES ONLY) | 16 | 13 | 11 | 14 |
| (WIVES AND HUSBANDS) | 18 | 10 | 12 | 15 |
| ALL TREATMENTS | 12 | 7 | 7 | 9 |

**RESULTS of the program are given as of the end of last December. The figures show the accepters as a per cent of the married women aged 20 to 39, by "treatment" and density sector.**




**INDIRECT DIFFUSION of family planning was particularly marked in the case of the intra-uterine device. Almost all women who accepted contraception without home visits chose this device (*dark segments of bars*) rather than a traditional method (*light segments*).**

many as a half—or even a third or a fourth—of the remaining group to begin practicing contraception within a few years, it has probably achieved a good deal. In this kind of work, then, having an impact on 10 per cent of the target population in a year or so is not a disappointing failure but a substantial success; one should report "Fully 10 per cent," not "Only 10 per cent"! Another way to appraise the Taichung results to date is to recognize that whereas in February, 1963, about 16 per cent of the married women from 20 to 39 were practicing contraception, by March of this year about 27 per cent were doing so, an increase of nearly 70 per cent.

The impact of such a program is not felt immediately or at one time or evenly. At the outset the acceptance rate was remarkably constant, but after some seven weeks, when 40 per cent of the home visits had been made and word-of-mouth reports of the program were well established, the curve began to climb steadily [*see bottom illustration on preceding page*]. It hit a plateau in about four weeks and stayed there for about a month before declining. This was the height of the program, when two-thirds of the home visits had been completed and interest was strong. By the beginning of June, when nearly all the visits had been made, the cream had been skimmed: the women who were strongly motivated toward family planning had heard of the program and had decided what they would do about it. By the end of the summer follow-up visits were reaching less motivated women and the curve returned to its starting point. In the fall, when home visits ended but supplies and services were still available, the acceptances settled to a lower but steady rate.

A program of this kind, then, apparently starts off reasonably well, builds up quite rapidly and achieves roughly half of its first year's return within the first four months. The important thing is to develop a "critical mass" that can generate enough personal motivation and social support to carry on without further home visits. A poor country simply cannot afford visits to the entire population, so any realistic plan must rely heavily on personal and informal contacts from trusted sources; it may be that the job will have to be done by relatives, neighbors and friends or not at all. The task of a planned program will thus be to develop enough knowledgeable and convinced users of contraceptives to start a movement that reaches out to the ill-informed and unconvinced.

The indirect effects were extremely important in Taichung. The most dramatic indication is the fact that by the end of 1963 some 20 per cent of the acceptances had come from women who did not even live in the city. (That figure has since risen to almost 25 per cent.) Within the city about 60 per cent of the acceptances were from "Everything" *lin*'s; the other 40 per cent were divided about equally between the "Nothing" and the "Mail" *lin*'s. Even in the "Everything" neighborhoods about a sixth of those who accepted contraceptives actually came forward before their scheduled home visits had been made. Direct home visits, in other words, accounted for only some 40 per cent of the acceptances by the end of December.

As for the effectiveness of various concentrations of effort, the proportion of those who accepted contraceptives was indeed higher in the heavy-density sector, but this effect was almost completely within the "Everything" *lin*'s themselves [*see top illustration on this page*]. The indirect effect—the "rub-off" from the home-visit areas to the "Nothing" and "Mail" *lin*'s—was remarkably constant in the three sectors. Our tentative conclusion is that the maximum return for minimum expenditure can be obtained with something less than the heavy-sector degree of concentration. Finally, the added effect of visiting husbands as well as wives was not worth the expense, perhaps because in this program the preferred contraceptive method was one involving the wife alone.

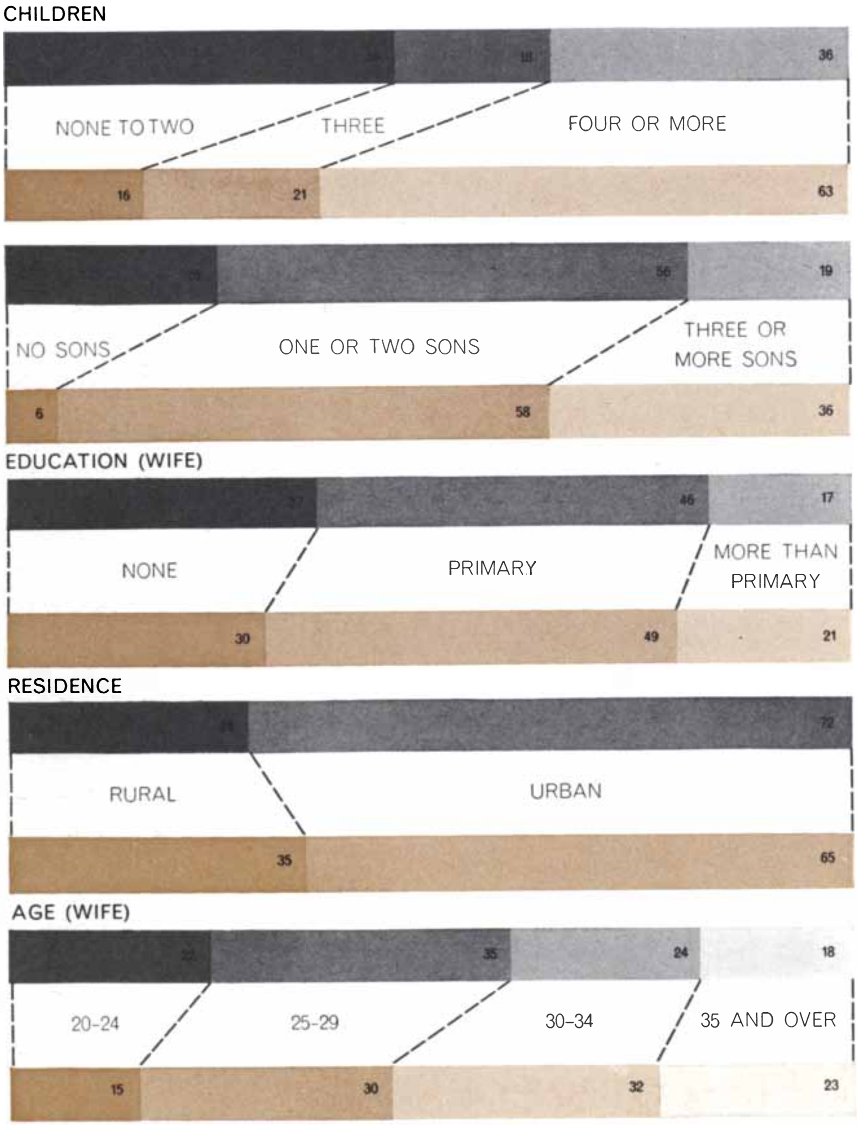
The nature of the contraceptive method, as a matter of fact, has more of an effect on the success of a program than may have been generally recognized. A "one-time" method requires far less field effort over a long term than a method dependent on resupply and sustained motivation. In Taichung the choice turned out to be overwhelmingly for the intra-uterine devices, which were preferred by 78 per cent of those who accepted contraceptives; 20 per cent selected one of the more traditional methods (mainly foam tablets or condoms) and 2 per cent chose the oral pill (which was, to be sure, the most expensive method). The women themselves, in other words, elected the "one-time" method. This was particularly significant in view of the method's high effectiveness and what might be called its "accountability" through scheduled medical follow-ups. The six-month checkup shows that only some 20 per cent of the devices have been removed or involuntarily expelled, whereas about 30 per cent of the women who chose the traditional methods are no longer practicing contraception regularly.

The Taichung study revealed another significant advantage of the intra-uterine device: a striking tendency for information about it to be disseminated indirectly by word of mouth, obviating much of the task of communication and persuasion. Nearly 75 per cent of the new devices were accepted without the necessity of a home visit, compared with only 15 per cent in the case of the traditional methods. The intra-uterine devices "sold" themselves; what the home visits did, in effect, was to secure acceptance of the traditional methods [*see lower illustration on opposite page*]. Since last October, when the action program proper was terminated, more than half of those who have accepted contraceptives have come from a widening circle around the city, and almost all of these women have chosen the new devices. This is presumably what happens when word of the method reaches women who are ready for family planning but want an easier and "better" way than they have heard of before.

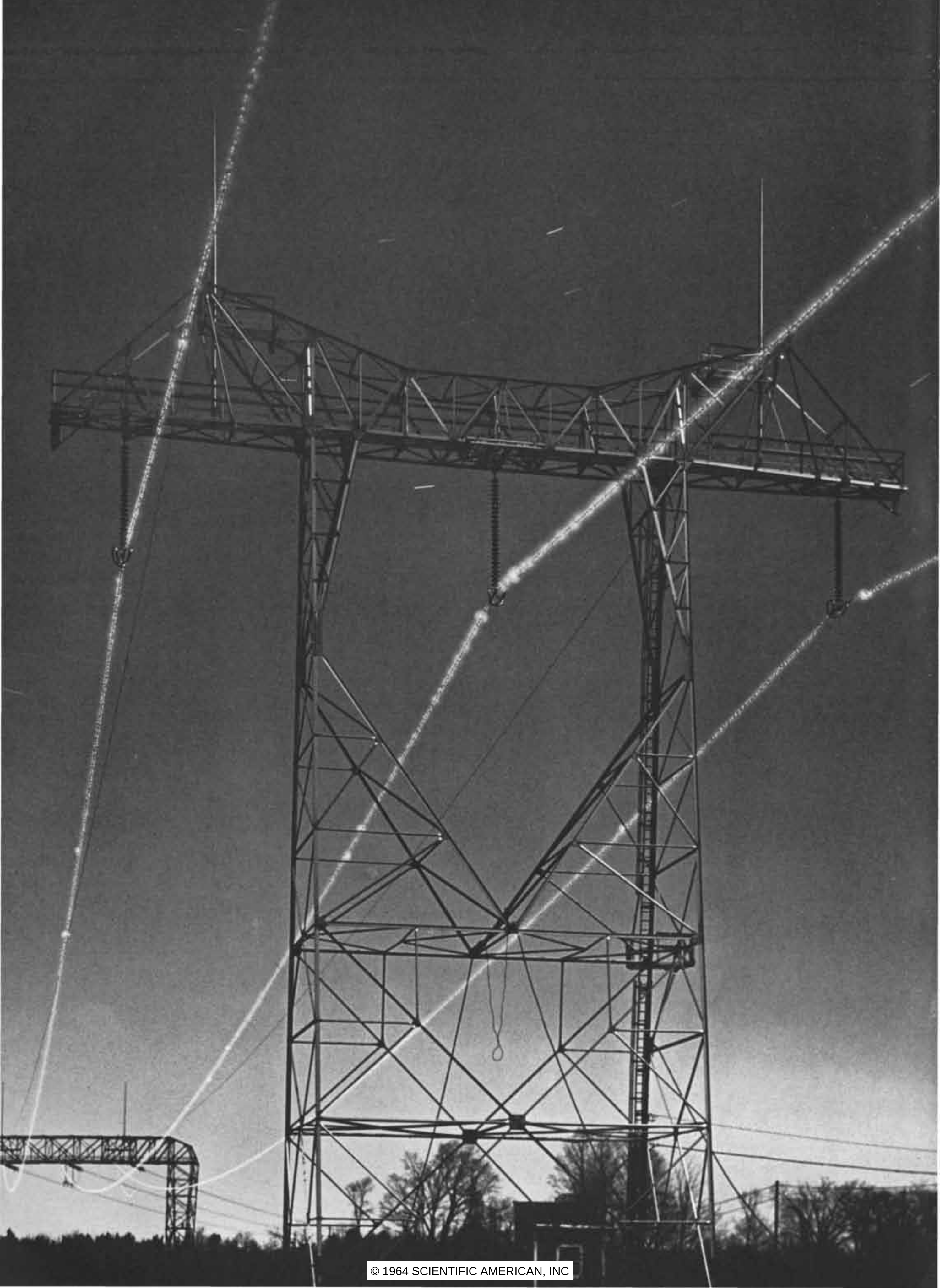
Family planning does not, of course, diffuse evenly among the different kinds of people in a community. Acceptance varies with education and age and—in Taichung at least—above all with number of children and number of sons. When couples in Taiwan have four children, they have all they want and they are ready to do something about it—if there is something available that is reasonably effective, inexpensive and easy to use. The evidence here is that whereas the slow long-term "natural" spread of contraception through a population reaches the better-educated people first, a deliberate and accelerated effort like the Taichung program can quickly have a major impact on the families that already have large numbers of children.

Taiwan is one of many low-income countries where rapid increases in population thwart economic development and threaten to slow further improvements in the standard of living. In the long run, to be sure, it seems likely that economic and social pressures combined with personal aspirations will lead individuals to limit their families. The underdeveloped countries, however, cannot wait for a long-term solution to their present crisis. The program in Taichung suggests that fertility control can be spread by a planned effort—not so easily or so fast as death control, but nevertheless substantially, in a short period of time and economically. (The cost of each acceptance was between $4 and $8, far below the eventual economic value of each prevented birth, which has been estimated as being between one and two times the annual per capita income.)

A good deal of the story in Taiwan remains to be told, of course, including the results of the sample survey and the critical check of official birth statistics over the next months and years. Health agencies in Taiwan are now extending the program to a larger segment of the population, testing the Taichung results and trying out new approaches in the slum areas of cities and in poor fishing and mining villages. At this point one can at least say that fertility in Taiwan is changing and can be changed—changing over the long run as the result of unplanned social processes but, most significantly, changeable in the short run as the result of a planned effort to help people have the number of children they really want.




**ACCEPTANCE of family planning varied in different groups. In this chart the women are categorized according to various characteristics. The gray bars show the per cent of the "currently eligible" women who fell into each category. The colored bars show the per cent of the new accepters of contraception who fell into the same categories as of the end of 1963.**



# High-Voltage Power Transmission

*By raising voltages the cost of transmitting power can be lowered. In 1953 the first 345,000-volt line was commissioned in the U.S. Today a 700,000-volt transmission line is being built in Canada*

by L. O. Barthold and H. G. Pfeiffer

The electricity that enters the home at 120 volts has customarily made part of the trip from its point of generation at a much higher voltage. High voltages are essential for transmitting large amounts of power at low cost, and as U.S. power consumption has increased over the years the need to use higher transmission voltages has grown accordingly. U.S. electric utilities now operate more than 100,000 miles of transmission lines that carry power at 138,000 volts and more than 20,000 miles of line that transmit power at 230,000 volts. It is customary to express voltages above 1,000 in kilovolts (kv.); thus 230,000 volts is referred to as 230 kv.

Within the past dozen years the electric-power industry has discerned economic merit in still higher voltages and has applied the term "extra-high-voltage transmission" to lines carrying more than 230 kv. The first extra-high-voltage line in the U.S. was built in the mid-1930's to carry power at 287 kv. from Hoover Dam to Los Angeles, a distance of some 200 miles. This remained the highest power-line voltage in the U.S. until 1953, when the American Electric Power Company commissioned a 345-kv. network that now interconnects electric systems in seven states of the East Central U.S.

Today more than 3,600 miles of 345-kv. line are in service. In the U.S. and Canada more than 1,000 miles of 500-kv. line are under construction; the first line should be operating by 1965. Also scheduled for service next year is the first section of three 350-mile, 700-kv. lines being built by the Quebec Hydro-Electric Commission to carry power to Montreal from a series of dams on the Manicouagan River in northern Quebec [*see illustration on page 41*]. Both here and in Europe there is discussion of 1,000-kv. transmission lines, and in France an experimental line capable of reaching 1,100 kv. is already being built.

Sweden was the first European country to employ extra-high-voltage transmission. In 1952 400-kv. lines were placed in service to carry hydroelectric power a distance of some 600 miles from dams in northern Sweden to centers of consumption in the south. As of last year five countries—Sweden, Norway, Finland, France and Germany—had 400-kv. lines in regular operation. In the U.S.S.R. a 500-kv. line has been in service since 1959 and a 750-kv. experimental line, 100 kilometers long, is scheduled for testing this year.

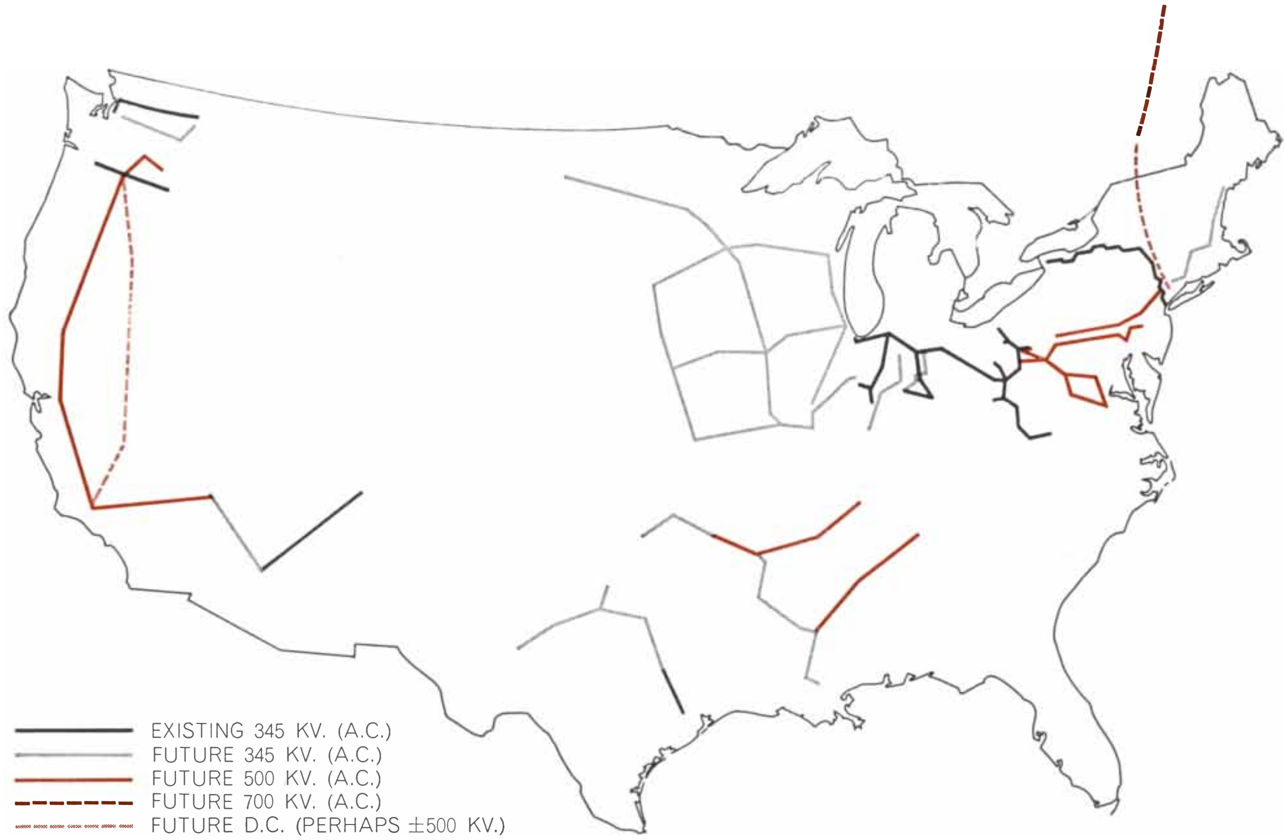
All these lines are designed for alternating current, but fresh study is being given to direct-current transmission, which may prove cheaper than a.c. transmission when much power must be sent overland for long distances. For sending power underwater by cable d.c. transmission has already proved to have advantages over a.c. transmission. The first successful commercial use of high-voltage d.c. was in a 60-mile cable link between Sweden and the island of Gotland in 1953. A similar cable now links the electric systems of England and France.

In 1962 the U.S.S.R. placed in service an experimental high-voltage d.c. transmission line that extends 290 miles from the Donets Basin to Volgograd. It has been operated intermittently at plus and minus 200 kv. (or 400 kv. between conductors) and is scheduled for operation in the near future at ± 800 kv. (1,600 kv. between conductors). The feasibility of transmitting Canadian hydroelectric power to New York City by direct current at about ± 500 kv. is being explored. Another d.c. line that is under study would ship energy from hydroelectric sites on the Columbia River in the state of Washington to southern California, a distance of 1,200 miles.

There are important economic reasons for wanting to raise transmission voltages. The basic equation of power transmission states that the amount of energy that can be transmitted by a line goes up approximately as the square of the voltage and decreases directly with the distance. In other words, if the distance is held fixed, a 700-kv. line can carry about four times more power than a line of 345 kv. A 700-kv. line several hundred miles long can transport about 2,900 megawatts, or enough to supply the average demands of the entire city of Chicago.

Transmission efficiency also increases with voltage. Conductors and insulators both contribute to the total energy loss in power transmission. The conductor loss is proportional to the square of the current; the insulator loss is proportional to the square of the voltage. Normally the insulator loss is negligible, which means that voltage can be raised with negligible penalty. Since the amount of power carried by a transmis-

**CORONA DISCHARGE** is produced by a voltage overstress on the General Electric Company's extra-high-voltage experimental line near Pittsfield, Mass. The line, part of Project EHV, is designed to carry three-phase alternating current at 500,000 and 700,000 volts (500 and 700 kv.). Each phase requires a separate conductor. At these high voltages it is advantageous to use a "bundle" of two or more conductors, spaced about 18 inches apart, for each phase. When this photograph was taken, however, G.E. engineers were making special tests with only one conductor per phase. A corona discharge therefore occurred at about 700 kv. Streaks in the sky are images produced by stars.




**U.S. HIGH-VOLTAGE LINES of 345 kv. now in operation (*black*) are shown together with lines of the same or higher voltage now under construction or planned for completion before 1970. All the lines depicted are designated for alternating current except for two tentative d.c. lines: one from Canada to the vicinity of New York City, the other between the Pacific Northwest and the Los Angeles area. Some of the lines now planned for 345 kv. will probably be raised to 500 kv. by the time construction actually begins.**

sion line is the product of voltage and current, raising the voltage makes it possible to lower the current for a given power level. Lowering the current leads in turn to a sharp reduction in conductor losses.

In actual practice the selection of a line voltage involves a great many variables. Both equipment and construction costs increase with voltage. Another important variable, particularly in urban areas, is the cost of obtaining rights of way for new power lines. Since power capacity increases with voltage, many utilities are finding it economical to upgrade existing lines to the next higher voltage level, thereby making more efficient use of existing rights of way.

To guide the industry toward efficient design of 500-kv. and 700-kv. transmission lines, a number of major test lines have been built. These include the 500-kv. Coldwater line of the Ontario Hydroelectric Commission, the 500-kv. test line of the Pennsylvania Electric Company and the Apple Grove line of 500 kv. and 750 kv. sponsored jointly by the American Electric Power Company and the Westinghouse Electric Company. For the past four years the General Electric Company has operated a test line 4.2 miles long outside Pittsfield, Mass., as part of a $10-million program known as Project EHV. The highly instrumented General Electric line is capable of carrying out studies at 500 kv. and 750 kv. simultaneously.

Because such voltages are defined in a specific way, a few definitions are in order. In the U.S. it is standard practice to transmit electric energy in the form of alternating current of 60 cycles per second. For efficiency power is transmitted on a three-phase circuit, which calls for three conductors. The term "three-phase" indicates that the peak voltages on the three conductors are spaced a third of a cycle apart, which means that a voltage peak occurs on one of the three conductors every 180th of a second [*see upper illustration on page 44*].

The voltage rating of a three-phase circuit is determined by the "effective" voltage—more precisely the "root-mean-square" voltage—between any two conductors. The root-mean-square value is .707 times the crest, or peak, voltage, so that to obtain an effective voltage of 500 kv. the peak voltage must be 500 kv. divided by .707, or 707 kv. (The voltage between the line and the ground is less than the effective voltage by a factor of $1/\sqrt{3}$, or about 290 kv. for a line rated at 500 kv.)

In what follows we shall draw primarily on experience gained in the General Electric test program. The program has embraced every aspect of high-voltage transmission from the construction of towers to the evaluation of conductor and insulation requirements. To simulate the switching surges and lightning impulses that would occur on a line several hundred miles in length the test system is provided with a three-million-volt impulse generator.

Because conductors represent from 20 to 30 per cent of the $100,000 or so required to build a mile of 500-kv. line, their design has been intensively examined. The fundamental economic basis for selecting the size of a conductor was first set forth by Lord Kelvin more than 60 years ago. His "law" simply states that the economical size is that for which the additional annual charges on the investment exactly equal the additional annual cost of the energy lost. In other words, it does no good to reduce conductor losses by choosing a larger conductor if the added cost exceeds the value of the energy saved. For a long line a change of as little as 3 per cent in the diameter of the conductor may represent a difference of several hundred thousand dollars annually in the value of energy lost.

As voltages have been raised beyond 345 kv., corona discharge around conductors has presented more and more of a problem. A corona discharge occurs when the strong electric field around a conductor causes a breakdown of the insulating properties of the surrounding air [*see illustration on page 38*]. These discharges, which appear as a brief glow or luminous plume, usually occur at surface deformities on the conductor, such as those due to scratches, adhering particles or raindrops.

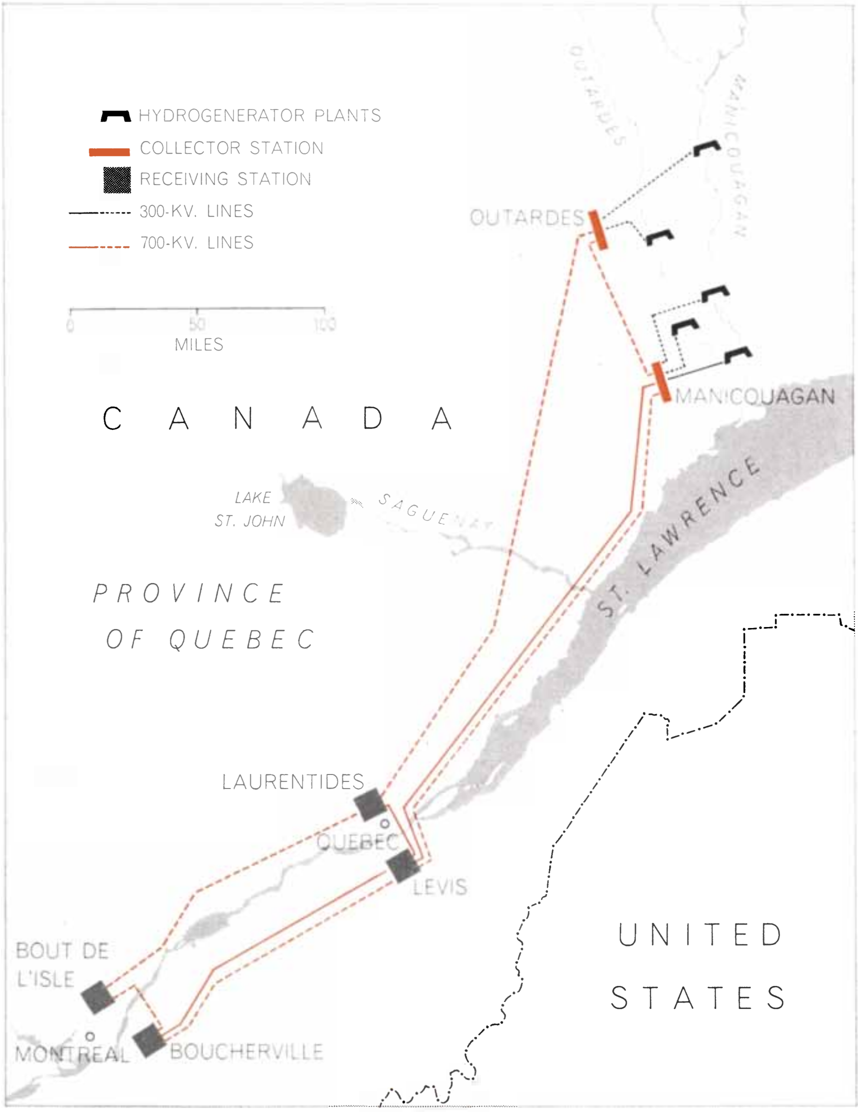
Corona discharges usually last only a small fraction of a microsecond and dissipate no more energy than that consumed by a 40-watt light bulb operating for a second. In the aggregate, however, they can represent a significant power loss and, even more troublesome, can generate a great deal of radio noise, which interferes with radio reception in the standard amplitude-modulation (AM) broadcast band.

Corona losses and noise emission can be reduced by increasing the size of the conductor. Still better results can be obtained by dividing current flow between two or more conductors spaced about 18 inches apart and joined by conducting spacers every few hundred feet. Such a conductor "bundle" requires no more conducting material (usually aluminum) than a single conductor and as a bonus the line offers less impedance to the flow of alternating current. Most 500-kv. lines will use two conductors per phase; the 700-kv. lines of Quebec Hydro will use four conductors per phase.

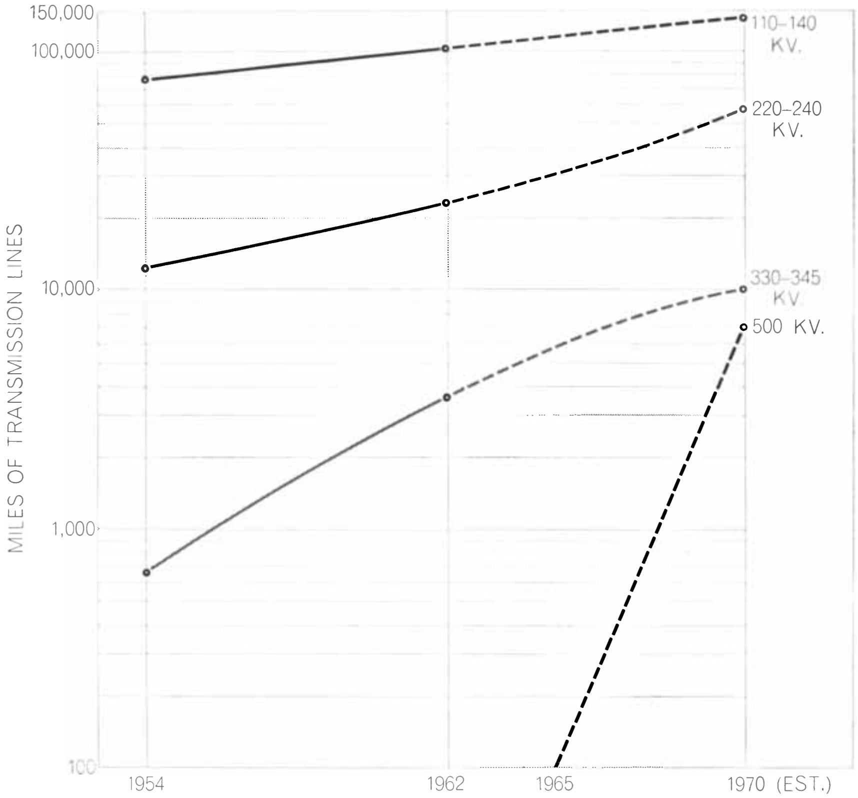
The General Electric extra-high-voltage project has developed methods for predicting the radio-noise output for lines still in the design stage. It has been found, for example, that the radio-frequency propagation characteristics of a line help to determine the total noise field. On a typical 500-kv. line more than half of the total noise energy recorded at any given point near the line is generated by corona bursts more than a mile away. Noise levels can increase more than tenfold during a rainstorm when the droplets on the bottom of the conductor favor the generation of corona plumes.

Power loss due to corona on a 500-kv. line, which is normally only one or two kilowatts per mile, can increase by a factor of 100 in the rain. The actual energy lost in this way is not significant unless the time of maximum loss coincides with the time of maximum power demand. The probability of this coincidence is one of many contingencies that add to the high cost of supplying brief, peak demands for energy, for which generating capacity must stand ready.

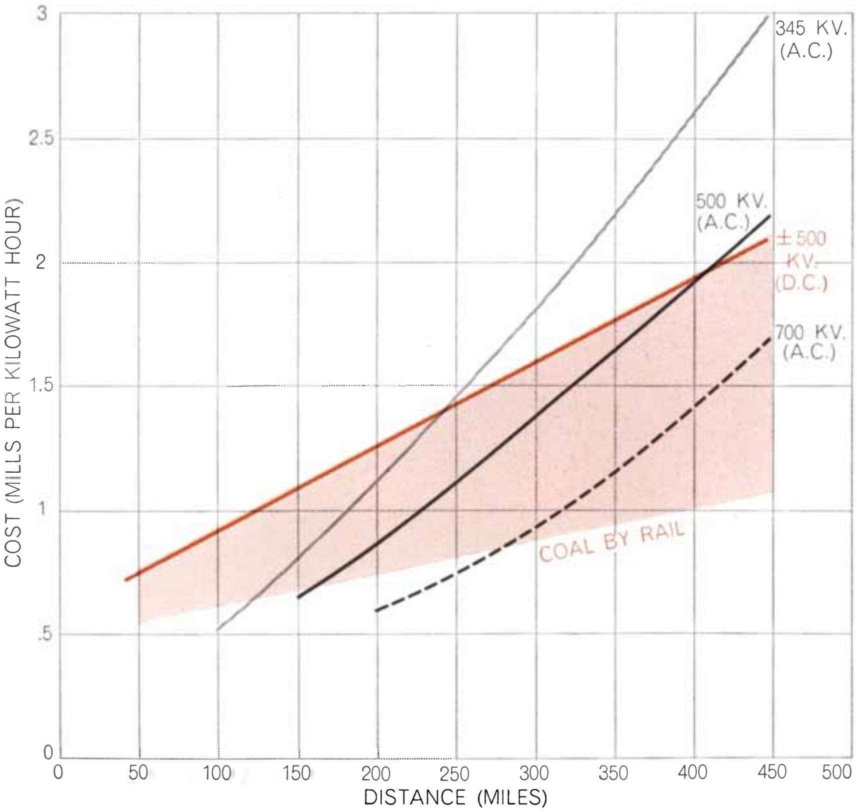
Indeed, the extensive interconnection of electric power systems finds its basic justification in reducing the standby generating capacity needed by any one system. A recent study showed that as the transmission capacity of an extra-high-voltage line joining two major systems was increased up to 800 megawatts, each additional megawatt of transmission capacity was equivalent to the installation of an additional megawatt of generating capacity in both systems.




**CANADIAN 700-KV. LINE** will carry alternating current from hydroelectric sites in northern Quebec to the cities of Quebec and Montreal, a maximum distance of 350 miles. The 700-kv. line, being built by the Quebec Hydro-Electric Commission, will consist of 1,000 miles of line by 1970 and an estimated 5,000 miles by 1985. Solid lines show portions of system under construction; broken lines show projections to 1970. Hydroelectric resources in Quebec are adequate to supply more than four times the present power demand.




**HIGH-VOLTAGE TRANSMISSION MILEAGE** in the U.S. has been climbing steadily since 1953, when the first lines of 345 kv. were placed in service. The first 500-kv. lines are now under construction and should be ready for testing late this year or early next year.




**COST OF ENERGY TRANSPORTATION** is shown for electricity by wire and coal by rail (*broad colored band*). Electricity costs assume parallel circuits for reliability and loads proportionate to capacity. A 700-kv. line can carry four or five times as much power as a line of 345 kv. Lowest costs for coal by rail are achieved by "unit trains" that carry only coal.

Yet transmission capacity typically costs only a hundredth as much as generating capacity.

Weather, which so heavily influences the performance of conductors, has an even greater effect on the performance of insulators. The three types of electrical stress that affect insulation are: the normal 60-cycle voltage, overvoltages that arise when current is switched onto a line and voltage surges caused by lightning. The design of insulators for 60-cycle voltage is well salted with conservatism to ensure continuity of service under the most severe weather anticipated. No particular test is needed for the first of these three types of stress. The normal 60-cycle voltage constitutes a continuous "test" of insulator strength, day in and day out in all kinds of weather, 60 times a second.

Switching surges, on the other hand, lend themselves to statistical analysis. They occur only several times a year and the severest of them can exceed the normal peak of the 60-cycle voltage by a factor of three or more. Statistical methods are useful in predicting how often a severe surge may come at a time when wind, rain, air density and so forth combine to reduce the insulation strength to its minimum.

In their extra-high-voltage studies, General Electric engineers learned that the strength of a given insulator assembly subjected to switching surges could drop as much as 30 per cent when it was removed from an idealized laboratory setup and installed outdoors on a transmission tower. The insulation strength depends on the design of the structure supporting the insulator and is not at all proportional to the length of the insulator. Such tests suggest that a technical or economic limit to a.c. transmission may exist in the region between 1,500 kv. and 2,000 kv.

Realization that insulator strength was dependent on tower design has led to full-scale tests of the towers proposed for many of the extra-high-voltage lines now under construction in the U.S. and Canada. These studies try to assess the probability of insulator failure under conditions of complex interplay among such factors as the geometry of the tower structure, the weather environment and the strength and duration of the switching surge. It has been interesting to learn that wood structures, which have been preferred for the transmission of intermediate voltages, have shown unexpected advantages for extra-high-voltage lines.

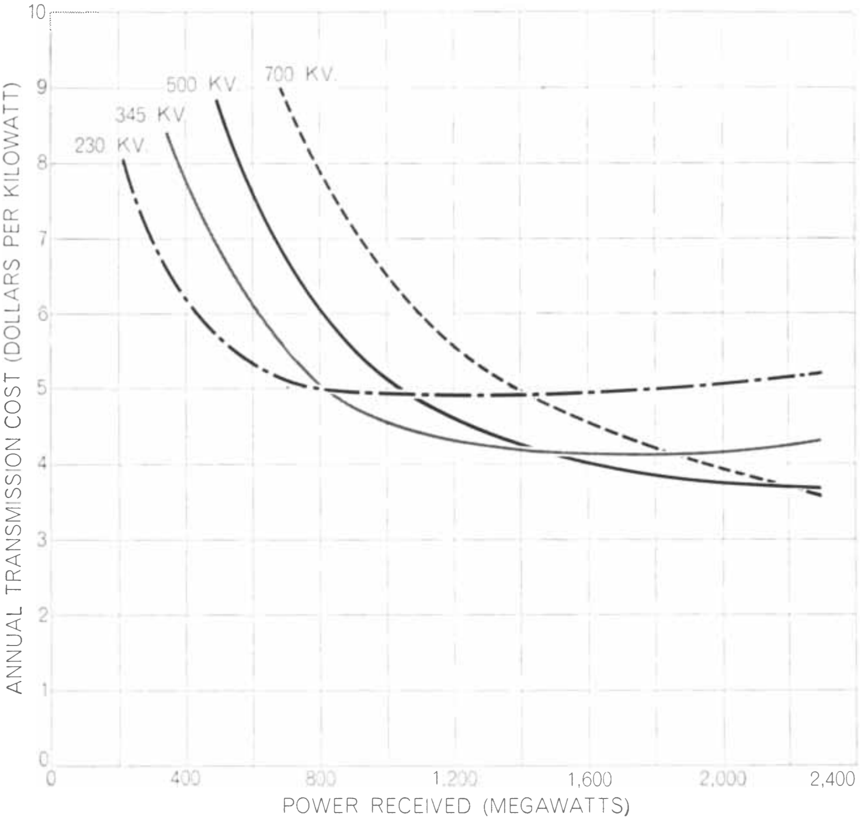
The voltage surges caused by lightning rise much more steeply than switching surges, reach much higher values and usually drop to half their value in a few tens of microseconds; this is roughly a hundredth of the time required for a switching surge to drop to half its value. The geometry of the tower structure is of little consequence in lightning surges because here the failure occurs along the surface of the insulators.

Virtually any lightning stroke that hits a power-line conductor causes a flashover, or short circuit, that allows thousands of amperes of current to flow across the insulator that has failed. The short circuit is detected at the line terminals by protective relays that cause circuit breakers to interrupt the current flow, thereby isolating the faulty line section from the rest of the power system. In the most modern systems all this can take place in two cycles (a thirtieth of a second). Normally the relays are adjusted to restore the line to service in less than 25 cycles, which allows time for the dissipation and cooling of the combustion products formed at the insulator by the electric arc. If current flow is restored too soon, a second short circuit may result.

Lightning will strike most lines 10 to 50 times a year, but almost all the strokes are intercepted by shield wires that are placed above the conductors and connected to the ground at each tower. Even strokes caught by the shield wires, however, will sometimes cause a flashover owing to voltages induced in the tower as the lightning current flows to ground.

The frequency of lightning failures on a proposed transmission line can be successfully predicted by the use of scale models of lines and towers built to a fiftieth of actual size. Although it is not possible to bombard the line with miniature lightning strokes, once a stroke is assumed to have made contact the lightning column extending into the sky and other effects can be accurately modeled to represent the subsequent electrical response. The voltages appearing across the insulators on the scale model are proportional to those expected on the actual line. By varying the stroke current and its rate of increase, by varying the resistance between the base of the tower and terrain (as it will vary along the right of way), the impulse duty served by an insulator can be predicted in statistical terms.

Traditionally designers of transmission lines have sought to ensure adequate insulation performance by adopting a reasonably pessimistic value for each relevant variable and assuming that they would all coincide in time. Not only has this approach leaned heavily on intuition in defining what "reasonably pessimistic" means; it has also ignored information that bears directly on the long-term performance of the line, for example the historical record of weather conditions along the proposed right of way.




**AMOUNT OF POWER TO BE TRANSMITTED is an important variable in cost analysis, as shown by these curves for different voltages. All are based on 100-mile transmission and a minimum of two circuits. A 230-kv. system requires three circuits above 1,100 megawatts and four above 1,500. A 345-kv. system requires a third circuit above 2,000 megawatts.**

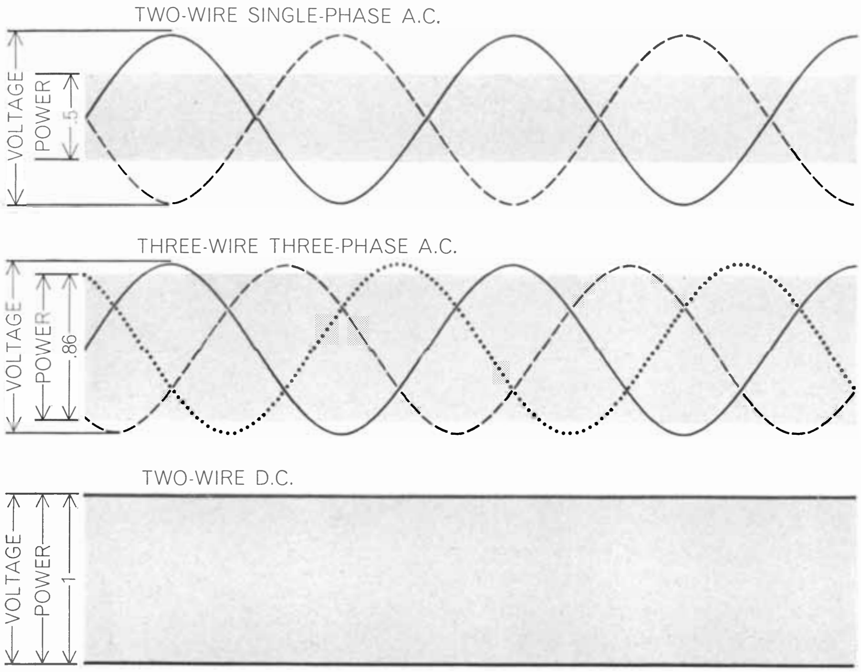
In its extra-high-voltage project General Electric has developed a method for computing the performance of a proposed line by taking into account the meteorological history of the right of way. The method is called meteorologically integrated forecasting, abbreviated "metifor." It uses as a weather history the hourly weather observations extending back 10 or 20 years, as reported by U.S. Weather Bureau stations in the vicinity of the right of way.

To analyze the performance of an insulator arrangement one begins by determining the strength of the insulator under a variety of simulated weather conditions. The metifor program then indicates the historical frequency with which such conditions occurred and constructs a "histogram" of insulation strength. The histogram correlates wind (which swings the insulator closer to the tower), air density, humidity, precipitation and so on, which have a collective effect on insulator strength.

The metifor program normally constructs two histograms for each insulator arrangement being studied. The first is for a complete sample of weather conditions; the second is restricted to weather variables during thunderstorms.

To predict the probable frequency of failures caused by switching surges, the statistical distribution of switching surge magnitudes is compared with a histogram of insulation strength. Whenever this strength is exceeded by a switching surge, line flashovers result. Performance predictions of this sort help to determine the balance in design features that will yield the fewest surge failures. More important, they make it possible to tailor the reliability of a line to satisfy its particular role in the entire transmission system, thereby leading to economies in construction.

In the early days of the electric-power industry there was a vigorous debate between engineers who advocated power lines carrying a constant current and those who recommended lines carrying a constant voltage. Except for isolated



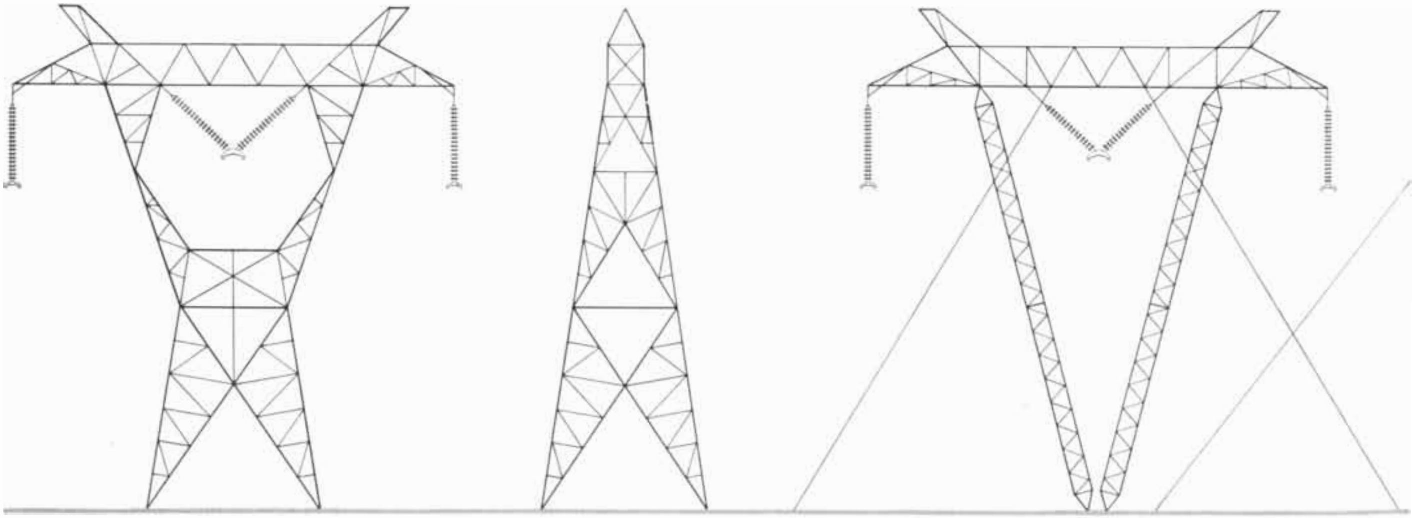

**COMPARISON OF A.C. AND D.C. SYSTEMS** shows how the average amount of power transmitted (*gray area*) is related to peak voltage. This voltage determines the maximum electrical stress applied to conductors and insulators. This stress is intermittent in an a.c. system, hence it carries less power than a d.c. system designed for the same peak stress.

applications, the constant-voltage system prevailed. There was an even more spirited argument over the relative merits of the alternating-current and direct-current systems. The a.c. system won out principally because a.c. could more easily be transformed into higher voltages and could be transmitted more efficiently than low-voltage d.c. In the early power systems a.c. was reconverted to d.c. for consumption. Only recently have electrical engineers recognized the unique advantages of high-voltage d.c. for the bulk point-to-point transmission of power.

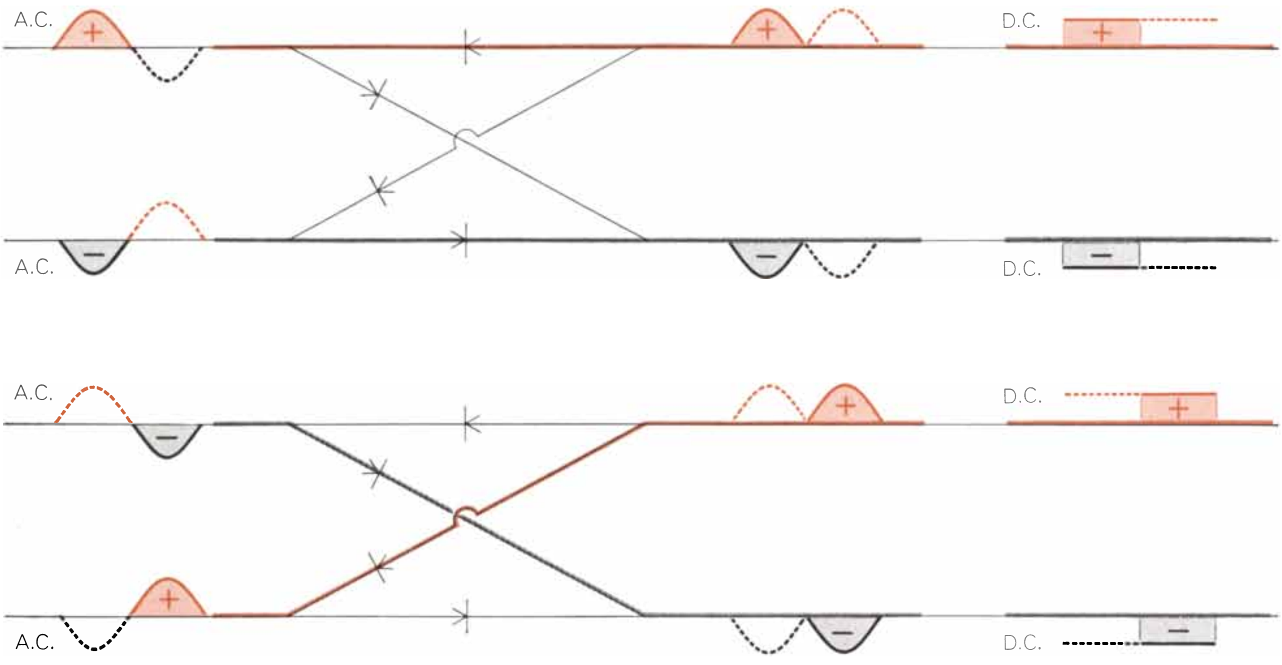
The peak voltage on a d.c. line, unlike that on an a.c. line, is equal to the rated voltage. Thus a d.c. line can carry more power than an a.c. line for a given maximum voltage between conductors. Moreover, a d.c. transmission line needs only two conductors, instead of the three required for a three-phase a.c. line. As a result a d.c. line costs about 25 per cent less than a three-phase a.c. line of equal capacity. This saving in line itself, however, must be weighed against the higher cost of terminal equipment. A d.c. system, therefore, usually offers a net saving only when power must be transmitted long distances over land or by cable under water.

One of the problems in transmitting a.c. is that the terminal ends of a transmission system must be kept in phase, or in step. An out-of-step condition between two terminals of a transmission line is somewhat analogous to the fracture of a shaft connecting two mechanical systems. To extend the analogy, the phase relationship between two ends of an a.c. line is comparable to the amount of twist in a shaft; both are measures of the amount of energy being transmitted. In d.c. transmission there are no phase relations to worry about. Like the fluid drive of an automobile, a d.c. system can transfer power continuously and efficiently over a wide range of load conditions.

In d.c. power transmission it is still necessary to generate a.c. in order to attain high voltages. A.c. can be converted to d.c. by means of rectifier tubes in which an electrically charged gas, usually mercury vapor, supports a



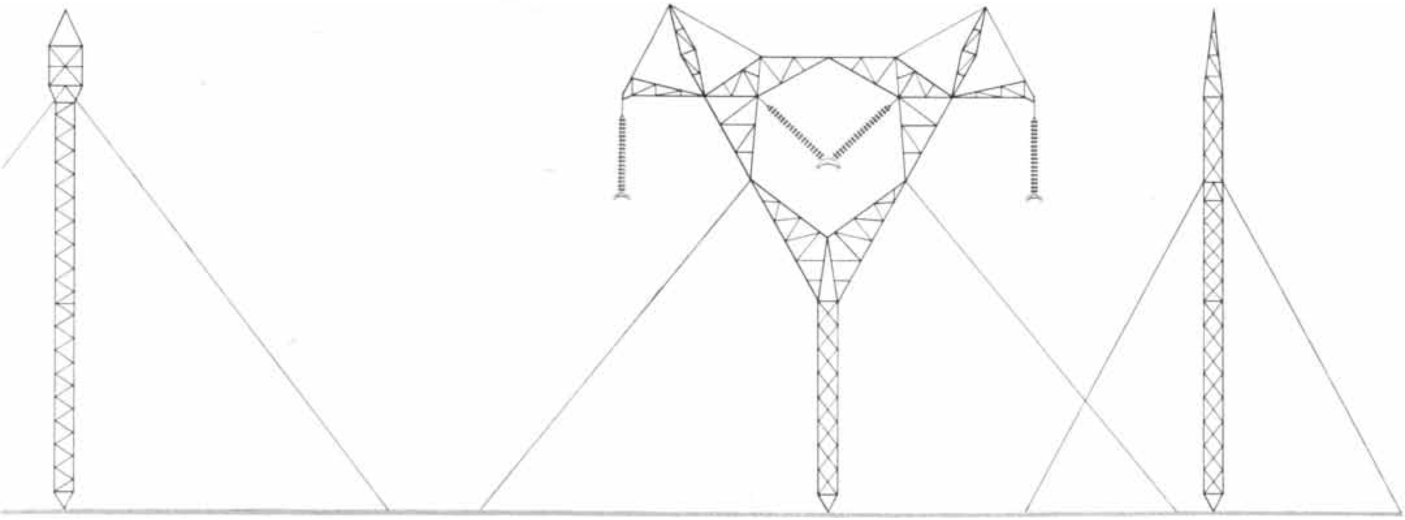
**TRANSMISSION TOWERS** have been redesigned in various ways to save weight and cost, at a negligible sacrifice in reliability. The three towers shown here in front and side views are designed to support a three-conductor, three-phase 500-kv. line. The conventional tower at left contains 6.6 tons of steel. The guyed "V" tower (*center*) requires 4.3 tons of steel. The guyed "Y," or "slingshot,"




**CONVERSION FROM A.C. TO D.C.** is accomplished by means of rectifier tubes, represented by the arrowhead symbol. The arrowhead indicates the direction of electron flow. The top diagram shows the electron flow when the voltage on the upper a.c. line is positive and that on the lower line is negative. The bottom diagram shows the electron flow in the second half of the a.c. cycle when the polarity is reversed. The d.c. line serves as a reservoir of electric charge, which removes the humps from the voltage curves.

flow of electrons in one direction. In a single-phase a.c. circuit electrons are supplied by one wire during half a cycle and by the other wire during the other half-cycle. By means of a suitable rectifying arrangement, known as a bridge rectifier, the electrons supplied alternately by the two wires are collected and fed to one wire (the negative wire) of the d.c. line. Similarly, the electrons returning in the second wire of the d.c. line (the positive wire) are fed alternately, through rectifiers, to the two wires of the a.c. circuit [*see illustration above*]. Rectification of three-phase a.c. is accomplished in a like manner by adding a third bridge rectifier. At the receiving terminal the d.c. can be reconstituted into a.c. by means of "inverters," which are identical with rectifiers.

An attractive feature of d.c. is that a two-conductor line can transmit power even with one conductor out of service, by using the earth as a return pathway. This is not practicable with a.c. To make sure that the current entering the earth



tower (*right*) can be built with only 3.6 tons of steel or with 1.5 to two tons of aluminum. Typical cost of a 500-kv. line ranges from $75,000 to $100,000 per mile, depending on the choice of towers. For a 200-mile line the lighter and cheaper structures offer a saving of approximately $5 million. For a 200-mile line of 345 kv. the saving with the lighter towers would be approximately $2.5 million.

does not corrode water mains or other subsurface structures, carefully designed ground electrodes must be provided near the d.c. terminals. Properly grounded, the return current will go deep into the earth's substrata.

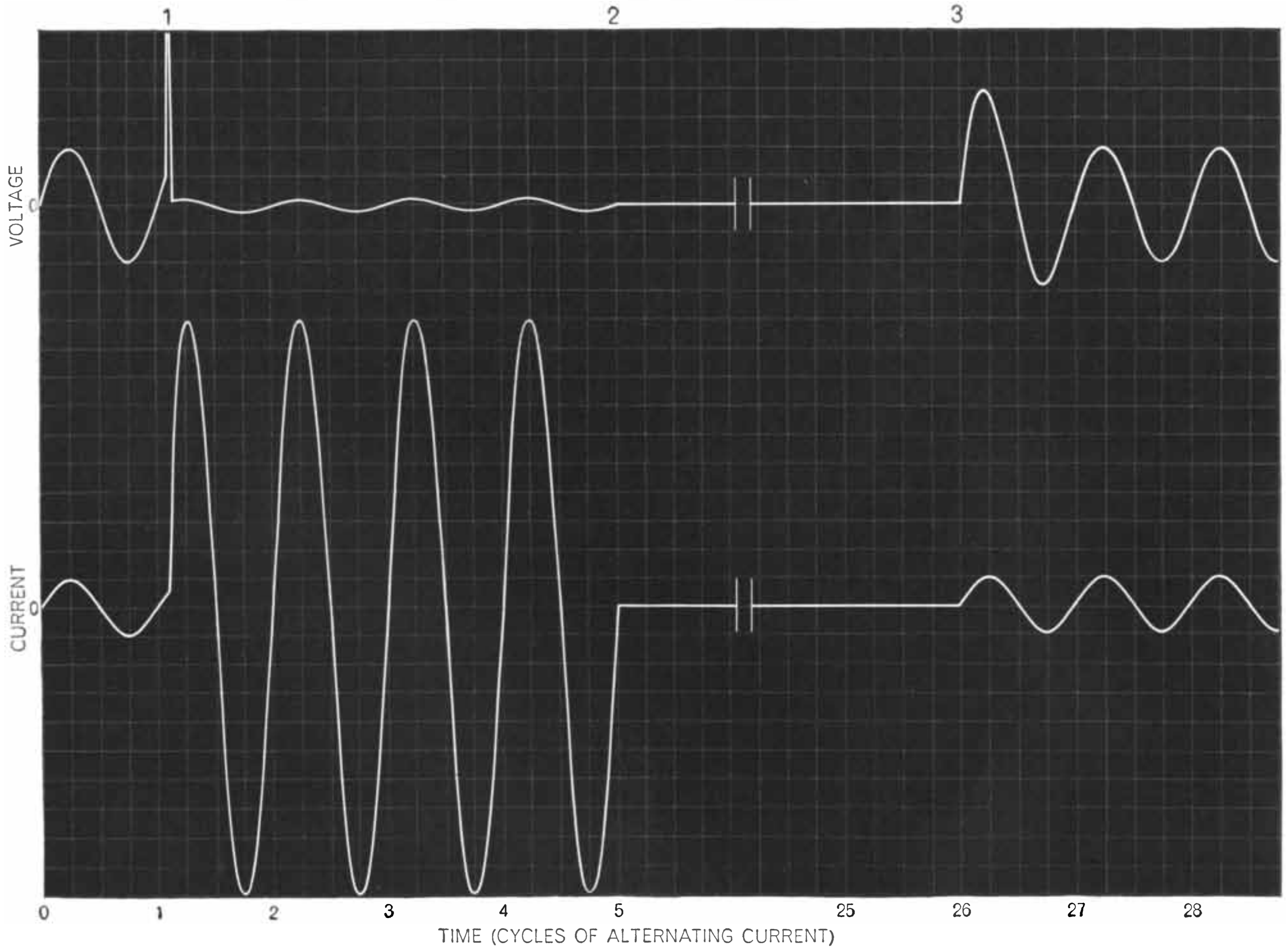
Experience in the U.S. with d.c. transmission has been quite limited. The first overhead d.c. transmission line employing mercury-arc rectifiers to transfer energy between two a.c. systems was a 15-kv. line built by General Electric in the mid-1930's. It ran a distance of 17 miles between Schenectady and Mechanicville, N.Y., and was capable of carrying 5,250 kilowatts.

In an era of rapidly evolving technology it is reasonable to ask if any mode of power generation or transmission might make the transmission line obsolete. Alternative suggestions fall into two broad categories: ways of generating electricity in small quantities at the point of consumption, thereby eliminating the need for transmission entirely, and transmission of electricity without wires.

The point-of-consumption generation of electricity comes up against both general and specific difficulties. In general the plant size and capital cost needed to provide for peak loads would seem to present a virtually insurmountable obstacle to any power-generating method now in sight. It has been estimated that if each home had its own power supply, the generating capacity needed to meet peak demands would be about 10 times the total capacity now installed in central generating plants. There are also important problems of achieving reliability and a closely regulated power supply in small units.

The fuel cell, which converts chemical energy directly to electric energy, is the only device with any promise at all for point-of-consumption power generation. It generates electricity with an efficiency of 70 to 90 per cent, compared with 40 to 45 per cent in the best central stations. Moreover, the fuel cell seems best adapted to units of small output. Thus there is a remote chance that by high efficiency it can offset the drawbacks mentioned. A specific problem of the fuel cell is that it generates low-voltage direct current, which is not easily converted to a.c. at the voltage now used in homes.

Wireless transmission of electric power has long been an intriguing idea but




**LIGHTNING AND SWITCHING SURGES** are responsible for most of the power failures experienced on high-voltage lines. The two curves above, idealized from oscilloscope traces, show how voltage and current may vary during surges of both types. At the outset, voltage and current are in normal relation, alternating 60 times a second. At *1* lightning strikes the line and the voltage rises in a few microseconds to many times the normal voltage. This causes an insulator to flash over and provides a direct electrical path between the conductor and the ground. For the next two to four cycles the current flow rises to 10 times normal values and the voltage falls correspondingly. The insulator fault is quickly detected by relays at the nearest switching station and at *2* power-driven circuit breakers have opened their contacts, isolating the line. After 20 cycles (*3*), which allows time for the fault to clear itself, the line is reactivated, producing a switching surge on the leading edge of the voltage wave. After a few cycles the line is normal again.

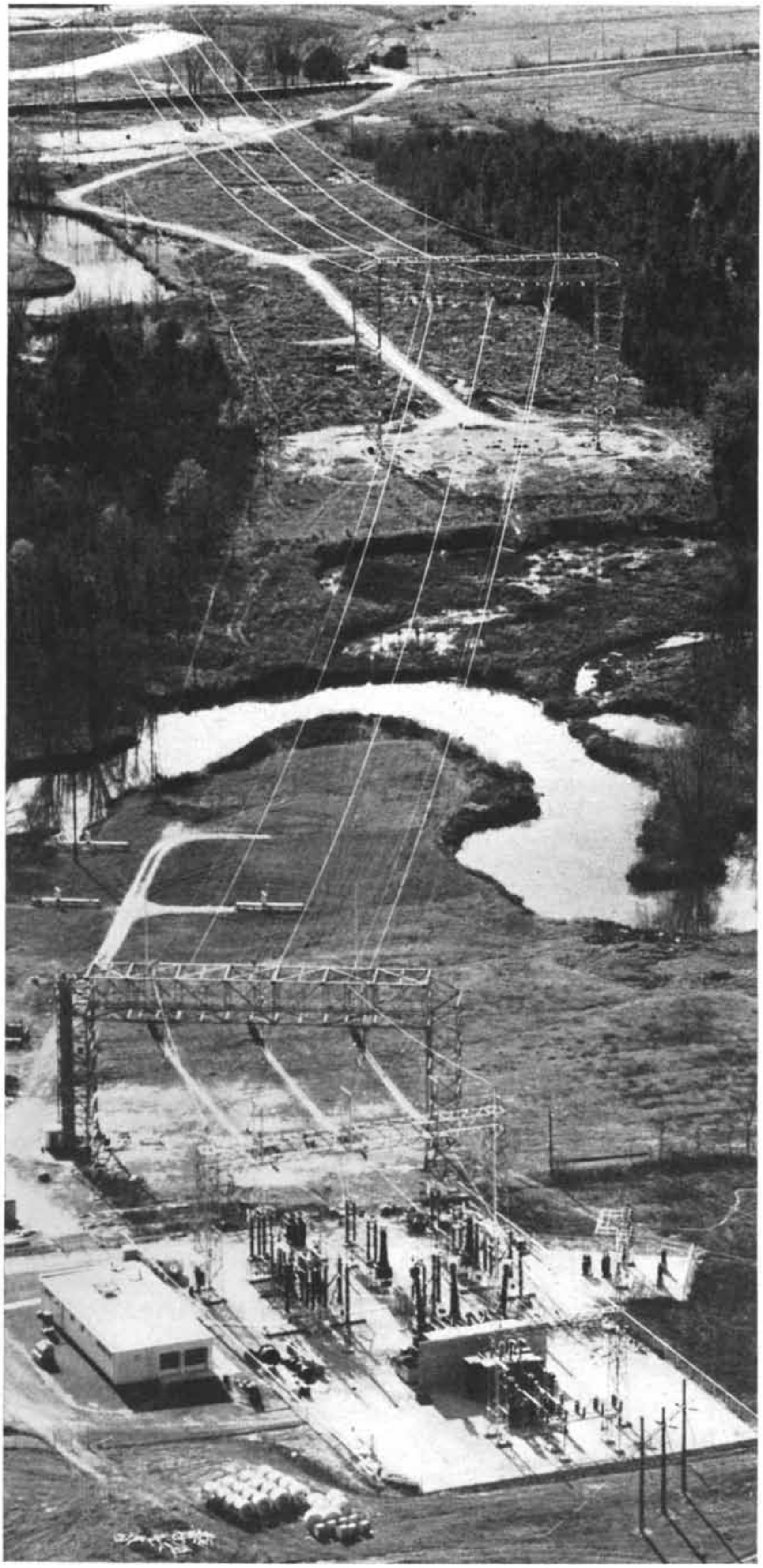
in the past all the proposed schemes have suffered from four problems: low efficiency in the conversion of electricity into a form suitable for wireless transmission, high absorption of the energy in air, losses due to the fact that it is difficult to focus the power in a beam sufficiently narrow to be conveniently received, and low efficiency in converting the transmitted energy into a useful form.

If one considers only the transmission losses, one finds that the absorption of energy in air depends on the distance the power is transmitted divided by the length of the electromagnetic wave. The width of the transmitted beam depends on wavelength and the size of the transmitting antenna.

For purposes of discussion let us consider a microwave beam with a wavelength of 30 centimeters, equivalent to a frequency of 1,000 megacycles. This wavelength combines relatively low absorption in air (2 per cent for each 10 miles of path length) with reasonable focusing properties. A dish antenna about 110 feet in diameter would produce a fairly narrow beam. At a distance of 10 miles a receiving antenna about 350 feet in diameter would be needed to capture about 95 per cent of the transmitted energy. Subtracting the loss for air absorption, only 93 per cent of the emitted energy would be received. Compared with conventional power lines, which have efficiencies of well over 99 per cent, an energy loss of 7 per cent would be unacceptable.

The newest device for the possible attainment of wireless power transmission is the laser, which produces a sharply defined beam of intense radiation in the visible or infrared region of the electromagnetic spectrum. Present lasers are extremely inefficient, but with further development it is conceivable that useful amounts of power can be transmitted by laser beam. The insurmountable problem here is that visible and infrared radiation are heavily absorbed by fog, rain or snow.

Finally, one must consider the effect of transmitting large amounts of power in unshielded beams. It has been estimated that a 1,000-megacycle radio beam with a power density of 10 watts per square foot would injure anyone who entered its path; a density of 25 kilowatts per square foot, approaching the level needed for bulk energy transfer, would be lethal on short exposure. All things considered, it is not likely that wires and high-voltage transmission lines will soon be obsolete.



**AERIAL VIEW OF PROJECT EHV, sponsored by General Electric, shows the transformer substation (*foreground*) and part of the 4.2-mile extra-high-voltage transmission line.**

# HYBRID NUCLEIC ACIDS

One strand of nucleic acid will combine with another wherever the subunits of the two strands are complementary. Artificial combinations clarify the flow of information in the living cell

by S. Spiegelman

One of the most useful techniques for studying how genes work depends on the remarkable fact that certain chainlike molecules found in the living cell can "recognize" other chains whose molecular composition is complementary to their own. If one molecule is composed of subunits that can be symbolized by the sequence CATCATCAT..., it will recognize the complementary sequence GTAGTAGTA... in a second molecule. As we shall see, these particular letters represent the chemical subunits that transmit the genetic information. When two such complementary chains are brought together under suitable conditions, they will "hybridize," or combine, to form a double-strand molecule in which the subunits C and G and A and T are linked by the weak chemical bond known as the hydrogen bond. This article will describe how hybridization has been exploited to study the cell's mechanism for manufacturing proteins.

A typical living cell synthesizes hundreds of different proteins, most of which serve as the enzymes, or biological catalysts, that mediate the myriad chemical reactions involved in growth and reproduction. Proteins are large chainlike molecules made out of some 20 different kinds of amino acids. According to current theory the sequence of amino acid units in a protein is specified by a single gene, and the genes are strung together in the chainlike molecules of deoxyribonucleic acid (DNA). The subunits of DNA that constitute the genetic code are four "bases": adenine (A), thymine (T), guanine (G) and cytosine (C). Normally DNA consists of two complementary chains linked by hydrogen bonds to form a double helix. Wherever A occurs in one chain, T occurs in the other; similarly, G pairs with C. It is evident that each chain contains all the information needed to specify the complementary chain.

The flow of information in a cell begins with the base-pairing found in the double helix of DNA. Three principal modes of information transfer are distinguished by the end purposes they serve [*see illustrations on opposite page*]. The first is a duplication, which provides exact copies of the DNA molecule for transmission from one generation of cells to the next. The copying process utilizes the same "language" and the same "alphabet" that are present in the original material.

The second mode of transfer is a "transcription," which uses the same language but a slightly different alphabet. In this step DNA is transcribed into ribonucleic acid (RNA), a chainlike molecule that, like DNA, has four code units. Three are the same as those found in DNA: A, G and C. The fourth is uracil (U), which takes the place of thymine (T). One particular variety of RNA carries the actual program for protein synthesis. Although this variety of RNA is frequently called "messenger RNA," I prefer to speak of "translatable RNA" or "RNA messages." A "messenger" cannot be translated, but a message can.

The third mode of information transfer converts the information from the four-element language of translatable RNA to the 20-element language of the proteins. This step is properly regarded as a translation. Since every translation calls for a dictionary, it is not surprising that the cell uses one also. The cellular dictionary is made up of a collection of comparatively small RNA molecules known as transfer RNA (or soluble RNA), which have the task of delivering specific amino acids to the site of protein synthesis. Each amino acid is attached to a transfer-RNA molecule by a specific activating enzyme.

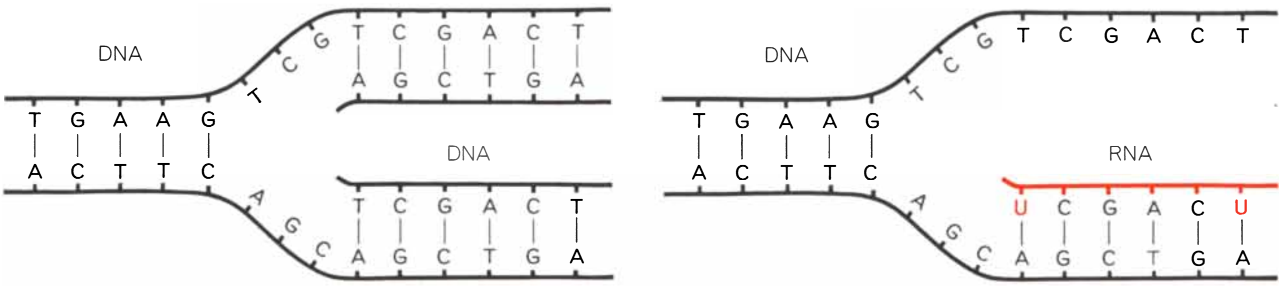
The actual synthesis of protein molecules is accomplished with the help of ribosomes, which evidently serve to hold the translatable RNA "tape" in position while the message is being "read." Ribosomes are small spherical particles composed of protein and two kinds of RNA. One kind is about a million times heavier than a hydrogen atom; the other is about 600,000 times heavier. They are respectively called 23S RNA and 16S RNA, designations that refer to how fast they settle out of solution when they are spun at high speed in an ultracentrifuge.

Thus we see that cellular RNA is divided into two major categories: translatable and nontranslatable. The translatable variety (messenger RNA) constitutes only about 5 per cent of all the RNA in a cell; it is usually unstable and must be continuously resynthesized. The nontranslatable varieties of RNA (transfer RNA and the two kinds of ribosomal RNA) make up about 95 per cent of the RNA found in a cell and are extremely stable.

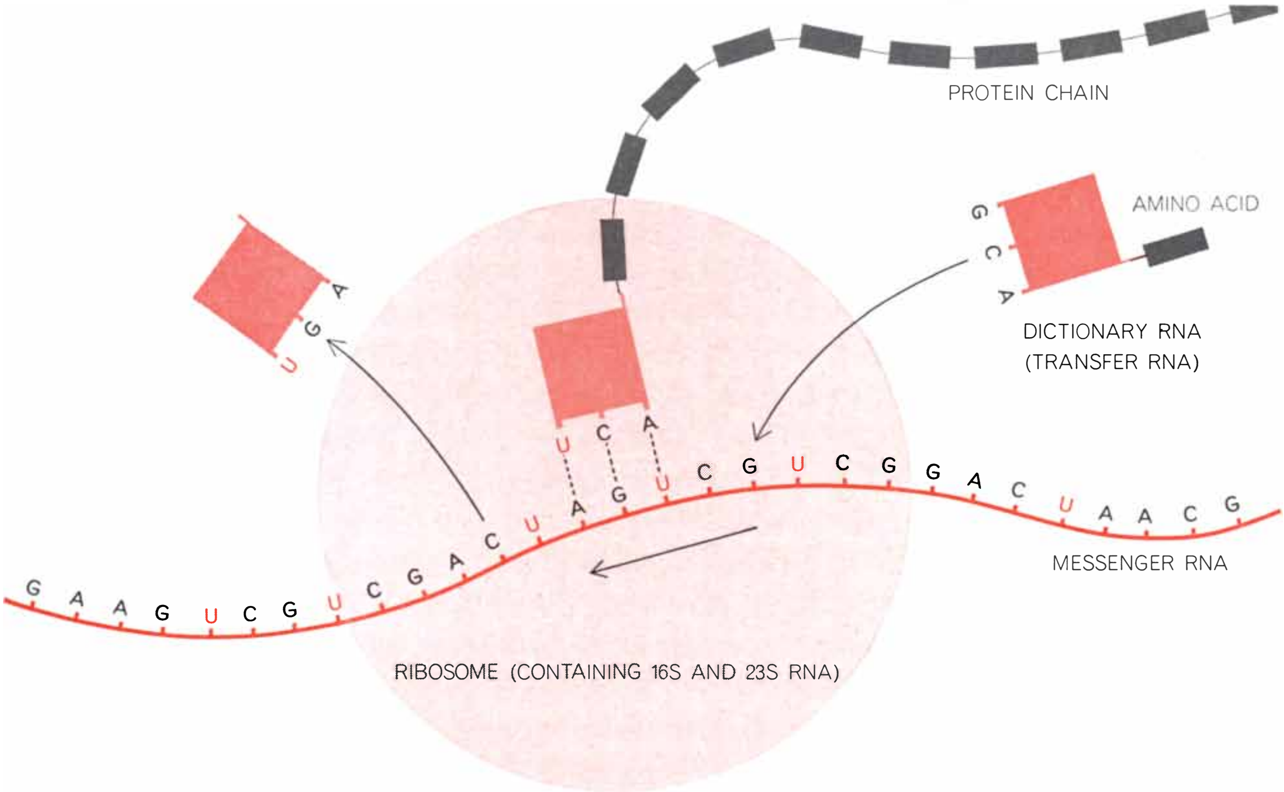
This picture of the genetic mechanism has arisen from the contributions of a large number of investigators using a wide variety of methods of analyzing gene function. I shall focus attention on some of the things that have been learned about the translatable and nontranslatable forms of RNA by exploiting the ability of RNA to hybridize with DNA of complementary composition. In effect this technique enables one to return an RNA molecule to the site of its synthesis on a particular stretch of DNA.

Early in 1958 my colleagues Masayasu Nomura and Benjamin D. Hall and I at the University of Illinois undertook to re-examine a remarkable experiment described in 1955 by Elliot Volkin and Lazarus Astrachan of the Oak Ridge National Laboratory. These workers had used radioactive isotopes to identify and study the RNA produced when the colon bacillus is infected with the bacterial virus designated T2. Infection occurs when T2 injects into the cell of the bacterium a double helix of DNA bearing all the information needed for the synthesis of new virus particles. Volkin and Astrachan had concluded that the RNA synthesized in the infected cells mimicked the composition of the T2 DNA.

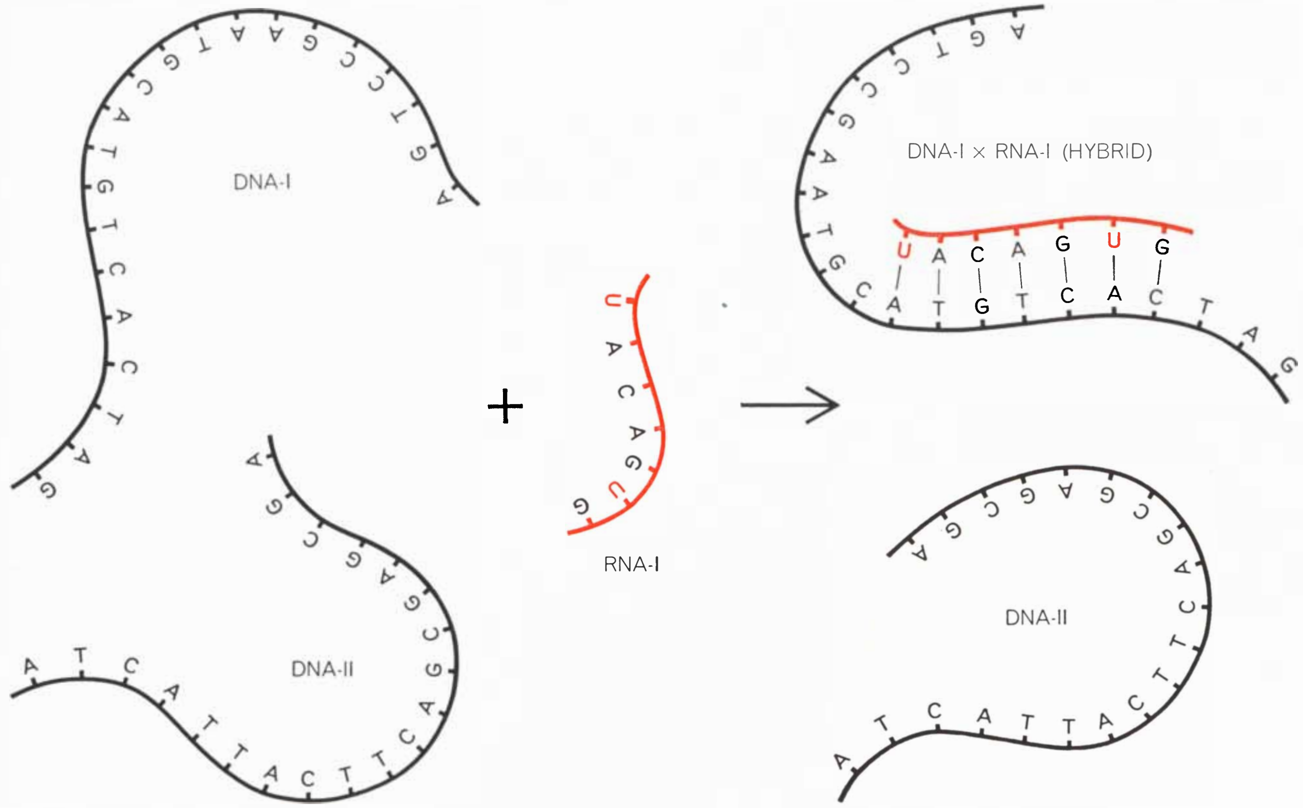
At the time neither the experimenters nor anyone else thought that the RNA might represent a genetic message formed on a DNA template. It was suggested, rather, that this new kind of




**FLOW OF GENETIC INFORMATION** involves duplication (*left*), transcription (*right*) and translation (*below*). Genetic information resides in giant chainlike molecules of deoxyribonucleic acid (DNA), in which the code "letters" are four bases: adenine (A), thymine (T), guanine (G) and cytosine (C). DNA normally consists of two complementary strands in which A pairs with T and G with C. During duplication, by an unknown mechanism, a new complementary strand is synthesized on each of the parent strands. In transcription only one strand of the DNA serves as a template and the new molecule formed is ribonucleic acid (RNA). In RNA the base uracil (U) takes the place of thymine as the partner of adenine. RNA molecules can be translatable or nontranslatable.

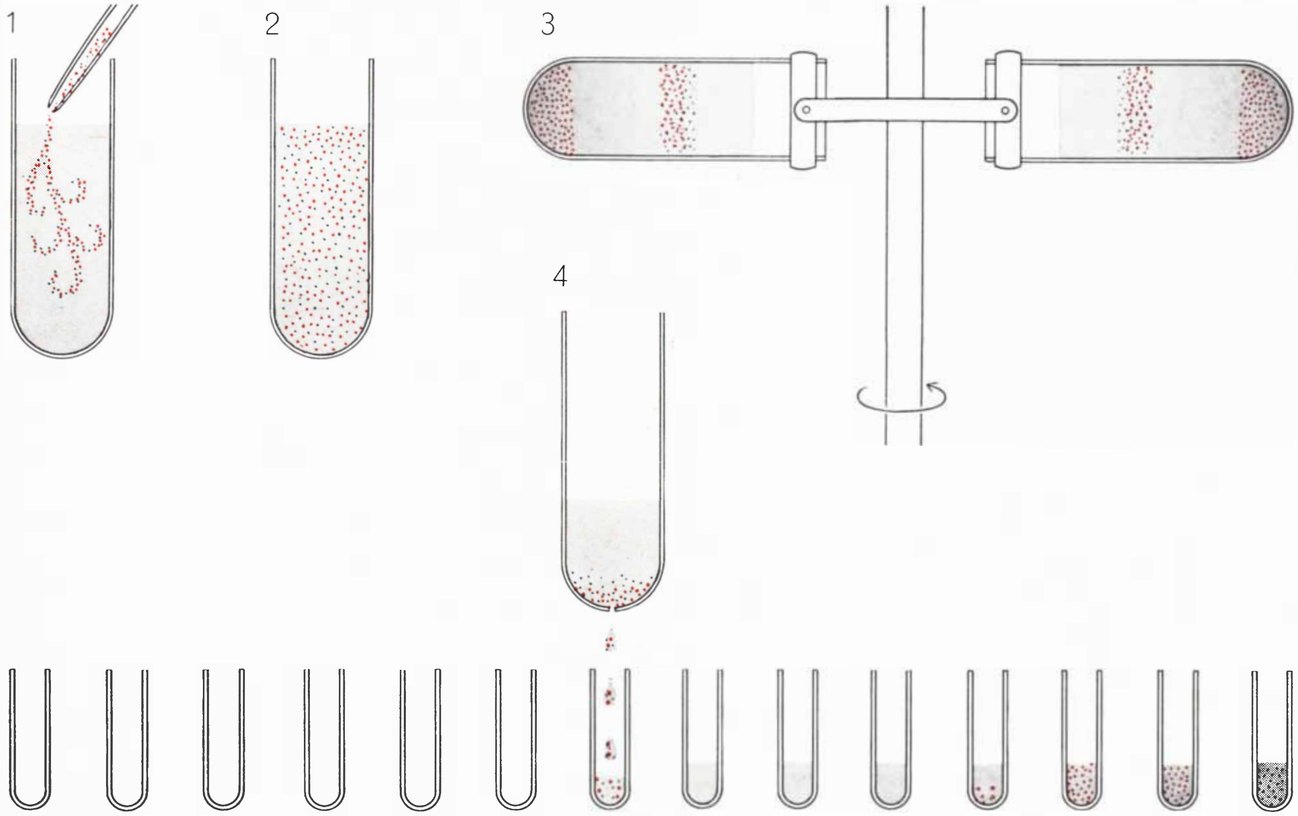



**TRANSLATION PROCESS** converts genetic information from the four-letter "language" of nucleic acids (DNA and RNA) into the 20-letter language of proteins. The letters of the protein language are the 20 amino acids that link together to form protein chains. If the DNA code is transcribed into translatable, or messenger, RNA, the RNA message becomes associated with one or more particles called ribosomes, which mediate the actual synthesis of protein. Ribosomes are made up of protein and two kinds of nontranslatable RNA, identified as 16S and 23S. Still another form of RNA called dictionary, or transfer, RNA delivers amino acids to the site of protein synthesis. It appears that a group of three bases in messenger RNA identifies each particular amino acid. According to one hypothesis the code group is "recognized" by a complementary set of bases in dictionary RNA. Evidently the ribosome serves as a "jig" for positioning amino acid subunits on the growing protein chain as the messenger RNA "tape" travels by.




**HYBRIDIZATION** can occur when the base sequence in a strand of RNA matches up with that in single-strand ("denatured") DNA.

Here RNA-I is "challenged" with genetically related DNA-I and unrelated DNA-II. Only the genetically related strands hybridize.




**DENSITY-GRADIENT TECHNIQUE** reveals if hybridization has taken place between RNA and DNA. The sample in question is added to a solution of cesium chloride (*1 and 2*). After centrifugation (*3*) the salt solution attains a smooth gradation in density. RNA (*color*), DNA (*black*) and RNA-DNA hybrids form layers according to their density. Fractions (*4*) can then be analyzed.

RNA was a precursor of the DNA needed to complete new virus particles. No doubt the experiment was misinterpreted and then neglected because it came so early in the modern history of DNA investigation. The helical model of DNA had been proposed only two years before by James D. Watson and F. H. C. Crick. Moreover, the experiment involved rather complex calculations and assumptions to support the view that the infected cells contained a distinctive new kind of RNA. It is clear in retrospect that this was the first experiment suggesting the existence of RNA copies of DNA.

It seemed to us that the Volkin-Astrachan observations were potentially so important that the design of an unequivocal experiment was well worth the effort. We set out, therefore, to see if bacterial cells infected with the T2 virus contained an RNA that could be specifically related to the T2 DNA. In our first experiments we sought evidence for this new type of RNA by physically isolating it from other RNA's. Two different procedures were successful. One (electrophoresis) measures the rate at which molecules migrate in an electric field; the other (sucrose-gradient centrifugation) measures their rate of migration when they are spun in a solution of smoothly varying density. Both of these methods showed that the RNA synthesized after virus infection was indeed a physically separable entity, differing in mobility and size from the bulk cellular RNA.

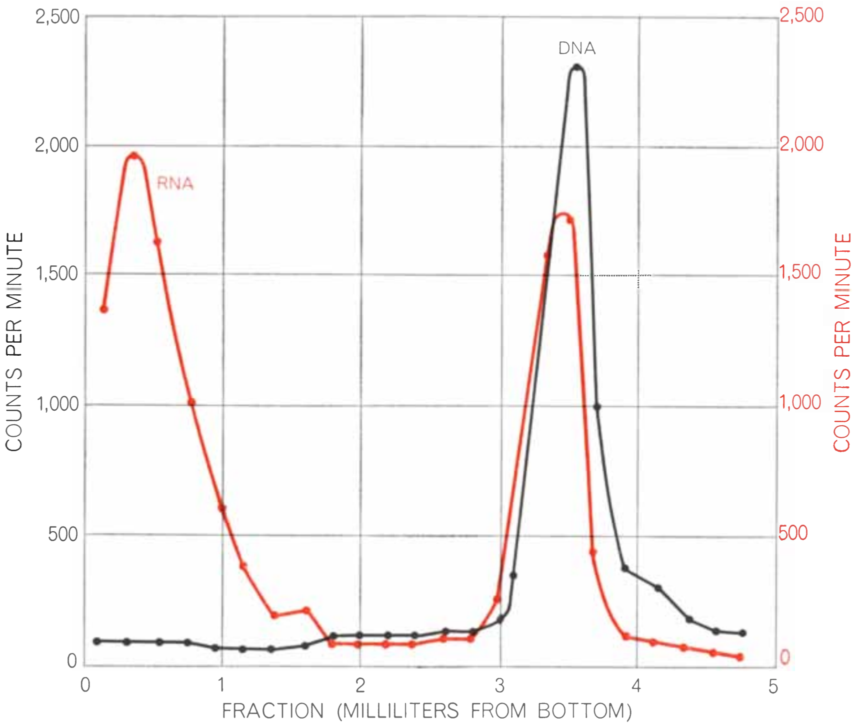
We found further that the ratio of the quantities of the bases (A, U, G and C) in the T2-specific RNA mimicked the ratio of the quantities of their counterparts (A, T, G and C) in the DNA of the virus. This suggested the possibility that the similarity might extend to a detailed correspondence of base sequence. A direct attack on this question by the complete determination of the sequences of bases was, and still is, too difficult.

Just at the right time, however, two groups of workers independently published experiments showing that if double-strand DNA was separated into single strands by heat (a process called denaturing), the two strands would re-form into a double-strand structure if the mixture was reheated and slowly cooled. This work was done by Julius Marmur and Dorothy Lane of Brandeis University and by Paul Doty and his colleagues at Harvard University. These investigators showed further that reconstitution of the double-strand molecule occurs only between strands that originate from the same or closely related organisms. This suggested that double-strand hybrid structures could be formed from mixtures of single-strand DNA and RNA, and that the appearance of such hybrids could be accepted as evidence for a perfect, or near perfect, complementarity of their base sequences. It had already been shown by Alexander Rich of the Massachusetts Institute of Technology and by Doty that synthetic RNA molecules containing adenine as the only base would form hybrid structures with synthetic DNA molecules containing thymine as the only base.

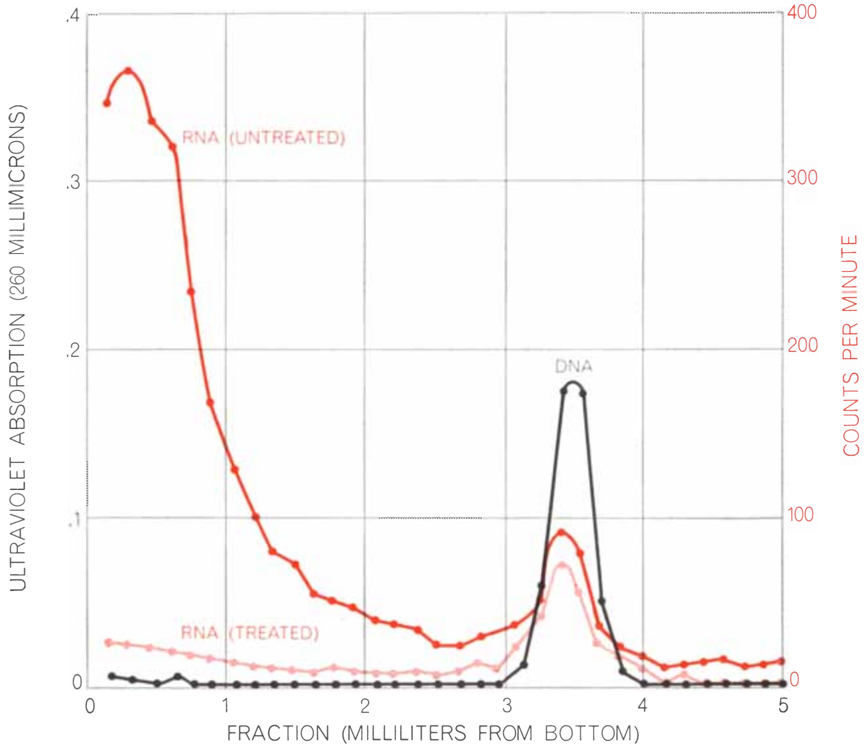
With this work as background, we undertook to determine if T2 RNA would hybridize with T2 DNA. It was first necessary to solve certain technical problems. We had already devised methods for obtaining T2 RNA in a reasonable state of purity. The question was how to design the experiment so that if a hybrid structure formed, we could be certain of detecting it and identifying it as such.

All previous work on the reconstitution of two-strand DNA had involved sizable amounts of material that could form optically observable layers when it was spun in an ultracentrifuge. In our experiments the amount of hybrid material formed would probably be so small that it would escape detection by this method.

The detection method finally evolved combined several techniques. One depended on the fact that RNA has a slightly higher density than DNA; consequently RNA-DNA hybrids should have an intermediate density. Molecules of different densities can be readily separated by the density-gradient method developed by M. S. Meselson, Franklin W. Stahl and Jerome R. Vinograd at the California Institute of Technology. In this method the sample to be analyzed is added to a solution of a heavy salt, cesium chloride, and the mixture is centrifuged for about three days at more than 30,000 revolutions per minute. Under centrifugation the salt solution attains a smooth gradation in density, being most dense at the bottom of the sample tube and least dense at the top. The components of the sample migrate to layers at which their density




**HYBRIDIZATION EXPERIMENT** shows that RNA produced after a cell has been infected with the T2 virus is genetically related to the DNA of the virus. The RNA is labeled with radioactive phosphorus and the T2 DNA with radioactive hydrogen (tritium). The sample is subjected to density-gradient centrifugation (*see bottom illustration on opposite page*) and the radioactivity of the various fractions is determined. Although some of the RNA is driven to the bottom of the sample tube, much of it has hybridized with the lighter DNA fraction and thus appears between three and four milliliters above the bottom.




**HYBRIDIZATION OF BACTERIAL RNA AND DNA is demonstrated for the bacterium *Pseudomonas aeruginosa*. Untreated RNA chiefly represents messenger RNA obtained by a special "step-down" procedure described in the text. In this experiment the presence of DNA in centrifuged fractions is determined by ultraviolet absorption. The coincident peaks in the two RNA curves represent RNA bound in RNA-DNA hybrids. "Treated RNA" refers to a portion of the sample that was treated before centrifugation with ribonuclease, an enzyme that normally destroys RNA. Although the enzyme has little or no effect on the hybridized RNA, it largely eliminates unhybridized RNA from the centrifuged sample.**

exactly matches that of the salt solution. In place of the analytical ultracentrifuge we employed a centrifuge with swinging-bucket rotors, which permits actual isolation and analysis of various fractions. For this purpose the plastic sample tube is punctured at the bottom and the fractionated sample is withdrawn drop by drop for analysis [*see bottom illustration on page 50*].

To ensure a sensitive and unambiguous detection of the hybrid we labeled RNA with one radioactive isotope and DNA with another. The T2 RNA was labeled with radioactive phosphorus (P-32) and the T2 DNA with radioactive hydrogen (H-3). The beta particles emitted by P-32 have a characteristic energy different from those emitted by H-3; thus the isotopes can be assayed in each other's presence. The existence of hybrids in the centrifuged fractions would be signaled by the appearance of a layer containing the P-32 label of the RNA and the H-3 label of the DNA. Subsequently we observed that the layer of the hybrid fraction coincided closely with the layer of the unhybridized DNA. We could therefore dispense with the radioactive label on DNA and establish its presence simply by its strong absorption of ultraviolet radiation at a wavelength of 260 millimicrons.

With these techniques we soon found that T2 RNA indeed hybridizes with T2 DNA. Furthermore, analysis of the hybrid confirmed that it was similar in overall base composition to T2 DNA. It was then necessary to show that hybrid formation occurs only between RNA and DNA that are genetically related. We exposed T2 RNA to a variety of unrelated DNA's from both bacteria and viruses. No hybrid formation could be detected, even with unrelated DNA's having an overall base composition indistinguishable from that of T2 DNA.

From these experiments one can conclude that T2 RNA has a base sequence complementary to that of at least one of the two strands in T2 DNA. Thus the similarity in base composition first noted by Volkin and Astrachan is a reflection of a more profound relatedness.

These experiments also tell us something about the events that take place when a virus invades a bacterial cell. If precautions are taken to ensure that all the cells in a given sample are infected with the DNA virus, one finds that none of the RNA synthesized later can hybridize with the host DNA. This suggests that one of the first steps taken by a virulent virus in establishing infection is turning off production of the host's messenger RNA. Evidently RNA transcribed from the viral DNA provides the genetic messages needed for the formation of various proteins required to manufacture complete virus particles. Subsequent studies at the University of Cambridge by Sydney Brenner, François Jacob and Meselson have shown that the T2 messenger RNA is able to make use of ribosomes preexisting in the host cell for the synthesis of proteins.

We wondered next whether the transcription of the DNA code into RNA messages was a universal mechanism or whether it might be restricted to the simple mode of replication followed by viruses. The study of the flow of genetic information in normal cells is a problem of considerable difficulty. As noted above, about 95 per cent of the RNA present at any given moment is of the nontranslatable variety, consisting of ribosomal RNA and transfer, or dictionary, RNA. It is precisely because the translatable RNA molecules are so few—only about 5 per cent of the total amount of RNA—that they were overlooked for so long in normal cells. The detection of the RNA messages of T2 was made easy because the synthesis of ribosomal and transfer RNA is turned off in virus-infected cells.

We decided to look for a situation in normal cells that would imitate the advantages provided by infected ones. It had been known that the total RNA content of cells is positively correlated with rate of growth, and since most of the RNA is ribosomal RNA, a high growth rate implies a high content of ribosomes. What happens if cells are subjected to a "step-down" transfer, that is, a transfer from a rich nutrient medium to a poor one? The growth rate declines, usually by about half. More important, for a generation after they have been placed in a poorer medium the cells contain more ribosomes than they can usefully employ. We reasoned that in this period the synthesis of ribosomal RNA might stop. Since protein production continues at a low rate, however, some synthesis of RNA messages, which must be continuously replaced, should persist.

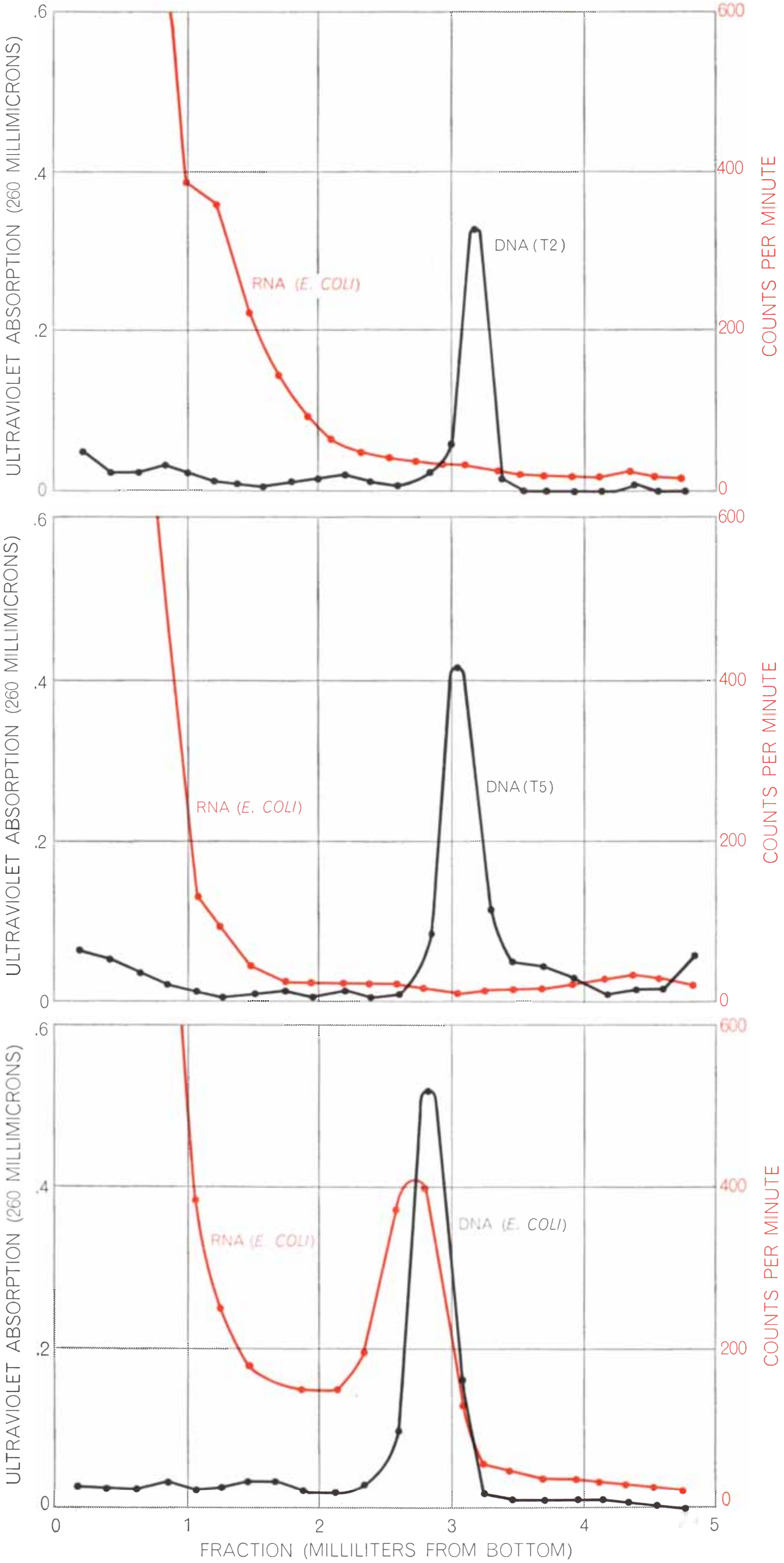
My colleague Masaki Hayashi undertook experiments to determine if this was the case. If it was, any RNA synthesized after step-down transition would be different from the ribosomal RNA. Hayashi selected three species of bacteria with DNA's of widely different base composition. In all three species the RNA synthesized after step-down transition possessed all the features that had characterized the RNA produced in virus-infected cells. These included instability, a base composition similar to that of the organisms' DNA's and a range of molecular sizes different from that of the ribosomal RNA.

Hybridization tests were carried out between the message-RNA fraction and genetically related DNA as well as with genetically unrelated DNA. The results were clear-cut. Hybrid structures were formed only when the mixture contained RNA and DNA of the same genetic origin. An experiment in hybrid formation that involved RNA and DNA from the bacterium *Pseudomonas aeruginosa* is summarized in the illustration on the opposite page.

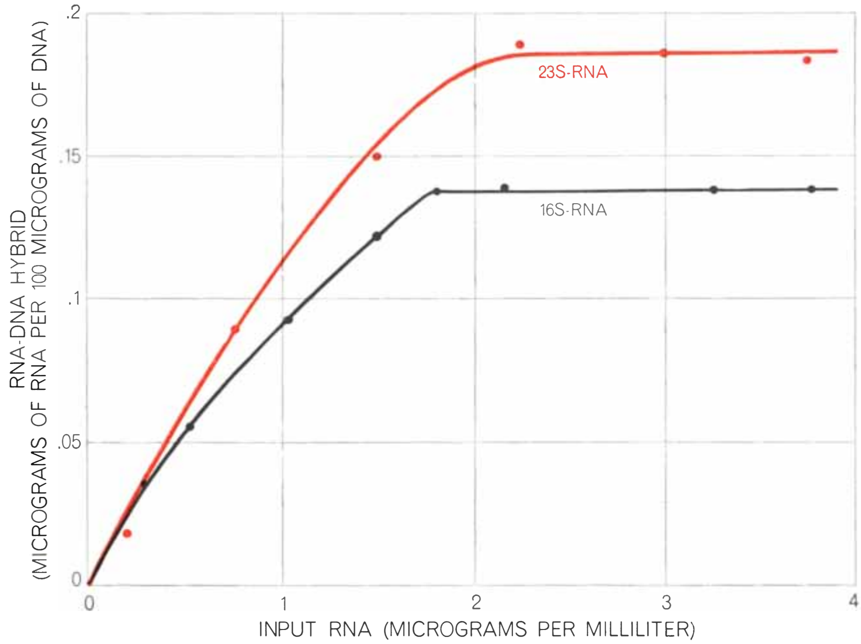
This particular experiment illustrates an interesting and useful property of RNA-DNA hybrids. A portion of each sample of hybrid material was treated with the enzyme ribonuclease, which normally destroys RNA. One of the curves shows the amount of RNA in each fraction that was resistant to the enzyme. It can be seen that the RNA bound in the hybrid is quite resistant, whereas the free RNA is almost completely destroyed. This phenomenon turned out to be very useful for distinguishing between free and hybridized RNA. We can conclude from Hayashi's studies, and from those of others, that the flow of information from DNA to translatable RNA occurs normally in bacteria and is probably a universal mechanism in protein synthesis.

By the time these investigations were completed we were convinced that the RNA-DNA hybridization technique could be developed into an extremely powerful and versatile tool. Accordingly we decided to put it to a severe test. The problem we wanted to solve was this: Where do the nontranslatable molecules of RNA—ribosomal RNA and transfer RNA—come from?

Let us consider first the ribosomal variety. Two principal alternatives can be suggested for its mode of origin. Either it is formed on a DNA template or it is not. If it is formed on DNA, it should be complementary to some seg-




**HYBRIDIZATION OF RIBOSOMAL RNA provides evidence that, like messenger RNA, it too is formed on a DNA template. In this experiment ribosomal RNA of the 23S variety was obtained from the colon bacillus (*Escherichia coli*). The top and middle curves show that no hybridization occurs when the RNA is challenged with single-strand DNA from the T2 and T5 viruses. When challenged with DNA from *E. coli*, however, hybridization is seen.**




**SATURATION CURVES indicate what fraction of the DNA molecule is set aside for producing the two forms of ribosomal RNA designated as 16S and 23S. The RNA and DNA samples were obtained from *Bacillus megaterium*. The results show that about .14 per cent of the DNA molecule is complementary to 16S and about .18 per cent to the 23S form.**

ment of DNA and hence subject to hybridization.

It has been known for some time that the base composition of ribosomal RNA is not correlated with that of DNA found in the same cell. This, however, tells us nothing about the origin of the RNA; the DNA segment needed to serve as a template for ribosomal RNA might be so small as to constitute a nonrepresentative sample of the DNA's overall base composition.

Some three years ago one of my students, Saul A. Yankofsky, undertook the job of determining if hybridization could shed any light on this problem. The major complication was that a ribosomal RNA molecule appeared to be only about a ten-thousandth as long as the entire DNA molecule in a typical bacterial cell. We were faced, therefore, with the task of designing experiments that would detect hybridizations involving only a minute segment of DNA.

Theoretically the required sensitivity can be attained simply by labeling RNA so that it has a suitably high level of radioactivity. If no radioactivity was found in association with DNA, one could conclude that no hybrid had been formed. Experiments of this sort would require RNA labeled at a level of about one million counts per minute per microgram. The trouble with such high levels of radioactivity is that irrelevant "noise" can spoil the experiment. It is easy to detect 100 counts per minute above the background level of radiation. Thus if as little as .0001 microgram of unhybridized RNA accidentally got into the DNA fraction, it would be detected and give a false reading. Such accidental contamination could occur in a number of ways. For example, the ribosomal RNA preparation might contain traces of radioactive translatable RNA that would hybridize with DNA. Small amounts of ribosomal RNA might be mechanically trapped by strands of DNA. Or there might be partial hybridization resulting from accidental coincidences of base complementarity over small regions.

By a variety of biological and technical stratagems it was possible to design a satisfactory experiment. Organisms were chosen with a DNA base composition far removed from that of ribosomal RNA, thereby making it possible to show that hybridized material actually contained ribosomal RNA. Contamination of the radioactive ribosomal RNA preparation by radioactive translatable RNA was eliminated by a simple trick. After the RNA in the cells was labeled with a suitable isotope the cells were transferred to a nonradioactive medium for a period long enough for the labeled RNA messages to disappear. Ribosomal RNA, being stable, retains its radioactive label. Finally, to avoid false readings from RNA that was either mechanically trapped or accidentally paired over short regions, all suspected hybrids were treated with ribonuclease. The RNA in a genuine hybrid is resistant to this treatment.

It was noted earlier in this article that ribosomes contain two types of RNA, designated 23S RNA and 16S RNA. The outcome of a series of hybridizations between 23S RNA obtained from the colon bacillus and three different DNA preparations is presented in the illustration on the preceding page. A ribonuclease-resistant structure appears in the DNA-density region only when the DNA and the ribosomal RNA are from the same organism. These results clearly imply that ribosomal RNA is produced on a DNA template.

An extension of these studies gave us an answer to the following question: How much of the DNA molecule is set aside for turning out ribosomal RNA? To get the answer we simply add increasing amounts of ribosomal RNA to a fixed amount of DNA and determine the ratio of RNA to DNA in the hybrid at saturation. The illustration at the left shows the outcome of this experiment with the ribosomal RNA of *Bacillus megaterium*. The results indicate that approximately .18 per cent of the total DNA molecule is complementary to 23S RNA and .14 per cent to 16S RNA.

The difference in these two saturation values suggests that 23S RNA and 16S RNA are distinctively different molecules, but the evidence is not unequivocal. Although different in size, the two ribosomal RNA molecules have essentially the same base composition. There is still no direct way of telling whether they have the same or different base sequences. The similarity in base composition and the fact that the 23S RNA has about twice the weight of the 16S RNA had led, however, to the concept that the 23S-RNA molecule is a union of two 16S-RNA molecules.

To probe the matter further we designed an experiment to find out if the two kinds of ribosomal RNA compete for the same sites when they are hybridized with DNA. Hybridization mixtures were prepared that contained fixed amounts of DNA and saturating concentrations of 23S RNA labeled with P-32. To these we added increasing amounts of 16S RNA labeled with H-3, after which we determined the relative amounts of P-32 and H-3 in the hybrid structures. If the two kinds of RNA have an identical sequence, the entry of the H-3-labeled 16S RNA into the hybrid should displace an equivalent amount of P-32-labeled 23S RNA. If the sequences are different, the 16S RNA should hybridize as though the 23S material were not present. The experiment decisively supported the second alternative [*see illustration on this page*].

Following these experiments, there seemed little doubt that the third variety of RNA, transfer RNA, would also be found to originate on segments of DNA. The small size of transfer-RNA molecules made hybridization experiments even more difficult than the earlier ones. Nevertheless, the experiments were successfully carried out by Dario Giacomoni in our laboratory and by Howard M. Goodman in Rich's laboratory at M.I.T. Both workers obtained virtually identical results. They demonstrated by specific hybridization that the DNA of a cell contains sequences complementary to its molecules of transfer RNA. The amount of DNA set aside for the cell's genetic dictionary was found by both groups to be about .025 per cent, or less than a tenth of the combined space allotted to the two types of ribosomal RNA.

These experiments also ruled out an interesting possibility. The molecules of transfer RNA contain only about 80 bases (compared with about 2,000 for 16S RNA) and it was conceivable that the sequence of bases in transfer RNA's might be the same, or much the same, in the cells of different organisms. This possibility seemed more likely when Günter von Ehrenstein of Johns Hopkins University and Fritz A. Lipmann of the Rockefeller Institute showed, in a joint experiment, that transfer RNA's from the colon bacillus can serve as a dictionary in translating the RNA message for the synthesis of the protein hemoglobin from materials present in the red blood cells of the rabbit.

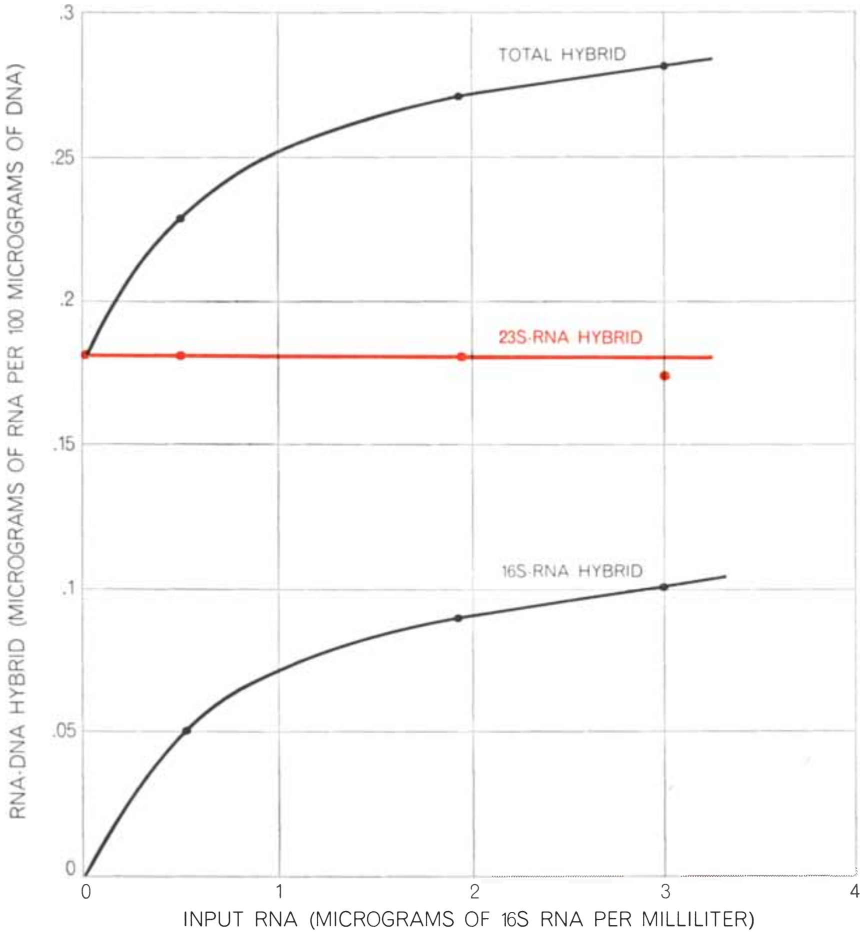
Giacomoni was able to show, however, that the base sequence in transfer-RNA molecules differs from organism to organism. In one such experiment a mixture of transfer-RNA molecules from two different organisms was challenged with DNA molecules obtained from one of them. For identification the genetically related transfer RNA was labeled with P-32 and the unrelated variety with H-3. Only the related RNA formed a hybrid; the genetically unrelated RNA did not [*see chart at left in illustration on next page*].

Instead of using one kind of DNA and two kinds of transfer RNA, one can reverse matters and also demonstrate specificity. For this purpose it is helpful to choose DNA preparations that migrate to different layers when they are subjected to density-gradient centrifugation. In such a mixture a hybrid will form only with radioactively labeled transfer RNA that is genetically related to one of the DNA's. In the experiment performed in our laboratory the DNA was obtained from two bacteria, *Pseudomonas aeruginosa* and *Bacillus megaterium*, and the transfer RNA was obtained only from the latter [*see chart at right in illustration on next page*].

These experiments reveal an interesting feature of the biological universe. It is assumed that only three of the 80-odd bases in a transfer-RNA molecule provide the means for "reading" the three-base code "words" in the RNA message. Although evidence is lacking on this point, it is possible that a temporary association between three bases in transfer RNA and three bases in the RNA message guarantees that the correct amino acid is deposited where it belongs in a growing protein chain [*see lower illustration on page 49*].

If this picture is accepted, what is the role of the other 70-odd bases in transfer RNA? The function of the noncoding portion is unknown, but its presence provides an opportunity for biological individuality, from species to species, without disturbing the dictionary function of the molecule. The fact that the base sequences are different in the transfer RNA's of different organisms shows that this opportunity has not been neglected in the course of biological evolution.

We have now seen that all forms of RNA can be traced back to their point of origin on the DNA template. But the double-strand helix of DNA represents two templates, one the complement of the other. When any given segment of DNA is transcribed, two entirely different RNA molecules can be produced, depending on which strand of the DNA molecule serves as a template. Assuming that the entire length of the DNA molecule contains genetic




**COMPETITION TEST shows that 16S and 23S ribosomal RNA form hybrids with different segments of the DNA molecule. The 16S RNA was labeled with tritium, the 23S RNA with radioactive phosphorus. Increasing amounts of 16S RNA were added to hybridization mixtures containing a saturating concentration of 23S RNA. Subsequently the relative amounts of tritium and radioactive phosphorus in the hybrids were determined. Since the two kinds of RNA hybridize without interference they must have different base sequences.**

information that must be transcribed into RNA, there are three possibilities: (1) All of both strands are transcribed into complementary RNA; (2) both strands serve as templates, but in any given segment only one strand or the other is transcribed; (3) only one strand is transcribed.

Here again the hybridization test has supplied evidence to decide among the alternatives. Ideally what is required is a method of separating the two strands of the DNA molecule. If this could be done, one could test the various forms of RNA against each strand and determine if hybridization occurs.

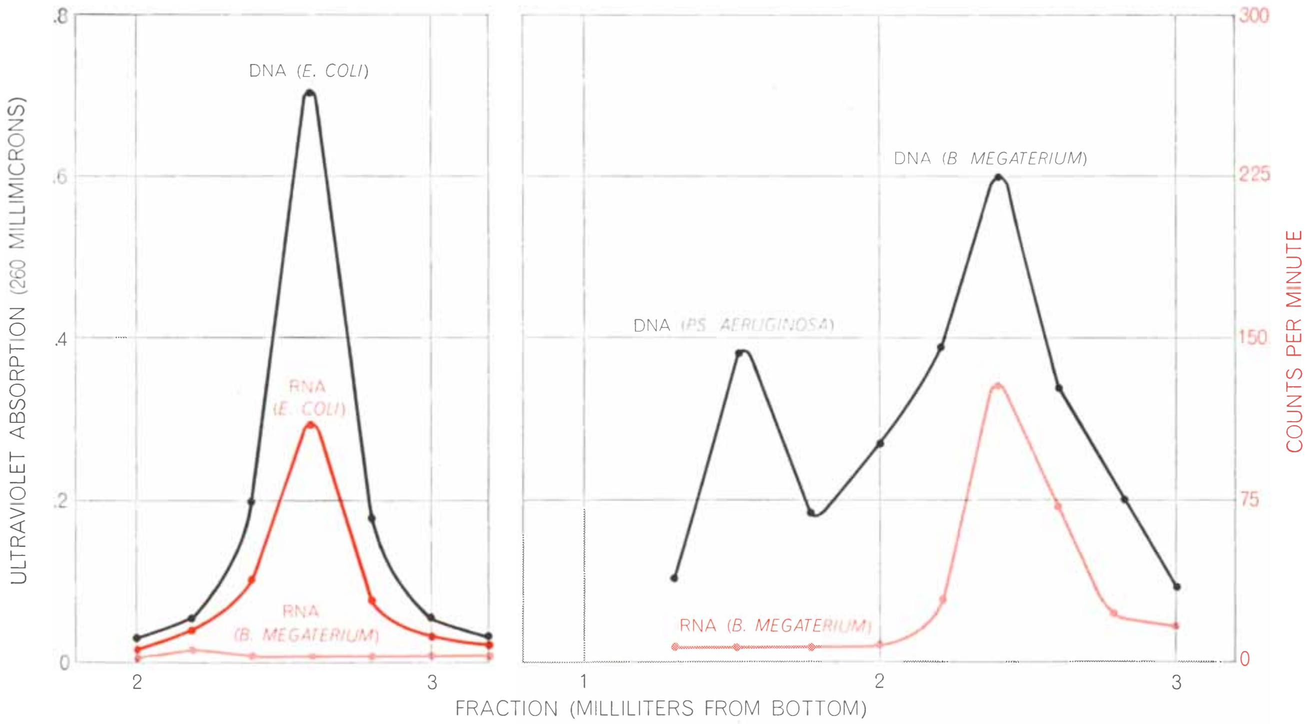
Although the two strands of normal DNA can be separated, no way has yet been found to obtain a pure preparation containing strands of only one type. Fortunately nature provides a solution to the problem in the form of an organism that contains a single strand of DNA. The organism is the small DNA virus $\phi$X174, discovered by Robert L. Sinsheimer at the California Institute of Technology. It is fairly easy to purify the virus particle and remove its DNA. Nature also provides a source of the complementary strand. When the virus infects a bacterial cell, the single strand of DNA serves as a template for the synthesis of a complementary strand, resulting in a normal double-strand DNA molecule. This molecule, known as the replicating form, can also be isolated for experimental purposes.

In order to run a hybridization test my co-workers Marie and Masaki Hayashi grew $\phi$X174 in infected cells in the presence of P-32 and extracted labeled molecules of translatable RNA. These molecules were then brought together with the single-strand DNA of $\phi$X174 and with a denatured sample of the double-strand form. The results obtained were satisfyingly clear. No hybrids were formed with the single-strand DNA, but excellent hybrids were produced with the DNA from the double-strand form. This implied that the RNA messages are complementary to the *other* strand in the two-strand DNA molecule, that is, the one not normally present in the $\phi$X174 particle. As a final confirmation we analyzed the base composition of the RNA that was hybridized. The results agreed with the expectation that it was complementary to only one of the two strands of the replicating form of $\phi$X174 DNA.

Using similar methods with other viruses, identical conclusions have now been drawn by two other groups: Glauco P. Tocchini-Valentini and his co-workers at the University of Chicago and Carol Greenspan and Marmur at Brandeis University. There seems little doubt that in all organisms only one strand of the DNA molecule serves as a template for RNA synthesis.

The original procedures of detecting hybrids involved lengthy high-speed centrifugations. Ekkehard K. F. Bautz of Rutgers University and Benjamin D. Hall of the University of Illinois have introduced the use of cellulose-acetate columns for hybridization experiments. Ellis T. Bolton and Brian J. McCarthy of the Carnegie Institution of Washington's Department of Terrestrial Magnetism have developed a convenient and rapid method using an agar column. Here the DNA is trapped on the agar gel and the RNA is hybridized with it. The RNA can then be removed by raising the temperature of the column and lowering the ionic strength of an eluting, or rinsing, solution.

The exploitation of the hybridization technique is still at an early stage, but it has already proved of great value in the analysis of gene function. It seems likely to play an increasingly important role in helping to illuminate many problems of molecular biology, including those pertinent to an understanding of the specialization of cells and biological evolution in general.




**TESTS FOR GENETIC RELATIONSHIP can be carried out by challenging the RNA from two different organisms with the DNA from one of them. In one experiment (*left*) transfer RNA from *E. coli* was labeled with radioactive phosphorus; transfer RNA from *B. megaterium* was labeled with tritium. Only the former hybridizes with *E. coli* DNA. Conversely, in a second experiment (*right*), transfer RNA from *B. megaterium* hybridizes with genetically related DNA but not with DNA from *Ps. aeruginosa*.**

## Kodak reports on:

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### I-r for i-r's sake

**He is telling the man that a set of 11 microfilm magazines like the one in his hand and the one he has inserted in the top of the reader holds the 21,000 infrared absorption spectra that at least one publisher now sells in microfilm form. Other magazines (or rolls, aperture cards, film jackets, microfiches—all of which are compatible) will supplement this basic library with the man's own spectra. When matching "fingerprints" or when deducing the structure of a new compound by comparison with related ones, the larger the library the easier the task, provided the indexing system is good. When it yields a desired number, the man will insert the proper magazine and let the microfilm race until the code lines on the film, seen against the scale alongside the screen, find their mark. On the screen appears the desired spectrum. The piece of paper is a "hard" copy thereof, such as emerges from the slot in the base at a touch of that button he is pressing. Nobody gets a chance to ruin the integrity of the file.**

Consider a man who holds down a job determining the identity of unknown substances. On his income tax return he has written "chemist." His family thinks of him holding a test tube up to the light and scowling at it. Actually, a far more typical working pose would show him rummaging through heaps of long strips of paper as he searches for an i-r absorption spectrum that some pinhead has misplaced. In moments of agonizing self-appraisal he knows that the way analytical chemistry is practiced today, a more orderly approach to information storage and retrieval may earn several times as many points as the ability to name from memory nine ways to test for urea.

Expertise on the i-r (information-retrieval, that is) problems of the modern analytical laboratory can hardly be expected to come from within. Recordak Corporation, 770 Broadway, New York City 10003, a subsidiary of Eastman Kodak Company, *can hardly wait* to send a representative who is well aware that every lab has to work differently, that some will have us do their microfilming for them, that some will want to lease the right kind of microfilmer and do it themselves, that some generate enough spectra to justify buying their own microfilmer, etc., etc.

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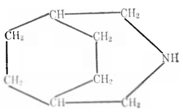


The only reference to the compound turned up in an intensive literature search reports nothing more than failure of a scholarly effort to synthesize it. Industrial emotions quicken at standing in the presence of a new composition of matter. Sagacity in management of organic chemical market development can be displayed to advantage by adherence to such rules as, "Never sneer at a secondary amine."

The word is given: "A bit more money into the *3-Azabicyclo*[*3.2.2*]*nonane* project, please. Now let's start calling it AZBN."

In the face of discouragement from the literature, intentional syntheses with higher yields than the unintentional one are proved out. Samples go out to laboratories which have in the past signified interest in similar compounds. From one stately midwestern campus returns a report on certain thermodynamic anomalies observed in AZBN as a globular molecule. Very nice. From other laboratories, where a more direct interpretation is put on the dictum that knowledge is power, returns the query: "When will the price get realistic?"

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*Which lays a heavy burden on these weak words to prove they can seek out enough requests to Eastman Chemical Products, Inc., Chemicals Division, Kingsport, Tenn. (Subsidiary of Eastman Kodak Company) for a report on the properties and reactions of AZBN so that the small percentage of those who will find commercial promise therein, adding their visions to the visions already aroused by AZBN—as mutually non-competitive as anti-hypertension agents and rubber catalysts—, will in concert build up demand to bring down the price to where everybody will like it and we can all have a ball.*

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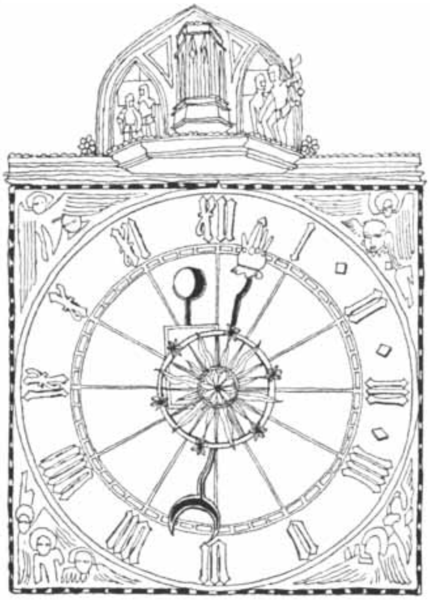
**This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science**





### "Mutual Irritations"

An "enlightened partnership" of the Federal Government, the universities and the scientific community this year is spending more than $1 billion of the taxpayer's money. The outlay covers three-quarters of all research expenditures by the universities. In an attempt to "reduce some mutual irritations" among the partners, the National Academy of Sciences has published a review of their triangular relationship and a 17-point set of findings and recommendations.

"Federal Support of Basic Research in Institutions of Higher Learning" is the work of the Academy's Committee on Science and Public Policy, headed by George B. Kistiakowsky of Harvard University. The committee began its work in June, 1963. A Congressional inquiry into the grant policies and administrative practices of the National Institutes of Health at that time had "marked the beginning of a period in which Government agencies have been revising their policies."

The 98-page report embraces "research project grants" and "fixed-price research contracts (not too unlike grants)" as "the backbone of Federal policy in support of basic research in science in universities."

"A recent trend toward unnecessary restriction of scientific freedom and increases in the bookkeeping chores of scientists" has been engendering irritation, however, between the Government and the scientific community. Irritation between scientists and their universities has been set up by another trend: "In some fields, basic research has moved into laboratories that have lost close touch with university teaching departments.... Some scientists retire from virtually all contact with students.... The stage is set for teaching of all kinds—graduate and undergraduate—to become a 'poor relation' to research in the university." Administrators who hope "to add to the prestige of their universities by encouraging large-scale research projects of high visibility" are held as culpable as the professor who would "use grant money to run up his salary far above the university scale."

Irritation across the third side of the triangle, between the Government and the universities, arises from "one of the most serious fiscal problems to develop in the operation of the project system." This is the payment of indirect costs to universities for the burden placed by vastly expanded research programs on "administrative buildings, maintenance services, accounting services, libraries and dormitories." The administrative officer "is tempted to do several dangerous things if indirect costs are not adequately covered: (1) He may divert funds from work in other branches of knowledge. (2) He may divert funds from the teaching function of the university. (3) He may neglect the proper administration of Federal funds. (4) He may divert Federal funds to questionable uses." The indirect-cost issue "has become a wedge not only between the Government and the universities but also between investigators and administrators on university campuses." From the investigator's point of view "the more money paid into indirect costs by the Government, the less remains available for research."

The report endorses "three auxiliary types of support." These are "institutional or general research grants related to existing totals of project grants"; "a system of *small research grants*...to junior scientists for individual research," and "development grants in support of ...institutions with potentiality for becoming strong in the future." The last would help to "protect the project system from the charge that it makes the rich richer and the poor poorer." Envisioning "the permanent interrelated system," the report concludes: "When development grants have done their work and increased the number of strong universities in every region of the nation, they should be phased out to let the project system, modified by supplementary institutional grants, take over."

Figures quoted in the report from National Science Foundation studies show that, even according to the testimony of university administrators and scientists, no more than half of the \$1.4 billion they spend on research goes to basic research. That the share of basic research may be still smaller is indicated by the fact that more than half of the Federal grant and contract money comes from the Department of Defense and the Atomic Energy Commission. More than two-thirds of the funds from these agencies are expended through "Federal contract research centers" sponsored by the universities.

## *Farthest Object*

The distinction "most distant object in space" has passed from a galaxy designated 3*C* 295 to one of the recently discovered quasi-stellar radio sources: 3*C* 147. The quasi-stellar sources, of which more than a dozen are now known, produce a starlike image on a photographic plate, yet each emits about 100 times more light than a typical galaxy of 100 billion stars. They are by far the brightest objects in the universe and hence can be observed over tremendous distances. The distance to 3*C* 147 is estimated at several billion light-years; a more precise figure cannot be given. It can be ascertained, however, that 3*C* 147 is 10 to 20 per cent more distant than 3*C* 295, report Maarten Schmidt of the Mount Wilson and Palomar Observatories and Thomas A. Matthews of the California Institute of Technology Radio Observatory.

The distance estimates are based on the familiar fact that the light received from distant objects is shifted toward the red end of the spectrum, indicating that the objects are receding as part of the general expansion of the universe. In spectrograms of 3*C* 147 made with the 200-inch telescope on Palomar Mountain, Schmidt has measured the displacement of spectral lines of ionized oxygen and ionized neon. The red shift of these lines amounts to 54.5 per cent of their undisplaced wavelengths. This corresponds to an apparent recession velocity of 76,000 miles per second, or 41 per cent of the velocity of light. The apparent recession velocity of *3C* 295 is 67,000 miles per second. The illustration below shows the position of *3C* 147 and *3C* 295 on the red-shift–velocity curve, along with the positions of two other quasi-stellar sources (see "Quasi-Stellar Radio Sources," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, December, 1963).

## *Third Scientist*

The appointment of Mary Ingraham Bunting to the Atomic Energy Commission brings to three the number of scientists on the A.E.C. A microbiologist and biochemist, she is the first woman to serve on the A.E.C. Mrs. Bunting has been the president of Radcliffe College since 1960. She has taken a leave of absence from that position.

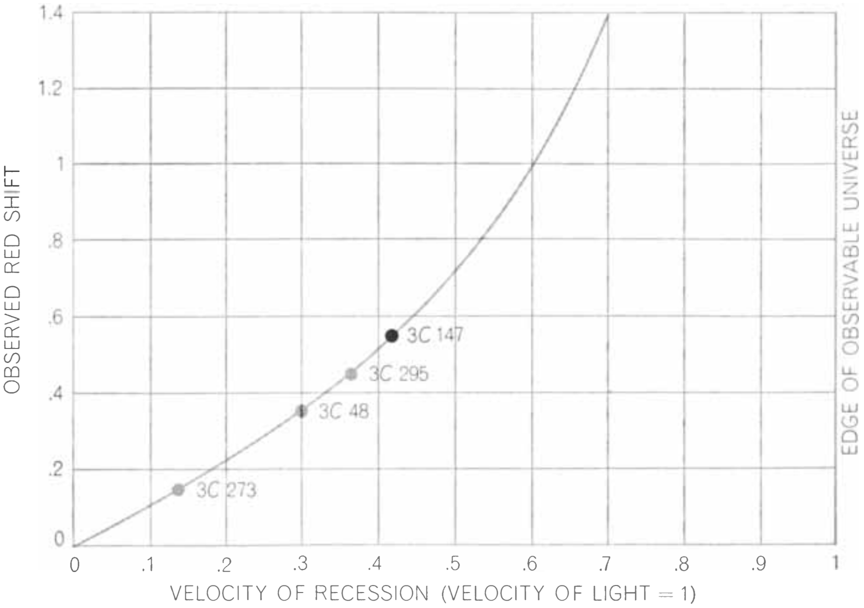
The other two scientists on the A.E.C. are its chairman, Glenn T. Seaborg, a chemist, and Gerald F. Tape, a physicist. Their colleagues, James T. Ramey and John G. Palfrey, are lawyers. Mrs. Bunting replaces Robert E. Wilson, a chemical engineer and oil-company executive, who resigned.

## *Three Colors, Three Receptors*

In 1801 Thomas Young suggested that the perception of color depends on the presence in the retina of three kinds of receptor that respond respectively to the three primary colors: red, green and blue. Now workers at Johns Hopkins University and Harvard University have confirmed Young's insight. They have produced direct evidence that in men and monkeys the cones—the cells in the retina that are responsible for color vision—are of three different kinds, that each contains a different light-sensitive pigment and that one of these pigments is sensitive to red light, one to green and one to blue. The two groups worked independently and reported their preliminary results in *Science* at about the same time.

Several investigators had been able to show that the retina contains at least two cone pigments, one apparently for sensing red and the other for green. They could not find any indication of a blue receptor. Nor could they determine whether the two pigments they did find were segregated in different receptors or were both present in the same receptors. To do that it was necessary to measure the color sensitivity of individual cone cells.

That is what Paul K. Brown and George Wald of Harvard and the Johns Hopkins group—W. B. Marks, W. H. Dobelle and E. F. MacNichol, Jr.—have now done. They mount bits of monkey or human retina (the latter donated by an eye bank) between pieces of glass. They orient the specimen under a microscope so that an extremely thin beam of infrared radiation passes through a single cone and falls on a photomultiplier tube. When visible light is substituted for the infrared radiation, the intensity of the beam is diminished




*Red-shift curve is extended by quasi-stellar radio source 3C 147* **(black dot)**

# INDUSTRIAL TECTONICS EXPLORES THE WORLD OF FRICTION

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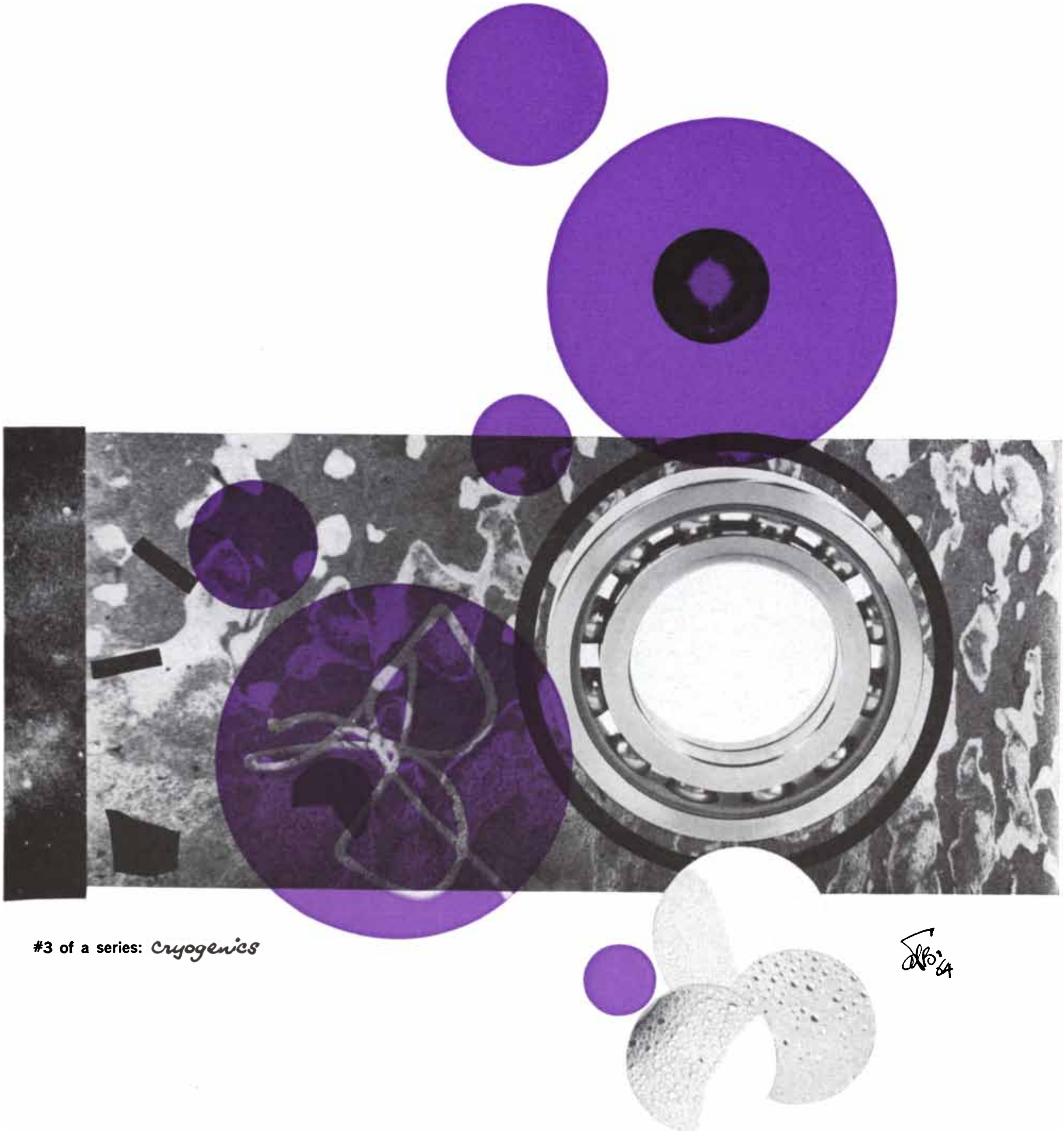

**#3 of a series:** *Cryogenics*

**INDUSTRIAL TECTONICS, INC.,** 18301 Santa Fe Avenue, Compton, California • Hicksville, New York • Ann Arbor, Michigan to the extent that its light is absorbed by the pigment in the cone. By comparing the intensity of the transmitted beam with that of a reference beam at various wavelengths across the spectrum, the investigators derive an absorption curve for the individual cone. The Johns Hopkins curves show peaks at 445, 535 and 570 millimicrons; that is, the cones are maximally sensitive in the violet, green and yellow regions of the spectrum. The curves of the Harvard workers peak at 450, 525 and 555 millimicrons. The results suggest strongly that color vision in man, monkeys and other primates is indeed mediated by three pigments in three kinds of cone, each of which is primarily responsible for sensing one of three colors.

## *Earlier Man, Earlier Pre-Men*

Two developments in recent weeks appear to have pushed far back in time the eras of the first men and of their forebears. The British paleontologist L. S. B. Leakey has discovered in Africa the bones of creatures he regards as the earliest men, for whom he has proposed the name *Homo habilis.* Elwyn L. Simons of Yale University has proposed a classification of pre-men that "increases tenfold the approximate time period during which human origins can now be traced with some confidence."

Previously the first true man had been thought to be *Pithecanthropus,* a creature that lived about 500,000 years ago. The bones Leakey and his colleagues have found appear to date as far back as 1.8 million years. Leakey describes the creatures as walking erect on feet almost identical with modern man's and as having hands of considerable dexterity. Leakey also announced that he has abandoned his earlier opinion that *Zinjanthropus,* a manlike creature whose bones he found in Africa in 1959, was on the line of evolution to man. A more recent find of a specimen about 200,000 years younger indicates, he said, that *Zinjanthropus* did not continue evolving toward man.

Simons' proposal relates to the transition from the dryopithecine apes of the Miocene-Pliocene epochs (25 million to two million years ago) to the first true hominids, or manlike creatures, of the early Pleistocene, which was the epoch following the Pliocene. In the *Proceedings of the National Academy of Sciences* Simons describes his determination that several fossil bones previously classified under such names as *Bramapithecus* and *Kenyapithecus* belong to the genus *Ramapithecus.* Since some of the bones have been dated by several methods as being 14 million to 15 million years old, *Ramapithecus* dates back to the Miocene epoch. In a comment separate from his paper, Simons said: "Since *Ramapithecus* is unlike the apes in dentition, and since it foreshadows in known parts the structure of the same parts in Pliocene relatives of man, it is logical to conclude that *Ramapithecus* is on, or near, our ancestral line. The exciting thing about this proposal is that we now have a forerunner of man nearly 10 times as old as . . . the earliest undoubted relative of man."

## *New Hormone*

A new pituitary hormone has been discovered by investigators at the University of California's Hormone Research Laboratory in Berkeley. The substance was first detected in an extract from the pituitary glands of sheep in the course of an experiment aimed at developing a speedier method of isolating the adrenocorticotropic hormone (ACTH); it has since been found in the pituitary glands of cattle as well. The main function of the new hormone appears to be to mediate the process by which the body changes stored solid fats into liquid form for use as a source of energy. It has been named the lipotropic hormone (LPH), or simply lipotropin, by its discoverers: Choh Hao Li, director of the Hormone Research Laboratory, Yehudith Birk and Phoebe Lohmar.

Reversing the usual procedure in the study of hormones, the Berkeley group isolated lipotropin and examined its chemical properties before beginning an investigation of its biological effects. The lipotropin molecule was found to consist of a single chain of 59 amino acid units arranged in a specific but as yet unknown sequence. In comparison there are 205 amino acid units in sheep lactogenic hormone (LTH) and 39 amino acid units in sheep ACTH (see "The ACTH Molecule," by Choh Hao Li; SCIENTIFIC AMERICAN, July, 1963). The new substance had been designated a "biologically active peptide" by Li and his co-workers until early in March, when they completed the final required step in the identification of a new hormone: the detection of it in the circulating blood of an animal.

It is not yet known whether lipotropin is produced in humans or whether the substance extracted from animals may have any effect on human physiological processes. The scarcity of human

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pituitary glands for investigation may delay further inquiry in this direction.

## *Death in Parts per Trillion*

A pesticide called endrin is probably responsible for the death of millions of fish in the lower Mississippi River and the Gulf of Mexico. The massive destruction of fish has occurred each fall and winter for the past four years. Before identifying endrin as the probable culprit the U.S. Public Health Service ruled out such possible causes as parasitic and bacterial diseases, lack of oxygen, traces of harmful metals and sharp changes in water temperature.

Dead and dying fish taken from the Mississippi were found to contain significant quantities (up to several parts per million) of endrin and another pesticide, dieldrin, together with two substances so far unidentified. Subsequent studies showed that endrin was present in all sick and dead fish. Other fish whose blood contained dieldrin but no endrin were healthy.

The study was made with the help of sensitive new tests, which have shown that the water of the lower Mississippi contains as much as 200 parts per trillion of endrin. A recent sample of the New Orleans water supply, which is drawn from the Mississippi, contained 25 parts of endrin per trillion. The Public Health Service states that endrin's presence does "not present any immediate health problems," presumably because milk can be sold if it contains less than 10 parts per billion (10,000 parts per trillion) of endrin. By previous analytical methods 10 parts per billion was considered virtually undetectable and therefore not alarming. On the other hand, Federal regulations prohibit the sale of certain vegetables if they contain any endrin whatever. How these regulations will be affected by the new analytical methods is yet to be determined. Meanwhile Government agencies have mounted an intensive study of the Mississippi River basin to see what pesticide-control measures should be taken.

## *Busy Depths*

A considerable increase in the tempo of direct exploration of the oceanic depths can be expected during the coming months. Beginning this month and continuing into the summer, the French bathyscaph *Archimède* will explore the deep trench off Puerto Rico in a program sponsored by several French and U.S. organizations. Among the objectives are geological examination of the rock outcrop near the base of the north wall of the trench and studies of the properties of the water in the trench.

Three new deep-sea craft are under construction and scheduled for launching this year. The *Alvin*, a two-man research submarine that will be operated by the Woods Hole Oceanographic Institution, will be able to descend 6,000 feet. The *Deepstar*, being built by the Westinghouse Electric Corporation in cooperation with Jacques-Yves Cousteau, will be able to take three men to depths of 12,000 feet; it will also be comparatively maneuverable and independent of ties with the surface. Likewise independent will be the *Aluminaut*, a 50-foot all-aluminum submarine under construction for Reynolds International, Inc.; it is expected to reach depths of up to 15,000 feet with a crew of three. Two other craft are already in operation: the U.S. Navy's bathyscaph *Trieste* and the small *Diving Saucer*, built by Cousteau.

## *Contact-Bend-Stretch Rolling*

An innovation in the rolling of steel and other metals may make it possible to use lighter and cheaper equipment in the manufacture of metal strip. The new technique, in which the strip is squeezed, bent and pulled simultaneously, is called "contact-bend-stretch" (C-B-S) rolling. It was invented by Louis F. Coffin, Jr., of the General Electric Research Laboratory. Further development will be undertaken by the U.S. Steel Corporation.

In conventional "contact-stretch" rolling a thick strip of metal is made thinner by pulling it between two heavy rollers. From a study of the effects of plastic strain on metals, Coffin found that less pressure and tension are required to reduce the thickness of the strip if plastic bending is added to the forces usually applied in a rolling mill. One form of C-B-S rolling involves five rollers, around which the strip travels in four loops. The overall size and weight of such an arrangement is considerably less than that of a conventional rolling mill of similar capacity.

Strips up to 12 inches wide have already been rolled by the new process. In one case the thickness of a strip of stainless steel was reduced from .09 inch to .012 inch in four passes and without annealing the metal between passes. To do the same job conventional rolling methods would require about a dozen passes and several intermediate annealings.

# The Chemistry of the Noble Gases

*The first chemical compound containing a noble, or supposedly inert, gas was achieved in 1962. The chemistry of this rapidly growing class of compounds promises to shed light on the nature of the chemical bond*

by Henry Selig, John G. Malm and Howard H. Claassen

Not quite two years ago the foundations of chemistry were shaken by a surprising development. It was discovered that the "noble" gases, which were supposed to be chemically inert, could enter into chemical reactions and form compounds. To chemists this was as startling as the fall of the conservation of parity was to physicists. Chemical theory and laboratory experience had indicated that the noble gases could not combine with other elements. Yet in 1962 they were made to do so, and it soon developed that noble-gas compounds could be produced with ridiculous ease.

Inorganic chemists immediately began to investigate the phenomenon with the powerful techniques of modern chemistry. The activity generated by the discovery can be judged from the fact that less than a year later an international conference on the chemistry of the noble gases was held at the Argonne National Laboratory, and more than 40 investigators from 30 institutions in several countries came to discuss their findings. By now more than 100 papers on specific investigations in noble-gas chemistry have been published in chemical journals. Probably never before has so much detailed information about a class of compounds been developed in so short a time. More is known now about the chemistry of xenon, one of the noble gases, than about that of some far more common elements.

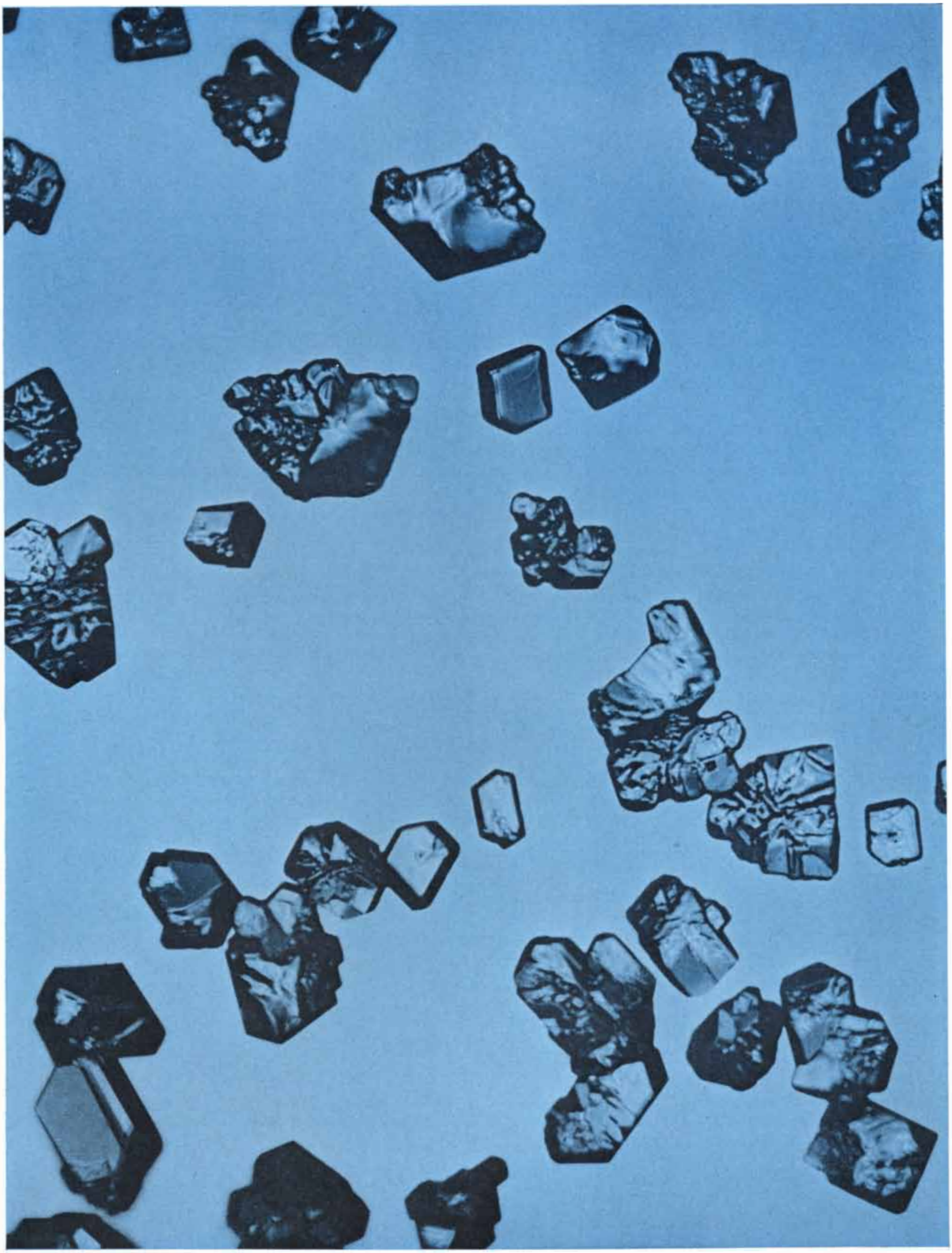
The new compounds no doubt will prove useful in various ways; some uses are already obvious. More important, however, is the light their chemistry promises to shed on the nature of the chemical bond.

It was Henry Cavendish, the 18th-century English chemist, who first uncovered evidence that such a thing as a noble gas could exist. In 1785 he removed the oxygen and nitrogen from air by chemical means and found that about 1 per cent of the original air was still left in the vessel. No chemical operation he knew of could either precipitate or identify the remaining gas. A century later the physicist Lord Rayleigh encountered the same barrier from another direction. In the course of measuring the density of various elements to test the hypothesis that all the elements were built up from atoms of hydrogen, Rayleigh discovered that the nitrogen he got from air was always heavier than the nitrogen obtained from a chemical source such as ammonia. Suspecting that a heavier gas might be mixed with the atmospheric nitrogen, Rayleigh joined forces with the Scottish chemist William Ramsay in an effort to isolate the unknown gas. After long, painstaking experiments Ramsay succeeded in getting rid of the nitrogen and obtaining a small residue of gas. He subjected this gas to an electric discharge, and in the spectroscope it showed spectral lines that demonstrated that it must be a new element.

## A New Column in the Periodic Table

Rayleigh and Ramsay named the element argon, from a Greek word meaning "inactive," because it refused to engage in any chemical activity. There was a difficulty about placing argon in the periodic table of the elements: the table had no vacancy for an element of argon's atomic weight. Ramsay decided that it had to go into a new column added to the table—a column in which, appropriately, argon would have a valence, or combining power, of zero. This meant that the other occupants of the column, as yet undiscovered, must also be inert. Ramsay suspected that some of them might be gases present in trace amounts in the air. By hard work he and his colleague Morris W. Travers discovered in the air the extremely rare gases neon, krypton and xenon. Ramsay then identified another inert gas found trapped in rocks as helium (whose spectral lines had been detected 30 years earlier in spectra of the sun). The new column of elements was completed in 1900 when radon was discovered as a gas emitted in the radioactive decay of radium. For the discovery of the inert gases Ramsay and Rayleigh were in 1904 respectively awarded the Nobel prize in chemistry and in physics.

The group of six elements—helium, neon, argon, krypton, xenon and radon—came to be known as the noble gases because they disdained to enter into chemical relationships. Some of them could be trapped in the combinations called clathrates, in which atoms of the inert element are caged in the lattice of a crystal. This association, however, is not ascribed to a true chemical bond. Indeed, the possibility of a noble gas forming any chemical bond seemed to be virtually ruled out on theoretical grounds. A chemical bond is created by the transfer of electrons from one atom to another or the sharing of electrons between atoms. The noble gases are set apart by the fact that all of them have an outer shell of eight electrons. This was considered, for all practical purposes, a "filled" shell: no electrons could be added to it and it was extremely difficult to pull an electron away from it. Consequently it became a textbook axiom that the noble-gas elements could not form chemical bonds because their atoms would neither donate nor accept



CRYSTALS OF XENON TETRAFLUORIDE ($XeF_4$) were made at the Argonne National Laboratory by heating a mixture of xenon and fluorine in a nickel container for one hour at 400 degrees centigrade. After the excess fluorine was removed the compound was sublimed into a glass container, where these crystals appeared. The blue background is artificial; the crystals themselves are colorless.

| | MELTING POINT (DEGREES C.) | VAPOR PRESSURE AT 25 DEGREES C. (MILLIMETERS OF MERCURY) | COLOR OF SOLID | COLOR OF VAPOR |
|---|---|---|---|---|
| XENON DIFLUORIDE ($XeF_2$) | 140 | 3.8 | WHITE | COLORLESS |
| XENON TETRAFLUORIDE ($XeF_4$) | ~114 | 3 | WHITE | COLORLESS |
| XENON HEXAFLUORIDE ($XeF_6$) | 46 | 28 | WHITE (LESS THAN 42 DEGREES C.) YELLOW (MORE THAN 42 DEGREES C.) | YELLOW |
| XENON OXYTETRAFLUORIDE ($XeOF_4$) | –28 | 32 | WHITE | COLORLESS |

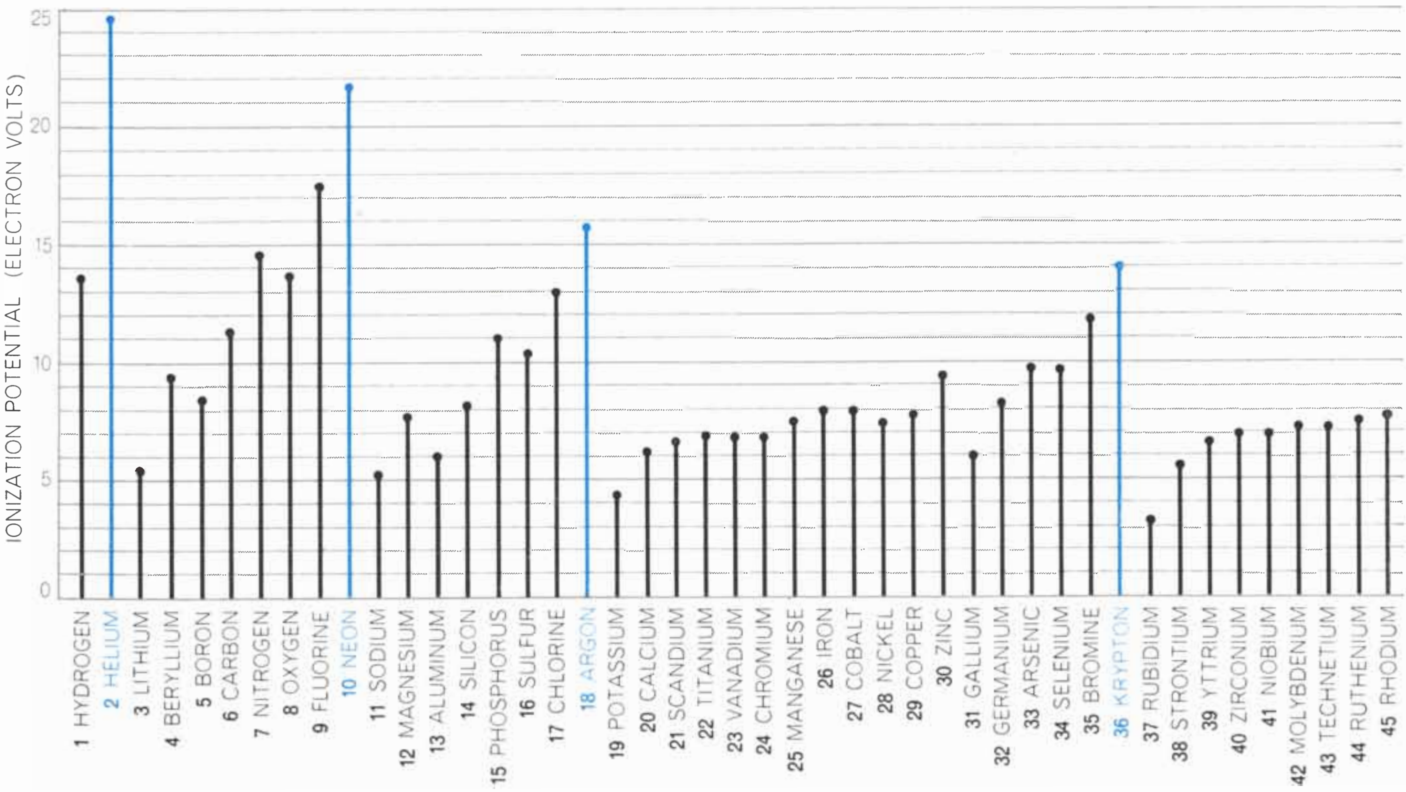
**SOME PROPERTIES** of the three fluorides and one oxyfluoride of xenon identified so far are listed here. Fluorides are formed in steps by successive additions of fluorine. Xenon oxytetrafluoride is formed by reacting xenon hexafluoride with silica or water.

electrons in the kind of transfer or sharing required to effect a bond.

A few theoretical chemists, notably Linus Pauling of the California Institute of Technology, argued that the noble elements might be pulled into chemical combination by hyperreactive elements such as fluorine. Pauling went so far as to suggest (in 1933) the formulas of some possible compounds: krypton hexafluoride ($KrF_6$), xenon hexafluoride ($XeF_6$) and certain "perxenates" (such as $H_4XeO_6$). He reasoned that bond lengths and the possible packing arrangements of atoms would allow these compounds to be formed. Several chemists immediately took up his suggestion and tried to produce reactions between the noble gases and fluorine or chlorine. They failed to find any evidence of the formation of compounds. The failure of these and other attempts over the years eventually convinced chemists that the noble elements were indeed immune to chemical activity.

## The First Noble-Gas Compound

The production in 1962 of the first noble-element compound, like the discovery of the noble gases themselves, came about not through a direct search but as a by-product of another investi-




**IONIZATION POTENTIALS** of the elements up to uranium are presented in this chart; the noble gases are shown in color. Ionization potential is defined as the potential difference through which a bound electron must be raised to free it from the atom or molegation. The starting point of this investigation was the gas uranium hexafluoride—a substance that played the crucial role in the separation of fissionable uranium 235 in the wartime atomic-bomb program. After the war a group of investigators, originally headed by Bernard Weinstock, at the Argonne National Laboratory undertook a systematic study of the chemistry of hexafluorides and produced a series of interesting cousins of the uranium compound, namely hexafluorides of platinum, ruthenium and rhodium. As extremely reactive gases these substances provided rich material for laboratory experiments.

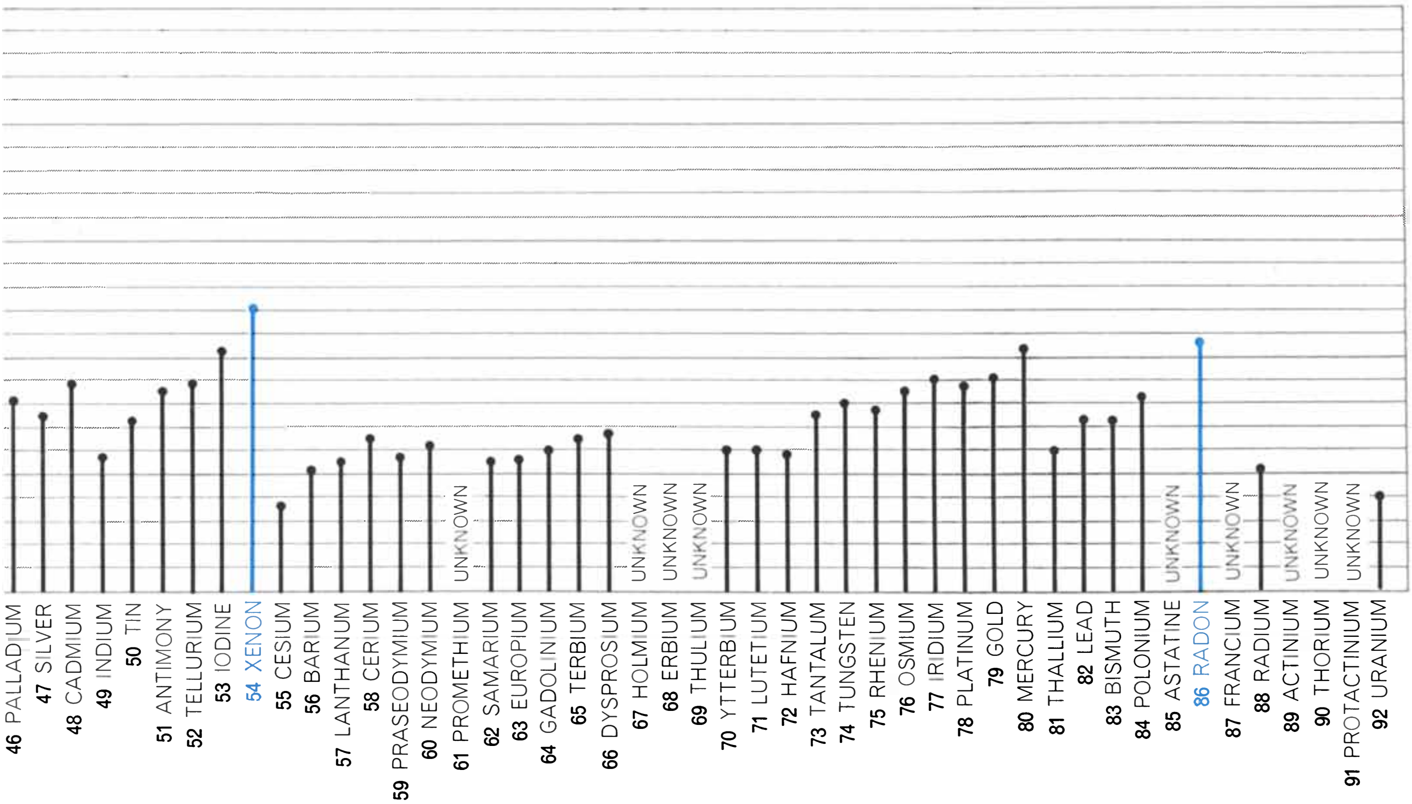
At the University of British Columbia, Neil Bartlett took up experiments with platinum hexafluoride and found that it was capable of forming a rather surprising compound. He and his colleague D. H. Lohmann reacted platinum hexafluoride with oxygen and discovered that they combined in a one-to-one ratio: one molecule of oxygen to one of platinum hexafluoride. The two molecules were joined by an ionic bond, which means that in the combination the oxygen molecule became a positive ion and the platinum hexafluoride portion a negative ion: the compound was $O_2^+(PtF_6)^-$. The remarkable feature of the reaction was the ionization of the oxygen molecule. This molecule holds its electrons with extreme tenacity; pulling an electron away from it is so difficult that no positive ion of molecular oxygen had ever been observed before as part of a stable compound. Yet platinum hexafluoride had ionized the molecule easily at room temperature. The affinity of the hexafluoride for electrons was powerful indeed.

Bartlett quickly noted that the oxygen molecule's resistance to the removal of an electron was almost exactly the same as that of the noble gas xenon. The energy required to remove an electron from an atom or a molecule is called its ionization potential [*see illustration at bottom of these two pages*]. For the oxygen molecule this energy amounts to 12.2 electron volts; for the xenon atom it is 12.13 electron volts. If platinum hexafluoride could pull an electron away from oxygen, perhaps it could also remove one from xenon. In so doing it would force the xenon atom into chemical combination with the hexafluoride by means of an ionic bond.

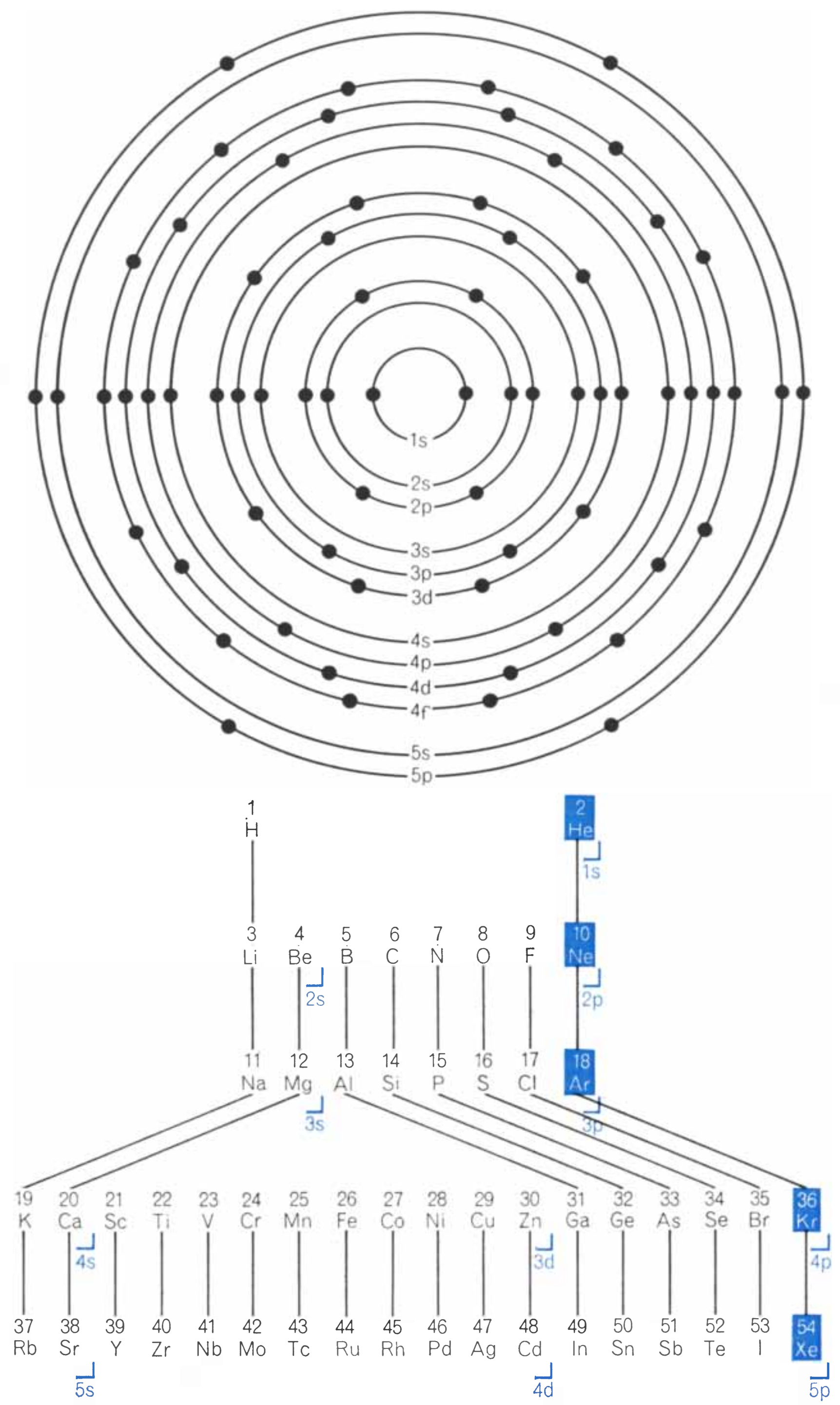
Bartlett set up a simple experiment in glassware containing platinum hexafluoride, which is a deep red vapor, and xenon gas, the two gases being separated by a glass diaphragm. When the diaphragm was broken and the two gases mixed, they promptly combined and formed a yellow powder! There could be no doubt that they had united in a compound: the platinum hexafluoride and most of the xenon had disappeared. Bartlett believed that the compound was $Xe^+(PtF_6)^-$, analogous to $O_2^+(PtF_6)^-$. Later work has indicated, however, that the formula is more complex.

## The Compounds Multiply

Bartlett's report of his experiment, published as a letter in the *Proceedings of the Chemical Society of London* in June, 1962, immediately aroused intense interest. At Argonne, the birthplace of platinum hexafluoride, we quickly confirmed the reaction of xenon with that substance and found that it would react with ruthenium hexafluoride as well. One aspect of the results, however, was rather puzzling. According to the amounts consumed in the reaction, ruthenium hexafluoride reacted with xenon in the ratio of about three molecules of the hexafluoride to one atom of xenon. This showed that




cule to which it is attached. The variation of ionization potential with atomic number is a strikingly graphic representation of the periodicity of the chemical properties of the elements. A periodic table of the elements up to xenon appears on the following page.




**PERIODIC TABLE at the bottom of this illustration presents the 54 elements up to xenon according to differences and similarities in their chemical properties. The noble gases are indicated by the solid colored rectangles. The element immediately to the left of each noble gas is a halogen. Elements in each horizontal row differ from one another in their chemical properties. The lines running from top to bottom connect elements of similar chemical properties. Above the symbol for each element is its atomic number: the number of positive charges in its nucleus or the number of electrons bound by them. In each horizontal row the colored brackets designated 1*s*, 2*s*, 2*p* and so on denote the filling of subshells of electrons, and it is largely the number of electrons in the outer shell that determines the chemical properties. The electron-shell structure of xenon is given in the schematic drawing at the top of the illustration. In spectrographic terminology the shells are designated 1, 2, 3, 4, 5 and so on. The subshells are designated *s*, *p*, *d* and *f*. The maximum number of electrons (*black dots*) in any *s* subshell is two, in any *p* subshell six, in any *d* subshell 10 and in any *f* subshell 14. In most elements all the inner subshells are filled, and electrons add to the outer shell with increasing atomic number. If the rest of the periodic table were shown, radon, a noble gas with an atomic number of 86, would appear just below xenon.**

the reaction could not be the same as that in the case of oxygen, where the ratio of combination was one molecule of oxygen to one of the hexafluoride. It began to look as if, instead of combining with the entire hexafluoride molecule, xenon was uniting with the fluorine and forming xenon fluoride. In other words, the hexafluoride was simply fluorinating the xenon.

We therefore proceeded to the experiment of trying to react xenon directly with fluorine itself. A mixture of fluorine and xenon (five parts of fluorine to one part of xenon by volume) was heated in a nickel vessel for one hour at 400 degrees centigrade and then rapidly cooled. At room temperature the product became a white solid that grew into large, beautiful crystals within minutes [*see illustration on page* 67]. By weighing and chemical tests we found that the substance was the simple compound xenon tetrafluoride ($XeF_4$). The reaction had consumed all the xenon and left an excess of fluorine gas.

At Argonne and other laboratories two other fluorides of xenon, the difluoride and the hexafluoride ($XeF_2$ and $XeF_6$), were soon prepared by much the same method, using different amounts of fluorine. Other systems for producing xenon fluorides have also been developed, some of them employing electric discharges or ionizing radiation instead of heat to spark the reaction. Certain stable compounds of fluorine, as well as fluorine itself, can serve as the fluorinating agent; it is only necessary to split off the fluorine atom by some means, such as heat or an electric discharge, so that it can react with the xenon.

Thus the noble gases were reclaimed from an exotic realm of their own and brought into the family of chemical elements. It was something of an anticlimax to discover that the supposedly inert gas xenon could be teased into a chemical union simply by heating it with fluorine in a nickel can or running the mixture through a heated nickel tube. As a matter of fact in 1933 Don M. Yost and Albert L. Kaye of the California Institute of Technology had performed the experiment subjecting a mixture of xenon and fluorine in a quartz vessel to an electric discharge. Quite possibly they produced a xenon fluoride, but unfortunately they lacked some of the techniques now available for working with reactive fluorides. Had they possessed them, the noble elements would have lost their nobility and the chapter in chemical textbooks on the inertness of these elements would have been corrected long ago.

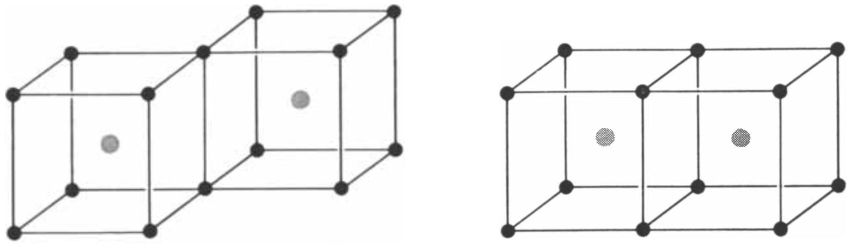
The successes with xenon launched attempts to produce compounds of the other noble gases. Radon, which has a lower ionization potential than xenon, should react with fluorine even more readily; indeed, it might even form compounds with chlorine. Unfortunately radon's intense radioactivity presents severe obstacles to chemical experimentation. Its longest-lived isotope has a half-life of only about four days; as little as a millionth of a gram of it must be handled by remote control behind shielding, and its radiation tends to break up any chemical bonds as rapidly as they are formed. Nevertheless, experiments in heating trace amounts of radon with fluorine have established that it will form a fluoride, although it has not yet been determined which of the fluorides was produced. Further work with larger amounts of radon is under way.

The preparation of compounds of the lighter rare gases—krypton, argon, neon and helium—presents a different and more difficult problem. Substantially more energy is required to pull an electron away from those atoms than from xenon, and any compounds they form are likely to be unstable at room temperature. Fluorides of krypton ($KrF_2$ and $KrF_4$) have, however, been produced in several laboratories by means of electric discharges or ionizing radiation applied to mixtures of the two elements chilled to a low temperature by liquid nitrogen. At room temperature these compounds break down into their constituent elements.

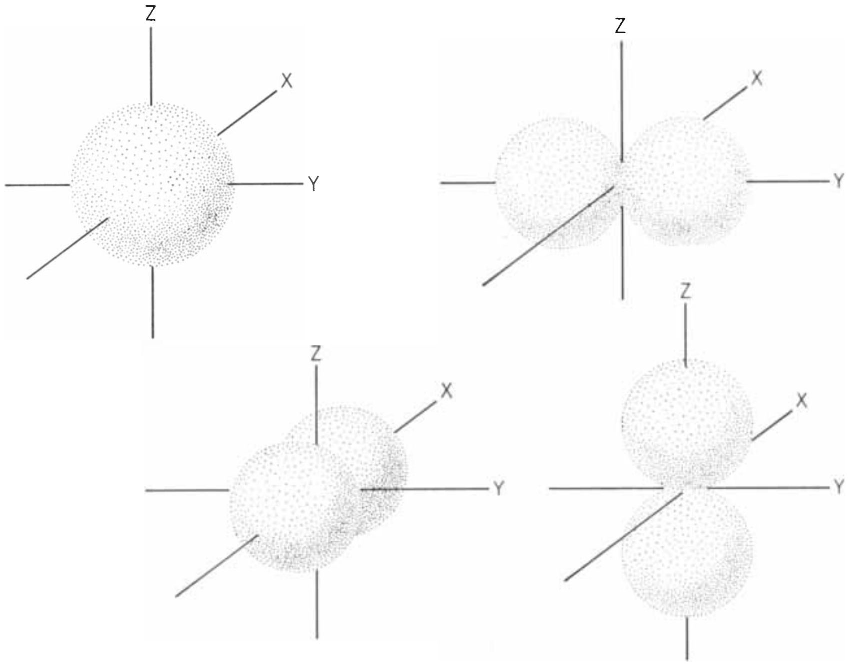
The chemistry of the noble gases, therefore, remains essentially the chemistry of xenon, at least so far. The chemical behavior of xenon has itself, however, provided excitement enough.

## The Chemistry of Xenon

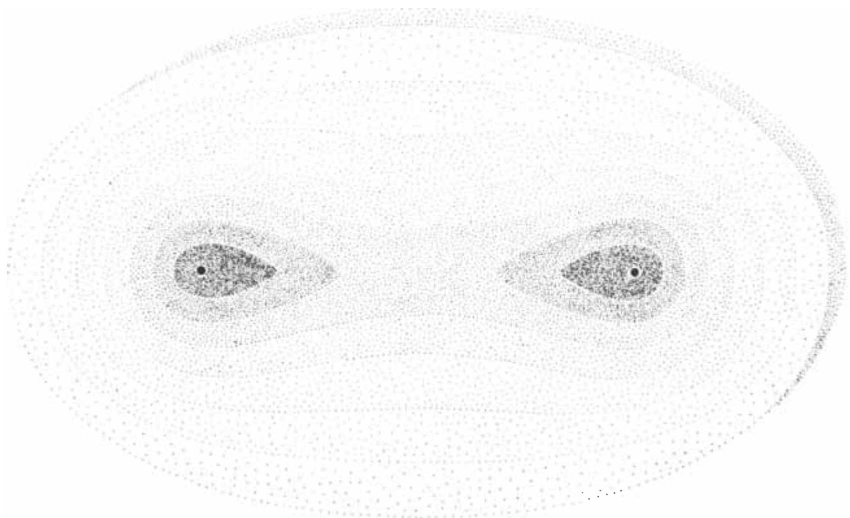
The three fluorides of xenon are formed in steps by successive additions of fluorine; that is, xenon combines with fluorine to form $XeF_2$, then $F_2$ is added to make $XeF_4$ and finally another addition of $F_2$ produces $XeF_6$. All three compounds are white solids at ordinary temperatures, except that xenon hexafluoride turns yellow above 42 degrees C. (about 108 degrees Fahrenheit). The hexafluoride is considerably more volatile than the other two fluorides, and it is yellow in the vapor form, whereas the others are colorless [*see top illustration on page 68*]. Chemically the hexafluoride is



**MODEL OF THE ATOM** proposed by Gilbert N. Lewis in 1916 pictured outer electron shell as a cube, with electrons located at corners and occupying all eight corners when shell was filled. In a singly bonded molecule such as fluorine (*left*) the two cubes would share an edge; in a doubly bonded molecule such as oxygen (*right*) they would share a face.




**ELECTRON-CLOUD MODEL OF THE ATOM** was developed during the 1920's to satisfy the requirements of quantum mechanics. The density of the cloud at any given point represents the probability of finding the electron at that point. Each electron cloud, or orbital, is occupied by one or two electrons. The 1*s* orbital (*top left*) is spherical around the origin. Other three pairs are *p* orbitals and are directed along different axes in space.



**ELECTRON CLOUD OF HYDROGEN MOLECULE** ($H_2$) is distributed symmetrically around the two nuclei. The gradations in shading indicate the relative probabilities per unit of volume of finding the two electrons; the darker the shading, the higher the probability.

by far the most reactive of the three.

Each of the xenon fluorides easily reacts with hydrogen and is reduced to elemental xenon, the fluorine being removed by the formation of hydrogen fluoride. This reaction enabled us to confirm the identification of the three fluorides when we first prepared them. Another interesting reaction that was soon discovered is that of xenon hexafluoride with silica ($SiO_2$). This reaction goes: $2\ XeF_6 + SiO_2 \rightarrow 2\ XeOF_4 + SiF_4$. The xenon product is called xenon oxytetrafluoride. It is a volatile liquid at room temperature.

The most interesting aspect of the chemistry of the xenon fluorides is their reaction with water. In the case of the difluoride the products of hydrolysis are simply xenon, oxygen and hydrogen fluoride. The reactions of xenon tetrafluoride and xenon hexafluoride with water, however, yield an exotic new compound: xenon trioxide ($XeO_3$). It is a colorless, nonvolatile solid. The substance turned out to be dangerously explosive. Before this fact was recognized it led to several laboratory explosions, fortunately none of them serious. Since then workers with the xenon fluorides have taken care to store and handle them under scrupulously dry conditions, lest they take up water and inadvertently form the trioxide. In solution xenon trioxide is stable and presents no hazard; it becomes explosive only when the water evaporates and the trioxide is left in the dry, solid state.

At this point the chemistry of xenon begins to show striking resemblances to the chemistry of the halogens (iodine, chlorine and so on), which occupy the adjacent column in the periodic table. Like xenon, the halogens also form unstable and highly reactive oxides. Investigations suggested by this similarity have disclosed other analogies, as well as differences, between compounds of xenon and those of the halogens.

In xenon trioxide the xenon atom has a valence of six. Solutions of this compound in water are called xenic acid. The analogous compound of iodine ($HIO_3$) consists of hydrogen and iodate ions ($H^+$ and $IO_3^-$) and is a strong acid. The xenic acid molecule, on the other hand, does not dissociate into ions; consequently it is a weak acid. In this respect it is much more like the acid of tellurium, on the other side of iodine in the same row of the periodic table: there is no evidence for the existence of ions in telluric acid.

As might be expected, in view of the weakness of the xenon-oxygen bond, a solution of xenon trioxide is a strong oxidizing agent: it will liberate chlorine from hydrochloric acid ($HCl$) and oxidize the iodides to iodine. Xenon emerges from these reactions as the elemental gas. A solution of xenon trioxide can act as an oxidant without the introduction of foreign ions into the system; the only other oxidant known to possess this property is ozone gas ($O_3$). Xenon trioxide is so ready to give up its oxygen that in a strongly basic solution it seems to decompose, although slowly, into xenon and oxygen, possibly by oxidizing the water.

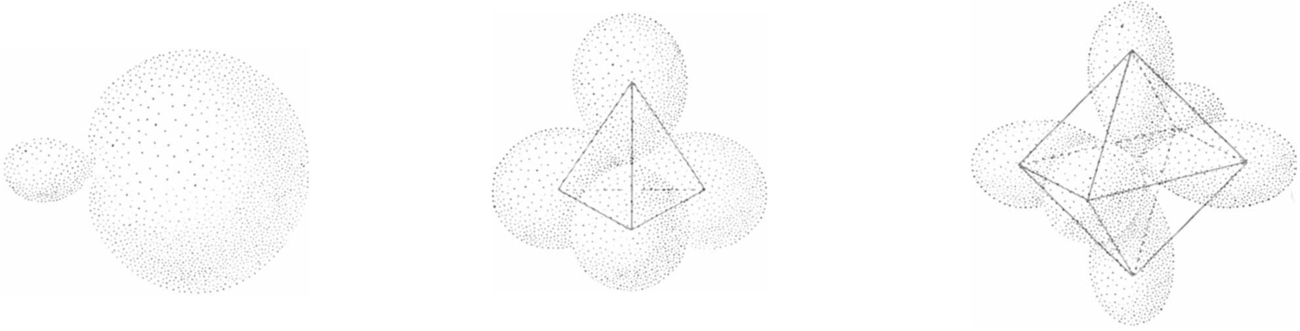
One of the properties that xenon shares with the halogens is that in a basic solution of the oxide the xenon atoms will undergo "disproportionation." This is a reaction that changes the valence state of the atoms, some emerging with a higher valence and some with a lower valence than in the original compound. An example in the halogen family is the breakdown of the chlorate ion ($ClO_3^-$), where the valence of chlorine is five, into a chloride ion, with a valence of minus one, and ions of perchlorate, in which the chlorine has a valence of seven, the maximum for this element: $4\ ClO_3^- \rightarrow Cl^- + 3\ ClO_4^-$. Xenon disproportionates in a similar manner. For example, xenon trioxide, reacting with the hydroxyl ion ($OH^-$) in an alkaline solution, gives rise to free xenon, essentially in the zero valence state, and a perxenate, where the valence of the xenon atom is eight, the highest that xenon (or any element) can have: $4\ XeO_3 + 12\ OH^- \rightarrow Xe + 3\ XeO_6^{-4} + 6\ H_2O$. Octavalent xenon can also be produced by bubbling ozone gas through a strongly basic solution of hexavalent xenon.

Perxenates (compounds of octavalent xenon) have already been produced in several stable varieties. One is the sodium salt ($Na_4XeO_6$ with perhaps some $H_2O$ molecules attached). Other metal perxenates have also been identified. Some of these salts are rather insoluble. The soluble perxenates have been found to be stable only in strongly alkaline solutions.

The outstanding property of the perxenates is their oxidizing power: they are probably the most powerful oxidizing agents known. This property alone will make them quite useful in organic and inorganic chemistry. They will undoubtedly be stocked before long on the reagent shelves of many laboratories. Similarly, the xenon fluorides, although they are more difficult to handle, will be used as fluorinating agents; they have the advantage that, after they have donated their fluorine, their volatile remains (xenon and the difluoride and tetrafluoride) can easily be pumped away.

## The Basis of Noble-Gas Chemistry

Let us now consider the theoretical aspects of noble-gas chemistry. The discovery of the first noble-gas compounds at once aroused chemists to a re-examination of the theory of the chemical bond. How could the existence of these compounds be reconciled with the "closed shell" picture of the noble gases? Were the compounds formed by some



**HYBRID ORBITALS are produced by the *s*, *p* and *d* electrons in the outer shell of an atom. According to the valence-bond hypothesis, any or all of these electrons can participate in the formation of a chemical bond. An *sp* hybrid orbital is at left, tetrahedral $sp^3$ orbitals in center, octahedral $sp^3d^2$ orbitals at right. Molecules are formed when two orbitals containing one electron each overlap.**

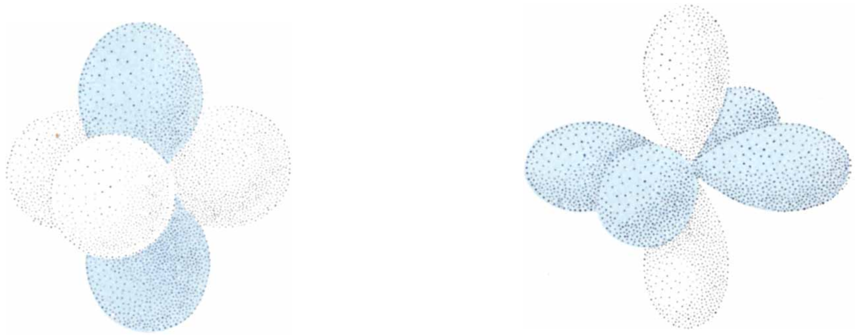
exotic kind of bond, some freakish arrangement of bonding electrons that had unusual properties?

Chemists at a number of laboratories, principally the national laboratories of the Atomic Energy Commission, probed the structure of the xenon compounds with a wide array of tools: infrared and Raman spectroscopy, X rays, neutron beams, nuclear magnetic resonance and even the Mössbauer effect (resonance absorption of gamma rays of sharply defined energy). The probing produced no surprises: there was nothing at all unusual about the bonding of the xenon compounds. In bond length (the distance between two atoms linked by a bond), in the strength and stiffness of the bonds and in the shape of the molecules, the xenon fluorides proved to be very similar to the fluorides of iodine, xenon's neighbor in the periodic table.

To understand the specific character and patterns of the bonds formed by noble-gas compounds, it has been necessary to take a new look at the chemical bond in its quantum-mechanical aspect.

The modern view of the chemical bond owes much to a famous paper, "The Atom and the Molecule," published in 1916 by the chemist Gilbert N. Lewis. On the basis of the newly emerging picture of atoms as consisting of shells of electrons around a central nucleus, Lewis showed how the electrons could form bonds between atoms. Consider, as a simple case, the lithium and fluorine atoms. Lithium has two electrons in the first shell, which can hold no more than two, and a third electron starting the next shell. Fluorine, on the other hand, has seven electrons in the same shell—one short of the number (eight) that would complete this shell. Lithium will give up an electron relatively easily and fluorine will gain in stability by receiving an electron. Together the two atoms can form a stable combination by the transfer of lithium's outer electron to the fluorine, which effectively will fill the fluorine atom's outer shell and leave the lithium atom with just the filled two-electron shell. By giving up an electron, lithium becomes a positive ion; that is, it now has a net positive charge, because the three units of positive charge in its nucleus are no longer balanced by three units of negative charge. Similarly, the fluorine atom becomes a negative ion by virtue of its extra electron. As a result the lithium and fluorine atoms are bonded together by the electric attraction of their opposite charges. Lewis named this the "ionic" bond.

Obviously the ionic bond could not explain all the cases of chemical bonding. Again fluorine offers a simple illustration. Two fluorine atoms unite to form the fluorine molecule ($F_2$). This is a considerably more stable arrangement than the fluorine atom alone; in fact, except under special circumstances fluorine atoms are never found in the single state. The bond that ties two fluorine atoms together is plainly not ionic. All fluorine atoms have an equally strong affinity for electrons—an equally strong disposition to acquire an electron to fill the outer shell. If one fluorine atom drew an electron from another, leaving the latter with only six in its outer shell, the situation would still be unstable: the combination would not last. Examination shows that in fact neither atom in the fluorine molecule is ionized. Lewis hypothesized that the two atoms "share" electrons: each uses one electron belonging to its partner to complete its own outer shell. Thus, by sharing two electrons mutually, one donated by each partner, both atoms in the molecule effectively have filled outer shells and form a stable combination. Lewis called this sort of arrangement a "covalent" bond. He extended the idea to the sharing of more than two electrons. For example, in the molecule of oxygen ($O_2$), whose atoms have only six electrons in the outer shell, the two atoms must share four electrons to fill the shells of both.



**XENON HYBRID ORBITALS** for xenon difluoride (*left*) and xenon tetrafluoride (*right*), predicted by the valence-bond model, agree with the observed structure of these compounds. The white orbitals contain two electrons each and are called "lone pairs"; they do not participate in the bonding. The colored orbitals contain one electron each and overlap with fluorine orbitals (not shown here), which also contain one electron each, to form "shared pairs." In xenon difluoride the five xenon orbitals resemble a triangular double pyramid with the three lone pairs disposed in a plane bisecting the molecule. In xenon tetrafluoride the four shared pairs lie in a plane with the lone pairs above and below the plane.

It was not easy to see precisely how the shared electrons could constitute a bond. Reasoning from the fact that the outer shell of every atom (except helium) had room for just eight electrons, Lewis drew a model of the atom that pictured the shell as a cube, with the electrons positioned at the corners and occupying all eight corners when the shell was filled. In a singly bonded molecule such as that of fluorine the two cubes would share an edge; in oxygen they would share a face [*see top illustration on page 71*]. This model failed to cover the case of molecules that had triple bonds or those in which the atoms were rotated or twisted around a single bond. It was so successful, however, in explaining many of the observed features of chemical combination that the model was considered basically sound.

## Quantum-mechanical Models

Simplicity soon had to give way, however, to the complexities that came with the quantum picture of the atom developed in the 1920's. The new picture had the electrons in rapid orbital motion around the nucleus; the motions of the electrons now had to be described by differential equations; the solutions of such equations are so difficult that no one has yet been able to arrive at a precise description of the motions for more than three particles, and a simple molecule such as $O_2$, counting its two nuclei as just two particles, has a total of 18 particles! What is more, it is impossible, according to the uncertainty principle of quantum mechanics, to describe the exact motions or orbit of even a single electron. It can only be pictured as a cloud, the density of the cloud at any given point representing the probability of finding the electron at that point.

The electron cloud is called an orbital. Roughly speaking, it can be described as the electron's region of influence. A given orbital has a certain shape and direction. The exclusion principle says that each orbital may be occupied by one or two electrons; if two, they must be of opposite spin. That is, the orbital may be either "singly occupied" or "filled" with two electrons. The orbitals themselves are determined by certain quantum numbers that represent the shells and subshells of electrons: the shell number indicates the orbiting electron's average distance from the nucleus and its energy level; the subshell number (expressed as the letter *s*, *p*, *d* or *f*) determines the electron's angular momentum and the shape of its orbit. The first shell (the one closest to the nucleus) has only one subshell (*s*) with just one orbital, which contains one electron in the case of hydrogen and two electrons in all higher elements. The second shell consists of an *s* subshell, limited to two electrons, and a *p* subshell with three orbitals, so that it may have as many as six electrons. Thus the second shell as a whole contains a total of eight electrons when it is filled in the element neon (which, in electronic terms, is described as $2s^2 2p^6$). The exclusion principle prohibits any two orbitals from having the same direction; as a consequence the three *p* orbitals must be arranged in directions perpendicular to one another, namely, along the $x$, $y$ and $z$ axes in three-dimensional space [*see middle illustration on page 71*].

This picture describes the situation in individual atoms. When atoms are combined in molecules, the picture becomes much more complicated. Now the electronic orbitals are not centered on just one nucleus but are influenced by all the nuclei of the molecule. In the simple case of the hydrogen molecule the electron cloud is spread symmetrically around the two nuclei [*see bottom illustration on page 71*].

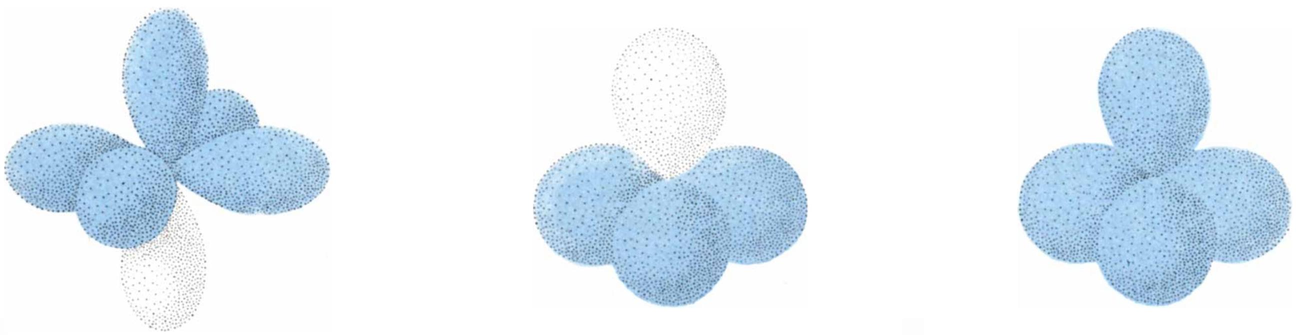
The present view of chemical bonding, then, calls for a description of the bonds in terms of the interaction or combination of electron orbitals. To do this quantitatively, so that bond strengths and the shapes of molecules can be predicted accurately, involves extremely elaborate calculations for any molecule more complicated than that of hydrogen. Theoretical chemists have been working on the problem from two different approaches. One of these, a quantitative method, attempts to describe the xenon fluoride molecules on the basis of molecular orbitals formed by combinations of the *p* electrons in the outermost shells of the xenon and fluorine atoms (that is, the electrons in the $5p$ subshell of xenon and the $2p$ subshell of fluorine). The other approach, called the valence-bond method, gives a picture that is not quantitative; nevertheless, it has proved to be a very useful model and has accurately predicted the structure of those xenon fluorides whose shapes have been definitely ascertained so far.

## Valence Bonds

The valence-bond description is an extension of Lewis' concept of the sharing of pairs of electrons between atoms; the sharing is now reinterpreted in the light of the motions of the electrons and the rules of quantum mechanics. The new scheme pictures the chemical bond as an overlapping of two atomic orbitals, each of which is occupied by one electron; in other words, singly occupied, or half-filled, orbitals. For instance, two hydrogen atoms form a molecule by overlapping the orbitals of their respective single electrons. Whenever two such orbitals overlap, an attractive, or binding, force results. The strength of the bond depends on the amount of overlap: the greater the overlap between two atoms, the stronger the bond. On the other hand, when two filled orbitals (each containing two electrons) overlap, they repel each other, and the force of repulsion tends to push such atoms apart when they are present in the same molecule by virtue of other overlapping orbitals that bind them. Because the pair of electrons in such an orbital cannot take part in the sharing that forms a bond, it is called a "lone pair," as opposed to the "shared pair" consisting of the two single electrons in bonding orbitals.

In the new picture the ionic bond and the covalent bond are no longer two distinctly different types. Whether a bond will be ionic or covalent or something in between depends simply on where the two electrons involved spend their time. If they spend all their time near one atom, the bond is ionic; if they divide their time equally between the two atoms, it is covalent. In most actual cases the character of the bond is somewhere between these extremes, the electrons tending to favor one of the atoms but not spending all their time there.

The valence-bond picture can account in a simple way for the shape of the water molecule. The oxygen atom has three $2p$ orbitals, extending in directions perpendicular to one another. Oxygen has four *p* electrons; consequently one of its three *p* orbitals contains two electrons (and is thereby filled) and each of the other two orbitals has only one electron. In the water molecule these two oxygen orbitals are overlapped by the singly occupied orbitals of two hydrogen atoms. The two bonds would be at right angles to each other were it not for the fact that the bonds are partly ionic. Be-



**THREE OTHER XENON COMPOUNDS are portrayed here according to the valence-bond model. In xenon oxytetrafluoride (*left*) the six xenon orbitals are disposed octahedrally. The four orbitals in the plane bisecting the molecule overlap with fluorine orbitals (not shown here) to form shared pairs. The orbital at the top, opposite the lone-pair orbital, overlaps with an oxygen orbital (not shown), forming another shared pair. In the two oxides of xenon, xenon trioxide (*center*) and xenon tetroxide (*right*), the orbitals assume tetrahedral configurations. In xenon tetroxide all four xenon orbitals overlap with oxygen orbitals (not shown), whereas in xenon trioxide one of the bonding orbitals is replaced by a lone pair. Each of these three xenon compounds has an iodine analogue.**

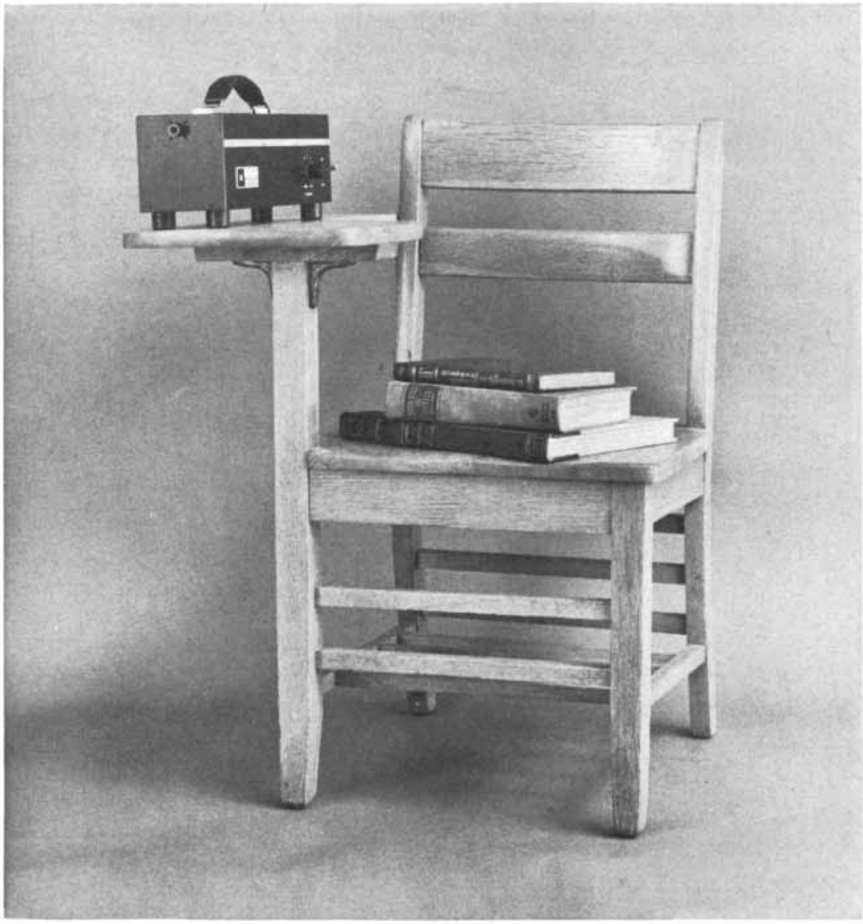
cause the two hydrogens have slight net charges they push each other apart so that the angle of the bond is greater than 90 degrees. The angle, as measured, is 104.5 degrees.

This theoretical explanation of the shape of the water molecule is actually oversimplified. According to the valence-bond hypothesis, any or all of the electrons in the outer shell (the *s* and *d* electrons as well as the *p*) may participate in the formation of bonds. They combine to produce what chemists call hybrid orbitals. (Strictly speaking, what are combined are the Schrödinger wave functions that define the orbitals.) Hybrid orbitals have the property of extending out in one direction more than pure *p* and *d* orbitals; therefore they allow more overlap in bond formation [*see illustration on page* 72]. In these terms the water molecule involves all six of the electrons (*s* and *p*) in oxygen's outer shell. These occupy four hybrid orbitals, two of which contain unshared pairs (lone pairs) of electrons whereas the other two are occupied by single oxygen electrons paired with the single hydrogen electrons. In this structure, with four orbitals instead of three, the angle between the two bonds should be 109.5 degrees if there is no disturbing force. Actually the lone pairs, as we have noted, repel each other, and this force of repulsion is stronger than the repulsive force between the hydrogens. As a result the angle between the bonds is reduced to 104.5 degrees.

## The Bonding of Noble Gases

Now suppose we apply the valence-bond concept to the question of how the noble gases may be bonded in compounds. Because in these atoms the outer electron shell is filled, they can combine with other atoms only by sharing electrons; that is, the bonds must be covalent rather than ionic. And in the xenon fluorides the valence shell of shared electrons must contain more than eight electrons, contrary to the old idea that eight is the maximum for a completed shell.

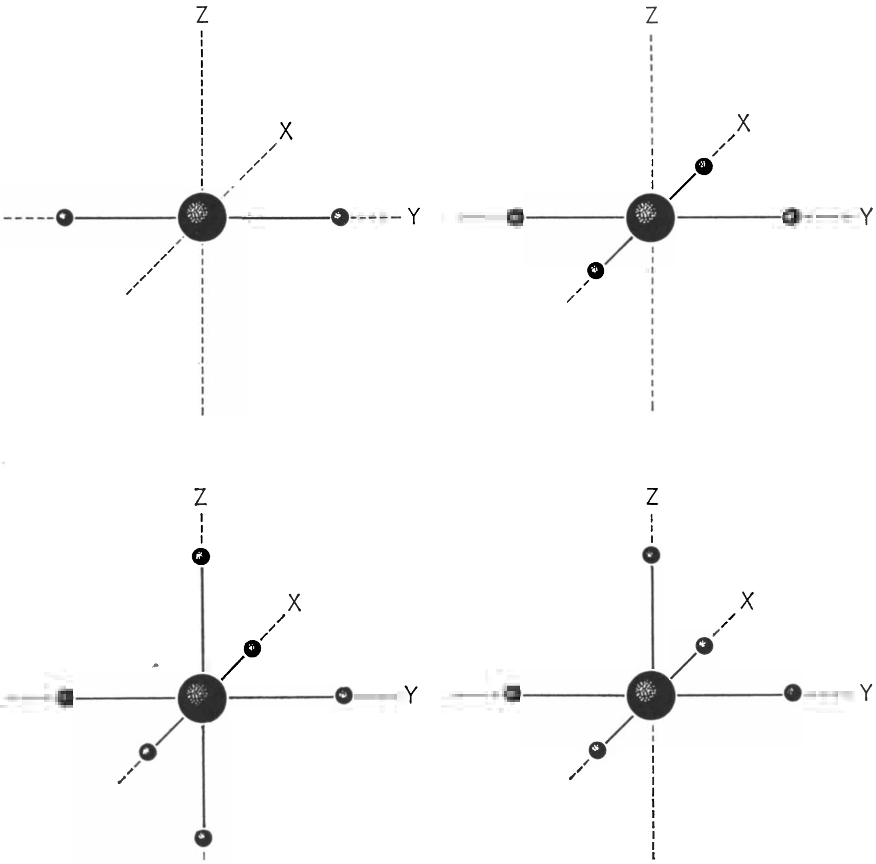
Actually it has long been known that there are very stable compounds in which atoms share a total of as many as 12 electrons. The sulfur fluoride molecule ($SF_6$) is such a compound. The six electrons in the outer shell of the sulfur atom pair up with electrons from the six fluorine atoms to form a stable shell of 12 electrons around the sulfur. Here we have six hybrid orbitals, extending out from the central atom and producing a molecule with an octahedral shape. Six orbitals are possible because there



are *d* electrons available, along with the *s* and *p*, to participate in the hybridization. Hybrid orbitals of this kind (denoted $sp^3d^2$) are very common.

From the fact that the xenon tetrafluoride molecule has 12 electrons in the valence shell (eight from xenon and four from the four fluorine atoms) the valence-bond model predicts that the molecule must have an octahedral shape. The four fluorine atoms, linked to the central xenon atom by shared pairs of electrons, should be at the corners of a square, and xenon's four remaining valence electrons should form two lone (unshared) pairs, which, because such pairs repel each other, should be separated, one above and one below the plane of the square. On the basis of the same considerations, the xenon difluoride molecule should have the structure of a double pyramid, with the xenon atom in the center, the two fluorine atoms in a line at the apexes of the pyramids and the three lone pairs of xenon electrons at the corners of a triangle around the middle, that is, as far apart from one another as possible [*see illustration on page 73*]. The spectroscopic examination of these molecules has confirmed that their structures are actually as the model predicts.

The concept of hybrid orbitals accounts in a general way for the fact that the lighter noble gases do not form stable compounds. Energy must be supplied to produce hybrid orbitals, because the electrons must be raised to a higher energy state. In the case of xenon this energy requirement apparently is more than compensated by the energy gain resulting from overlapping of the hybrid orbitals in compounds, so that the compounds are stable. The lighter noble gases, with higher ionization potentials, probably require more promotional energy for hybridization. If this requirement is greater than the gain




SYMMETRICAL ARRANGEMENT OF ATOMS in the simple xenon compounds is evident in these drawings. The molecules shown are xenon difluoride (*top left*), xenon tetrafluoride (*top right*), xenon hexafluoride (*bottom left*) and xenon oxytetrafluoride (*bottom right*). The large balls in each case are the nuclei of xenon atoms; all the small balls are fluorine nuclei, except for the one at the top of xenon oxytetrafluoride, which is an oxygen nucleus. According to the valence-bond model the structure of xenon hexafluoride is not symmetrical but distorted. The structure shown here is drawn from a calculation of molecular orbitals and is identical with the structure of the 15 other hexafluoride molecules.

from overlapping, the compound cannot be stable. That would explain why compounds of krypton, a lighter gas than xenon, are comparatively unstable and compounds of the still lighter noble gases have not been detected at all.

It cannot be contended that the valence-bond model gives a full or definitive description of the bonding in xenon compounds. We believe, however, that it is a useful theory, particularly as it has disclosed and clarified the similarities between the compounds of xenon and those of the halogen family of elements, the next-door neighbors of the noble gases in the periodic table. Their electronic relationship is actually quite close in terms of the valence-bond picture. For example, the chloride ion ($Cl^-$) has a total of 18 electrons, counting its extra one, and the argon atom has the same number. The configuration of the electrons is virtually the same in both cases. This means that if argon could be coaxed into combination with oxygen, it would form a "perargonate" ($ArO_4$) analogous to the perchlorate ion ($ClO_4$). Chemists have already identified a perxenate ($XeO_4$) that is analogous to and has the same number of electrons as the well-known periodate ion ($IO_4$).

As we have noted, the valence-bond model is only one of the methods that have been invoked to study the bonding of the noble gases. The other main approach has been based on quantitative calculation of molecular orbitals. Both the molecular-orbital calculations and the valence-bond model agree in predicting the structures for xenon difluoride and xenon tetrafluoride that have actually been observed. The two approaches differ, however, in their predictions about the molecular geometry of xenon hexafluoride. According to the molecular-orbital scheme, this molecule should be a symmetrical octahedron; according to the valence-bond concept, the octahedron must be distorted because of the presence of an extra unshared pair of electrons [*see illustration on opposite page*]. The compound is difficult to examine spectroscopically because it is so reactive that it attacks the windows needed to pass light through its container, but when and if its structure is finally established by spectroscopic or other methods, the issue between the two models may be resolved.

In any event, the noble gases have given birth to an exciting new chemistry, which turns out to be not so very different from the chemistry of the more common elements.

# Dwarf Galaxies

*The most common type of galactic system in the universe, these sparsely populated stellar assemblages have proved to be very useful in investigating the evolution of galaxies*

by Paul W. Hodge

During the 1920's, when the development of large reflecting telescopes first enabled astronomers to discriminate reliably between gaseous nebulae within our galaxy and other galaxies outside it, it was widely believed that galaxies were all roughly of the same size, mass and intrinsic luminosity. A few, such as the nearby spiral galaxy in the constellation of Triangulum, appeared to be appreciably smaller than the average, and others, such as the even closer spiral in Andromeda, appeared to be unusually large. Two or three tiny, irregular systems were also known to exist. On the whole, however, the external galaxies did not seem to differ greatly. Indeed, one method of estimating the distance of these objects was based on the assumption that they are almost all of equal intrinsic luminosity.

In 1938, however, Harlow Shapley, working with photographic plates made at the Harvard College Observatory's Boyden Station in South Africa, discovered two extremely faint, elliptical objects in the southern sky. He named them the Sculptor and Fornax systems, after the constellations in which they were found. Further study showed that they were independent stellar systems whose total luminosity was less than a thousandth of the luminosity of our galaxy. Although they contained about as many stars as the larger globular clusters in our galaxy, their linear dimensions were much greater than those of any globular cluster. In other words, they were very sparsely populated with stars and therefore inconspicuous.

The discovery of these dwarf galaxies came as something of a surprise to proponents of the idea that galaxies are all more or less the same. Both the Sculptor and Fornax systems are quite close to our galaxy. Since they were so inconspicuous, it seemed reasonable at the time to suppose that extragalactic space is heavily populated with similar systems too faint to be detected. Subsequent observations have made it abundantly clear that this is the case. As more powerful telescopes have been put into operation, more and more of these faint systems have come into view, with the result that astronomers now believe dwarf galaxies are the most common type of galactic system in the universe.

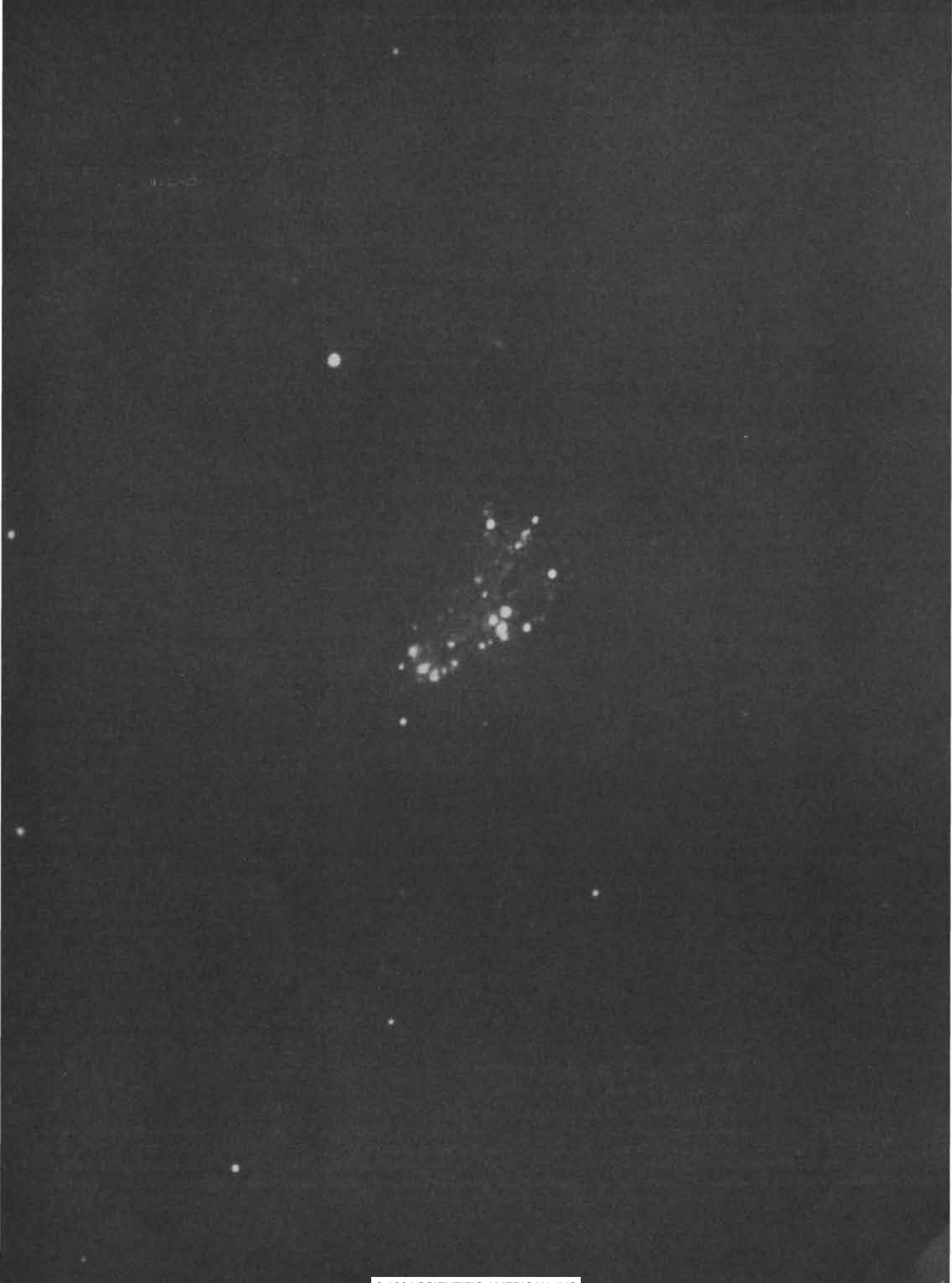
In addition to their obvious importance to the study of how matter is distributed in the universe, dwarf galaxies have proved to be valuable subjects for the study of the evolution of galaxies, the structural and dynamical properties of galaxies and the gravitational interactions between galaxies. In all of these investigations the chief advantage of studying dwarf galaxies is their simplicity compared with the more extensive and more thickly populated galaxies.

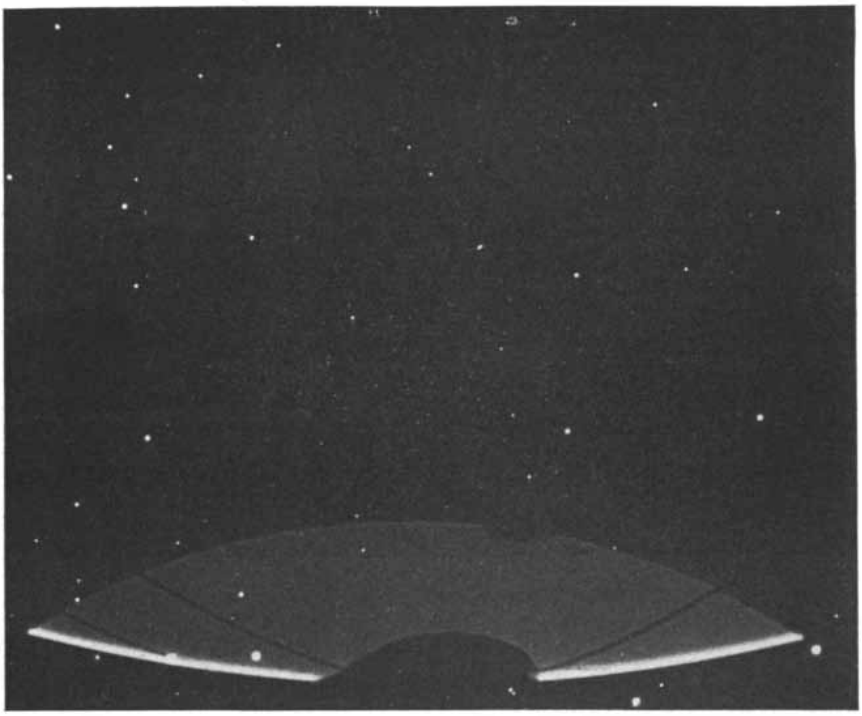
Although the Sculptor and Fornax systems are smoothly elliptical in shape, many dwarf galaxies have no apparent symmetry. Several of these irregular dwarf systems have been intensively investigated with the large telescopes of the Lick, Mount Wilson and Palomar observatories in California. They have been found to differ from the Sculptor and Fornax systems not only in their shape but also in their stellar content. The irregular systems contain many stars that are bright and blue, indicating that the stars are very hot and comparatively young, whereas the smooth, elliptical systems contain only old stars.

In 1948, when the wide-field 48-inch Schmidt telescope went into service on Palomar Mountain, its first task was to make a complete survey of the northern sky. One of the most exciting by-products of this survey was the discovery by R. H. Harrington and Albert G. Wilson of four more dwarf galaxies of the Sculptor type. The new dwarfs were named, after the constellations in which they were found, the Leo I, the Leo II, the Draco and the Ursa Minor systems. All four are sparsely populated and remarkably inconspicuous; two are difficult to perceive even on plates made with the largest telescopes. An accurate distance is known only for the Draco system. Walter Baade and Henrietta H. Swope, using photographic plates and measurements made with a photoelectric light meter attached to the 200-inch Palomar telescope, gauged its distance to be some 330,000 light-years. Using a less accurate technique, Baade found that the distance to the Ursa Minor system was roughly the same. For the two dwarf systems in Leo, only crude approximations are possible, placing them at a distance of some 750,000 light-years.

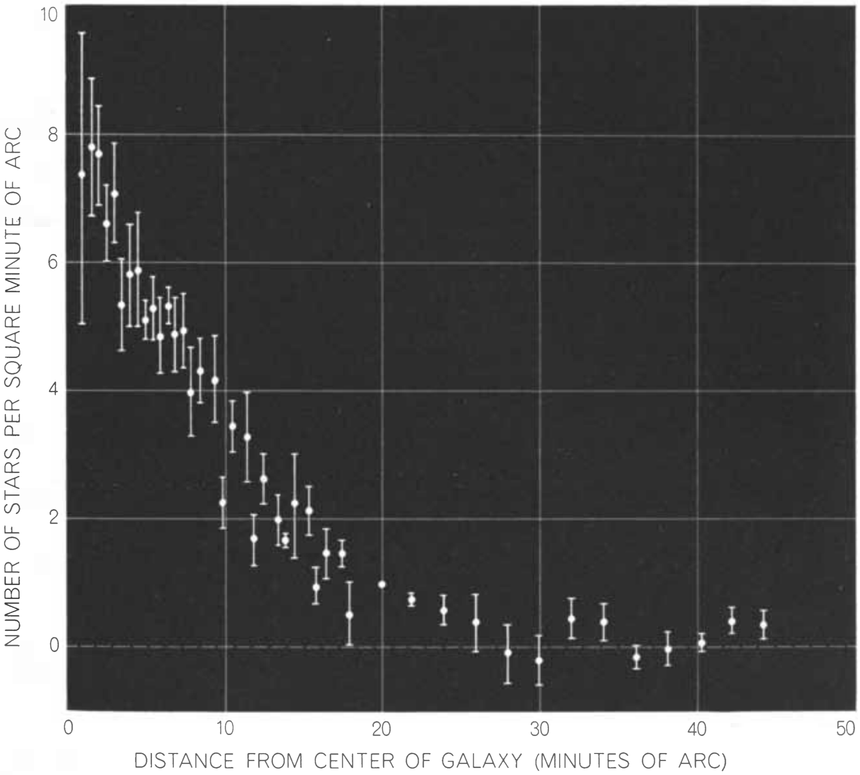
The discovery of the four new systems brought the total number of nearby dwarf galaxies to 10 and demonstrated that such systems dominate the volume of space around our galaxy to a distance of more than two million light-years. The possibility still existed, however, that the preponderance of dwarf systems among the local group of galaxies was not representative of the distribution of galaxies throughout the

**IRREGULAR DWARF GALAXY in the constellation of Virgo was photographed with the 120-inch reflecting telescope at the Lick Observatory in California. This tiny system appears to have a diameter of only a few hundred light-years; its exact distance and hence its exact size are as yet unknown.**





**ELLIPTICAL DWARF GALAXY** in the constellation of Leo was also photographed with the 120-inch Lick reflector. The apparent position in the sky of this faint system is near the bright star Regulus, although of course the galaxy is vastly farther away. The bright, fan-shaped image below the galaxy is a reflection of Regulus produced inside the telescope.

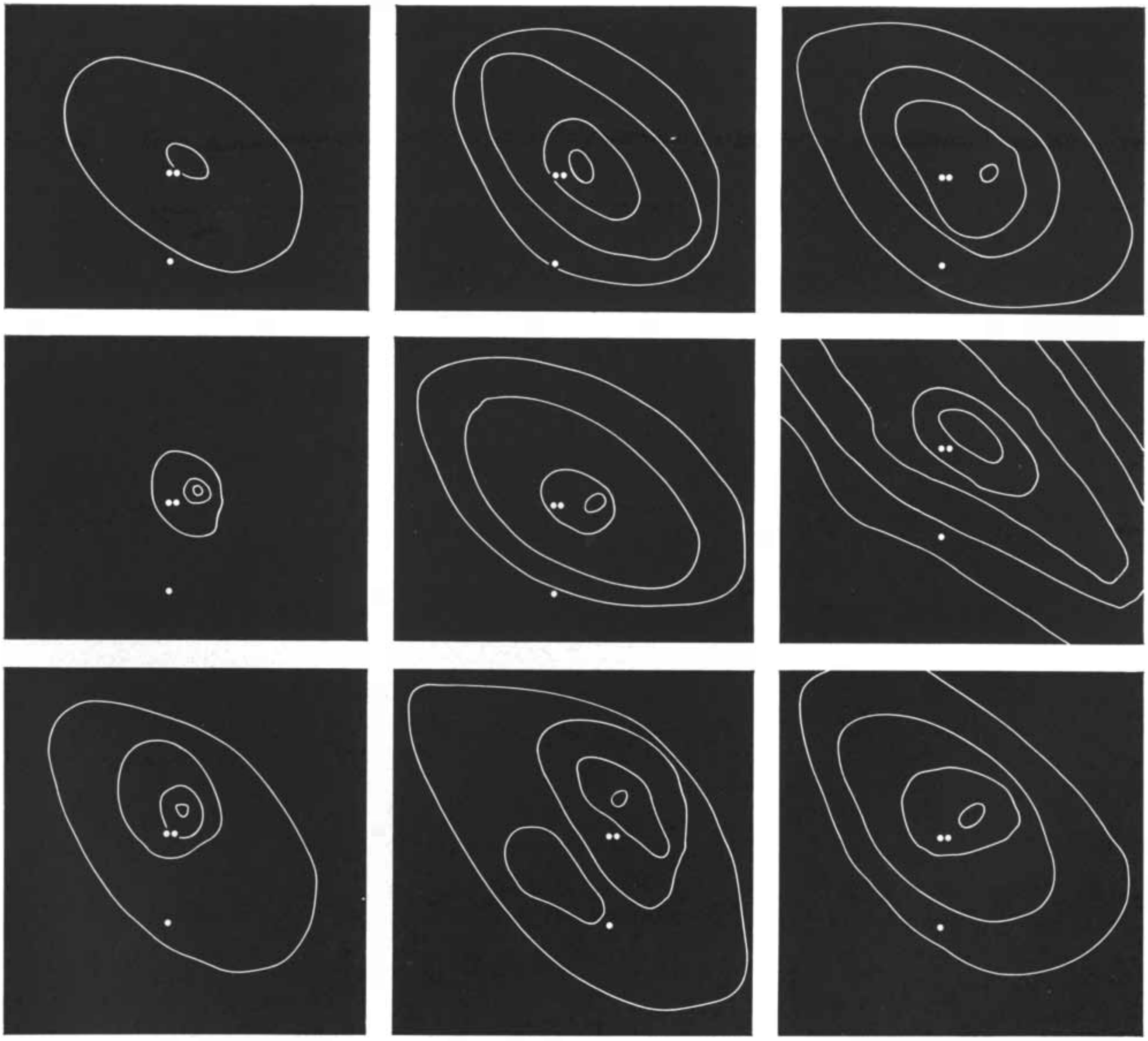



**DISTRIBUTION OF STARS** along the major axis of the Ursa Minor dwarf galaxy, a smooth, symmetrical system similar to the one in Leo, is shown in this chart. Only stars brighter than the 21st magnitude were counted. An average background count of about one star per square minute of arc was subtracted from the actual count; this explains the fact that some readings are less than zero. The approximate experimental error for each reading is indicated. Even the center of the Ursa Minor system has a very low stellar density.

entire visible universe. It was therefore with considerable interest that astronomers greeted the report in 1950 that Gibson Reaves of the Lick Observatory had detected large numbers of dwarf galaxies in the nearest large cluster of galaxies: the Virgo cluster. A complete census of the galactic population of the Virgo cluster has not yet been compiled, but the estimates made by Reaves and others prove beyond a reasonable doubt that in this large cluster, as in the local group of galaxies, there are many more dwarf galaxies per unit of volume than there are normal galaxies. In 1956 a similar study was made of another large, nearby cluster of galaxies: the Fornax cluster. (This should not be confused with the Fornax dwarf galaxy; although both are in the constellation of Fornax, they are separated by several degrees in the sky.) The ratio of dwarf systems to bright systems in the Fornax cluster was found to be at least five to one, with the likelihood that an even larger proportion of the fainter dwarfs had gone undetected. As a result of these and similar surveys, it now appears that dwarf galaxies are in a considerable majority among galaxies in general; according to one hypothesis the actual ratio may be expressed by the statement that the density of galaxies in space increases exponentially with their decreasing luminosity.

The low stellar density of a typical dwarf galaxy presents the principal problem in detecting these systems; the same property, however, is also a major asset in analyzing the structure of the systems and the dynamical properties of stars within them; in a large galaxy the concentration of stars is often too dense for them to be examined individually. Knowledge gained from structural analyses of dwarf systems has in turn been applied to the general problem of the evolution of galaxies, a subject about which remarkably little is known. In particular, a comparison of the structures of the two main types of dwarf galaxy—the smooth, elliptical systems of the Sculptor type containing only old stars, and the ragged, irregular systems containing large numbers of young stars—has proved especially helpful in laying the groundwork for an investigation of the evolution of galactic systems.

Consider the structure of the Ursa Minor system, a typical symmetrical system of the Sculptor type. Star counts show that this system is essentially smooth and featureless; it is ellip-



**STAR CONTOURS, or "isodents," for the Ursa Minor dwarf galaxy indicate that there is a gradual decrease in the density of stars in this system outward from the center. Each contour line represents a stellar density one unit lower than the line just inside it. The nine pictures shown here are derived from counts of stars on seven different photographic plates. Because of the faintness of the stars in the Ursa Minor system, its exact shape is difficult to establish. The three white dots in each picture are conspicuous, "landmark" stars.**

tical in outline and the density of stars decreases smoothly outward from the center. Even at the center the stellar density is low: roughly one star per million cubic light-years, or less than a thousandth of the stellar density in the neighborhood of the sun. The stars in the Ursa Minor system are all about 10 billion years old; there seems to be little or no variation in star type over the entire galaxy. All this suggests that the Ursa Minor system is in an advanced stage of evolution. The symmetry and smoothness of the system indicate that any original irregularity in the distribution of mass throughout the galaxy has been erased by the passage of time.

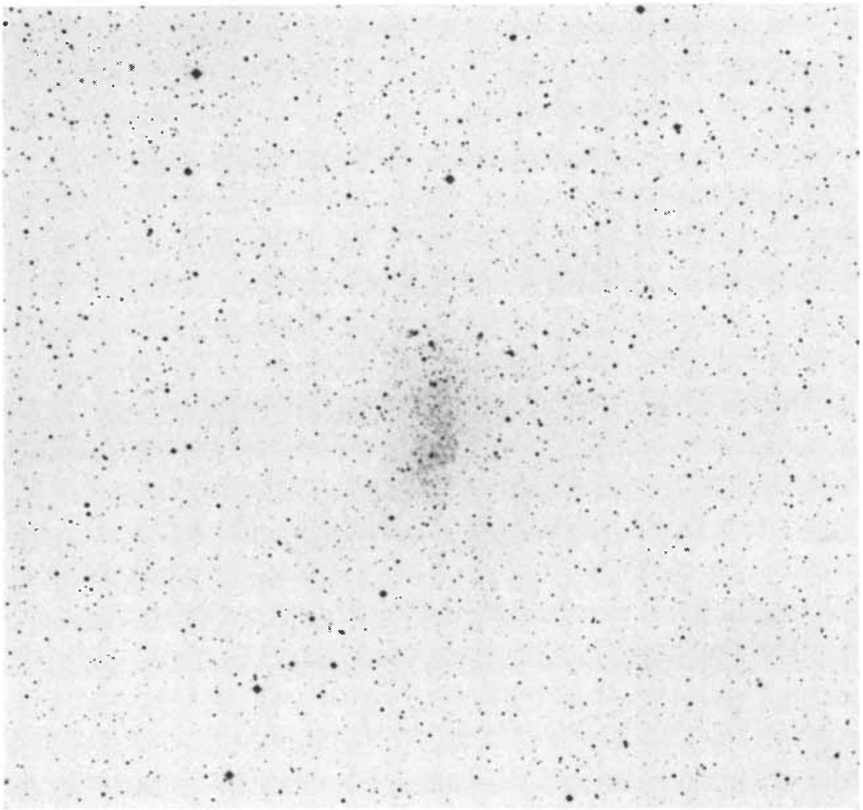
Although the present appearance of the Ursa Minor dwarf galaxy would thus seem to be explained simply by supposing that it is very old, the explanation has a serious flaw. Calculating the time it takes for a system as low in density as the Ursa Minor dwarf to "relax," or smooth out, by individual gravitational interactions of stars yields a figure of about 10,000 billion years. This is obviously much greater than the 10 billion years indicated by the system's stellar population and also greater than the currently accepted age of the universe (10 to 20 billion years). The disagreement can be resolved by assuming that the system must have smoothed itself out and reached a state of dynamical relaxation *before* its stars were born, while most of its mass was in the form of large clouds of gas. *After* this preliminary smoothing there must have been a period of fast and efficient condensation of stars out of the gas clouds, so that little or no gas remained. From then on the stars in the galaxy gradually evolved to their present state. There may well have been an original deficiency of massive stars compared with regions, say, in the neighborhood of the sun; massive stars are known to eject

DWARF COMPANIONS of two giant galaxies are barely visible in these photographs made with the 48-inch Schmidt telescope on Palomar Mountain. The dwarf galaxy in the top photograph is the faint patch at lower right. The giant elliptical galaxy is designated NGC 3377. The bright streak is a meteor trail. The dwarf galaxy in the bottom photograph is at bottom center. The giant spiral galaxy is designated NGC 2903; both dwarfs are unnumbered. In both photographs the giant galaxy and its dwarf companion are at about the same distance from the solar system, so that the photographs give a fairly accurate idea of their relative size.

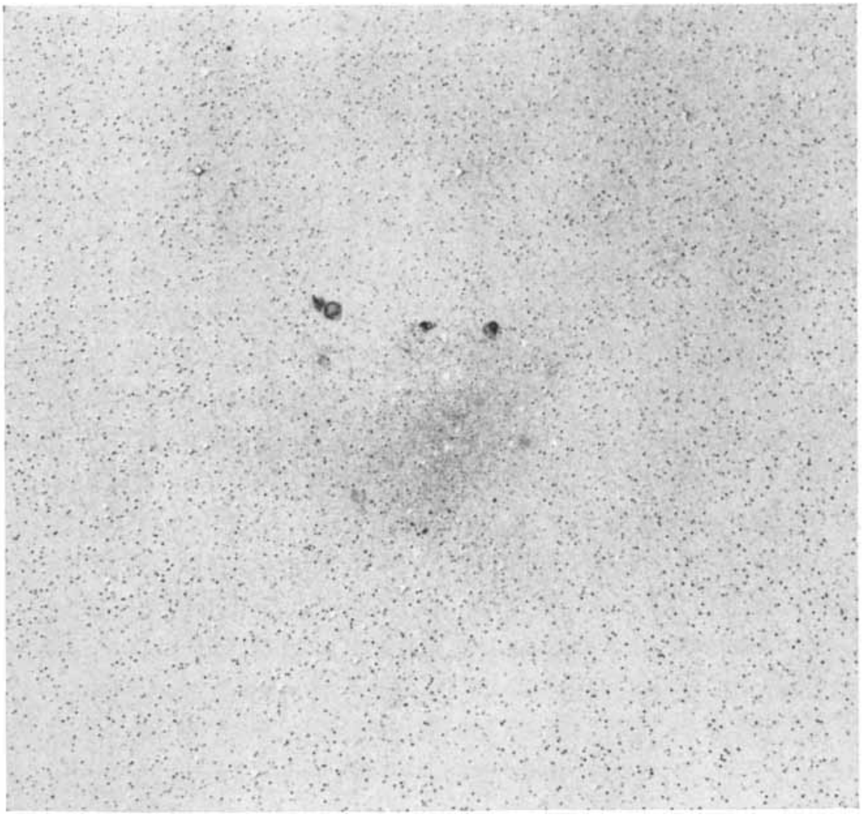
large amounts of gaseous material during the later stages of their evolution, but no evidence of such material has been detected in the Ursa Minor system.

A tentative scheme for the evolution of a dwarf galaxy of the Sculptor or Ursa Minor type is therefore as follows: A protogalaxy consisting of an irregular cloud of gas and probably some dust, with a mass of a little less than a million times that of the sun, existed in intergalactic space somewhat more than 10 billion years ago. Regions of the gas began to condense, dividing the primordial cloud into several smaller clouds. Collisions and interactions between these smaller clouds tended to smooth out the system and make it symmetrical. The collisions probably also speeded condensation in the clouds by redistributing the angular momentum of the protogalaxy's rotation. When the density in each cloud reached a critical limit, a star was formed. Virtually all the gas in the system was used in this burst of star formation, so that from then on no new stars were born. At present only stars with life expectancies of 10 billion years or more are visible, because all the more massive and more rapidly evolving stars have long since burned out and become dark masses of degenerate gas.

The evolution of a dwarf galaxy of the irregular type is probably quite different. As an example of this type, consider the case of IC 1613. (The letters IC stand for Index Catalogue, a supplement to the New General Catalogue of nebulae compiled late in the 19th century by the Danish astronomer Johan Ludwig Dreyer.) IC 1613 was first investigated in detail by Baade, who then devoted many years of study to it. The special attention given to IC 1613 by Baade and others has made it possible to reconstruct a probable evolutionary pattern for this galaxy. Unlike the Ursa Minor system, in which all the stars are very old, IC 1613 contains stars with a wide range of ages, including many young blue stars. By measuring the color and luminosity of the stars in the system and by submitting these quantities to the theoretical scheme of stellar evolution, it is possible to show that IC 1613 contains stars as young as a few million years as well as stars probably as old as those in the Ursa Minor galaxy (about 10 billion years). In principle it should be an easy matter to reconstruct the history of IC 1613 by assigning an age to each observable star and by assuming that the distribution of the observable stars is rep-



**NEGATIVE PRINT** of the irregular dwarf galaxy NGC 6822 was made with the 48-inch Schmidt telescope. Astronomers often use negative prints to accentuate fine details.



**POSITIVE AND NEGATIVE PRINTS** were superimposed to show gas clouds in NGC 6822 where stars are being formed. Positive recorded yellow light and shows stars as bright points. Negative recorded radiation from ionized hydrogen and shows clouds as dark objects.

resentative of the entire stellar population. In practice this requires a complete and accurate set of measurements of the luminosity and color of every observable star in the system, a job that is not impossible but that has not yet been carried out. Measurements have been made, however, of the luminosity of most of the system's brightest stars and of its overall color; these can be combined to construct a rudimentary history of the galaxy.

Like the smooth, elliptical dwarfs, IC 1613 probably originated as an irregular cloud of gas and possibly some dust. This material slowly condensed into small aggregates, probably smaller than those of the Ursa Minor system, and stars began to form in some of the aggregates. Not much can be ascertained about the middle age of the system, but the evidence suggests that the formation of stars continued at a roughly uniform rate. The last billion years or so of the galaxy's history can be reconstructed with greater confidence. Patches of new stars have burst out sporadically in various parts of the system all during this most recent period; today there are at least two regions in which extremely young stars can be found. Measurements of the overall color of IC 1613 indicate that the oldest stars, which are now red, are distributed in a fairly regular sphere, strongly suggesting that the stars are now thoroughly mixed throughout the system.

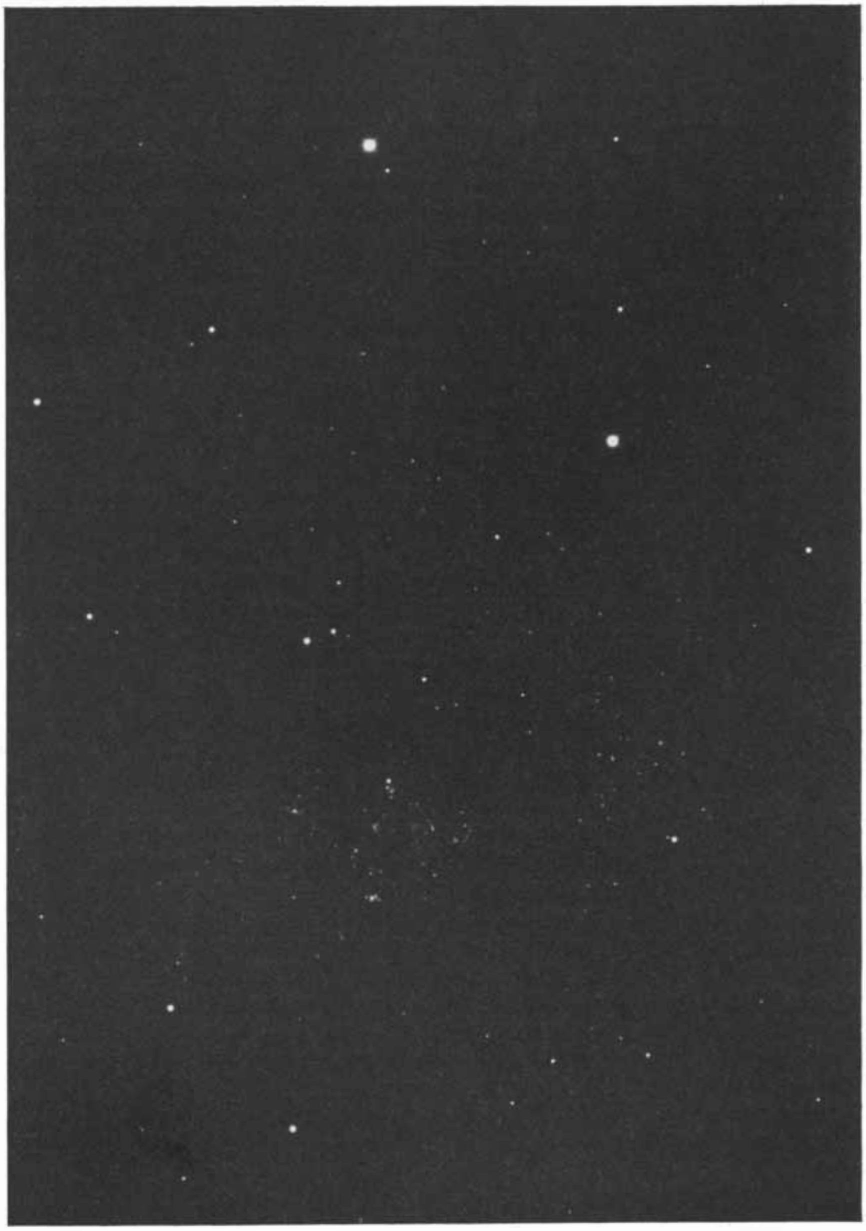
Another line of inquiry in which the dwarf galaxies have been particularly helpful to the astronomer has to do with the interactions between them and any nearby giant galaxy. According to theory, a cluster of point masses near a much larger mass is limited in size by the gravitational influence of the larger object. In the case of the dwarf galaxies in Sculptor, Fornax, Leo, Ursa Minor and Draco, all of which are quite close to our galaxy, it does appear that the size of these objects is limited in a predictable way. This observation can be used to deduce several important details of how two neighboring galaxies interact and how their interaction affects their structure.

First, the predicted radii of the dwarf systems can be compared with the observed radii, and the agreement or lack of agreement can be used as a check on whether or not forces other than Newtonian gravitation are at work. Such a determination would be vitally important to astronomers, because there have been suggestions that some of the properties of galaxies and clusters of galaxies can be explained only by the assumption that non-Newtonian or even nongravitational forces are at work at very large distances. The question of whether the Newtonian law of gravitation breaks down or changes when intergalactic distances are involved may be settled by a study of the nearby dwarf galaxies. This would provide a means of checking Newtonian gravitation at distances greater than those between planets in our solar system; so far interplanetary distances are the largest for which the check has been accurate. The results of our comparisons between observed and computed radii show that, within the anticipated uncertainties, there is close agreement between the observable facts and the predictions of Newtonian gravitation. The uncertainties involved are fairly large, because so many uncertain quantities must be considered: the mass of our galaxy, the distance and mass of each dwarf galaxy, the relaxation properties of the dwarf's outer stars and the dwarf's motion with respect to our galaxy. In spite of this uncertainty the agreement for the six dwarf galaxies studied so far indicates that no gross departure from Newtonian gravitation exists for distances up to 750,000 light-years.

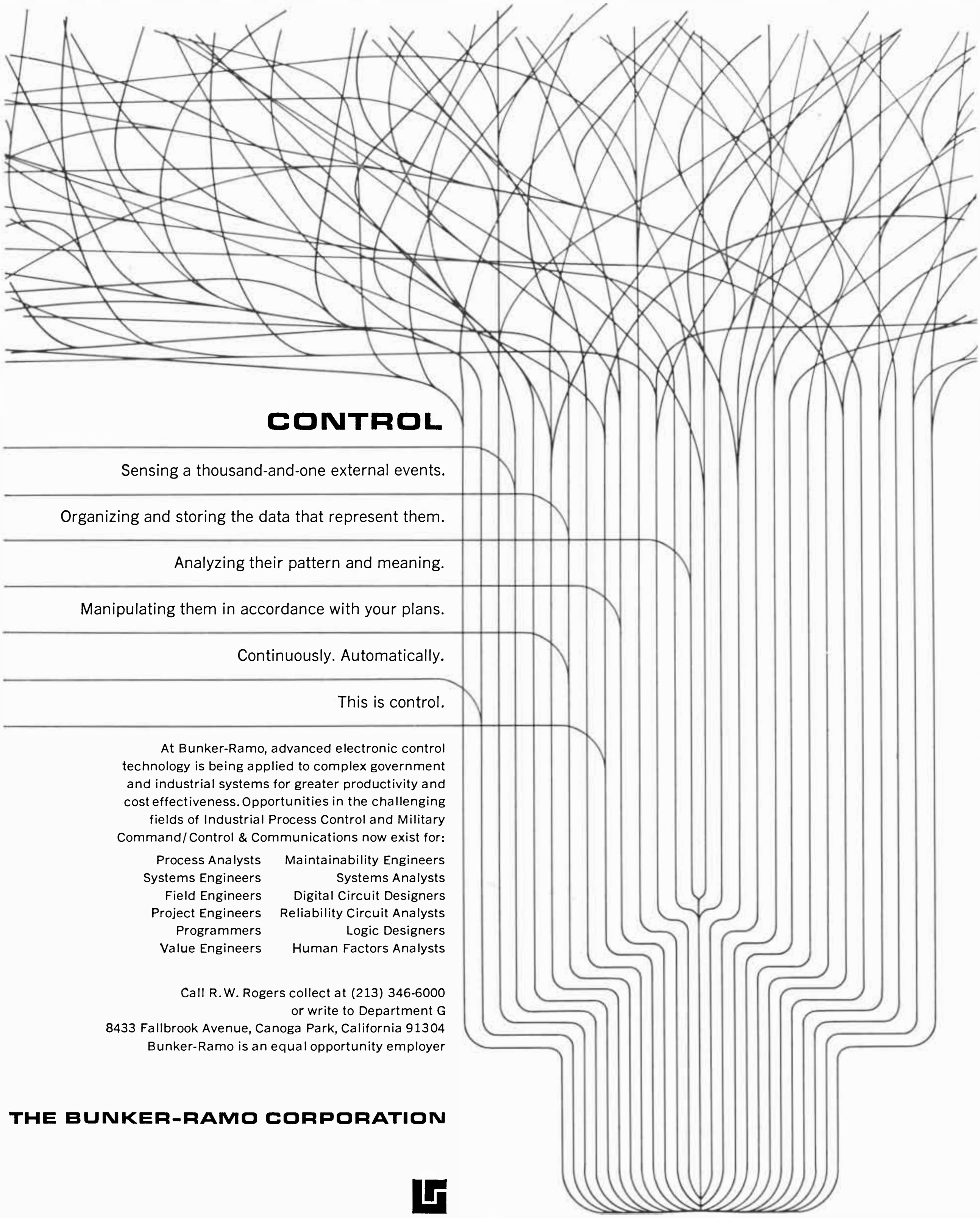
The observed radii of the nearby dwarf galaxies can also be used to compute the total mass of our galaxy, providing a check on the many independently derived models of the distribution of mass in the galaxy. This method also has some inherent uncertainties, one arising from the fact that the masses of the dwarf galaxies are so poorly known. Nonetheless, from a consideration of the limiting radii of a large number of nearby dwarfs, J. C. Brandt of the Kitt Peak National Observatory has calculated the total mass of our galaxy and has found evidence, now supported elsewhere, that previous estimates were too low by about a factor of two. The total mass of our galaxy as computed by Brandt is 400 billion times the mass of the sun.

A third way in which the gravitationally limited radius of a nearby dwarf galaxy is potentially useful is that it may be able to tell us something about the dynamical reaction time for that particular dwarf system. If we assume Newtonian gravitation and employ a figure for the total mass of the dwarf that has been determined by some other method, we find individual discrepancies between computed and observed limiting radii that may be due to the individual reaction time of that galaxy, that is, to the specific interval between the time that a force is exerted on a system and the time that its effect is evident in the system's structure. Since reaction times for dwarf galaxies of the Sculptor type are thought to be very long, the presently observed limiting radius may actually refer to a time in the distant past when the galaxy was either closer to or farther away from our galaxy than it is now. Thus small discrepancies may be due to the fact that the observed distance we use to compute the effect of the force exerted by our galaxy does not apply to the residual effects the dwarf now displays.

Considering the short time astronomers have known of the existence of dwarf galaxies, much has been learned from them. Although only a handful of astronomers have had access to the large telescopes necessary to work with these extremely faint objects, our understanding of their contents, structure and evolutionary history is developing rapidly. As more large telescopes are built the contributions of the dwarf galaxies to our understanding of galactic systems in general are certain to multiply.



IC 1613 is a dwarf galaxy of the irregular type. This positive print, made with the 120-inch Lick reflector, shows the system as a chaotic mixture of stars of different brightnesses.



# LEUKEMIA

## Although this disease characterized by the accumulation of white blood cells is almost always fatal, advances in knowledge of its cause and management give promise that it may someday be curable

by Emil Frei III and Emil J. Freireich

Leukemia is an almost invariably fatal cancer of the tissues in the bone marrow and lymph nodes that manufacture blood cells; it is characterized by the excessive accumulation of leukocytes, or white blood cells. In 1961 (the most recent year for which complete figures are available) 12,783 inhabitants of the U.S. died of the disease; 2,140 of them were children younger than 15. Today more children in the U.S. between the ages of four and 14 die of leukemia than of any other disease. Moreover, the incidence of the disease in the U.S. appears to be increasing: it was 2.3 cases per 100,000 persons in 1930, 3.8 per 100,000 in 1940 and 6.1 per 100,000 in 1961. Some of this increase is undoubtedly due to advances in diagnosis and statistical reporting, but not all. Although no treatment is yet known that can permanently reverse the course of the disease, in recent years a number of drugs and improvements in supportive treatment have significantly alleviated the suffering and prolonged the useful life of many leukemia patients.

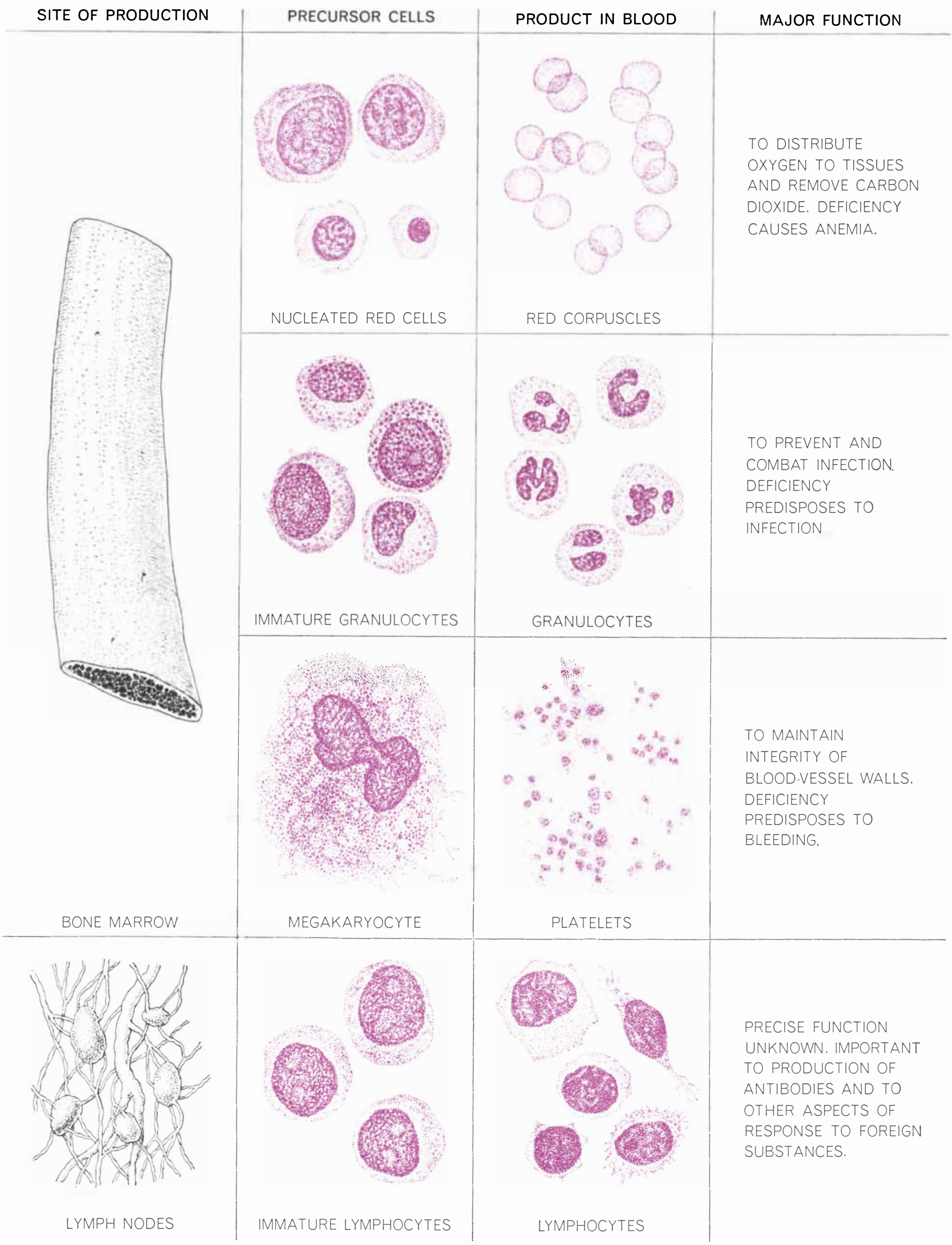
Different types of leukemia are identified by the kind of white cell affected. One of the two major types is lymphocytic leukemia; it involves the lymphocytes, which are produced in the lymph nodes. The other is granulocytic leukemia (often called myelocytic leukemia); it affects the granulocytes, which are produced by myeloid, or bone-marrow, cells. Each type can occur in either acute or chronic forms. In acute leukemia the rate of accumulation of white cells is considerably faster than it is in chronic leukemia. Normally each cubic millimeter of human blood contains between 5,000 and 10,000 white cells of all kinds. The number of white cells in the blood of a person suffering from leukemia can exceed 500,000 per cubic millimeter. In acute leukemia the white cells are larger than normal cells and resemble precursor or immature forms of these cells. These leukemic cells are not able to carry out the normal functions of white cells; for example, they do not act against invading microorganisms. In chronic myelocytic leukemia the white cells are more mature, closely resemble normal cells and seem to be able to combat microorganisms.

As they increase in number leukemic cells invade the blood-cell-manufacturing tissue, particularly the bone marrow, and drastically reduce the production of normal cells, both red and white. One result is anemia: a decrease in the number of circulating red cells. Because of the decline in the number of normal white cells, the patient is more susceptible to infection. He may also be susceptible to hemorrhage because of a decrease in the number of platelets, the tiny bodies in the blood that are produced in the bone marrow and play an important role in blood clotting [see "Blood Platelets," by Marjorie B. Zucker; Scientific American, February, 1961]. Infection and hemorrhage account for some 80 per cent of the serious manifestations of leukemia and immediate causes of death in leukemia patients. The uncontrolled increase in the number of white blood cells also results in, among other symptoms, fever, pain in the joints and bones, and swelling of the lymph nodes, the spleen and the liver.

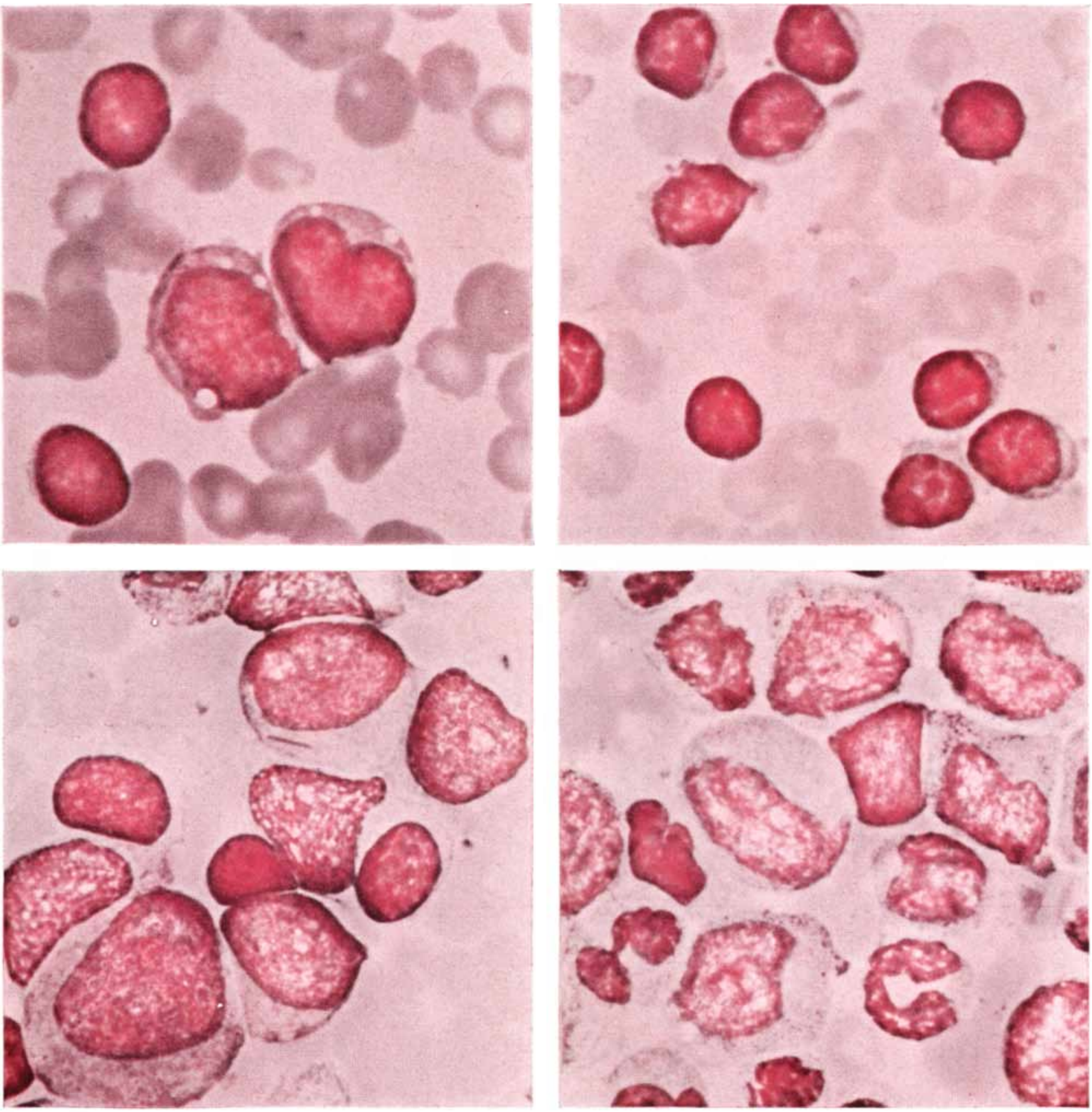
Although the fundamental cause of human leukemia remains unknown, certain contributory factors have been identified. One is ionizing radiation. When the dose of radiation is greater than 200 rads (the rad is a unit of radiation effect in living systems), there is a linear relation between the size of the dose and the frequency of leukemia. The frequency of the disease among those who survived being within 1,000 meters of "ground zero" at Hiroshima was 30 times greater than that of unexposed Japanese populations. A relation between the incidence of leukemia and the amount of ionizing radiation has also been found in a population of arthritis patients who had received X-ray treatments of the spine. The leukemia that appears among those who have been exposed to ionizing radiation is myelocytic; its latent period—the span of time between exposure and clinical detection—ranges from two to 15 years. Radiation, however, is only one factor in leukemia; the large majority of leukemia patients have no history of significant radiation exposure.

Heredity plays a major role in many forms of leukemia that have been investigated in animals, but studies of human leukemia provide little evidence that the present or future members of the family of a leukemia patient are more likely to develop the disease than anyone else. Nevertheless, a few exceptions to this generalization are known, and it is clear that the probability of leukemia is markedly increased for a person who has an identical twin with the disease.

There can be no doubt that leukemia has something to do with the hereditary material. The incidence of the disease is high among persons with mongolism, a condition that physicians now call Down's syndrome. This condition results from the abnormal distribution of chromosomes in the formation of an egg cell [see "Chromosomes and Disease," by A. G. Bearn and James L. German III; Scientific American, November,




**CELLULAR ELEMENTS OF BLOOD** consist of red corpuscles, white cells (lymphocytes and granulocytes) and platelets. These are produced by precursor cells in the lymph nodes and bone marrow. Leukemia results from alteration and excessive accumulation of white cells, which then interfere with the production of the normal cellular elements of the blood. Thus the major complications of leukemia are anemia, infections and bleeding. The enlargement of the various cells here is some 1,000 diameters.



**LEUKEMIC CELLS** of the four major types of the disease have been stained to make them visible in these photomicrographs. At top are lymphocytic leukemic cells from acute (*left*) and chronic (*right*) forms of the disease. At bottom are cells of acute (*left*) and chronic forms of myelocytic or granulocytic leukemia. The small, light-colored bodies are red cells. Enlargement is some 1,300 diameters. The chronic leukemia cells look like normal, mature leukocytes, whereas acute leukemia cells resemble precursor cells.

1961]. A normal person has 46 chromosomes—23 pairs—in each of his body cells; a patient with Down's syndrome has 47. The extra chromosome is associated with either one of the pairs designated 21 and 22. Although the relation of this chromosome abnormality to leukemia remains speculative, it is of considerable interest that an abnormality in the same group of chromosomes occurs in the leukemic cells of some 80 per cent of patients with chronic myelocytic leukemia. It consists of the deletion of approximately 60 per cent of one of the chromosomes in pair 21 or pair 22.

This kind of abnormal chromosome, called the Philadelphia chromosome because it was discovered by Peter C. Nowell of the University of Pennsylvania School of Medicine, has not been found in other types of leukemia. It appears early in the course of chronic myelocytic leukemia and persists thereafter, suggesting a causal relation. Recently Jacqueline J. Whang and J. H. Tjio of the National Institutes of Health have found the Philadelphia chromosome in the precursor cells of red blood cells and of platelets from patients with the same type of leukemia. Perhaps the initial change that gives rise to the leukemia occurs in an earlier precursor common to all three types of blood cell.

Another factor in leukemia is the age of the patient: different forms of the disease predominate in different age groups. Acute lymphocytic leukemia occurs mostly in children; the peak incidence is in three- and four-year-olds. Acute myelocytic leukemia is primarily a disease of young adults. The chronic lymphocytic form is found largely in people between 50 and 70. Chronic myelocytic leukemia tends to affect individuals between 30 and 50.

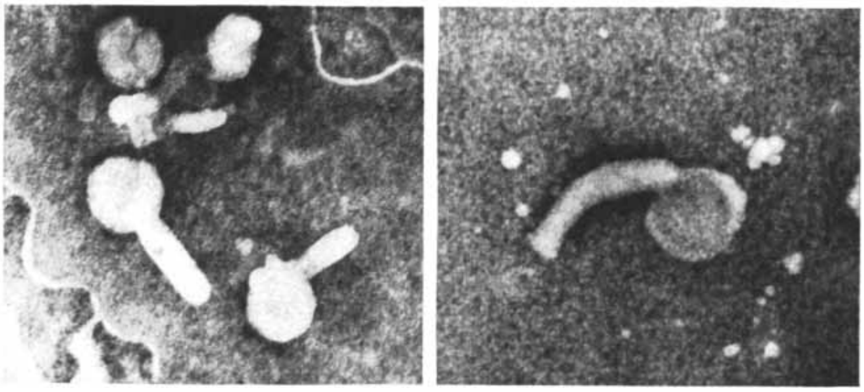
In this connection an observation in mice has suggested the possibility of a congenital stimulus for acute lymphocytic leukemia in children. Viruses that cause leukemia in mice are most potent when they are administered to newborn mice. The mice, however, do not show symptoms of leukemia for some months. In the same way a virus contracted by a human infant at or soon after birth might bring on acute lymphocytic leukemia several years later.

The possible role of viruses in human leukemia has stimulated much current investigation. In 1954 Ludwik Gross of the Veterans Administration Hospital in the Bronx demonstrated that a virus can cause leukemia in mice, and since that time a number of leukemias in rodents have been traced to virus infection. Newborn animals are much more susceptible than older animals. The latent period is usually a matter of months.

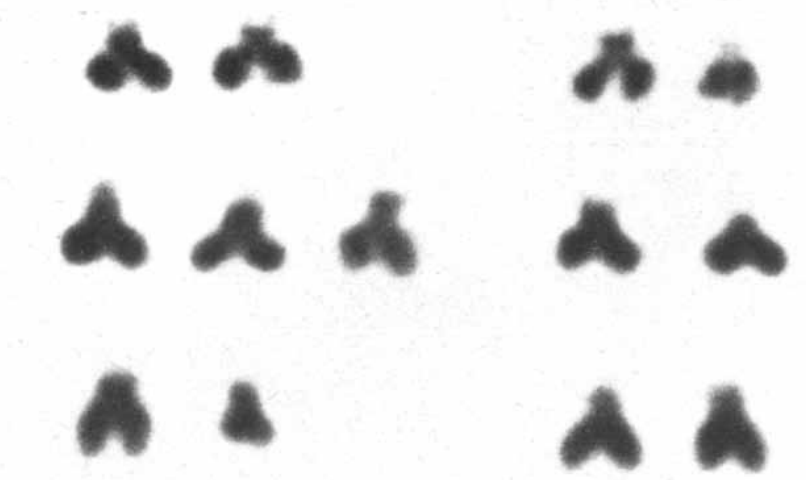
Virus-like particles in the tissues of leukemia patients have been revealed in electron micrographs made by Leon Dmochowski of the M. D. Anderson Hospital and Tumor Institute in Houston. Such particles have been isolated from the blood of seven out of 52 patients with leukemia by Albert J. Dalton, John B. Moloney and George H. Porter of the National Cancer Institute. Charles Burger, Norman G. Anderson and R. M. Knisely of the Oak Ridge National Laboratories have detected the particles in the large majority of the patients they studied. These bodies have been found in only one of the 40 normal individuals whose blood was examined.

It may be, of course, that leukemia is not caused by the particles but simply allows for their multiplication by lowering resistance to infection. The next steps will be to demonstrate that the particles are viruses, to isolate them and grow them in nonhuman tissues and finally to find out if infecting experimental animals with them gives rise to leukemia. The obstacles are many. Viruses that cause leukemia in one animal species may not necessarily do so in another, which indicates that it may be difficult to grow a human leukemia virus in animals. Another difficulty is that whereas many viruses can be studied with the aid of the changes they produce in cells grown in tissue culture, the viruses associated with leukemia have not so far been observed to cause such changes. Nevertheless, blood and tissues from leukemia patients, particularly those in whom virus-like particles have been detected, are being injected into newborn monkeys and other animals and into tissue culture. The successful transfer of the particles would have profound implications, one of which is the possibility of developing a vaccine.

If at least some human leukemia is caused by a virus, it is possible that the disease is contagious. There is little evidence for this possibility beyond the fact that in the U.S. there are several geographic clusters of leukemia cases. A form of cancer known as the Burkitt lymphoma, which closely resembles leukemia, occurs almost exclusively in central Africa. The tumor usually appears in the jawbone of children. Its extremely high incidence in a limited geographical area, along with other evidence, points toward transmission by an insect.



**VIRUS PARTICLES** (*left*) from a mouse with Moloney virus leukemia have hexagonal heads and tails that closely resemble a particle (*right*) found in the blood of a child with acute leukemia. The enlargement of these electron micrographs is some 70,000 diameters.



**CHROMOSOME CHANGES** observed in Down's syndrome (mongolism) and in chronic myelocytic leukemia affect chromosome pairs numbered 21 and 22. At top are normal 21 and 22 chromosome pairs. In middle are chromosomes from a patient with Down's syndrome. There is an extra chromosome. At bottom are 21 and 22 chromosomes from a patient with chronic myelocytic leukemia. About 60 per cent of one chromosome is missing. This is the Philadelphia chromosome, found only in the leukemic cells and some precursors.

A growing body of clinical and experimental evidence suggests that the cellular transformation that gives rise to leukemia is related to changes in the immune system: the system by which the body manufactures antibodies to remove antigens, or foreign substances. Normally the immune system has the capacity of "self-recognition": it does not produce antibodies against the tissues of its own body. Some patients with chronic lymphocytic leukemia, however, make antibodies that act against their own red blood cells. This "autoimmunity" and the consequent destruction of red cells quickly lead to a grave anemia. The source of the autoantibodies in chronic lymphocytic leukemia is probably the leukemic lymphocytes themselves; as we have noted, these lymphocytes, unlike the lymphocytes characteristic of acute leukemia, resemble normal, immunologically competent leukocytes. A similar phenomenon has been observed in a strain of mice by M. Bielschowsky in New Zealand and Sir Macfarlane Burnet in Australia; the mice regularly develop autoimmunity to red cells and frequently exhibit microscopic changes similar to those of leukemia. It is conceivable that in all leukemias there is a lack of the self-recognition that normally brings cells under the restraining and directing influences of other cells.

At this point we shall relate the information we have presented so far to a theory of the origin of leukemia. It would appear that a change or series of changes in a normal immature leukocyte can render it incapable of maturing and of responding to the restraining and directing influences of the body. All the progeny of the original cell or cells possess these characteristics; thus the original change can be regarded as a genetic mutation. This means that the hereditary material of the cell—the deoxyribonucleic acid (DNA)—has been altered. The genetic hypothesis is consistent with the observation that exposure to ionizing radiation increases the incidence of leukemia; ionizing radiation is well known to cause mutations. It is also consistent with the chromosome changes observed in Down's syndrome and in chronic myelocytic leukemia. Moreover, although the interaction of viruses with the genetic material needs elucidation, it is known that some viruses cause permanent changes in the genes. Some recent experiments suggest, however, that the change may occur not at the genetic level but at another level of cell function.

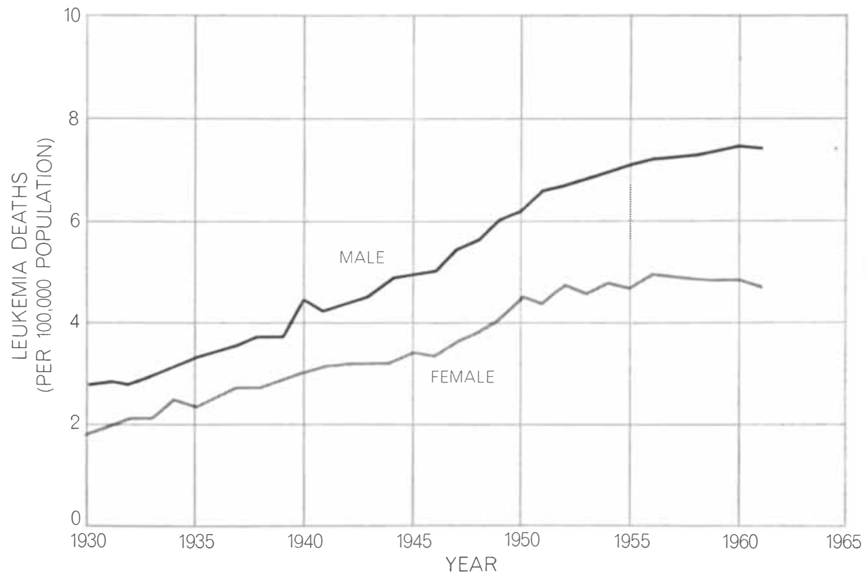
We shall devote the remainder of our discussion largely to acute lymphocytic leukemia in children and the treatment of it. We have selected this type of leukemia because much greater progress has been made in its control than in the control of other types, and because many of the generalizations that can be made about it apply to other forms of leukemia.

The modern treatment of acute lymphocytic leukemia has increased the median survival time of patients from two or three months to 16 months. A few patients now survive for more than five years. In other types of leukemia, treatment is effective in alleviating symptoms and temporarily controlling the leukemic process but life expectancy has not been substantially increased.

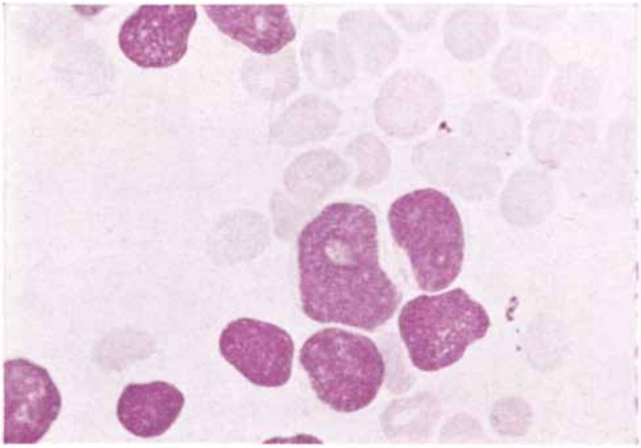
Part of the treatment is transfusion to combat the complications of leukemia: anemia, hemorrhage and the inadequate production of red cells, platelets and normal white cells. Since red cells can be stored for three weeks, and remain in the patient's circulation for more than three months after transfusion, the transfusion of red cells from blood banks is a practicable and effective technique. Platelets, on the other hand, should be transfused within a few hours of donation; they survive in the recipient for only four to seven days. Our studies at the National Cancer Institute show that fresh platelet transfusions from many different donors can be administered repeatedly and will control hemorrhage in the large majority of leukemia patients.

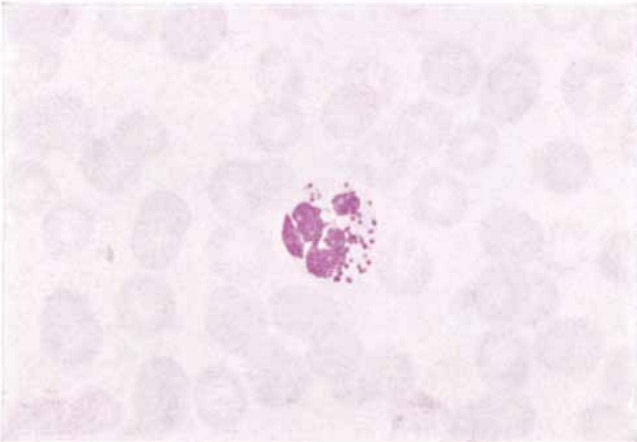
The transfusion of white blood cells presents a more difficult problem. Normal donors have few circulating white cells compared with red cells and platelets. In order to obtain sufficient quantities of functioning white cells we have had to select donors with chronic myelocytic leukemia, whose blood contains more than 200,000 white cells per cubic millimeter. These particular leukemic white cells can combat bacteria, and when they are transfused into seriously infected children with acute leukemia, they circulate and control some of the infections. Of course antibiotics are also employed against such infections, but in the absence of competent white cells they are often ineffective.

Another approach is the transfusion, or "grafting," of precursor blood cells, which are capable of replication and full maturation into circulating leukocytes, platelets and red corpuscles. The transfusion of bone marrow taken from healthy individuals was attempted unsuccessfully for some years. Finally in 1962 Georges Mathé of the Institut Gustave-Roussy in Paris succeeded. He first subjected his patients to large doses of ionizing radiation so that their immune response would be suppressed and would not destroy the foreign bone marrow. The grafts then functioned for as long as eight months. At the National Cancer Institute we have accomplished grafts in 12 patients with acute leuke-




**LEUKEMIA DEATH RATES in the U.S. have more than doubled since 1930, according to the American Cancer Society. Although better diagnosis and statistical reporting is partly responsible for the rising curves, most of the increase is real. The increase is unexplained.**





**COMPLETE REMISSION following treatment with an antileukemic drug is a dramatic event, characterized by a marked diminution of leukemic cells and the disappearance of clinical symptoms. Photomicrograph at left shows blood of a patient with acute lymphocytic leukemia. There are many leukemic cells. Four weeks later the patient, in complete remission, had normal blood (*right*).**

mia by the transfusion of cells from the bloodstream of patients with chronic myelocytic leukemia. The recipients were receiving antileukemic drugs, which, like radiation, tend to suppress the immune response. The transfused blood precursor cells "homed to," or "seeded," the bone marrow and persisted there for as long as three months, producing competent leukocytes, red cells and platelets that circulated in the blood. Conclusive evidence for this was the presence of cells in the bloodstream and in the bone marrow that contained the Philadelphia chromosome, which is never found in patients with acute leukemia except after such grafting [*see illustration on next page*].

Although transfusions or grafts control many complications of leukemia, the major effort in treatment is directed toward the destruction of leukemic cells and, it is hoped, the elimination of the entire leukemic-cell population. Since 1947 five classes of therapeutic agents that destroy leukemic cells to the point of "complete remission" have been identified. Complete remission is defined as the abatement of all symptoms and clinical signs of leukemia, the return in normal numbers of red cells, competent white cells and platelets, and a marked reduction in the number of leukemic cells in the bone marrow.

Such remissions are dramatic clinical events. Children with varying degrees of weakness, fever, infection, hemorrhage and pain within a few weeks appear to be perfectly healthy and return to full activity. In some instances even the most intensive clinical and laboratory studies fail to disclose evidence of leukemia. For this reason the earliest antileukemic agents aroused profound hopes. Eventually, however, clinical and laboratory evidence of leukemia always reappears. Complete remission lasts longer for patients taking some of the drugs if the drug is administered during remission. Thus the antileukemic activity of a drug is measured by its ability to induce remission and also to maintain the patient in remission. Perhaps the most important success of these agents is that they increase the time of survival [*see bottom illustration on page 95*].

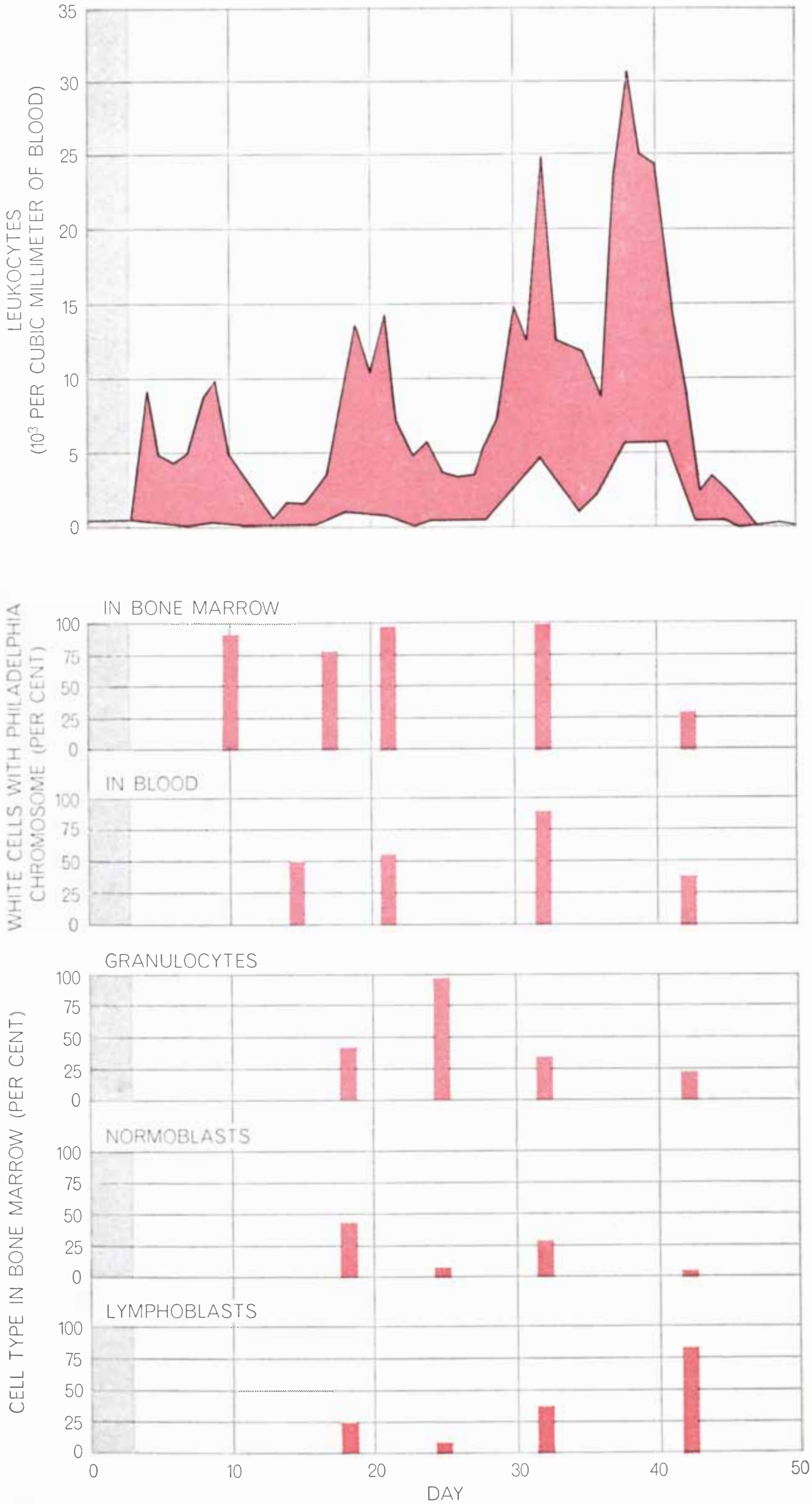
The first of the five types of drug to be tested was methotrexate; it was employed in 1947 by Sidney Farber of the Harvard Medical School. Methotrexate is a folic acid antagonist; that is, it interferes with the metabolism of folic acid, a vitamin that plays an important role in, among other things, the production of normal leukocytes. The molecule of methotrexate closely resembles that of folic acid and combines with the folic-acid-specific enzyme folic acid reductase even more readily than folic acid does. Once the enzyme has combined with methotrexate it cannot convert folic acid into tetrahydrofolic acid, which facilitates the addition of one-carbon-atom molecular units in a variety of biochemical syntheses. The most important of these is the synthesis of thymidylic acid, which is an immediate precursor of DNA. This activity of methotrexate adversely affects not only leukemic cells but also normal ones, particularly the cells of metabolically active tissues such as bone marrow and the lining of the gastrointestinal tract.

A second type of antileukemic agent, and one of the most effective in inducing and maintaining remissions, is 6-mercaptopurine. This drug interferes in some way as yet unknown with the synthesis of nucleic acids, including DNA. It was first prepared by George H. Hitchings of Burroughs Wellcome & Co., and its clinical activity was tested by Joseph H. Burchenal of Memorial Hospital in New York City.

Cyclophosphamide, which chemically resembles the "mustard" gases, is a third type of antileukemic agent. The fact that mustard gases depress the manufacture of normal leukocytes was accidentally discovered shortly before World War II. Since that time these substances and similar ones have been used effectively in the treatment of chronic leukemias and related conditions such as Hodgkin's disease and lymphosarcoma. Cyclophosphamide is the first mustard agent to bring about complete remissions in patients suffering from acute leukemia.

A fourth kind of antileukemic drug is vincristine, an alkaloid isolated from the periwinkle plant (*Vinca rosea* Lynn). Extracts of this plant were long believed to be of value in treating diabetes and other noncancerous conditions. Systematic studies of the extracts by Robert L. Noble of the University of British Columbia and Irving S. Johnson of Eli Lilly and Company revealed that in rats they decreased the normal leukocyte count and inhibited leukemias and related diseases. They also destroy leukemic cells and produce complete remissions in leukemia patients.

Finally there are the adrenal cortical hormones: cortisone, hydrocortisone and their chemical relatives. Because they were known to destroy lymphocytes they were tried on patients with acute lymphocytic leukemia. Frequently they bring about rapid, complete remissions




**REPLICATION OF TRANSFUSED WHITE CELLS occurs in patients with acute lymphocytic leukemia. For three days (*gray shading*) before the transfusion the recipient had no circulating granulocytes and very few white cells of any kind. Then he was given granulocytes from a patient with chronic myelocytic leukemia. For the next 43 days he had granulocytes in the blood and bone marrow. A large proportion of them contained the Philadelphia chromosome, which indicated that the transfused cells were replicating in the bone marrow and maturing. Top curve in top chart is total number of white cells, bottom curve the nongranulocytic white cells. Colored region represents granulocytes. The bars in the lower five charts show proportion and location of types of white cells on certain days.**

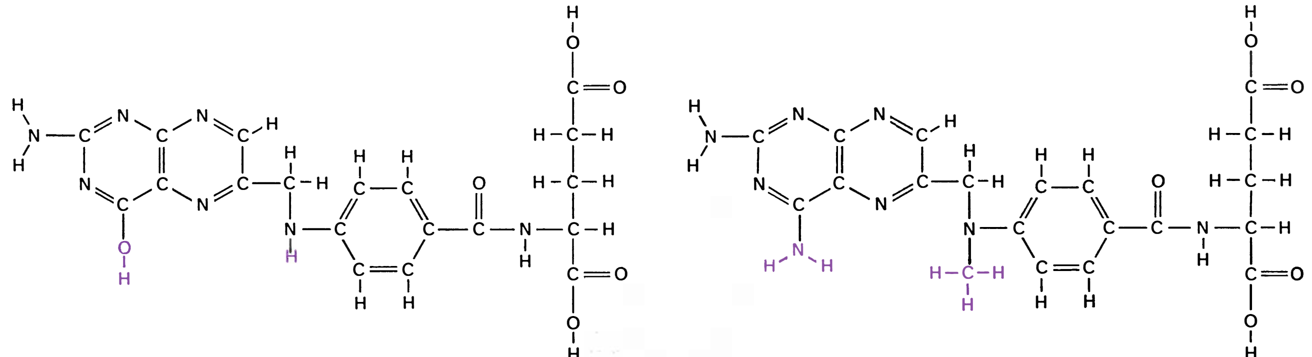


with fewer toxic side effects than the other agents.

Much research is now directed to learning how, at a biochemical level, the various agents produce their antileukemic and toxic effects. With such knowledge we may be able to identify in advance those patients who will be benefited by treatment. We may also be able to explain why patients who respond initially to the drugs eventually become resistant to them. Then we might learn how to overcome the resistance. Perhaps most important, this work should result in the preparation of related agents with greater antileukemic potency—agents that more selectively attack leukemic tissue.

In addition to new approaches to the treatment of leukemia that arise as a result of increasing knowledge of the chemistry of living cells, new antileukemic agents are being sought in a nationwide program of synthesis and screening integrated through the National Cancer Institute. Thousands of synthetic compounds and natural chemical products of plants, fungi, bacteria and even mammalian cells are being prepared and tested in a number of laboratories.

In spite of the fact that we have five different agents capable of producing complete remission, why have we not achieved indefinite survival or cure? How might we modify the use of present and future agents to achieve this goal? It is probable that in order to cure leukemia it will be necessary to eliminate the entire population of leukemic cells. Jacob Furth of the Columbia University College of Physicians and Surgeons has demonstrated that leukemia can be produced in animals by the transplantation of a single leukemic cell. Studies by Howard E. Skipper of the Southern Research Institute in Birmingham, Ala., have indicated that the cure of transplanted rodent leukemia necessitates the destruction of all the leukemic cells. It has been shown in animals that even the most effective agent will destroy only 99.999 per cent of the leukemic cells. Although this may seem very effective indeed, it is far from effective enough. A 60-pound child with leukemia has approximately $2 \times 10^{12}$ (two trillion) leukemic cells. Such an agent would reduce the number of cells to some $2 \times 10^7$ (20 million). This represents a reduction in volume from a liter (approximately a quart) to less than a cubic centimeter of leukemic cells and would probably be associated with complete remission. The remaining leukemic

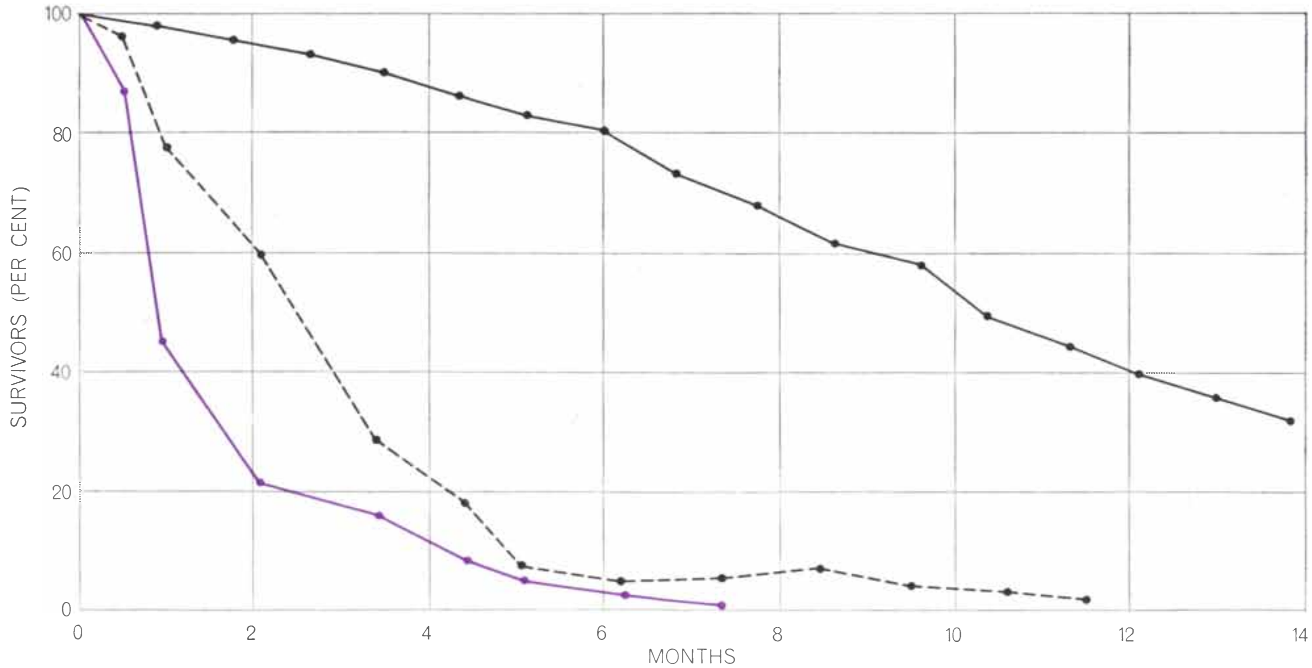



**CLOSE MOLECULAR RESEMBLANCE** between folic acid, a vitamin important to the production of nucleic acids, and methotrexate makes the latter an excellent antileukemic drug. Slight differences between the molecules are shown in color. Methotrexate binds with the enzyme that changes folic acid into an active form, thereby blocking biochemical processes that occur in the manufacture of leukocytes. Toxic effects of the drug arise because it stops vital processes in normal tissues as well as in cancerous tissues.

cells, however, eventually multiply back to a clinically significant population, resulting in a relapse. Antibiotics can cure bacterial infections, even though they do not kill all the bacteria, because the normal defenses of the patient—leukocytes, antibodies and so on—can destroy the remaining bacteria. If there are any normal defenses against the leukemic cell, they must be much less effective.

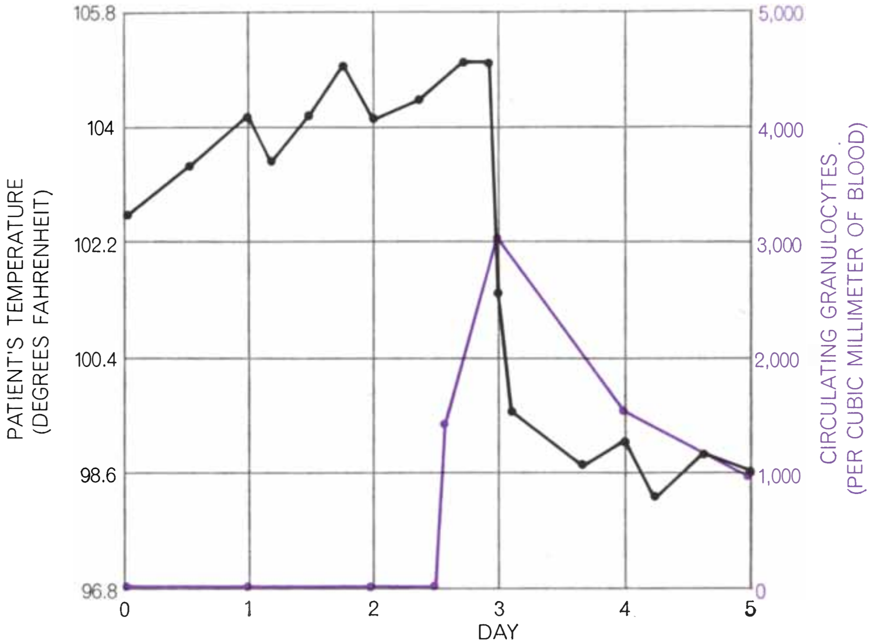
Why do small numbers of leukemic cells persist after treatment? Animal studies indicate that leukemic cells are not all alike. Some are more sensitive to the drugs than others, and the quantity of the drug that can be administered is limited by its toxic side effects on healthy tissues. In mice with certain forms of leukemia, methotrexate, through its ability to combine with the enzyme folic acid reductase, eliminates the vast majority of the leukemic cells. A few cells, however, are not eliminated because their level of folic acid reductase is high and therefore the effectiveness of methotrexate is low. Eventually, even in the continued presence of the drug, the number of these cells may increase until there are as many leukemic cells as before, most of them resistant to the drug. Whether the excess enzyme activity of the cells in the resistant population is stimulated by the drug, exists naturally in a few cells that survive treatment with the drug or results from some other mechanism is not known.

In addition to the search for new drugs, attempts are being made to improve the effectiveness of those already available. So simple a tactic as a change in the schedule and the route of administration of methotrexate has enhanced its effect. Fuller knowledge of the distribution of the drugs in the body, of their mechanism of action and of the

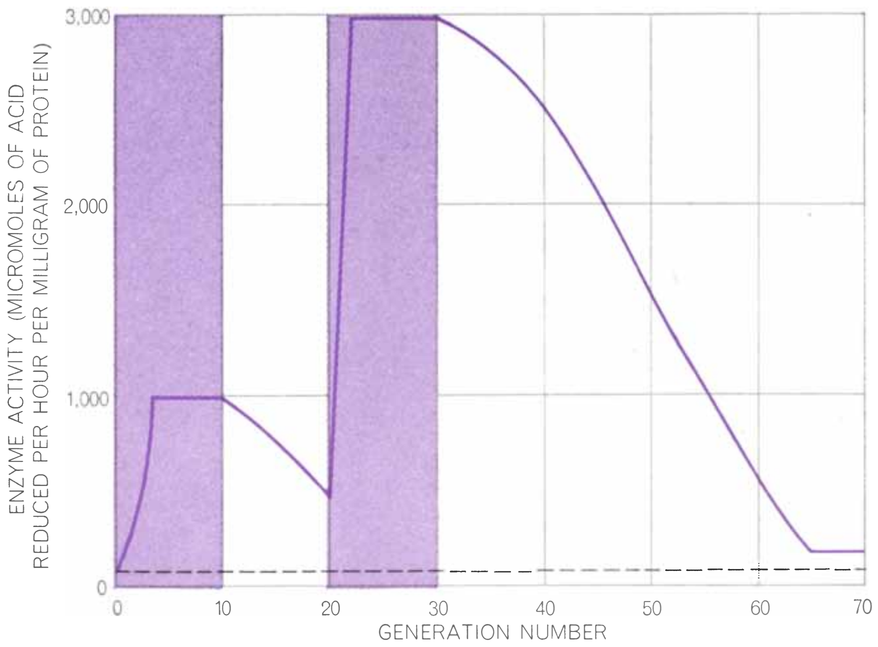



**REMISSIONS PROLONG SURVIVAL** in patients with acute lymphocytic leukemia. The colored line shows survival rates for patients who did not achieve remission. The solid black line is for patients who had one or more remissions. The broken black line shows what the survival rate would have been for these patients if they had not had remissions. Thus the improvement in the survival rate is due to time spent in remission. During remission the patients are free of symptoms and can lead essentially normal lives.

biochemistry and physiology of the leukemic cell will provide additional guidance for this approach. The use of agents in combination is also under examination. Such combinations are already improving the rate of complete remission. If one agent can eliminate all but a hundred-thousandth of the original cell population, a second agent with the same degree of activity but acting by a different mechanism would, when combined with the first, eliminate all the cells but a hundred-thousandth times a hundred-thousandth, or a ten-trillionth. Whereas clinical studies indicate that such combinations do eliminate a larger proportion of leukemic cells, there is no evidence as yet that permanent remissions have resulted.




**RESPONSE OF INFECTION** to transfusion of granulocytes is shown by rapid drop in temperature of patient with acute leukemia (*black curve*). Halfway through the third day the patient received a transfusion of granulocytes that continued to circulate in his bloodstream (*colored curve*). These granulocytes were able to act against the bacterial infection.




**DRUG RESISTANCE** of leukemia in successive generations of mice increases when methotrexate or similar drug is administered along with leukemic cells. The vertical scale is a measure of the activity of the enzyme folic acid reductase. The drug was administered in those generations covered by colored shading. As the curve shows, resistance to it increased rapidly when it was being used and declined when it was not used. The broken horizontal line marks the activity level of folic acid reductase in mice fully sensitive to methotrexate.

Leukemic cells may escape complete destruction not only by resistance but also by entering compartments of the body that exclude antileukemic drugs. The "blood-brain barrier" of the central nervous system, which excludes certain foreign substances from the brain, the meninges (sheathing membranes) of the brain and spinal cord, and the spinal fluid, also excludes antileukemic drugs. Autopsy studies indicate that in a majority of children with acute leukemia, leukemic cells have entered the meninges. This causes an increase in the pressure of the spinal fluid, which produces headaches, nausea and vomiting. Cortisone is the only antileukemic agent that penetrates these areas.

We do not know whether or not there are other pharmacological "hideouts." It has been found that the injection of methotrexate into the spinal fluid or the administration of X rays to the brain and spinal meninges is effective against leukemic cells in the central nervous system, but again not all the cells are destroyed. Eventually a family of resistant cells feeds back into the bloodstream, the bone marrow and the lymphatic tissue and causes relapse. Recent investigations by, among others, David P. Ball and C. Gordon Zubrod of the National Cancer Institute have defined the properties a drug must have in order to cross the blood-brain barrier, and antileukemic agents with such properties are being prepared.

Even if it should someday be possible to eliminate every single leukemic cell from the body of a patient with leukemia, further efforts may be needed to produce permanent remission. The primary cause of the disease, be it ionizing radiation, a virus, a genetic change or something else, may still be present and act on a line of susceptible cells to reinduce leukemia. If, for example, the cause should be a virus, it may be necessary to control the virus or eliminate the susceptible cells. At this stage we cannot even speculate on how important reinduction may prove to be.

In spite of such difficulties, those of us who work in the investigation and treatment of leukemia are optimistic. The progress that has been made in a relatively few years has made us hopeful that the control of human leukemia will be achieved in the not too distant future.

# Arithmetic Behavior in Chimpanzees

*In which Dennis and Margie are taught how to recognize numbers and "write" them in binary form. The manner in which chimpanzees master the "language" of mathematics may illuminate human verbal behavior*

by Charles B. Ferster

Language appears to be a skill that can be attained only by man. Attempts to teach animals to use words have generally failed, in spite of ingenious and persistent efforts by laboratory experimenters. Even the famous chimpanzee Viki, although reared in a human home and taught like a human child, never learned to mouth more than half a dozen words. Many animals do, of course, communicate, but their "verbal"—that is, symbolic—communication is limited to a small number of sounds or other cues.

A new approach to the whole subject has been suggested, however, by the Harvard University psychologist B. F. Skinner. Analyzing verbal behavior in the same way that he has studied other forms of behavior, he concludes that it can be described in the same stimulus-and-response terms. Language can be defined as a set of symbolic stimuli that control behavior, and its effectiveness arises from the fact that all the individuals using a common language respond to the stimuli appropriately; the stimuli "control" almost identical performances in speaker and listener. In this light animals may be capable of more sophisticated language learning than they have been given credit for. Teaching them may be primarily a matter of choosing a system of stimuli and responses that are appropriate to their capacities.

At the Institute for Behavioral Research in Silver Spring, Md., Clifford E. Hammer, Jr., and I have been exploring this possibility with two chimpanzees as subjects. We are teaching them some of the elements of arithmetic. Essentially it is an effort to inculcate the meaning and use of symbols in the language of mathematics. The purpose of this program is not only to test the animals' ability to learn a symbolic language but also to try to find out something about the development of verbal behavior by studying the creation of the elements of such behavior *de novo* under controlled laboratory conditions.

We selected the language of arithmetic because it provides simple and unambiguous stimuli. Numbers, as descriptions of features of the environment, have a clear, precise meaning. Moreover, the language of numbers gets around the obstacle of vocal limitations, which make it difficult for an animal to speak words. The animal can "write" or "say" a number merely by pressing buttons or using some similar mechanism. The binary number system supplies an ideal tool for this purpose. The two digits in the system, 0 and 1, can be presented as a light that is on or off, and the animal can in turn write one or the other digit by pressing a key or moving a switch that turns a light on or off.

Our experiments have a further simplification: they omit communication from one subject to another. Ordinarily in the use of language the "reinforcement" of the speaker's verbal behavior (to put it in psychological terms) is provided by the reaction of the listener. In our controlled experiments the reinforcement is simply the delivery of food: when the animal matches a number or performs some other arithmetical task correctly, it automatically receives a food reward or some other indication that is called the reinforcing stimulus.

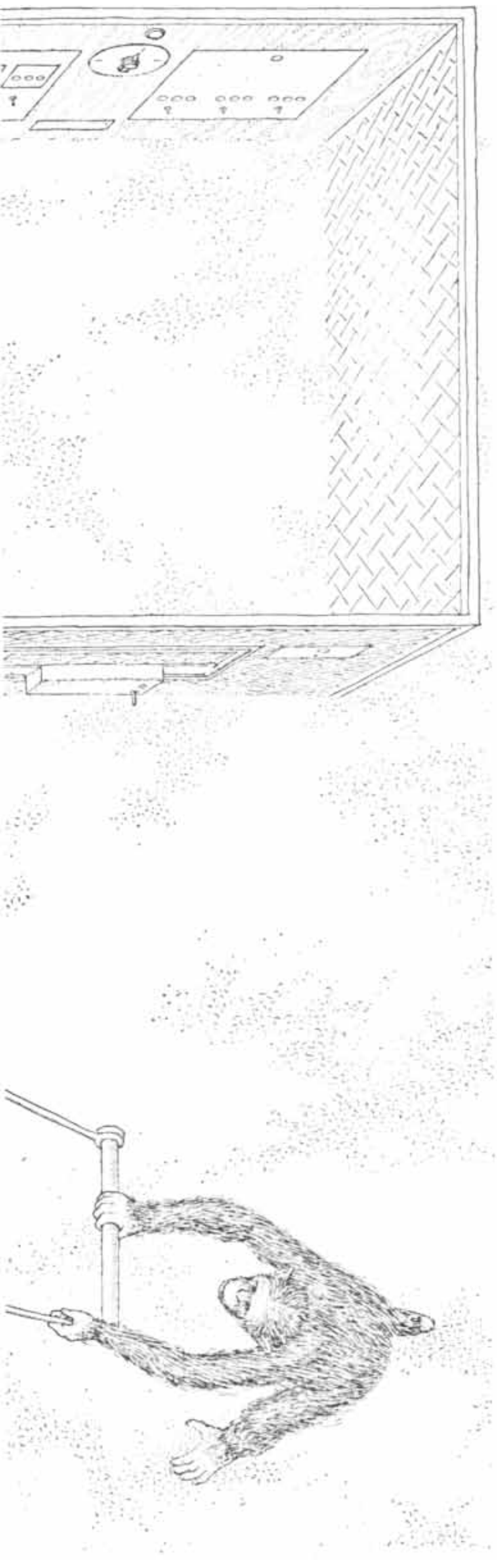
Our subjects are male and female chimpanzees named Dennis and Margie. We started with another female (Elizabeth), but she had to be replaced by Margie after 11 months because of erratic performance, which seemed to be due to some organic abnormality. When they entered the experiment, Dennis and Elizabeth were about three and a half years old; Margie was about three.

Because it was to be a long-term project in which we wished to watch the continuous development of the two chimpanzees under conditions that were as natural as possible, we set the pair up in a fairly large room where they lived together. They received food only by working for it, and their work consisted of the tasks in the experiment. The experimental apparatus is a series of three cages to which the animals have constant access [*see illustration on pages 100 and 101*]. They have been trained, as their first act on entering the cage, to go to a combination lock and move the pointer to a certain setting. The particular setting identifies the animal—it serves as its signature—and so we have a record of which chimpanzee has performed in each series of tests. The entrance door locks automatically when the combination lock is set, so that the animal cannot leave by that route and its companion is excluded. This ensures that only one of the animals will work in a given cage at a time.

The animal is presented with stimuli displayed in a panel mounted on one wall of the cage. It may be shown three triangles and be required to "write" the number 3 by pressing certain keys, or it may be required to match a binary number in lights by pressing the appropriate key, or it may be given any one of a number of other problems. For a correct response it is rewarded with a brief tone signaling that the answer is correct and by food delivered through a hopper according to a prearranged schedule: a pellet or biscuit for every five, 10 or some other number of successive re-

CHIMPANZEE works at an arithmetic problem in the author's laboratory. The animal, a female named Margie, has entered a small cage equipped with a test unit (*left*) and a food hopper (*top*). The unit includes a sample panel (which Margie is touching in order to start the experiment) and lights that the animal adjusts to "write" a binary number corresponding to the objects in the sample.

CHIMPANZEES LIVE in a large room that contains three small cages in which they perform their arithmetic tasks and obtain food. A hungry animal enters the cage at top right and works at the test unit on the back wall. After a while the stimuli there are turned off, the door to the next cage to the left is opened and the animal goes on to work on a new set of problems, as



**shown here. Then it leaves through the large cage at the extreme left. Ordinarily only one animal works in one of the test cages at a time.**

sponses without an error. An incorrect response is punished by a short blackout, or "time out"—a suspension of stimuli and rewards.

After the chimpanzee has performed for a certain interval (measured in time or in the number of trials) the stimuli are shut off and a door to the second cage opens. The animal moves along to this cage and works on further problems there. In the same way it is finally admitted to the third cage, where it receives fruit juice, and then it leaves the cages for the main area.

This arrangement, developed through experience as we proceeded with the experiments, has many advantages. The working of the system is largely automatic; the animals do not have to be watched or handled at any time. The various cages can be cleaned, repaired or altered without disturbing the chimpanzees (since they can be confined temporarily to one of the cubicles or let out of the room entirely through a transfer door that leads to another cage). The serial arrangement of the work cages allows us to separate the tasks and to provide a system of cumulative reinforcements that carry over from one cage to another.

The chimpanzees readily adapted themselves to the system. Each of them works about four or five hours a day, making some 4,000 to 7,000 trials on the apparatus, often at the rate of as many as three key-pressings per second.

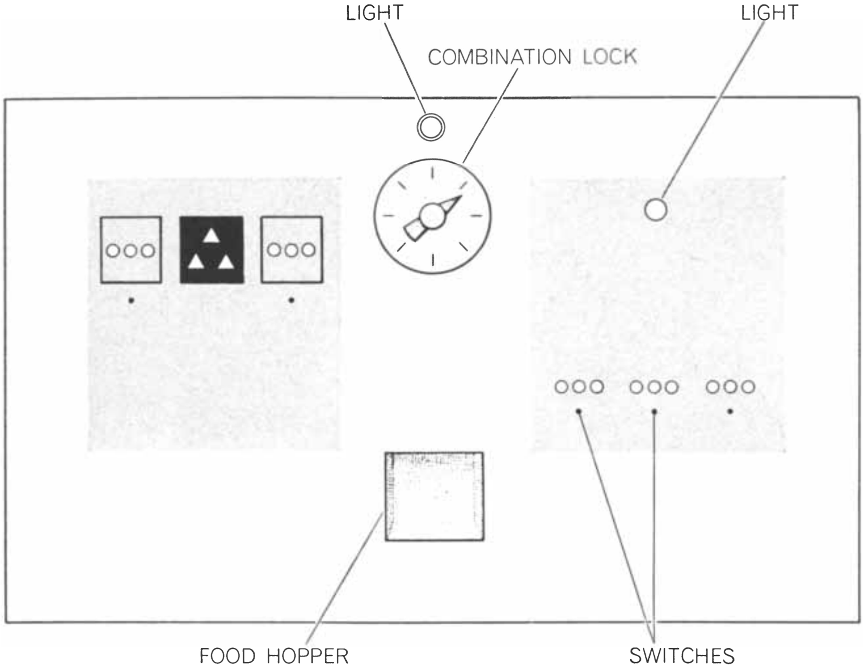
The repertory of arithmetic, of course, is very complex; we realized that the only hope of developing even a simple repertory for the chimpanzees was to build it in small steps. We began by training them to match given binary numbers. To initiate them into the operation of matching we first had them match colors. A color was shown in a window in the panel, and the chimpanzee was required to choose between two colors separately displayed, one of which matched the sample. When the animal pressed a key under the matching color, it received a reward—food or the brief tone that served as the conditioned reinforcement. When it chose the wrong (nonmatching) color, there was a blackout for a few seconds.

It took the chimpanzees about five days and 2,000 trials to learn to match colors accurately. Then binary numbers were substituted for the colors. Black and white circles served as the digits 0 and 1; three numbers were displayed in a row and the animal was required to match the number in the middle by selecting the identical one beside it, at either the right or the left [*see top illustration on page 103*]. We began with two-digit binary numbers as different from each other as possible (that is, 00 and 11). After the chimpanzees had learned to discriminate between these (Dennis mastered the problem in 15 sessions) the task was advanced to matching three-digit numbers (beginning with a choice between 001 and 111). Dennis needed only three sessions to achieve high accuracy in matching four specific three-digit binary numbers. Elizabeth, however, failed to develop any consistent discrimination and was replaced by Margie. Starting directly with binary numbers, without any preliminary training in matching colors, Margie learned much more slowly than Dennis, taking 53 sessions to arrive at an accurate ability to match three three-digit numbers.

These achievements were limited to the particular numbers that had been presented to the animals (four in Dennis' case, three in Margie's); what they had learned did not carry over to other numbers. We tested Dennis and Margie on the 21 possible discriminations between two three-digit binary numbers. (There are seven three-digit binary numbers, running from 001 to 111—the decimal numbers 1 through 7—and they can be paired for a choice in 21 different ways.) The chimpanzees performed with high accuracy on problems they already knew, such as selecting the match for 111 from the pair 111 and 001, but they made more errors when presented with numbers they had not seen before [*see top illustration on page 104*]. The more alike the two numbers appeared to be, the more difficulty the animals had in discriminating between them. The highest proportion of errors was made when the pair of numbers differed only by one digit or by slightly different positions of the digits.

It became evident that what the animals had learned was the likeness between specific physical stimuli rather than the abstract concept of identity itself. In other words, they could recognize that 111 was like 111 and that 001 was not, but they were not able to recognize and identify 111 in another context. This sort of identification, highly developed in man, is acquired only by extensive experience in matching many different kinds of stimuli.

Eventually Dennis and Margie learned to match each of the seven three-digit binary numbers from the 21 different combinations with good ac-




**TEST CAGE contains interchangeable test units. The animal sets the combination lock, thus putting its own "signature" on subsequent data, locking the door and turning on the experimental units. Then it works at either unit to earn food, which is delivered at hopper.**

curacy (fewer than five errors per 100 trials), but it took them hundreds of thousands of trials to acquire that ability.

Meanwhile the chimpanzees had been given another type of problem: matching number symbols to given numbers of objects—the first step in counting. We refer to this work as experiments in numerosity, or numerousness, which is one aspect of the concept of number.

The basic design of the experiments is simple. The animal is shown a certain number of objects (for example three triangles) and is required to choose, from two binary numbers displayed beside them, the one that corresponds to the number of objects [*see top illustration on opposite page*]. If the chimpanzee presses the key under the correct binary number, it receives a reinforcement; if not, it is punished with a blackout. Obviously this problem is considerably more complex than merely matching binary numbers themselves. It is no longer a matter of detecting a likeness between two identical sets of digits or topographical patterns; the animal must now find some link between a set of symbols and a radically different picture of physical objects. For the experimenter it becomes important to determine just how the animal connects one with the other.

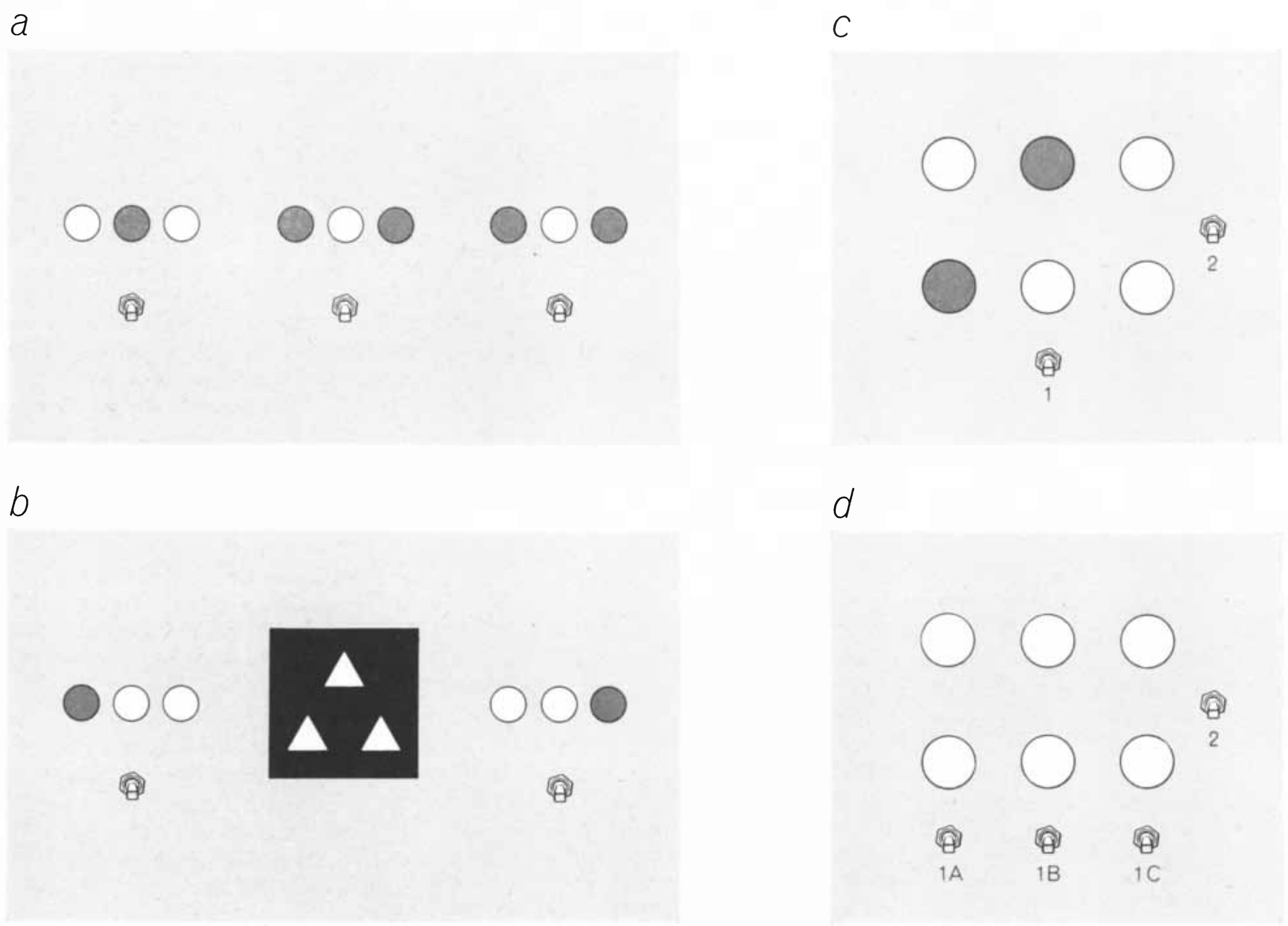
Here we must take note of some of the practical problems that run through the conduct of such experiments and consider how they have been handled. The first problem is that of inducing the animal to pay attention to the task. Presenting a picture of three triangles in a window, for example, does not guarantee that the chimpanzee will look at it or take any notice of it. Basically the solution has been to increase the likelihood that the animals will attend to the stimulus by requiring them to touch it; primates tend to pay attention to things they touch. In the experiment described in the preceding paragraph the apparatus is wired in such a way that the experiment will not start, and the chimpanzee therefore cannot receive a food reward, unless it first presses the window, thereby signifying that it is giving the window some attention.

The next problem is to maintain the animal's attention and make him work to improve his performance in the task. This cannot be accomplished simply by giving the animal a pellet of food whenever he happens to press the correct key. Instead we found it necessary to work out carefully calculated schedules of reinforcement in ratio to the animal's performance. We would begin, for instance, by sounding a tone each time the animal made a correct choice but rewarding him with food only after he gave three correct answers in succession; then, as his accuracy improved, he had to give more and more correct answers for the reward, until finally he was getting the food reinforcement only after 10 consecutive responses without error. Meanwhile the punishment for each error was increased by lengthening the blackout. As the experiments have progressed, the schedules of reinforcement have been refined and have become increasingly effective.

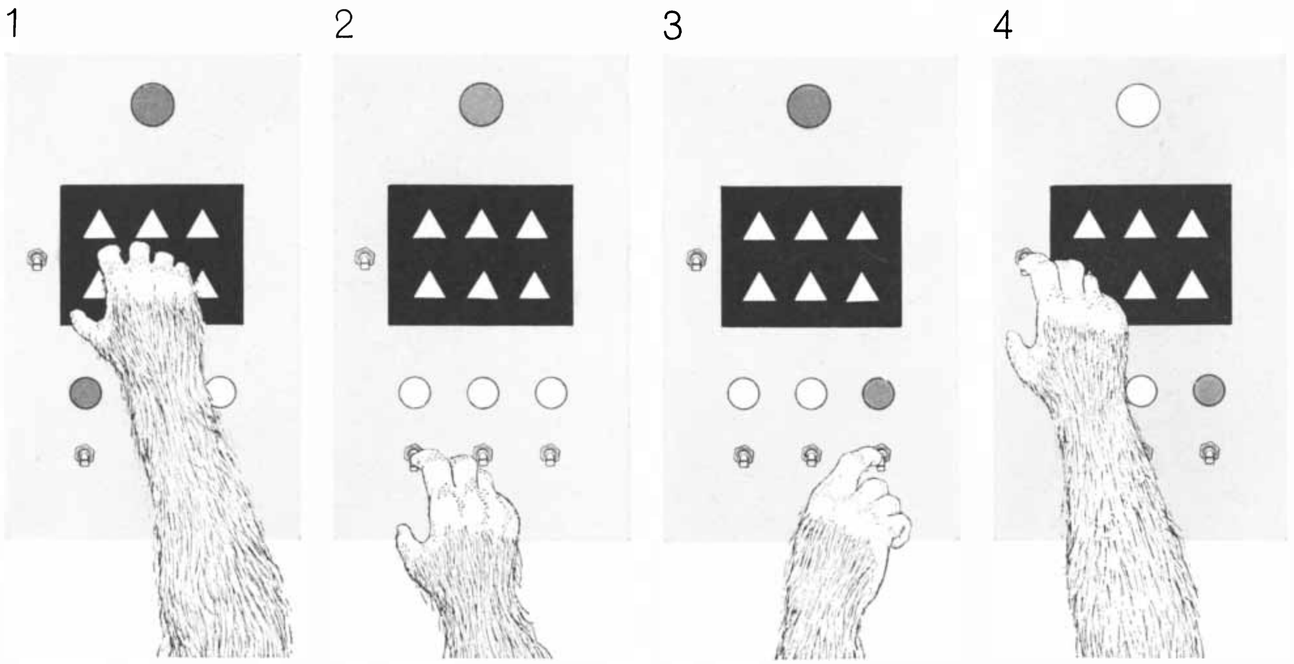
There remains the question of what the animals are responding to. Are they guided by the numbers themselves

| DECIMAL | BINARY | LIGHTS |
|---|---|---|
| 0 | 000 | ● ● ● |
| 1 | 001 | ● ● ○ |
| 2 | 010 | ● ○ ● |
| 3 | 011 | ● ○ ○ |
| 4 | 100 | ○ ● ● |
| 5 | 101 | ○ ● ○ |
| 6 | 110 | ○ ○ ● |
| 7 | 111 | ○ ○ ○ |

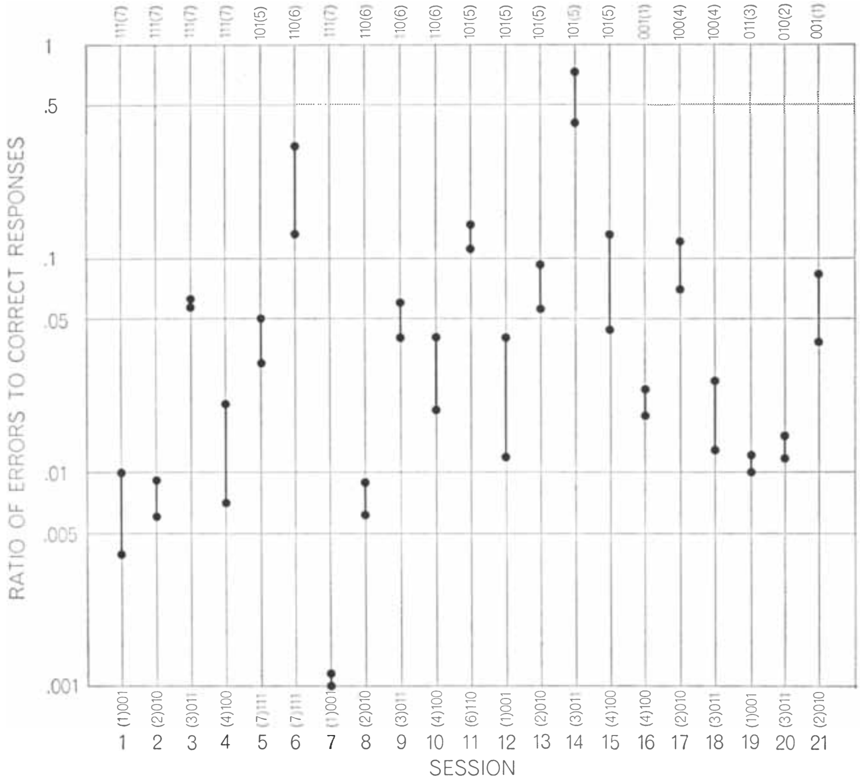
**BINARY SYSTEM, in which numbers are represented by only two digits, 0 and 1, is used for chimpanzee arithmetic. The digits are presented as lights turned off (*0*) or on (*1*). The table shows the decimal numbers 1 through 7 with binary and "chimpanzee" equivalents.**



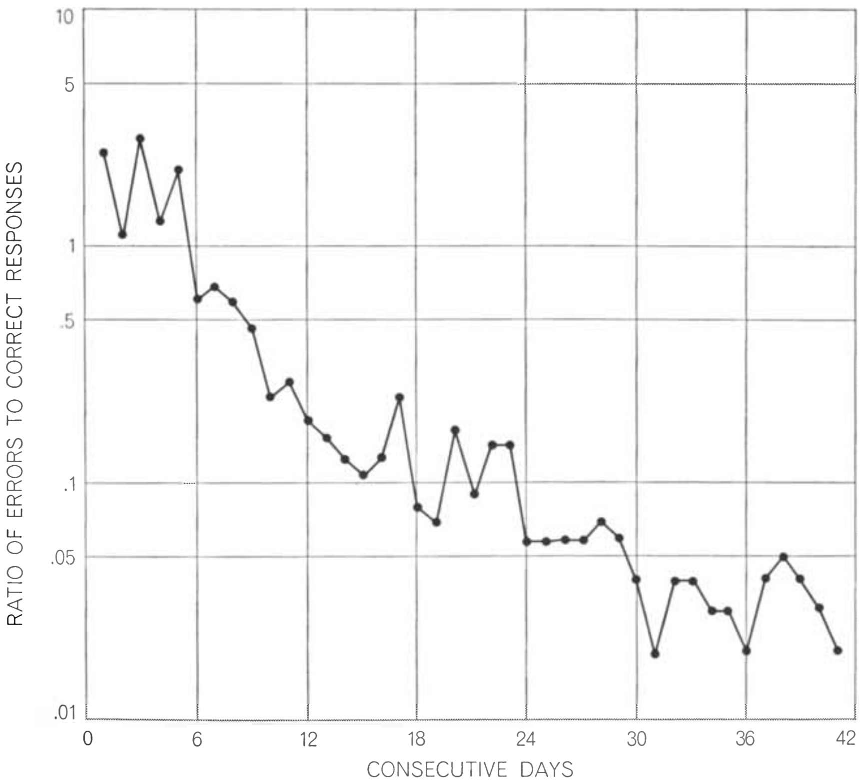

**FOUR TASKS** presented to the chimpanzees are depicted. In *a* the animals must press the center switch to light the two flanking binary stimuli, then press the switch under the matching stimulus to get a reinforcement signal. In *b* the sample is a "numerosity" stimulus instead of a binary number. The tasks at the right require "writing." In *c* the animal presses key *1* until the lower lights match the sample above, then presses key *2* for reinforcement. In *d* matching is done digit by digit, with three keys.




**TYPICAL PROCEDURE** is shown for a numerosity version of *d* in the top illustration. The animal touches the numerosity panel to turn on the binary-number lights below it (*1*). Then it presses keys that adjust the number to match the number of triangles in the sample (*2 and 3*). When the number appears to be correct, animal presses upper key and the reinforcement light comes on (*4*).




**ERROR LEVEL** varied as shown here when each of the 21 possible pairs of stimuli was presented on successive days. The two stimuli used each day are shown at the top and bottom of the graph. The upper of the two points plotted for each day shows the error ratio when the top number was the sample, the lower point the ratio when the bottom number was the sample. Scores were better for numbers the animal had been trained on. But scores were quite good even for new numbers, indicating a transfer to the new stimuli.




**DENNIS' PERFORMANCE** is graphed at a late stage in his learning of a "writing" task: adjusting a three-digit number to correspond to a sample binary number. Each point on the curve marks the ratio of errors to correct responses for trials made on successive days.

or by cues related to the way the numbers are presented? We found that the chimpanzees would memorize long sequences in the program pattern (for example the order in which the matching number appeared at the right or the left of the sample) rather than concentrate on the characteristics of the stimulus itself. This question became particularly acute when we undertook the numerosity experiments, testing the ability of the chimpanzees to learn the abstract concept of number. Early in these experiments we discovered that when they learned to associate a number with a group of objects, the association was usually with the arrangement or some other feature of the objects rather than with their number. We found this out by experimenting with changes in the pattern; when we shifted the arrangement of the three triangles, for instance, the chimpanzees became confused and no longer matched the binary number three (011) to the picture with their previous accuracy.

To rule out extraneous cues we therefore had to take special measures that would make the stimulus itself the center of attention and reduce it to its essential property—the property we wanted the chimpanzees to recognize. Some of the unessential factors, such as the order in which problems were presented, could be eliminated as significant cues simply by randomizing the order and other conditions. In the numerosity experiments we succeeded in bringing out the abstract property of number by varying the size, shape, arrangement and other physical properties of the objects presented, so that the chimpanzee could give the correct answer consistently only if it singled out the number of objects as the important property.

Both Dennis and Margie learned to match the correct binary number to one through seven objects with an accuracy of better than 95 per cent, frequently making fewer than five errors in a typical day's work of 3,000 trials. It took them 200 sessions and 500,000 trials to develop the first part of this repertory, but we later found ways to speed up their learning as they went on to the higher numbers.

The next undertaking was to teach the chimpanzees to "write" binary numbers. As a first step they were trained to match a number displayed in one row of lights by producing the same number in another row [*see top illustration on preceding page*]. Each row consists of three bulbs. As in all the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binary-number experiments, a lighted bulb represents 1 and an unlighted bulb 0. When a number is presented in the sample row, say 010, the chimpanzee presses a key under its own "writing" row. A pattern of lights representing a number then appears there; it may be any one of the seven possible combinations of three digits, and the particular number that will turn up at each pressing of the key is randomized. If the number happens to match the sample, 010, the chimpanzee can receive a reinforcement by pressing another key, but it will be punished by a blackout if it presses the second key when the numbers do not match. Thus the animal is trained to write numbers by pressing the key under its row until it produces a match for the sample, and then, and only then, to press the second key signifying that it recognizes the match.

After the chimpanzees had mastered this task their writing apparatus was refined by the addition of a separate key under each light, instead of one key for all three lights. They then had to write a number by pressing, or not pressing, each of the three keys. Essentially the performance was like writing with a typewriter, and it was now finer-grained than the situation in which the animal had written a number simply by pressing one key.

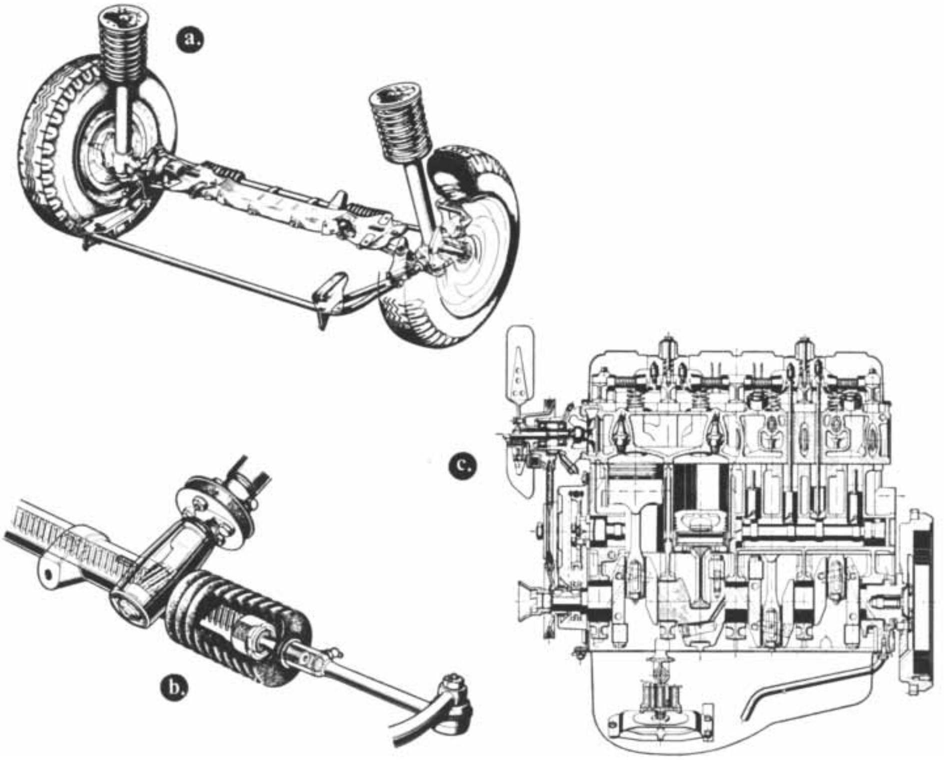
Once the chimpanzees had acquired the ability to duplicate a binary number we changed the problem to one in numerosity. Now the animals had to write the number that corresponded to the number of objects (triangles, squares or whatever) presented in the sample window.

**MARGIE, having completed a series of problems correctly, reaches into the food hopper to get a reward. The animals, fed only in return for work, keep at it four or five hours a day.**

Both Dennis and Margie have learned to identify from one through seven objects, by writing the appropriate binary number, with extremely high accuracy (only one or two errors per 1,000 trials). About 150 sessions, involving 170,000 trials, were required to develop this level of performance. Even more training had been required for the preceding "writing" experiments, however. This suggests that the animals were helped by a carry-over from the first writing experiments and from their earlier experience in numerosity experiments in which, instead of writing, they had matched the number of objects by choosing the correct binary number from a pair of numbers.

Although the chimpanzees unerringly write the numbers 1 through 7 when they see the corresponding number of objects, their performance is clearly not yet counting in the sense of an arithmetic enumeration of objects. We have been progressing in small steps, however, toward that end. Our first goal is to develop in the animals the abstract process of proceeding through a sequence of numbers, as a child will recite the numbers from one to 10 in order without referring to objects. Once that chain of verbal behavior has been synthesized in the chimpanzees, they should be able to go on to learn to count with precision any number of objects that is measurable by the length of the chain constituting their repertory.

By a series of steps in the laboratory, each built on the ones before, we have developed in these animals forms of behavior that bear a much more complex relation to the environment than chimpanzees normally show. It is only in the social world of man, depending vitally on communication, that such behavior—verbal behavior of the caliber represented by the performance of these chimpanzees in arithmetic—can arise naturally. Nevertheless, the experiments have demonstrated that, in a suitably organized environment, a chimpanzee can acquire many of the elements of a symbolic repertory such as arithmetic. As the experiments continue we hope to gain from this able and cooperative animal a great deal of information about man's verbal behavior and how it may be formed.

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# Early Concepts of the Senses and the Mind

*Man's understanding of how he perceives the real world was advanced in the 17th century by men who separated answerable physical questions from unanswerable metaphysical questions*

by A. C. Crombie

A ferment that stirred in men's thoughts about natural phenomena during the 17th century moved a scientist of the time to enthusiasm. Henry Power, an English physician and naturalist who was elected to the Royal Society in its infancy, wrote in his *Experimental Philosophy* of 1664: "These are the days that must lay a new Foundation of a more magnificent Philosophy, never to be overthrown: that will Empirically and Sensibly canvass the *Phaenomena* of Nature, deducing the Causes of things from such Originals in Nature, as we observe are producible by Art, and the infallible demonstration of Mechanicks: and certainly, this is the way and no other, to build a true and permanent Philosophy.... And he that will give a satisfactory Account of those *Phaenomena,* must be an Artificer, indeed, and one well skill'd in the Wheelwork and Internal Contrivance of such Anatomical Engines."

In those words Power characterized the program for research into living things set by the new "mechanical philosophy," which had been established earlier in the century by several investigators, notably Galileo Galilei and René Descartes. The philosophy was at the root of one of the most fruitful ideas guiding the modern study of the senses and the mind: the idea that the body is a mechanism. That idea was first successfully exploited in the experimental and theoretical inquiries made during the 17th century into the mechanisms of the sense organs, particularly the eye and the ear.

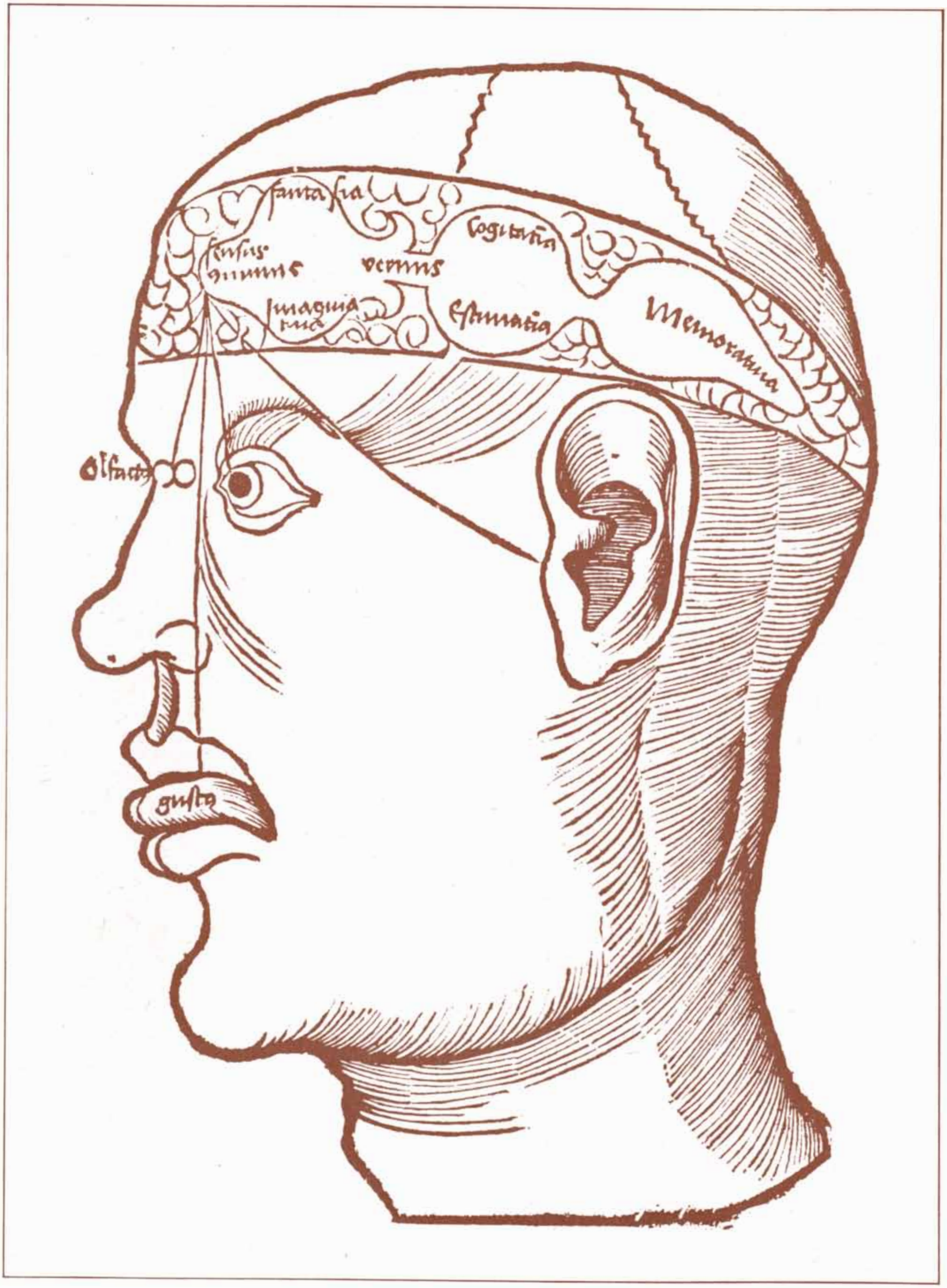
I shall argue the thesis that this "mechanistic hypothesis" made it possible to formulate and, as far as was technically possible, to solve the problems of how the sense organs worked; that moreover the hypothesis pointed the way to a new approach to the altogether different problem of how the information conveyed by the senses is transformed into perceptions. Two things about the hypothesis accounted for its achievements. The first was its ruthless commitment of the investigator, before he made any observations, to asking only one kind of question. Thereby the hypothesis provided the initial key to success by isolating the kind of problem that would yield to it. In a world that was assumed to be simply a system of mechanisms, the problem was to discover the particular mechanisms concerned.

Second, the commitment forced the recognition, as nothing less ruthless could, of its own limits. Once the full extent of the mechanistic commitment had become clear in the 17th century, it was comparatively easy to see that there were several different kinds of question involved in the inquiries into sensation and perception. By the end of the century clear distinctions had been made between three such kinds of question. One was physical and physiological: By what mechanisms are external physical motions transformed into internal physical motions of the sense organs, the nerves and the brain? Another question concerned the link between physiology and psychology: How do the physical motions of the sense organs, the nerves and the brain effect sensations in what Galileo called the "animate and sensitive body"? Finally there was the psychological problem of perception: What information does a person receive in visual, auditory and other perceptions; what sensory cues are necessary for him to have these perceptions?

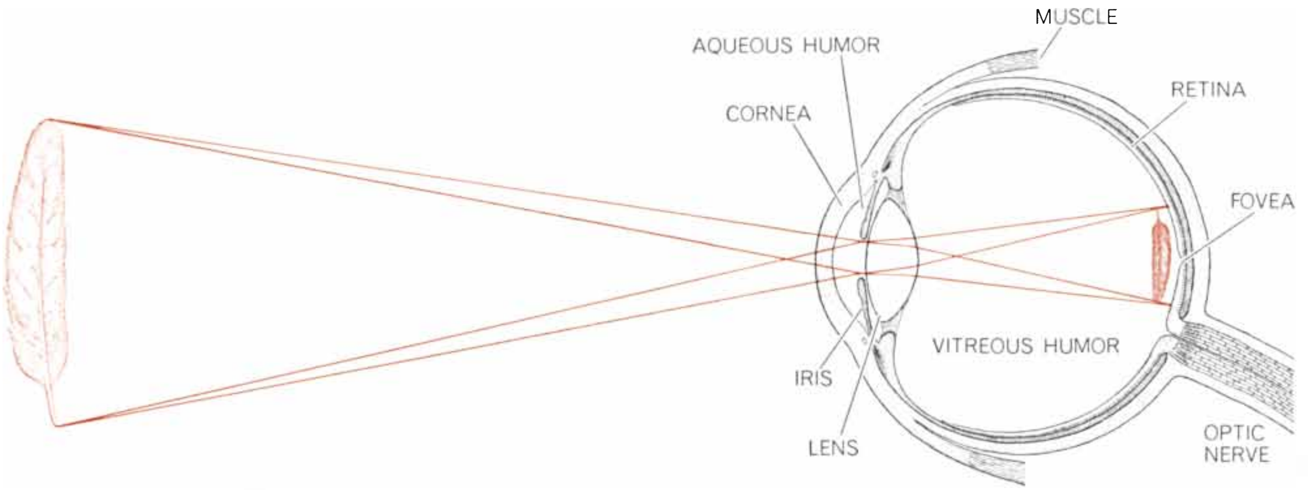
My argument is that the mechanistic hypothesis, applied as an instrument of thought, was the key to the success of 17th-century investigators because it transformed not the techniques, or even at the beginning most of the essential facts, but the formulation of traditional problems so that the essential distinctions described above could be made. The advances produced by the hypothesis began with, and gradually intensified, the recognition that these distinctions existed and that they required different modes of attack. In setting forth the argument I shall use as illustrations the study of vision, hearing and the coordination of sensory information and behavior.

Students of vision up until the 17th century never clearly recognized that there were at least three different kinds of question to be asked. Ancient and medieval authors on the subject invariably made their treatment of the physiology of the eye and of the means by which vision is effected serve as an explanation of how we see. In other words, they dealt with the problem as if it involved only a single question.

This can be seen in the theory of vision most widely accepted before Johannes Kepler arrived in 1604 at the explanation that is the basis of the modern understanding of vision. (Francesco Maurolico had arrived at a similar explanation earlier, but it was published posthumously after Kepler's.) The pre-Kepler theory was that of the Arab philosopher Ibn al-Haitham, better




**DIVISIONS OF BRAIN** according to a traditional early concept are shown in an illustration from Gregor Reisch's *Margarita Philosophica,* published in 1504. In the frontal cavity was the "common sensory," connected by nerves to the sense organs; that cavity also was the site of fantasy and imagination. The middle cavity was the seat of thought and judgment; the rear cavity, of the memory.




**STRUCTURE OF EYE** as now understood is portrayed as a contrast to the views of earlier investigators of vision. The inversion of the image as a result of refraction by the lens was a phenomenon that gave them particular difficulty. Even some investigators who were aware that inversion must occur concluded that a process within the eye preserved the erect image that is apparently seen.

known in the West as Alhazen, the Latin version of his name. Following the theories of his predecessors, particularly Euclid, Galen and Ptolemy, Alhazen supposed that a "visual cone" of rays extended from the object to the eye and that the lens was the sensitive organ [*see top illustration on opposite page*]. He then proposed the original theory that the image of the object was propagated by physical rays sent from each point on the object to a corresponding point on the sensitive forward surface of the lens, which thus brought about a perception of the whole object through the separate perceptions of each of its points.

This geometrical treatment of images enabled Alhazen to offer at once a solution to an ancient and puzzling problem: how the images of large objects got into the diminutive pupil of the eye. It also raised some difficulties. First, if each sensitive point on the lens was stimulated by every ray reaching it from all points on the object, the lens would not be able to distinguish different colors coming from different parts of the object. To overcome this difficulty Alhazen introduced the hypothesis that only the rays that struck the lens perpendicularly and without being weakened by refraction stimulated it fully. This made it necessary for him to suppose further that in the optical system of the eye the center of curvature of the cornea, of the aqueous humor and of the front surface of the lens all coincided at the center of the eyeball.

A second difficulty shows even more clearly how Alhazen's thinking was put on the wrong track by his attempt to make the mechanism by which the image is formed explain immediately how we see. He agreed with Galen that vision was not completed in the lens but that "the act of vision is accomplished in such a way that the visual image received by the crystalline lens passes through to the optic nerve." He also described an experiment with a camera obscura in which when a number of candles were set up outside "an opening leading into a dark place, with an opaque wall or body opposite the opening, the images of these candles appear on the body or wall, each distinctly."

Alhazen used this experiment simply to show that the images all passed in straight lines through the same hole unaffected by one another; this, he said, "is to be understood for all transparent bodies, including the transparent parts of the eye." His difficulty was that he knew that in an optical system such as the eye the image would be inverted unless some refraction occurred. "The image cannot proceed from the surface of the crystalline lens to the hollow [optic] nerve along straight lines," he wrote, "and still preserve the proper order of its parts. For all the lines intersect at the center of the eye, and if they continued straight on, their order of position beyond the center would be reversed: What is right would become left and vice versa, what is up would be down, and down up." So in order to preserve the erect image that he thought was necessary for the eye to cause us to see as we do, he supposed that the rays would be refracted at the back surface of the lens in such a way that they did not intersect. The two erect images formed at corresponding points in each of the eyes then united at the junction of the two optic nerves to form a single image that was conveyed by the "visual spirit" sent out from the brain to the "ultimate seat of sensation" in the cerebral cavity, the location of the "common sensory."

It was a stroke of genius for Alhazen to impose geometrical optics on anatomy. His difficulties arose because he was not resolute enough. Plainly it was a change of concept that gave Kepler success where Alhazen and several later investigators fell short. Kepler's new concept was based on a complete willingness to exploit the mechanistic hypothesis.

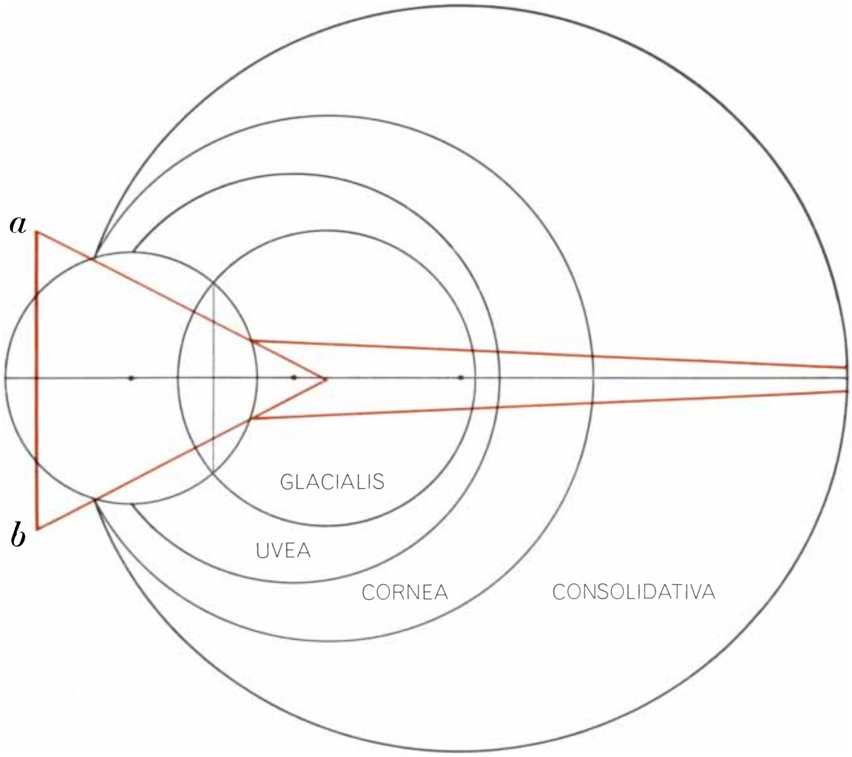
Several brilliant attempts to explain vision failed for want of complete commitment to the mechanistic approach. Alhazen was unable to see in the camera obscura a model for the formation of the image in the eye. Leonardo da Vinci compared the eye to a camera obscura and introduced what could be called an engineering approach to the problem of vision with a proposal to investigate it by means of models using glass balls, but like Alhazen and for the same reason he found it necessary to arrange the optics to suit the demand for an erect image [*see bottom illustration on opposite page*]. Giambattista della Porta made the same error, but it was he who gave Kepler the idea that the eye is a camera obscura. Felix Plater, who in 1583 put forward the fundamental idea that the retina and not the lens is the sensitive organ of vision and who published a greatly improved eye anatomy to which Kepler referred, drew from Kepler the comment: "Compare the true mechanism of vision as given by me with that given by Plater, and you will see that this famous man is no farther from the truth than is consonant with being a medical man who has not studied mathematics."

All the necessary knowledge was available before Kepler. He succeeded by seeing the problem in a new way. A year after the publication in 1604 of *Ad Vitellionem Paralipomena,* in which he gave his explanation, Kepler wrote of his cosmology: "My goal is to show that the heavenly machine is not a kind of divine living being but similar to a clockwork." His strategic judgment about vision, in keeping with this cosmological judgment, was to restrict the problem in the first place to discovering how the eye operates as an optical instrument like any other.

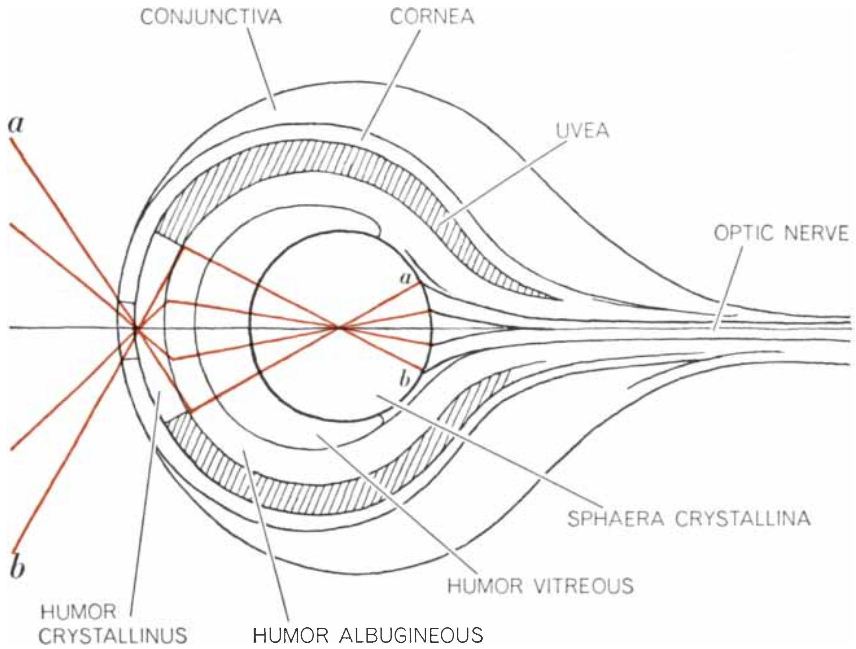
He solved this purely optical problem by showing that the formation of the image in the eye must be analyzed geometrically not as a cone of rays extending from a base on the object to a vertex in the eye but in terms of a multitude of cones coming from vertexes at every point on the object to a common base on the lens [*see illustration on next page*]. The physical process of seeing he described as follows: "Vision is brought about by a picture of the thing seen being formed on the white concave surface of the retina. That which is to the right outside is depicted on the left on the retina, that to the left on the right, that above below, and that below above.... Green is depicted green, and in general things are depicted by whatever color they have."

Kepler went a significant step further: he recognized that a physical description of the eye's operation carried the explanation of vision only part of the way, and that there were other questions the mechanistic approach could not answer. The psychophysiological question of how the physical processes of the eye effect sensations lay outside his mathematical solution. "I leave it," he said, "to natural philosophers."

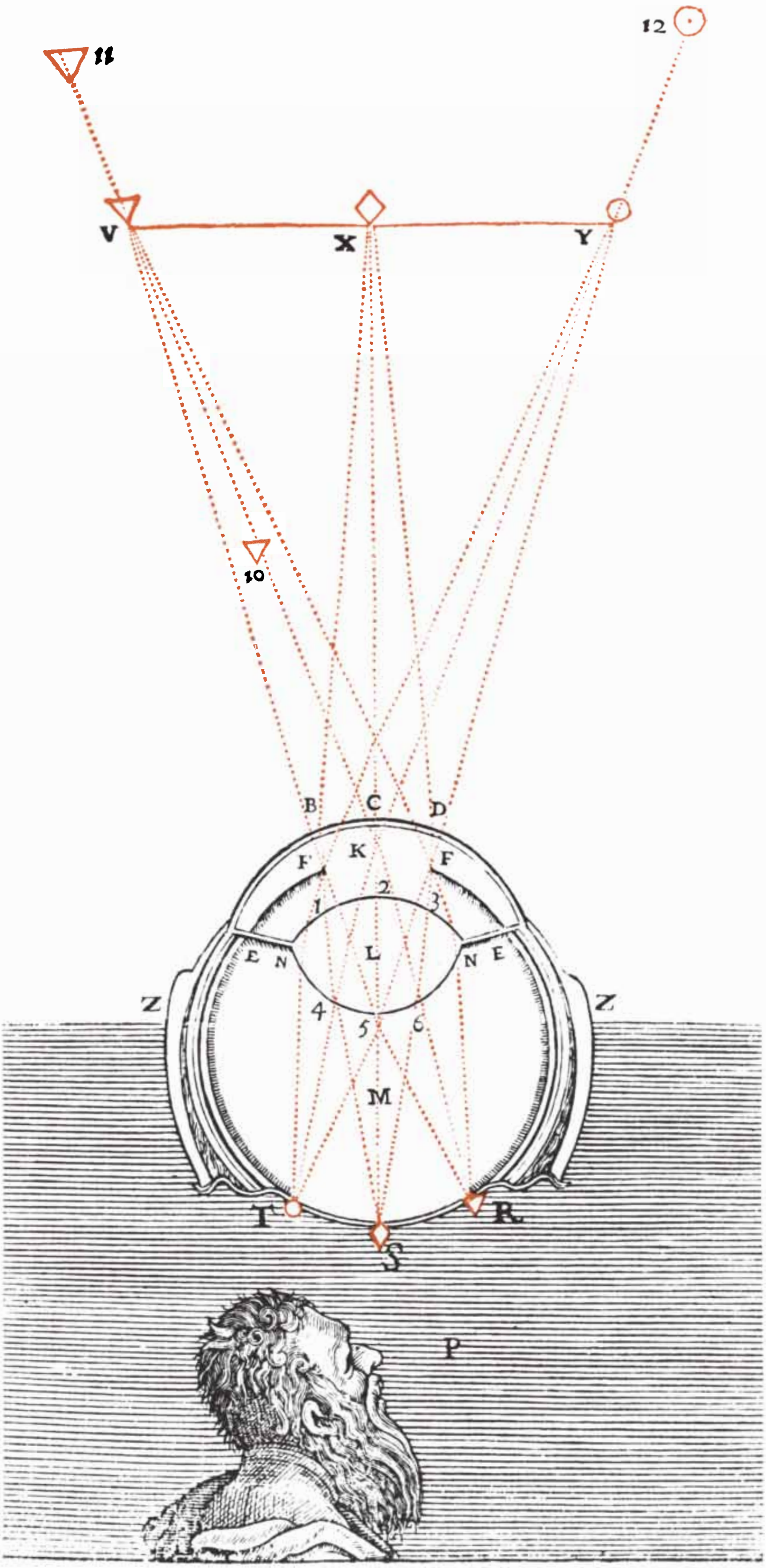
By asking questions that were answerable because they involved physical and mathematical analysis rather than philosophical speculation, Kepler opened the way to the solution of further problems of vision by purely physiological methods. Soon his own analysis of vision was amplified by others. Christoph Scheiner observed the formation of images on retinas by removing the




**GEOMETRICAL MODEL OF EYE** shows curvatures of refracting media according to Alhazen's theory of vision. A visual pyramid (*color*) had the object sighted (*a-b*) as its base; its apex was the center of the eye, which also was the center of curvature of the cornea, the *glacialis,* or lens, and the aqueous humor. Alhazen said that rays from the object struck forward surface of lens perpendicularly, so undergoing no refraction, but at rear of lens were refracted away from center of eye, thus keeping image erect. Dots show, from left, centers of curvature of vitreous humor; uvea, or choroid, and *consolidativa,* or sclera.




**LEONARDO DA VINCI'S CONCEPT** of the eye, here redrawn from a sketch in his *Codice Atlantico* with legends supplied from other passages, also arranged the physics of vision to preserve an erect image. Rays from an object sighted were, according to his theory, refracted by the *humor albugineous,* or aqueous humor, and then refracted again in the *sphaera crystallina,* or lens. Therefore they appeared upright on back of lens, as with rays *a* and *b.* Da Vinci, like other early investigators, thought lens was the sensitive organ.




**OPTICAL GEOMETRY** according to Johannes Kepler explained the inverted image. This illustration of Kepler's optics is from René Descartes's *La Dioptrique*. The man looking at a retina in a camera obscura sees an inverted image (*RST*) of the sighted object (*VXY*).

backs from the eyes of men and oxen shortly after death. Descartes corrected Kepler's optical analysis by using the newly discovered sine law of refraction and treating the lens in its actual flattened shape rather than as the sphere Kepler had described; he also attributed visual accommodation to changes in the shape and not in the position of the lens. By the end of the century the work of Christian Huygens, Isaac Newton and many others had established physiological optics as a discipline in which investigators were confident of how to proceed.

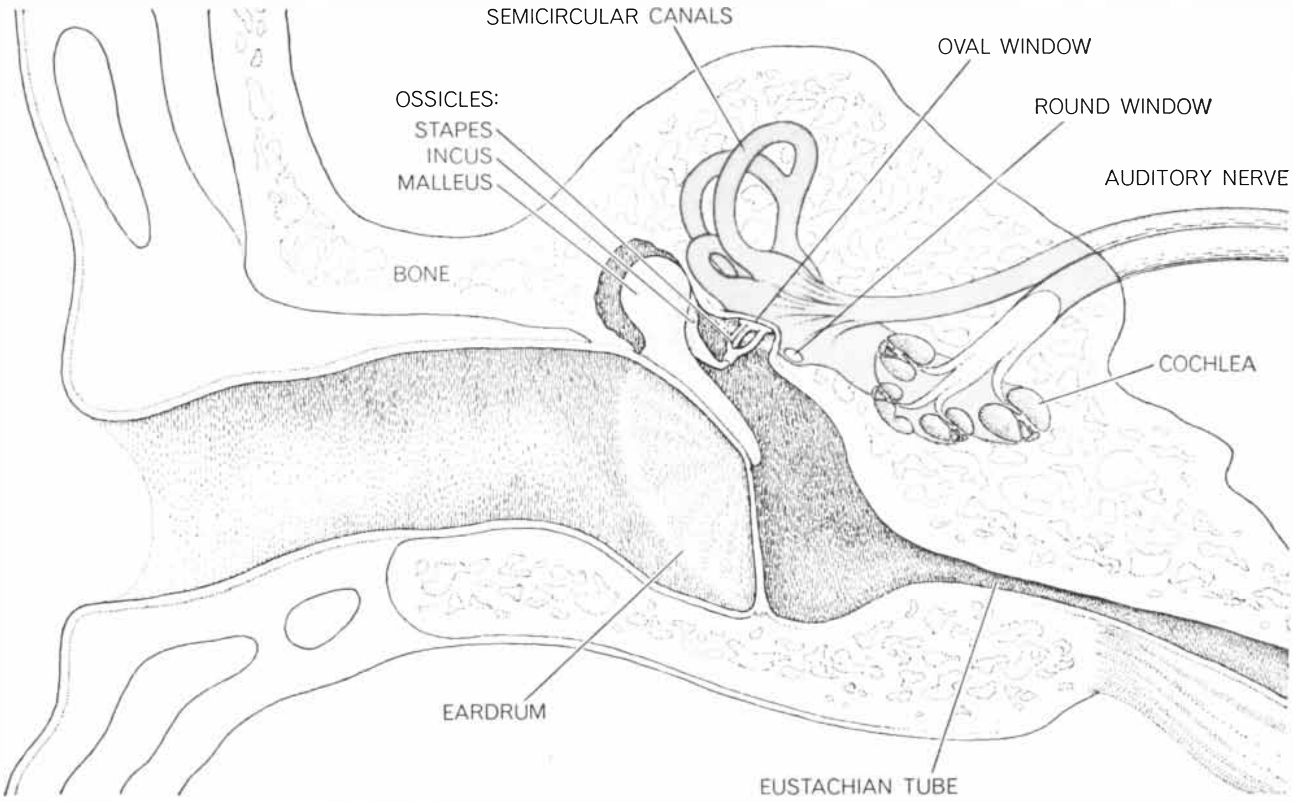
The study of hearing was at a considerable disadvantage compared with that of vision because of the primitive state of acoustics. The anatomists who began the investigation anew in the 16th century had at their disposal only an elementary, qualitative theory of sound and of hearing inherited from Greek and medieval sources; it in no way compared with the well-developed discipline of geometrical optics. Even so, here again the mechanistic program, once grasped and reinforced by the successful model presented by the inquiry into the mechanism of vision, offered a clear definition of problems for study. These involved three kinds of investigation: into the anatomy of the ear and its neural connections with the brain, into the physics of sound and into the problem of relating the results of these investigations in a theory of the auditory mechanism.

Anatomical research, beginning in Italy in the early 16th century not far from where Galen had left off, had by the early 17th century clarified and in large part discovered the principal elements of the auditory mechanism [*see top illustration on page 114*]. Full descriptions were eventually published by Thomas Willis in 1672 and by Joseph Guichard Duverney in 1683.

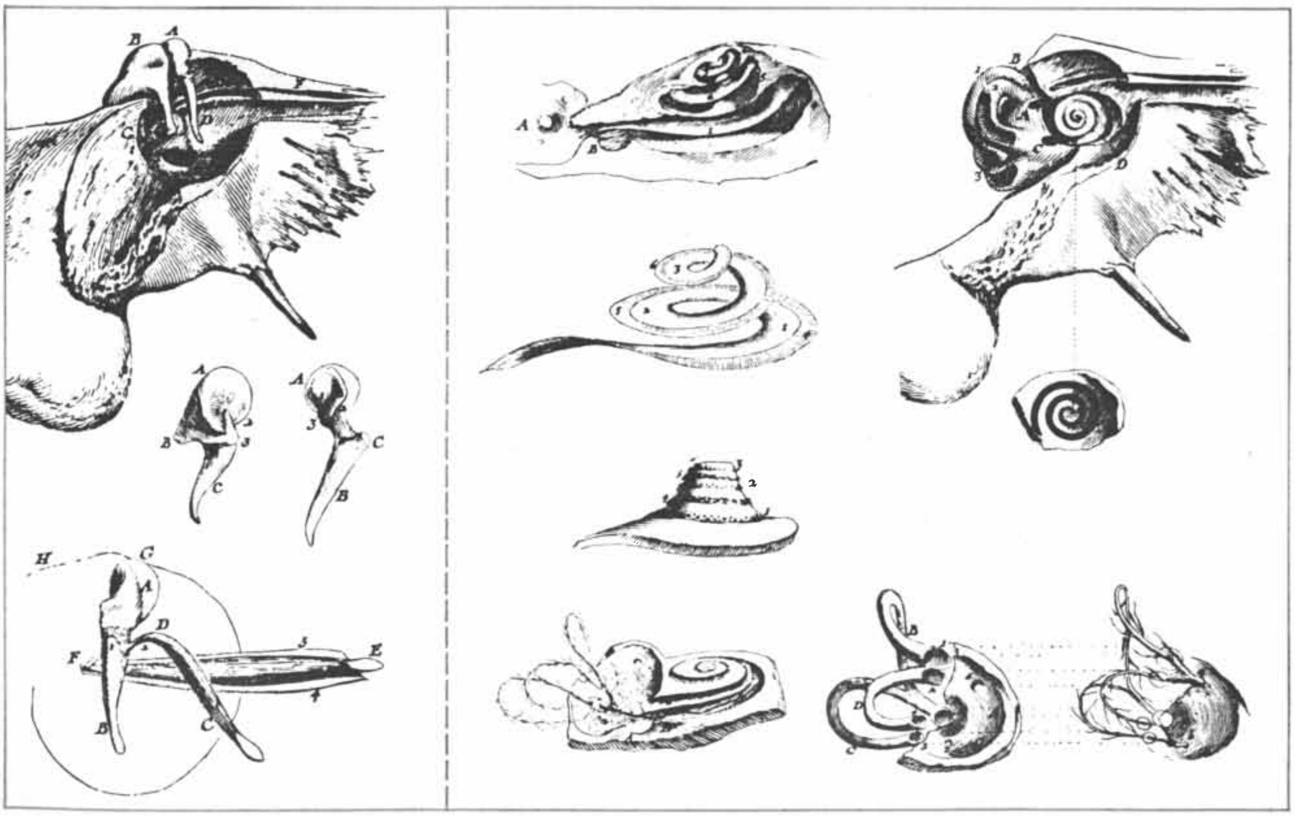
According to the theory of hearing inherited by these anatomists from ancient and medieval sources, a sounding body transmitted its motion to the contiguous air, which in turn propagated the motion to the ear, where the beating of the external air on the drum produced a corresponding motion of the "internal air" enclosed in the ear. As anatomical knowledge progressed, discussion centered on the identification of the organ sensitive to sound and the mode of operation of the other parts believed to modulate and transmit the pulses received from the external air and to present what the Dutch anatomist Volcher Coiter called "the image of the sound" to the sensitive organ for transmission to the "common sensory" in the brain. These different parts were thought to correspond to analogous parts in the eye. After a succession of opinions, beginning with the ancient view that the sensitive organ was the "internal air" itself and followed by the view that it must be the termination of the auditory nerve corresponding to the expansion of the optic nerve into the retina, Willis finally argued in his *De Anima Brutorum* in 1672 that the proper organ was the membranous spiral lamina of the cochlea. Along the length of the spiral the auditory nerve terminated in slender threads, so that here "the audible Species may be impressed on the Fibers and the ends of the sensible Nerves, inserted in this place, not at once or at large, but by little and little, and as it were in a just proportion and dimension." Hence it was here that "the proper Sensory of Hearing ought to be placed; for there is the sense, where the Nerve receiving the Idea of Sensation, is implanted." Willis could not, however, explain how the sensitive organ worked.

Similarly, opinion remained uncertain and unclear about the function of the middle-ear ossicle system in transmitting the drum's motion, in spite of comparisons made between the control of the tension of the drum by the ossicles and the tension exerted by the muscles in the eye in focusing or in altering the size of the pupil.

For many years the more critical investigators had been well aware of how little they understood the functions of the structures they were discovering. The essential requirements were recognized in the 17th century by Marin Mersenne: first, the combining of anatomy with the quantitative study of the physics of sound, and then the separation of the physiological problem of the mechanism of the sense organ from the psychological and philosophical problems arising from sensation and perception. Mersenne undertook studies of the speed of sound, the correlation of pitch with the frequency of vibration of strings, consonance and dissonance, and harmonic induction. Some years later, in 1677, Claude Perrault undertook a program of research in the Académie Royale des Sciences in Paris "to examine to the bottom everything concerned with the sense of hearing." The program was carried out with remarkable scientific sophistication by a group of physicists and anatomists who made intelligent use of the comparative method. With Duverney, aided by the physicist Edmé




**ANATOMY OF EAR** as now known is presented for comparison with the ideas put forward by ancient, medieval and renaissance students of hearing. Vibrations of sound produce vibrations of the eardrum, which are transmitted by the small, articulated bones of the ossicles to the oval window at the base of the cochlea. Vibrations of the fluid in the cochlea are converted into nerve impulses.



**17TH-CENTURY CONCEPT** of the ear is shown in illustrations from Joseph Duverney's *Traité de l'organe de l'ouïe*, published in 1683. At left are structures of the tympanic cavity, or middle ear, including the bones of the ossicles. At right are inner-ear structures, including at top right cochlea and semicircular canals. Other drawings show details of inner ear. Some of the structures are enlarged.

Mariotte, it yielded what Willis had been unable to provide: a theory based on an exact acoustical law (the law of harmonic induction) explaining how sound is received by the sensitive organ. With his elegant *Traité de l'organe de l'ouïe* in 1683 Duverney became, as far as was technically possible, the Kepler of hearing.

Duverney based his theory on a model: the vibrations induced in specific strings of a lute when those of a neighboring lute are plucked. Because the sound transmitted from one lute to another through a solid table is louder than it is when it is transmitted through the air, he argued that the ossicles, and not the air enclosed in the middle ear, played the major role in transmitting the vibrations of the drum to the oval window and so to the "implanted air" that he thought filled the labyrinth of the inner ear. On the grounds of its anatomy and neural connections he argued, as had Willis, that the membranous spiral lamina was the sensitive organ that responded to the vibrations transmitted to the "implanted air." Dividing the cochlea longitudinally into two separate spirals connected respectively with the oval window and the round window, he said that "this lamina is not only capable of receiving the vibrations of the [implanted] air, but its structure must make us think that it can respond to all their different characteristics." He thought it might respond to the lower notes at the wider bottom end and to higher notes as it narrowed upward. In this he was anticipating Hermann von Helmholtz' 19th-century resonance theory of hearing, which is now generally accepted.

By contemporary criteria of certification, however, Duverney himself recognized that his theory could not then be firmly established inside testable scientific knowledge; he presented it simply as a "conjecture" that he hoped was "credible." This of course it remained, even in the new form given to it when Domenico Cotugno showed in 1760 that the labyrinth including the cochlea was filled with fluid and not with air, until eventually technical scientific advances allowed Helmholtz to bring it within range of testability.

I turn now to the second part of my thesis: that by first successfully restricting the inquiry to specifically limited problems, the mechanistic hypothesis made it possible in the 17th century to recognize systematically the three different kinds of question involved in the phenomena of the "animate and sensitive body." The distinguishing of these kinds of question came about largely through the inquiries of Descartes into the coordination of sensory information and behavior.

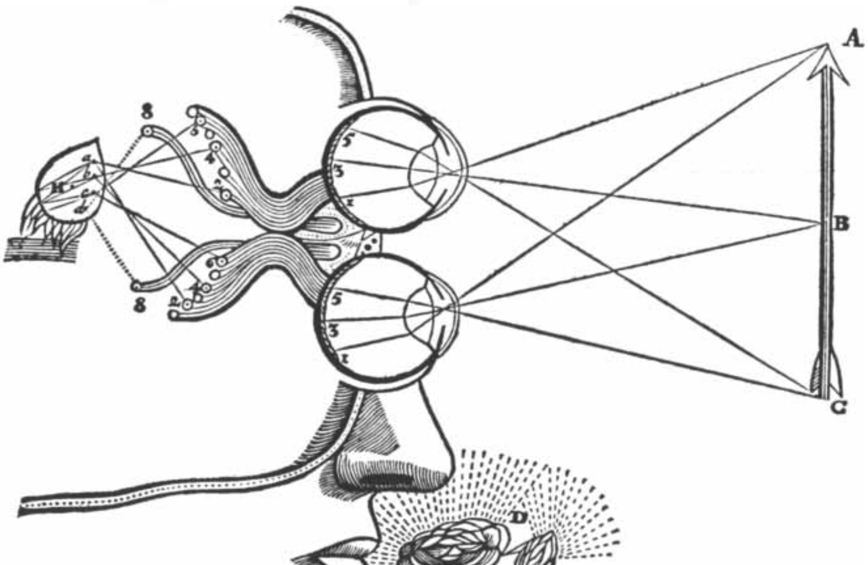
Kepler in his *Paralipomena,* as already mentioned, explicitly put aside the problem of how vision is effected by the body's sensory organs. In his later *Dioptrice,* however, he attempted once more to deal with the problem traditionally. He offered an account of the causation of sensation by means of a "representative image," which was simply a more mechanistic version of the ancient theory already used by Alhazen. Kepler wrote: "To see is to feel the stimulation of the retina, however it is stimulated. The retina is painted with the colored rays of visible things.... But this picture does not complete the act of vision until the image so received by the retina passes through the continuity of the spirits to the brain, and is there delivered to the threshold of the faculty of the soul." He suggested that the image might be transmitted from the eye to the "common sensory" in the brain through the visual spirit in the optic nerve as a wave is transmitted across water.

One of the great contributions made by Descartes, and by Mersenne, was that they clarified this problem by using a "representative image" that they kept rigorously mechanical. Thereby they were able to show that the traditional formulation of vision confused two quite different questions.

They began by distinguishing the case of animals from that of men. Kepler had treated the living eye as a dead optical instrument; Descartes in his *Traité de l'homme* and Mersenne in his *Harmonie universelle* extended this concept physiologically by treating the whole living animal body as a dead machine. Ruthlessly they allowed only one kind of question: What physical motions follow each preceding physical motion? They asserted that when the motion of light or sound impresses a physical image on the eye or ear, this is transmitted through a physical "animal spirit" to the brain, and that eventually through the physical structure of the neuromuscular system a physical response takes place—coordinated with other built-in responses.

In this approach the study of animal behavior was therefore the study of the coordination of physical states without sensation. As Mersenne put it: "Animals have no knowledge of these sounds, but only a representation, without knowing whether what they apprehend is a sound or a color or something else; so one can say that they do not act so much as are acted upon, and that objects make an impression upon their senses from which their action necessarily follows, as the wheels of a clock necessarily follow the weight or spring which drives them."

The crucial point about this approach is the argument that Descartes and Mersenne derived from it. The argument was that in this "animal machine"



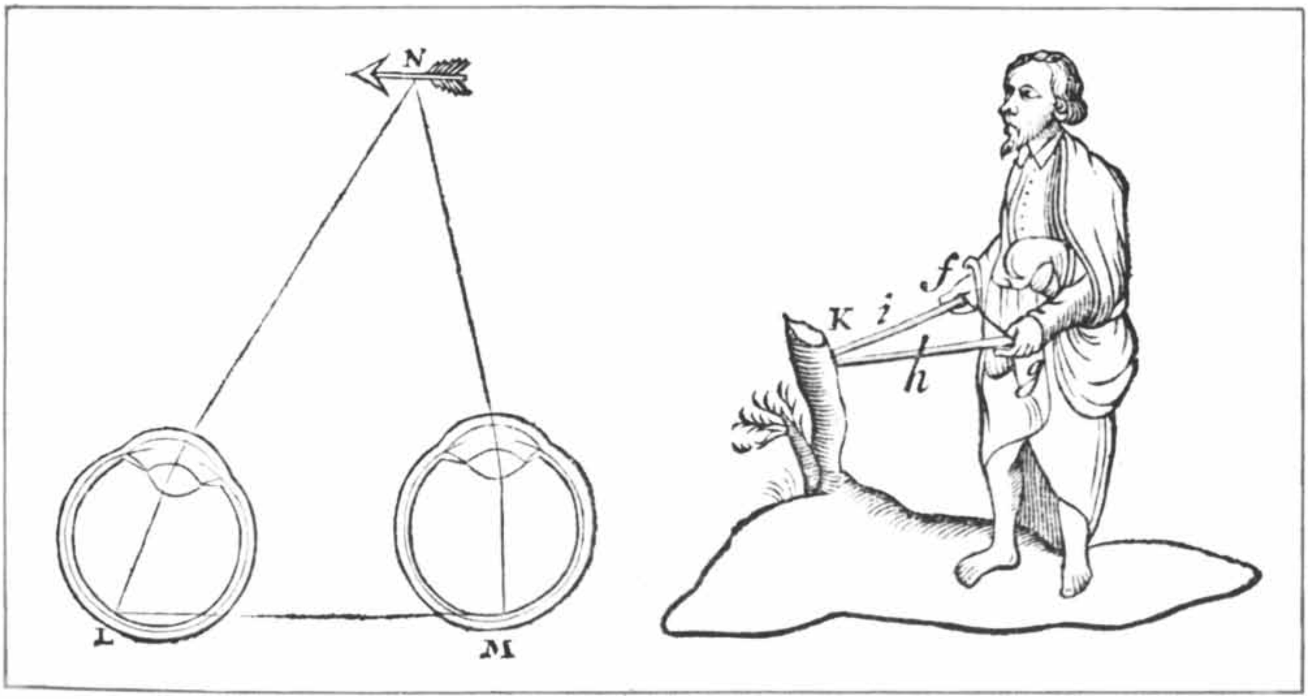

**COORDINATION OF SENSES in Descartes's view was a wholly mechanistic and neurological process. In this illustration, from his *L'Homme*, the visual stimulus going from the arrow to the coordinating pineal gland (*H*) prevents attention to the smell of the flower.**

science had to deal only with purely physiological questions, separate from all psychological questions about sensation. They recognized that physiology faced a scientific and technical frontier. Thereafter advances in knowledge of sensory physiology were restricted only by scientific and technical limitations. It was these that prevented real advances in the understanding of what happens behind the retina and the cochlea until the 19th century. Then progress became possible because of progress in physical optics and acoustics—in histology with the improved achromatic microscope and new chemical stains, and in electrophysiology with the work of Johannes Müller's pupils in Berlin, above all that of Helmholtz.

Having clarified this physiological frontier in the study of the animal body, Descartes then had no difficulty arguing that the question of how sensations are caused in men was a different kind of question encountering a different kind of frontier. He argued in *La Dioptrique* that an account of the "representative image" type did not touch the central problem (recognized clearly since Plato's time) of passing from a physical motion or image, produced by external stimuli in the sensory mechanisms, to a sensation in the sentient being. Discussing how he had removed the backs of the eyes of newly dead men or animals and placed a piece of paper or eggshell over the opening in order to watch the images produced on the retina, he went on to say: "While this picture, in thus passing into our head, always retains some degree of resemblance to the objects from which it proceeds, yet we need not think . . . that it is by means of this resemblance that the picture makes us perceive the objects. . . . Rather we must hold that the movements that go to form the picture, acting immediately on our soul inasmuch as it is united to our body, are so ordained by nature as to give it such sensations."

Thus Descartes's main argument against the "representative image" theory was that it was irrelevant because it took the physiological image as being the object instead of the means of sensing. He behaved then as though he recognized that the question of how physiological motions cause sensations belonged to a type to be explicitly classified by John Locke as in principle unanswerable because it concerns relations between different categories of subject. Descartes simply avoided the frontier Kepler had attempted to cross from motions to sensations: a philosophical frontier of knowledge established by what cannot be known. Instead he directed his attack wholly against a quite different frontier, reached by asking a different, answerable question: What physical and physiological clues determine different sensations? He pointed out that even in vision the image was not a strict representation of the object but more like a two-dimensional engraving that could suggest with a few strokes many different qualities, including not strictly visual ones; still less was the image strictly representative in the other senses. So, he wrote, "the only question we need raise is that of knowing how the images can supply to the soul the means of sensing all the diverse qualities of the objects to which they stand related."

The contribution I claim for Descartes and his stronger successors is, then, that they were able by their use of the mechanistic hypothesis to separate explicitly the answerable questions of physiology and of psychophysiological correlation from the unanswerable questions about the causation of perception that they had inherited from ancient and medieval sources. The mechanistic hypothesis in its brutal Cartesian form brought the exact lines of the scientific frontier of potentially testable propositions out into the open and so offered a clear view of what to do next to extend the area of scientific knowledge. The pushing back of this frontier by the direct study of living things led in turn to the recognition of the diversity of the answerable questions to be discovered in the subject matter of the "animate and sensitive body."




**PERCEPTION OF DISTANCE** according to Descartes is illustrated by these drawings from his *L'Homme*, published in 1664. He thought the mind perceived distance by means of the angle formed by the axes of the eyes in the sighting of an object (*left*), just as a blind man could calculate the distance to an object by the angle, or the separation, between two sticks of known lengths (*right*).

RECENT findings

RESEARCH LABORATORIES

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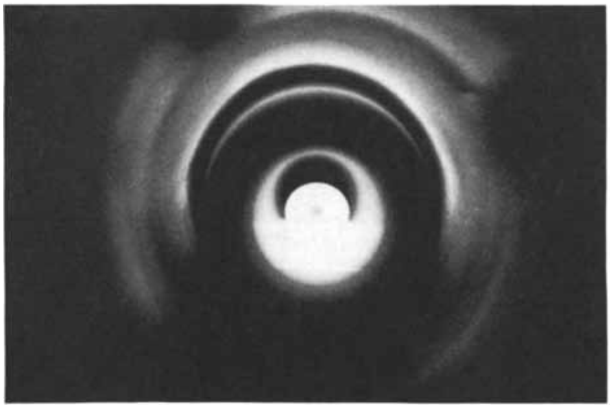
# WETTABILITY IN LIQUID-SOLID SYSTEMS

## How our work with synthetic composite materials led to a cutting tool material with a service life ten times that of the hardest tool bits previously developed.

Ford Motor Company scientists have been deeply involved with synthesizing composites from various combinations of metals, ceramics and plastics. This class of materials often is the only feasible approach to obtain specific properties to meet space age needs.

A prime problem is the formation of a strong bond between dissimilar materials such as metals and ceramics. This led to extensive study of the wettability in liquid-solid systems.

In the case of metal-ceramic composites, wetting is studied at Ford Research by placing a piece of metal on a flat ceramic and heating the combination until the metal melts. When molten, the metal forms a specific drop shape, governed by gravitational and surface forces. The extent to which the liquid will wet the solid is a measure of the adhesion between the two materials.



Bright central area is metal melting on a ceramic base in Sessile Drop Furnace. Photo taken at Ford Research Laboratories.

Working with many metals and ceramics in the course of these wettability studies, Ford scientists developed an exceptional material. This synthetic composite consisted of titanium carbide bonded with nickel and molybdenum.

Further testing and studies showed that this material had a high hardness and strength which seemed very well adapted to use as tool bits for metal cutting.

In comparison with the hardest tool bits previously developed, this new material offered a service life approximately 10 times longer.

An additional advantage lies in the fact that the materials involved are readily available. The carbide tools now in common use for metal cutting are based on a system of tungsten carbide and cobalt. Unfortunately, most of the world's sources for tungsten are concentrated in countries behind the Iron Curtain.

Today, Ford scientists are engaged in the investigation of basic concepts in many fields—constantly probing deeper in both theory and application with the aim of serving better.

**PROBING DEEPER TO SERVE BETTER**

Ford

MOTOR COMPANY

The American Road, Dearborn, Michigan

# MATHEMATICAL GAMES

## *The "tyranny of 10" overthrown with the ternary number system*

by Martin Gardner

*Somewhere in the darkness a woman sang in a high wild voice and the tune had no start and no finish and was made up of only three notes which went on and on and on.*

—Carson McCullers,
*The Ballad of the Sad Café*

Now and then a cultural anthropologist, eager to push mathematics into the folkways, will point to the use of different number systems in various primitive societies as evidence that laws of arithmetic vary from culture to culture. But of course the same old arithmetic is behind every number system. The systems are nothing more than different languages: different ways of uttering, symbolizing and manipulating the *same* numbers. Two plus two is invariably four in any notation, and it is always possible to translate perfectly from one number language to another.

Any integer except 0 can furnish the base, or radix, of a number system. The simplest notation, based on 1, has only one symbol: the notches an outlaw cuts in his gun or the beads a billiard player slides along a wire to record his score. The binary system (discussed in this department in December, 1960) has two symbols: 0 and 1. The decimal system, now universal throughout the civilized world, uses 10 symbols. The larger the base, the more compactly a large number can be written. The decimal number 1,000 requires 10 digits in binary notation (1111101000) and 1,000 digits in the 1-system. On the debit side, a large base means more digits to memorize and larger tables of addition and multiplication.

From time to time reform groups, fired with almost religious zeal, seek to overthrow what has been called the "tyranny of 10" and replace it with what they believe to be a more efficient radix. In recent years the duodecimal system, based on 12, has been the most popular. Its chief advantage is that all multiples of the base can be evenly halved, thirded and quartered. (The unending decimal fraction .3333..., which stands for 1/3, becomes a simple .4 in the 12-system.) There have been advocates of a 12-base since the 16th century, including such personages as Herbert Spencer, John Quincy Adams and George Bernard Shaw. H. G. Wells has the system adopted before the year 2100 in his novel *When the Sleeper Wakes.* There is even a Duodecimal Society of America. (Its headquarters are at 20 Carleton Place, Staten Island, N.Y. 10304.) It publishes *The Duodecimal Bulletin* and *Manual of the Dozen System* and supplies its "dozeners" with a slide rule based on a radix of 12. The society uses an X symbol (called dek) for 10 and an inverted 3 (called el) for 11. The first three powers of 12 are do, gro, mo; thus the duodecimal number 111X is called mo gro do dek.

Advocates of radix 16 have produced

| DECIMAL NUMBERS | TERNARY NUMBERS | | | |
|---|---|---|---|---|
| | $3^3$ | $3^2$ | $3^1$ | $3^0$ |
| 1 | | | | 1 |
| 2 | | | | 2 |
| 3 | | | 1 | 0 |
| 4 | | | 1 | 1 |
| 5 | | | 1 | 2 |
| 6 | | | 2 | 0 |
| 7 | | | 2 | 1 |
| 8 | | | 2 | 2 |
| 9 | | 1 | 0 | 0 |
| 10 | | 1 | 0 | 1 |
| 11 | | 1 | 0 | 2 |
| 12 | | 1 | 1 | 0 |
| 13 | | 1 | 1 | 1 |
| 14 | | 1 | 1 | 2 |
| 15 | | 1 | 2 | 0 |
| 16 | | 1 | 2 | 1 |
| 17 | | 1 | 2 | 2 |
| 18 | | 2 | 0 | 0 |
| 19 | | 2 | 0 | 1 |
| 20 | | 2 | 0 | 2 |
| 21 | | 2 | 1 | 0 |
| 22 | | 2 | 1 | 1 |
| 23 | | 2 | 1 | 2 |
| 24 | | 2 | 2 | 0 |
| 25 | | 2 | 2 | 1 |
| 26 | | 2 | 2 | 2 |
| 27 | 1 | 0 | 0 | 0 |

*Ternary numbers 1 through 27*

# SILICOLOGY

## Energy Absorption of Semi-Rigid Foams Increased Six-Fold by New One-Shot Process

In devising a new one-shot system for manufacturers of semi-rigid urethane foams, we met head-on (like football players) with some unique problems. Silicone surfactants played a major role in solving them.

Almost all semi-rigids are used as shock absorbers. Automotive crash pads and sunshields. Protective padding for delicate instruments and heavy equipment. Gaskets. Athletic equipment. (We understand football players often clash with the force of a car going fifty miles an hour.)

These end uses place harsh demands on manufacturers. They must supply cushioning material rigid enough to prevent strike-through. Yet the material must be soft enough and resilient enough to absorb shock without permanent deflection.

What is needed is a hybrid between a flexible foam with a high percentage of open cells and a rigid foam with mostly closed cells. Union Carbide's new one-shot system for manufacturing semi-rigid urethane foams is designed to balance these cellular problems ... and, do it economically.

Two silicone surfactants provide the key. One acts as a stabilizer. It gives the necessary film healing while the foam develops and rises. The other silicone surfactant opens the right number of cells at exactly the right time.

Together, in a one-shot process, these two surfactants perform a job that formerly required a more expensive two-step prepolymer system.

They give a much superior product, too. A foam that absorbs up to six times the energy of previous urethane foams, according to standard rebound tests. Density is reduced by 33%, and, significantly, compression set is reduced from 40-50% to zero-1%. (The table has more details.)

By varying the formula, manufacturers can obtain a considerable range in reactivity rates and physicals. A viscosity of 300 centistokes makes molding easier ... permits free flow into thin and intricate molds, eliminates rejections and void-repair problems.

Excellent green strengths are obtained without post-curing. Curing time-temperatures and cream times are compatible with current production equipment and schedules.

Union Carbide is the originator of surfactants for one-shot polyurethane foams and the leading innovator in silicones technology. You can select from the most complete product line, and benefit, too, from all the silicone research we are doing. Just see your Silicones man or mail the coupon below for any kind of information you want about silicones and their uses.

| Property | UNION CARBIDE'S One-Shot System | Typical Prepolymer Properties |
|---|---|---|
| Compression Set | 0-1% | 40-50% |
| Density | 4.5-6.5 lb/ft$^3$ | 8-11 lb/ft$^3$ |
| Resiliency (Rebound Ball Test) | 5% | 30% |
| Humid Aging (loss of load bearing) | 25-35% decrease | 40-50% decrease |
| Fillers (to eliminate shrinkage and to obtain properties) | None required | Required |
| Viscosity of System | 300 centistokes | 2000-4000 centistokes |
| "Green Strength" (time to reach minimum compression set) | <1 hour | >3 hours |

UNION CARBIDE

SILICONES

UNION CARBIDE is a trade mark of Union Carbide Corporation.

**Silicones Division**
**Union Carbide Corporation**
**Dept. 4E84-4401, 30-20 Thomson Ave.**
**Long Island City, New York 11101**

In Canada: Union Carbide Canada, Ltd. Bakelite Division, Toronto 12.

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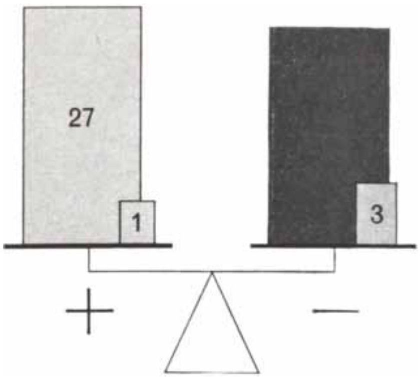



*How to weigh a 25-pound object*

the funniest literature. In 1862 John W. Nystrom published privately in Philadelphia his *Project of a New System of Arithmetic, Weight, Measure, and Coins, Proposed to Be Called the Tonal System, with Sixteen to the Base.* Nystrom urges that numbers 1 through 16 be called an, de, ti, go, su, by, ra, me, ni, ko, hu, vy, la, po, fy, ton. Joseph Bowden, who was a mathematician at Adelphi College, also considered 16 the best radix but preferred to keep the familiar names for numbers 1 through 12, then continue with thrun, fron, feen, wunty. In Bowden's notation 255 is written ƐƐ and pronounced "feenty feen." (See Chapter 2 of his *Special Topics in Theoretical Arithmetic,* published in 1936.)

It seems unlikely that the "tyranny of 10" will soon be toppled, but that does not prevent the mathematician from using whatever number system he finds most useful for a given task. If a structure is rich in two values, such as the on-off values of computer circuits, the binary system may be much more efficient than the decimal system. Similarly, the ternary, or 3-base, system is often the most efficient way to analyze structures rich in three values. In the quotation that opens this article Carson McCullers is writing about herself. She is the woman singing in the darkness about that grotesque triangle in which Macy loves Miss Amelia, who loves Cousin Lymon, who loves Macy. To a mathematician this sad, endless round of unrequited love suggests the endless round of a base-3 arithmetic: each note ahead of another, like the numbers on an eternally running three-hour clock.

In ternary arithmetic the three notes are 0, 1, 2. As you move left along a ternary number, each digit stands for a multiple of a higher power of 3. In the ternary number 102, for example, the 2 stands for $2 \times 1$. The 0 is a "place holder," telling us that no multiples of 3 are indicated. The 1 stands for $1 \times 9$. We sum these values, $2 + 0 + 9$, to obtain 11, the decimal equivalent of the ternary number 102. The illustration on page 118 shows the ternary equivalents of the decimal numbers 1 through 27. (A Chinese abacus, by the way, is easily adapted to the ternary system. Just turn it upside down and use the two-bead section.)

Perhaps the most common situation lending itself to ternary analysis is provided by the three values of a balance scale: either one pan goes down or the other pan goes down, or the pans balance. As far back as 1624, in the second edition of a book on recreational mathematics, Claude Gasper Bachet asked for the smallest number of weights needed for weighing any object with an integral weight of one through 40 pounds. If the weights are restricted to one side of the scale, the answer is six: 1, 2, 4, 8, 16, 32 (successive powers of 2). If the weights may go on either pan, only four are needed: 1, 3, 9, 27 (successive powers of 3).

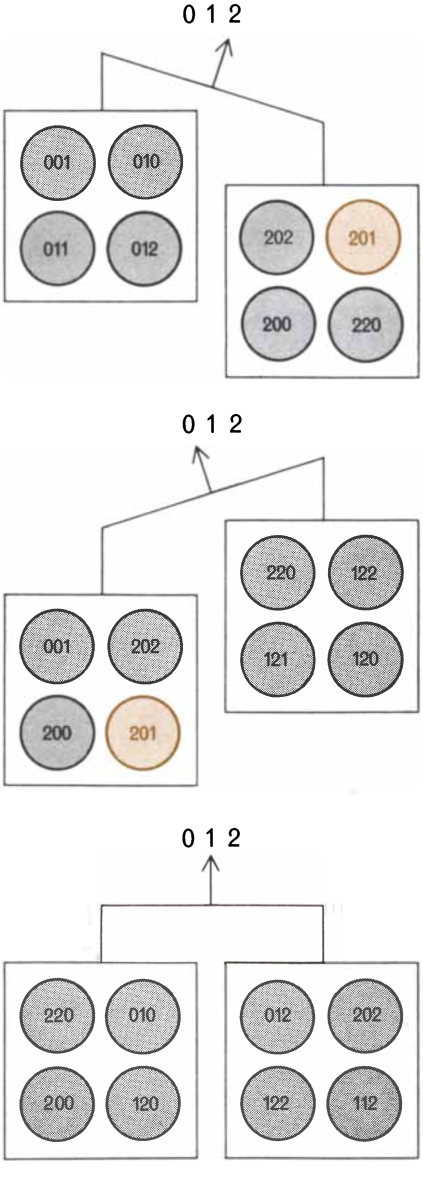
To determine how weights are placed to weigh an object of $n$ pounds, we first write $n$ in the ternary system. Next we change the form of the ternary number so that instead of expressing its value with the symbols 0, 1, 2 we use the symbols 0, 1, $-1$. To do this each 2 is changed to $-1$, then the digit to the immediate left is increased by 1. If this produces a new 2, it is eliminated in the same way. If the procedure creates a 3, we replace the 3 with 0 and add 1 to the left. For instance, suppose the weight is 25 pounds, or 221 in ternary notation. The first 2 is changed to $-1$, then 1 is added to the left, forming the number $1 -1\ 2\ 1$. The remaining 2 is now changed to $-1$, and 1 is added to the left, making the number $1\ 0 -1\ 1$. This new ternary number is equivalent to the old one $(27 + 0 - 3 + 1 = 25)$, but now it is in a form that tells us how to place the weights. Plus digits indicate weights that go in one pan, minus digits indicate weights that go in the other pan. The object to be weighed is placed on the minus side. The illustration at the top of this page shows how the three weights are placed for weighing a 25-pound object.

Suppose you wish to determine the weight of a single object known to have an integral weight of from one through 27 pounds. What is the smallest number of weights needed, assuming that they may be placed on either pan? There is no catch, but the question is tricky and the answer is not what you are first likely to think.

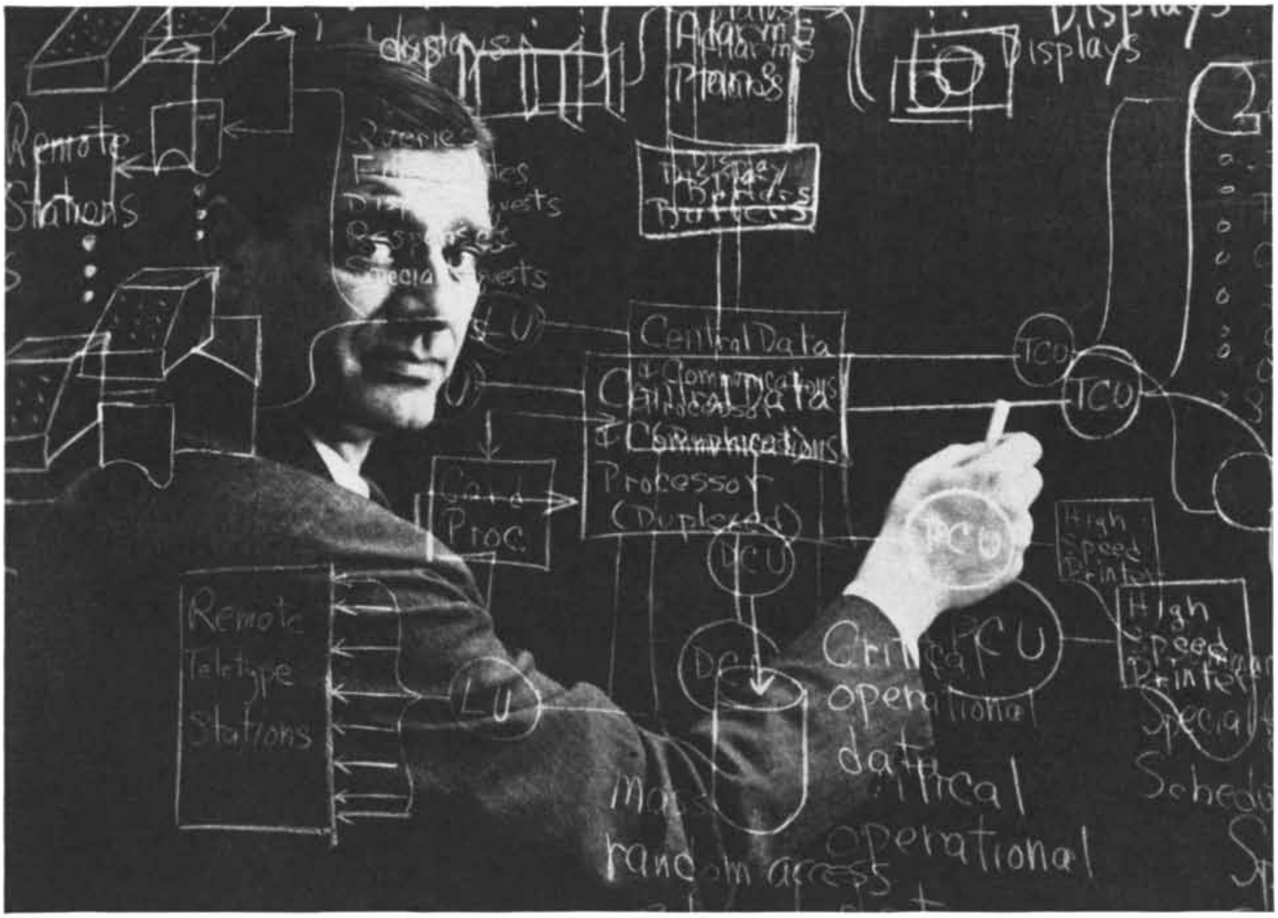
A more sophisticated balance-scale problem (dozens of papers have discussed it since it first sprang up, seemingly out of nowhere, in 1945) is the problem of the 12 coins. They are exactly alike except for one counterfeit, which weighs a bit more or a bit less than the others. With a balance scale

| | | |
|---|---|---|
| 1 | 001 | 221 |
| 2 | 002 | 220 |
| 3 | 010 | 212 |
| 4 | 011 | 211 |
| 5 | 012 | 210 |
| 6 | 020 | 202 |
| 7 | 021 | 201 |
| 8 | 022 | 200 |
| 9 | 100 | 122 |
| 10 | 101 | 121 |
| 11 | 102 | 120 |
| 12 | 110 | 112 |

*Ternary numbers for 12-coin problem*




*Three weighings to identify counterfeit coin*




# HAVE YOU EVER STEPPED BEHIND THE BLOCK DIAGRAM OF A TOTAL SYSTEM?

The experience can be shattering — or at least surprising for the unwary, or the superficial systems engineer. On the other hand, it can be a rich and rewarding professional experience for those who prefer to take a deeper view of systems.

Our own people tend to spend at least as much time "behind" our functional block diagrams, as in front of them. The approach is to block out the major elements of a system which will fulfill the function desired . . . then identify and isolate the salient problem areas and develop step-by-step solutions to these.

Our recent "RIPS" study illustrates the point:

ITT Data and Information Systems Division undertook a study to determine the space instrumentation requirements to support all U.S. space programs for the time period 1965-1970. Under contract to the Air Force Electronic Systems Division, the study involved the following activities:

**1.** Detailed analysis of over 40 space programs with a lesser analysis of an additional 100, to determine such items as tracking accuracies required, flight profiles, telemetry requirements, man control requirements, etc.

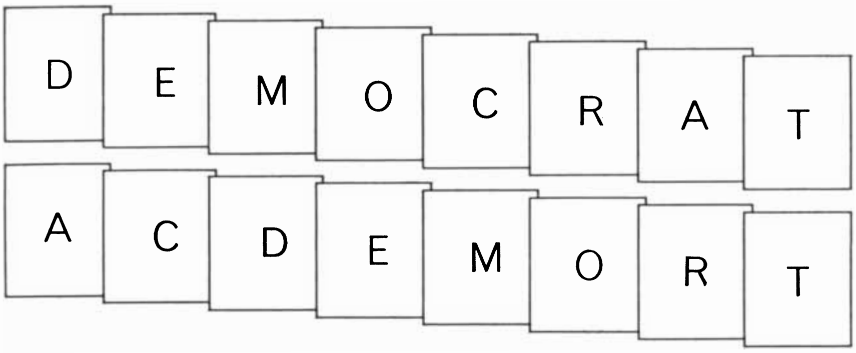
**2.** Since present space ranges were organized to support guided missiles and ballistic missiles, this study also produced a concept and plan for integrating these facilities into a global test environment. Control of this global test environment would be concentrated at a center equipped to support both local and global space programs. Provision for range control, test control and information flow between these ranges was included in the detailed concept.

**3.** Extensive studies were conducted in each area of technology to determine the metric instrumentation required; the capabilities of CW and pulse sensors were investigated in depth. Source of errors including geodetic refraction, timing and others were investigated and an overall error analysis conducted. Timing extensions to provide the accuracies required throughout the globe were also investigated. Calibration techniques using satellites for global calibration of RF and optical instrumentation were explored and suitable recommendations made. The processing, communication and display of information were thoroughly investigated. Planned facilities were mapped out against existing facilities to note deficiencies. Siting facilities were explored and recommendations for their use were made.

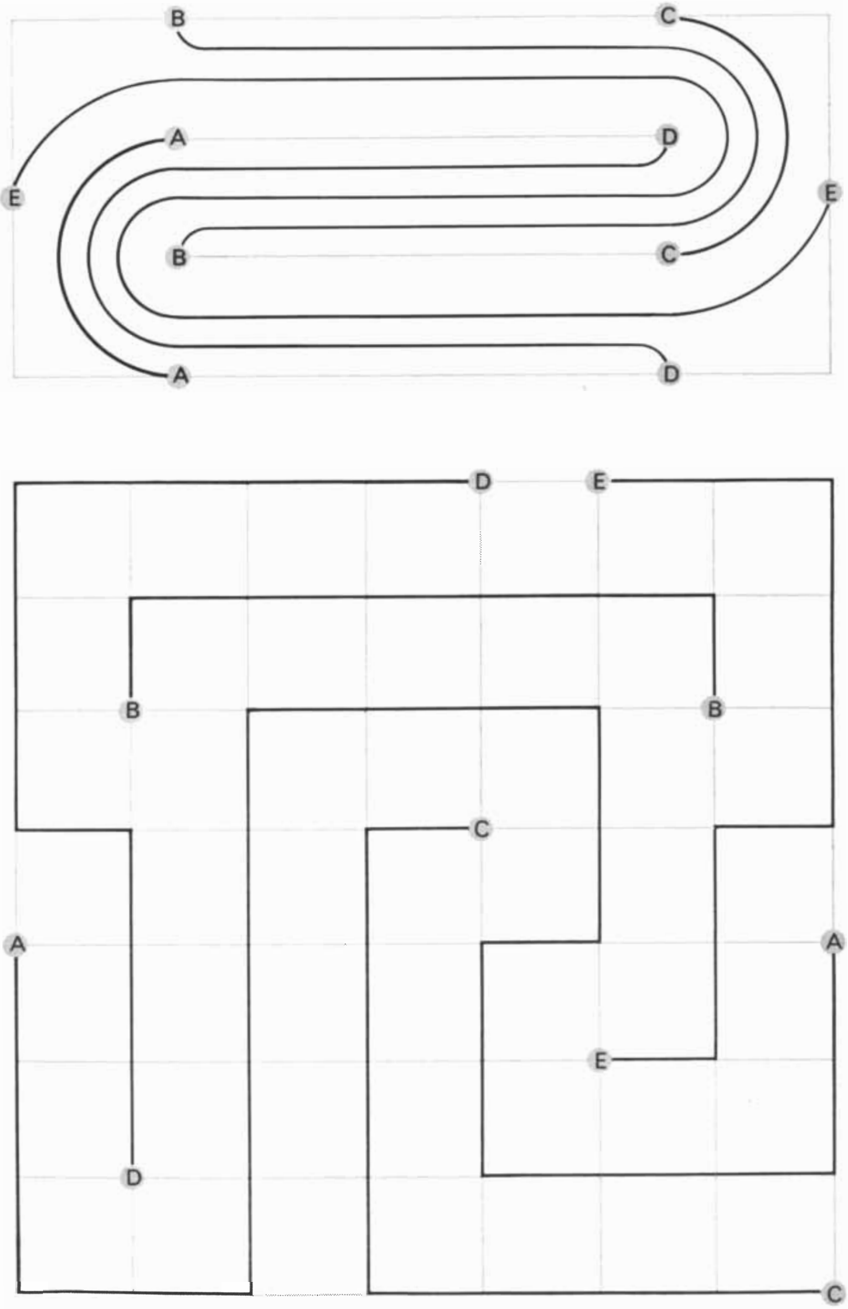
**4.** An analysis was conducted to determine the requirements for new sites to support global missions. Profiles and typical satellite orbits were prepared to determine pass-time capabilities of these stations and to highlight deficiencies in the present systems.

Actually, RIPS represents a relatively small proportion of our total systems activities. When you're ready to explore the opportunity side of DISD, you'll discover a great deal more. A good first step would be to write in confidence to Mr. E. A. Smith, Manager of Employment, Div. 93-ME, ITT Data and Information Systems Division, Route 17 and Garden State Parkway, Paramus, New Jersey. (An Equal Opportunity Employer)

**ITT** DATA AND INFORMATION SYSTEMS DIVISION




*Original (top) and desired sorting of DEMOCRAT cards*



*Solutions to last month's printed-circuit problems*

and *no* weights, is it possible to identify the counterfeit in three weighings and also know if it is underweight or overweight?

Although I constantly receive letters asking about this problem, I have avoided writing about it because it was so ably discussed by C. L. Stong in "The Amateur Scientist" department of this magazine for May, 1955. Now we shall see how one solution (there are many others) is linked with the ternary system.

First, list the ternary numbers from 1 through 12. To the right of each number write a second ternary number obtained from the first by changing each 0 to 2, each 2 to 0 [*see upper illustration at right on page 120*]. Next, find every number that contains one of the following pairs of adjacent digits: 01, 12, 20. Assign one of these 12 numbers (shown in color) to each of the 12 coins.

For the first weighing the four coins with a first digit of 0 go left, the four with a first digit of 2 go right. If the pans balance, put down 1 as the first digit of the counterfeit. If the left pan goes down, the counterfeit's first digit is 0; if the right pan goes down, it is 2.

For the second weighing the four coins with a middle digit of 0 go left, the four with a middle digit of 2 go right. The same procedure is followed to obtain the middle digit of the counterfeit. On the third weighing, coins with final digits of 0 go left, those with final digits of 2 go right, and the last digit of the counterfeit is obtained as before. The lower illustration at the right on page 120 shows the three weighings that identify the counterfeit as coin 201. Because the first and third weighings show this coin on the pan that goes down, the coin is clearly overweight.

Scores of simplified versions of this procedure have been devised. The best I know comes from W. Fitch Cheney, Jr., a mathematician at the University of Hartford. Label the coins with the letters of SILENT COWARD. The three weighings are SCAN against WORD, SCAR against LINE, SLOT against RAID. Put a ring around each word that goes down. If a pair balances, mark out all its letters from all six words. Inspect the circled words. If there is a letter not crossed out that appears in each word, it indicates the false coin and the coin is overweight. If there is no such letter, you are sure to find one not crossed out in each of the uncircled words. It then indicates an underweight counterfeit. The problem has been generalized. In four weighings one can identify the false coin, and tell whether it is light or heavy, among a maximum of $3^1 + 3^2 + 3^3 = 39$ coins; five weighings will take care of $3^1 + 3^2 + 3^3 + 3^4 = 120$ coins, and so on. More compactly, $n$ weighings take care of $\frac{1}{2}(3^n - 1) - 1$ coins.

Many card tricks are closely related to the 12-coin problem. One of the best is known as Gergonne's three-pile problem after the French mathematician Joseph Diez Gergonne, who first studied it early in the 19th century. Someone is asked to look through a packet of 27 cards and fix one in his mind. He holds the packet face down, deals the cards face up into a row of three, then continues dealing on top of these cards, left to right, until all 27 have been dealt into three face-up piles of nine cards each. After telling the magician which pile contains his chosen card, he assembles the piles by placing them on top of one another, in any order he wishes, turns the packet face down and again deals them into three face-up piles. Once more he indicates the pile in which his card fell. This is repeated a third time, then the assembled packet is placed face down on the table. The magician, who has not touched the cards throughout the entire procedure, names the position of the chosen card.

The secret lies in observing, at each pickup, whether the pile with the selected card goes on the top, the bottom or in the middle of the assembled face-down packet. These positions are designated 0 for the top, 1 for the middle, 2 for the bottom. The ternary number expressed by the three pickups, written from *right to left,* is the number of cards above the chosen card after the final pickup. For example, suppose the first pickup puts the pile on the top (0), the second on the bottom (2), the third in the middle (1). These digits, written right to left, give the ternary number 120, or 15 in the decimal scale. Fifteen cards are therefore above the selected one, making it the 16th card from the top. Of course, the trick can be done just as easily in reverse. The spectator chooses any number from 1 through 27, then the magician, making the pickups himself, brings the card to that number from the top.

If in dealing into three piles one is permitted to put each card on *any* pile, a powerful sorting method results. At this point the reader is asked to obtain eight file cards and print on each card one of the letters in the word DEMOCRAT. Arrange the cards into a packet, letter sides down, that spells DEMOCRAT from the top down [*see top illustration on opposite page*]. You wish to rearrange

*Solution to four-circle problem*

the cards so that, from the top down, they are in alphabetical order as shown in the bottom row of the illustration. It is easily done in one deal. Turn the top card, *D*, face up and place it as the first card of pile 1. The next three cards, *E, M, O*, go on top of the *D*. *C* becomes the first card of pile 2, *R* goes back on pile 1, *A* starts pile 3 and *T* goes on pile 1. Assemble by putting pile 1 on 2 and those cards on 3; then turn the packet face down. You will find the cards in alphabetical order, top to bottom. A single deal is also sufficient, as you can easily discover, for changing the alphabetized order back to DEMOCRAT.

Put the DEMOCRAT cards aside and make a new set that spells REPUBLICAN. Can *this* set be alphabetized in one operation? No, it cannot. What is the smallest number of operations necessary? Remember, the initial packet of face-down cards must spell the word from the top down. Each card is dealt face up, the piles are picked up in any order, then the packet is turned face down to conclude one operation. After the last operation the cards must be in the order ABCEILNPRU, top to bottom. If you solve this problem, see if you can determine the minimum number of operations needed to change the order back to REPUBLICAN. And if both problems seem too easy, try a set of cards that spell SCIENTIFIC AMERICAN. Next month in this department I shall explain how all sorting problems of this type can be solved quickly by a simple application of ternary numbers, and I shall also answer the problem of the weights.

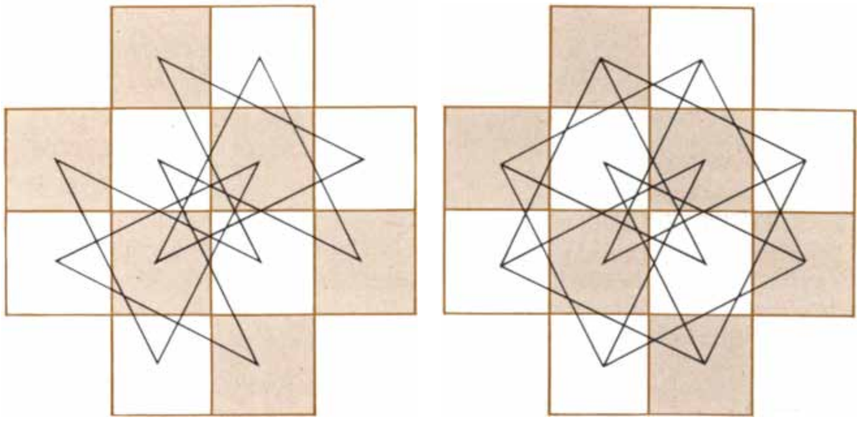
Last month's two printed-circuit problems are solved in the manner shown in the bottom illustration on page 122. A symmetrical, non-self-intersecting Euler line for the four-circle puzzle is shown at the top of this page, obtained by the coloring method explained last month. The path at the left in the illustration below traces a re-entrant knight's tour on the cross-shaped board. To determine if there is a single path that will go over every possible knight's move, we first draw a graph [*at right in illustration*] showing every move. Note that eight of the vertices are meeting points for an odd number of edges. In accordance with one of Euler's theorems given last month, a minimum of 8/2, or 4, paths are required to trace every edge once and only once. Each path must begin at one odd vertex and end at another.

To prove that no re-entrant knight's tour is possible on a board with an odd number of cells, first color the cells alternately, checkerboard fashion. Every knight's move carries the piece from a cell of one color to a cell of another, so that if the path is a closed circuit, half the cells in the path must be one color and half another color. But if a board has an odd number of cells, regardless of its shape there will be more cells of one color than of the other.

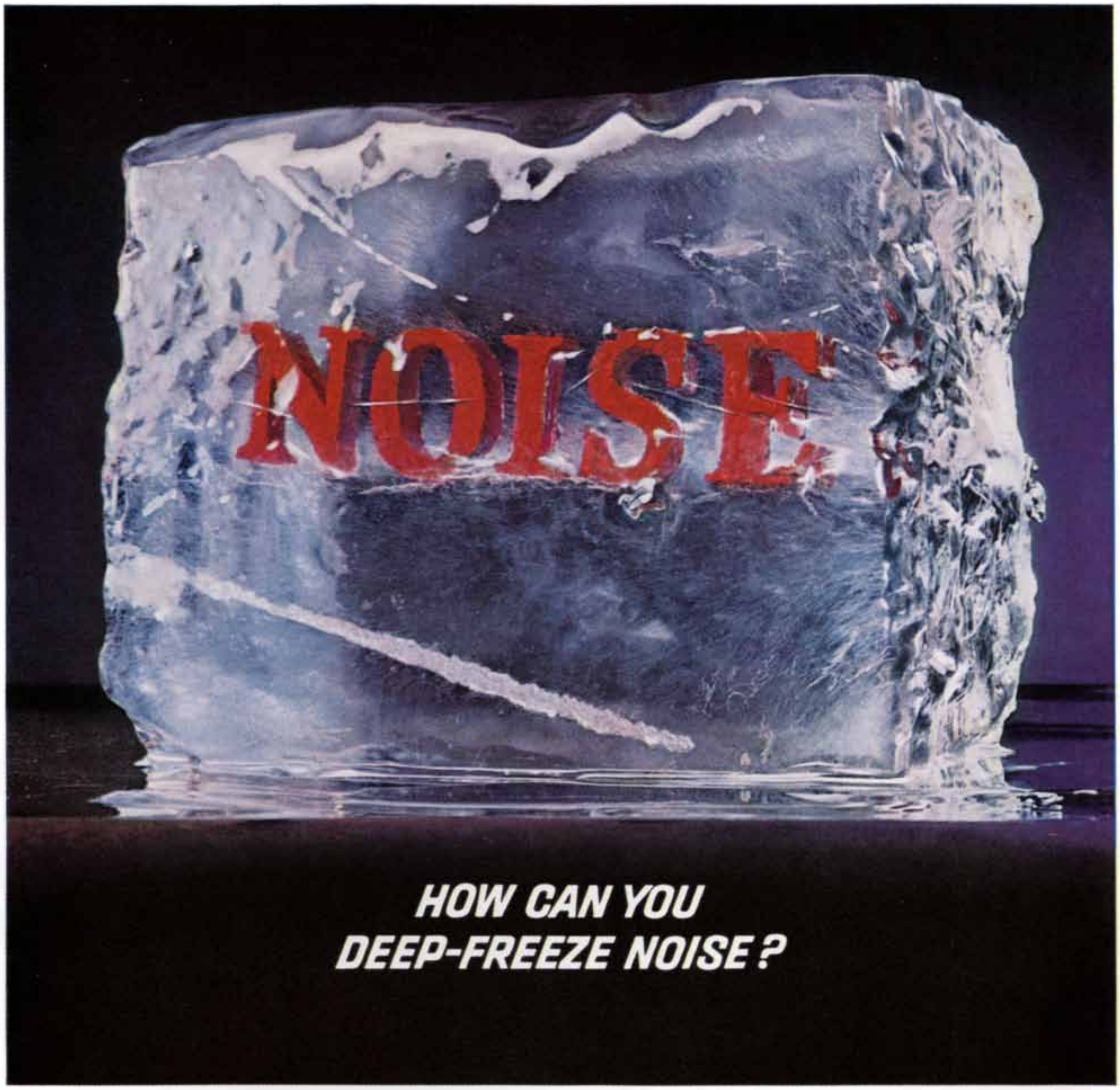
A number of readers improved on the minimum-move solutions for some of the sliding-block puzzles discussed in February. Alfred C. Collins, Jan-Henrik Johansson and Edward E. Roderick cut the number of moves, in sliding the large square of Dad's Puzzle from corner *A* to corner *B*, from 25 to 24. The 32-move solution for Ma's Puzzle was cut to 23 moves by Edwin J. Borrebach, Morrie Gasser, Richard Gellar, Phil Holt, Thomas Kew, Donald Oberly and Chris Villars. Sherley Ellis Stotts's Tiger-puzzle solution was cut from 49 to 48 moves by John Harris and Thomas Kew. Readers may enjoy searching for these improved answers. Some shorter solutions for the Tiger puzzle were received, but they involved (as did the published solution) the illegitimate move of rotating a piece within a space not large enough to make the rotation geometrically possible.

Readers interested in formal logic may not know of two unusual logic games now on sale around the country. WFF'N PROOF, developed by Layman E. Allen of the Yale Law School, employs special dice for playing a variety of games designed to teach the propositional calculus in the Łukaszewicz parenthesis-free notation. The expression WFF stands for a "well-formed formula" in this widely used notation. The other game, "What's That on My Head?" does not teach formal logic, but the propositional calculus is used informally in playing. Each player wears on his head a device that holds three cards, each of which bears one of six different letters. Players take turns drawing cards bearing questions and answer truthfully in terms of what they see on the heads of other players. The object of the game is to use this ever increasing amount of information for deducing the cards on one's own head. The best strategy seems to be that of using the technique devised by William Stanley Jevons as the basis of his famous 19th-century mechanical logic machine. One makes a list of all 56 possible combinations of the six letters, taken three at a time. As information comes in, appropriate combinations are eliminated until only one remains. It is not so easy, however, to decide what combinations to cross out, and there is an "egghead" version in which the possible combinations are too many for listing. The game was invented by Robert Abbott.

If these games are not available locally, information about WFF'N PROOF can be obtained by writing to Science Research Associates, Inc., 259 East Erie Street, Chicago, Illinois 60611, and about Abbott's game by writing to Robert Abbott, Box 1861, General Post Office, New York, N.Y. 10001.



*Graphs for re-entrant knight's tour* (left) *and for all knight's moves* (right)




# Sylvania/ECG has the answer

The Sylvania Electronic Components Group recently turned its skills in semiconductor design to the problem of shrinking the size and cost of amplifiers for long-range radio and radar reception at very high frequencies. Crux of the problem: How to prevent a weak microwave signal from becoming lost in the noise generated in the amplifier itself.

One very practical solution is found in a new Sylvania gallium arsenide varactor diode no larger than a grain of puffed rice. It is designed to permit operation at the temperature of liquid helium where the noise-producing random movement of electrons is literally frozen to a standstill.

Foiling noise in weak-signal reception is another example of advanced component design resulting from Sylvania ECG integrated research and engineering activities in all of the basic sciences, from solid-state physics to chemistry.

One of the many new electronic components developed by Sylvania ECG may well solve a problem you have in system design.

Sylvania Electronic Components Group, Sylvania Electric Products Inc., 730 Third Avenue, New York, N. Y. 10017.

SYLVANIA

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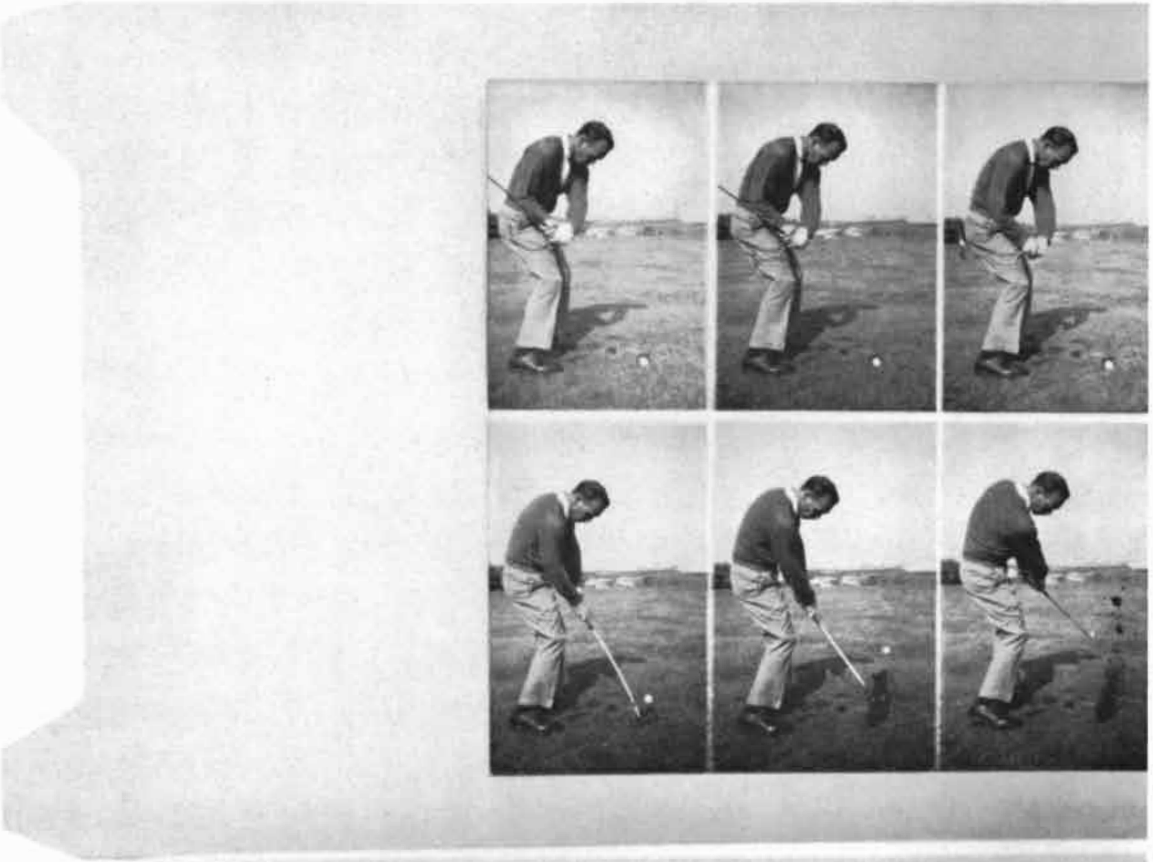
SYLVANIA/ECG OFFERS NEW CAPABILITIES IN: ELECTRONIC TUBES • SEMICONDUCTORS • MICROWAVE DEVICES • SPECIAL COMPONENTS • DISPLAY DEVICES



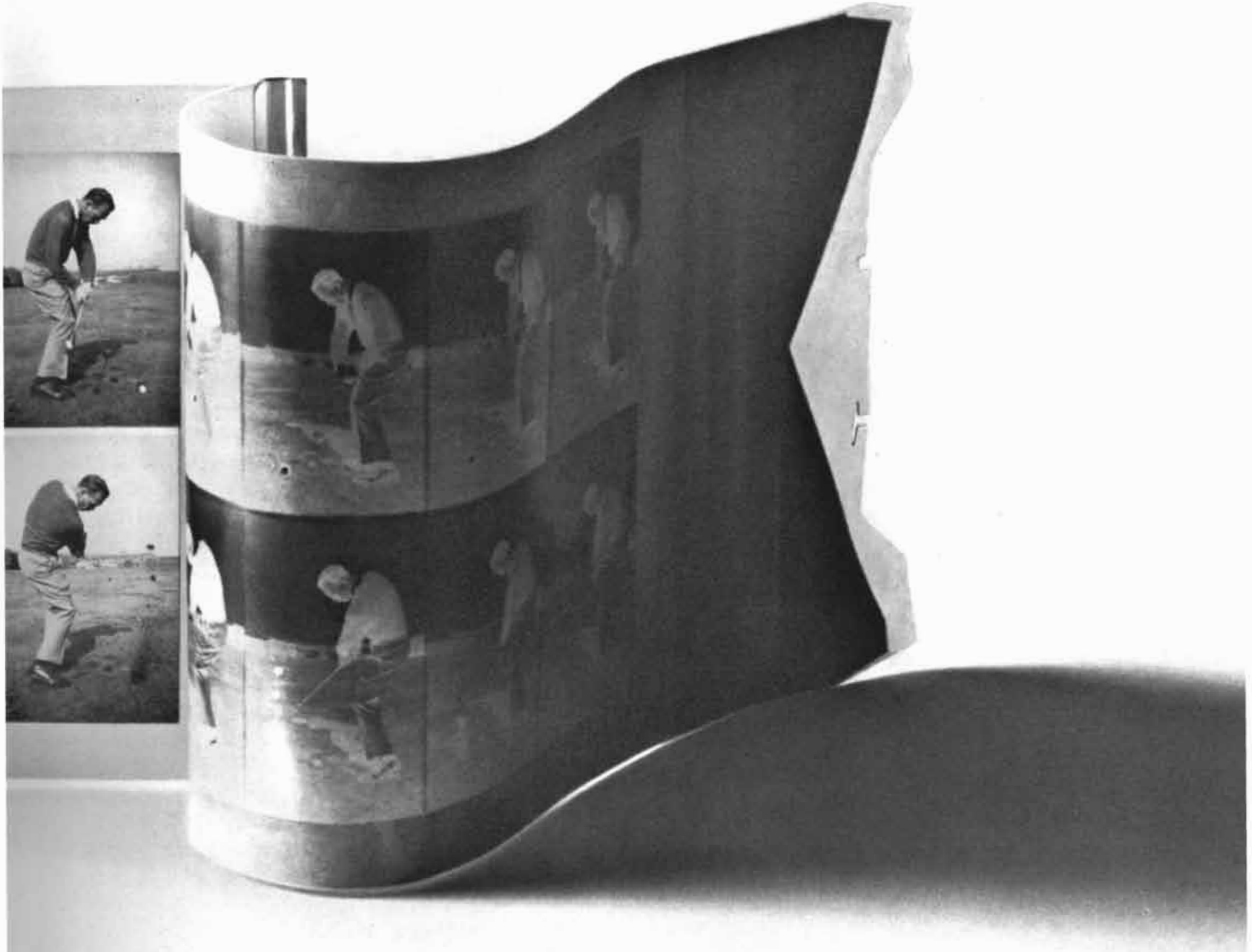
# If you've read all the books and you're

There's a good chance the new Graph-Check Sequence Camera, loaded with Polaroid 3000-speed Land film, can sharpen your game. Its 8 lenses and 8 shutters make sequential pictures on one sheet of film. And because it's Polaroid Land film, the picture is fully developed in 10 seconds and ready to analyze. When you see exactly what you're doing wrong, and see it so quickly, it's easier to correct.

With enough practice, your swing might look like our model's. His name is Arnold Palmer.

The team of Graph-Check camera and Polaroid Land film isn't all fun and games. It's also teaching orthopedic patients to walk and Navy pilots to improve their carrier landings.

A pneumatic sequence control lets you vary the timing to fit your requirements. You can take the sequence of 8 pictures in



# still slicing, maybe we can help.

as little as 1/10 second or as long as 10 seconds. If you'd like more information on the camera, write to Photogrammetry Incorporated in Rockville, Maryland.

We're telling you about it, not just because it uses Polaroid Land film, but because of the kind of thinking this new and unusual camera represents.

At first, our films did the same jobs conventional films did, only faster. But now, more and more people are using the speed and convenience of Polaroid Land film for *new* kinds of graphic recording. The Graph-Check Camera is a case in point: its usefulness depends on being able to see the picture on the spot.

We like the kind of thinking done by the Photogrammetry people. And we like to encourage it.

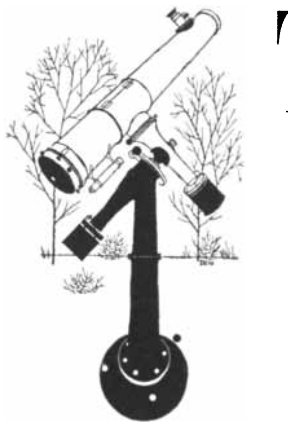
**Polaroid Corporation**

Re-entry Wake

Lincoln Laboratory of the Massachusetts Institute of Technology conducts a program of general research in selected areas of advanced electronics with emphasis on applications to national defense and space exploration. The program in *Re-entry Physics* consists of theoretical and experimental investigations of the electromagnetic effects associated with the passage of hypervelocity objects through the atmosphere. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 18, Lexington 73, Massachusetts.

Solid State Physics
Information Processing
Radio Physics and Astronomy
Radar Design
Control Systems
Space Surveillance Techniques
Re-entry Physics
Space Communications

A description of the Laboratory's work will be sent upon request.



# THE AMATEUR SCIENTIST

## *Blowing glass for the amateur laboratory is really not as difficult as it may seem*

Conducted by C. L. Stong

Although many amateurs cut, drill, grind and polish glass, few try their hand at blowing glass. This is not from lack of interest. Almost every experimenter has wished on occasion that he could enclose a rare specimen in a glass ampoule, repair a piece of laboratory glassware or make for pennies a glass apparatus priced at many times the cost of its raw glass tubing. In my opinion amateurs shun these operations primarily because glassblowing has acquired the reputation of a black art open only to the few whose bloodline traces back to the artisans of medieval Venice. This myth, like many, contains a germ of truth. A masterwork in molten glass created at the end of a four-foot iron pipe may seem to rank with sculpture by Michelangelo, but the glassblowing I shall discuss, the kind of most use to amateurs, is more comparable to painting a kitchen cabinet. Anyone can do it adequately with a day's practice. The greatest hurdle the novice must surmount is the conviction that he cannot blow glass. He can, and he will discover that it is a lot of fun. The beginner's work may lack perfection in appearance, but it will perform its intended function.

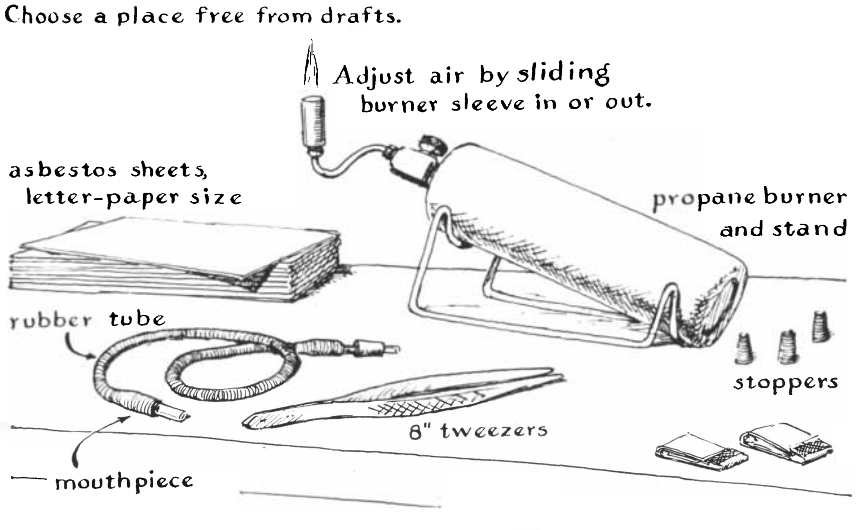
The next most difficult hurdle is concern over an operation that actually requires little skill: the annealing, or slow cooling, of the finished work. All glass, including Pyrex, must be annealed after it has been heated to the plastic state. Unless the hot glass cools slowly, strains develop that shatter the work. Beginners in glassblowing tend to become so carried away by their new skill that they slight the annealing and thus court failure. The easy technique of annealing will be explained in detail. Follow the directions and success will be yours.

The essential equipment for manipulating hot glass need not cost more than $10. Included is a propane torch of the kind sold by hardware stores for doing odd jobs around the house, an eight-inch pair of tweezers, an assortment of corks for plugging the glass tubes, a few sheets of asbestos paper, three feet of soft rubber tubing with a bore of about eight millimeters, a box of absorbent cotton, a small three-edged file and a small stock of soft glass tubing that ranges in size from six to 10 millimeters. Glass tubing can be ordered through drugstores from scientific supply houses. It normally comes in four-foot lengths and costs about $1 a pound.

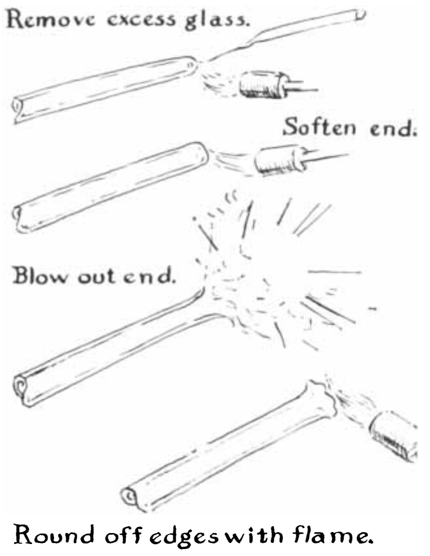
Begin by making a flexible blowpipe, which consists of the rubber tubing fitted with a glass mouthpiece at one end and a blowing cork at the other To make the pipe, begin by selecting a length of six-millimeter glass tubing. Grasp the piece near one end by your left hand (if you are right-handed) and brace it against the edge of the bench. With the file in your other hand make a transverse nick three inches from the end of the glass. The nick need not be deep. Use the side of your left thumb to guide the file and complete the nick with a single, inch-long forward thrust of the file; a pressure on the file of about eight ounces is adequate. Then moisten the nick with the tip of your tongue, grasp the tube with both hands an inch or so from the nick, point the nick away from you and break the tubing by simultaneously pulling the tube apart and bowing it toward you. The force of the pull should be on the order of five pounds. With luck the tube will part as a clean, right-angled break. Make two tubes, each three inches long.

Next set up the propane torch. The kit will doubtless include two burners, one for producing a broad, bushy flame and the other designed to give a pointed flame characterized by a light blue cone at the center. All propane burners have one or more ports for entraining air to support the flame. Make from sheet metal a sliding ring that can be used at certain times to close the air port. When the port is closed, the torch burns with a smoky flame that is used for annealing.

Fit the torch with the burner that produces the pointed flame. Light the torch and adjust the gas for a clear blue flame about two inches long. Holding one of the three-inch tubes between your thumb and forefinger, move the free half of the tube into and out of




*Equipment for glassblowing*




*Steps in flaring a tube*

the hot region just beyond the visible flame at the rate of about one stroke per second and simultaneously rotate the tube 180 degrees on its axis. The object is to heat that portion of the glass gradually to a temperature of several hundred degrees. After some 30 seconds move the tube slowly into the flame and confine the heat to the last quarter. After another 10 seconds bring the hot end of the tube to the center of the flame just beyond the light blue cone. Stop the stroke but continue the rotation and tilt the tube so that the open end faces the burner at an angle of about 45 degrees. By now the hot glass should be coloring the flame a bright yellow. In a few more seconds the cut end will reach a red heat. Watch the glass as the end softens. It will lose its sharp edge and flow to a nicely rounded surface.

When the edge becomes fully rounded, quickly return the tube to the hot region just beyond the flame. Resume moving the glass into and out of the heat. The object now is to cool the glass gradually, just as it was gradually heated to the plastic state. After a few seconds, and without removing the glass from the heat, use your free hand to close the air port of the burner with the sliding ring. Continue to stroke and rotate the glass while a thick coating of soot forms on the work.

In the meantime take with your free hand a wad of cotton the size of a fist. When soot fully covers the hot glass, plunge the end of the tube into the wad of cotton, wrap the cotton around the hot sides and lay the piece aside to cool. The cotton in contact with the hot glass will retard the rate of cooling and complete the annealing. It is well to hold the cotton in a fold of asbestos paper that can be closed to smother the flame if the material ignites.

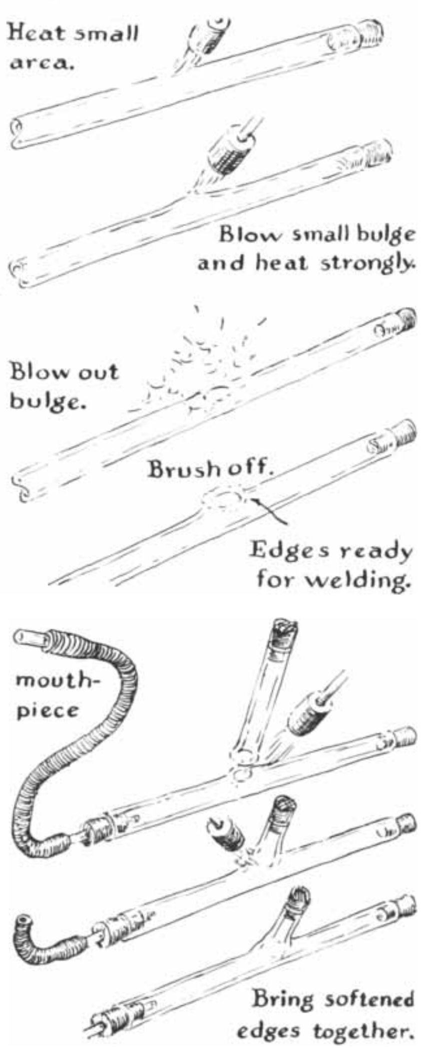
Soot and charred cotton can be removed with soap and water after the glass cools. Similarly "fire-polish" the remaining three ends of the two tubes. Finally, slip one tube part way into one end of the rubber tubing to serve as a mouthpiece. Then drill an axial hole for the second tube through a cork that makes a snug fit with the 10-millimeter glass tubing and join the cork to the rubber tubing by means of the second tube.

A piece of equipment you may want to make once you have the blowpipe is a test tube. Cut off a 10-inch length of 10-millimeter glass tubing, insert the blowing cork in one end, grasp the mouthpiece between your lips and gradually heat the outer three inches of the glass, following the same procedure as before until the hot glass begins to color the flame. Then open the gas valve to produce a four-inch flame. While continuously rotating the glass, heat the outer half-inch to redness. Keep the tube in a horizontal position. As the glass softens, the open end will begin to shrink and perhaps to droop. Control the rotation to bring the droop to the top and prevent the glass from sagging again.

When the color of the glass has turned to orange, remove the tube from the flame, grasp the hot end with the tweezers and pull it quickly away from the solid glass. This will close the tube in the form of a tapered end. A glass thread will stream from the point of the taper. Pass the thread through the flame about two inches from the tip of the tube. The thread will melt. Discard the outer portion. Return the tapered end to the edge of the flame. Grasp the remaining part of the thread with the tweezers and pull again. Melt off the excess thread as before, this time close to the tapered tip. Now hold the tapered end of the tube in the flame at a steep angle. Continue to rotate the work. As the glass softens and flows, the tapered point will become rounded; a thick lens of molten glass will form.

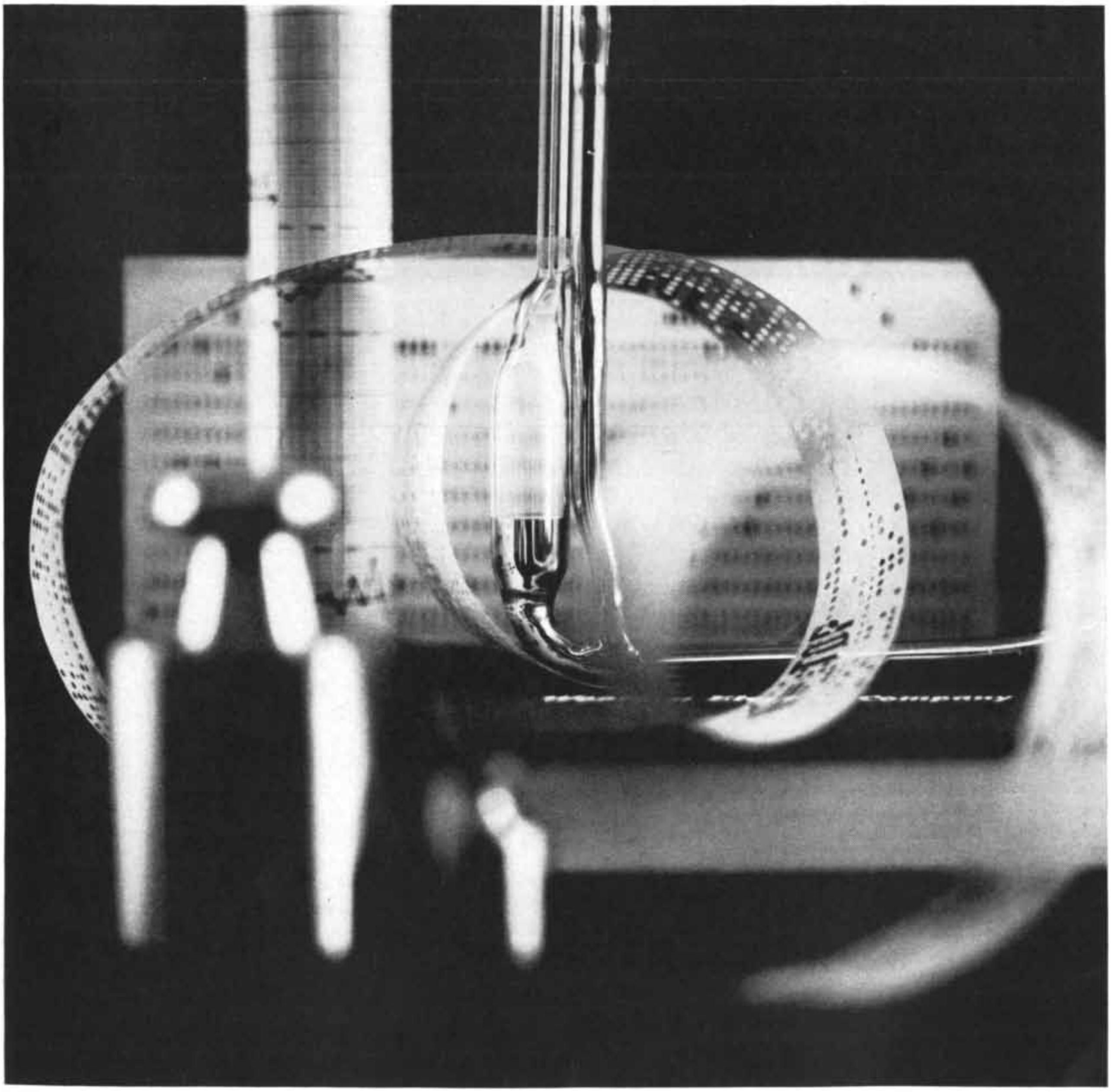
When the thickness of the lens has grown to about an eighth of an inch, remove the work from the fire and invert the tube at eye level. The thin portion of the glass at the edge will quickly cool to below redness. At this point blow gently into the mouthpiece and increase the pressure until the thick, hot glass expands into a hemisphere. Some people report that they can achieve better control of the glass by using a series of short puffs instead of maintaining constant pressure. If the glass solidifies before the hemispherical shape is achieved, return it to the fire. After the lens heats to redness remove the piece from the flame, wait until the thin portions cool and try again. The thin regions of the wall cool more quickly than the thick ones. Hence the delayed blowing tends to produce walls of uniform thickness. After the closure has been made anneal the glass by closing the air port. Hold the hot end of the glass in the smoky flame until it is heavily coated with soot and then wrap it in cotton. After the work cools fire-polish the open end. You have a test tube!

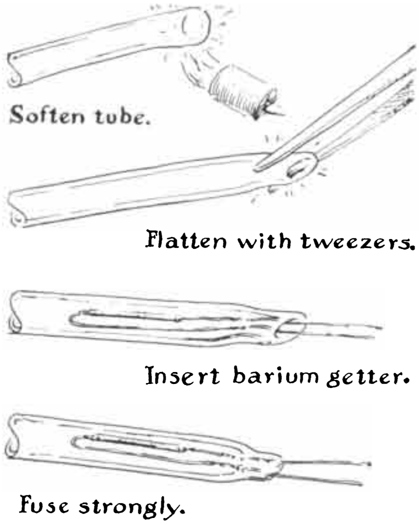
If desired, the test tube can be converted into an ampoule. Plug the open end with the blowing cork and heat a section of the tube uniformly about two inches away from the cork. During this operation the closed end must be sup-




*Making a T joint*

**QUALITY BY THE NUMBERS.** Western Electric must meet the most exacting standards in the communications products it manufactures and purchases in vast quantities for the Bell Telephone System. To this end, it pioneered the application of a new control concept, based on mathematical statistics, to monitor quality. Developed together with our associates at Bell Laboratories, it is called Statistical Quality Control. Complex processes are broken down into simple operations so that quantitative test results can be obtained. Results are plotted on control charts in the factory or laboratory to show limits of normal variation and indicate significant deviations from the acceptable level. With modern testing equipment and high-speed computers to analyze data, Statistical Quality Control helps Western Electric supply the Bell System with communications equipment in quantities undreamed of a generation ago —and to quality standards unsurpassed in industry. **WESTERN ELECTRIC**






*Placing a conductor in glass*

ported by your left hand so that the tube will not bend when the glass softens. Find the balance point of the outer portion and grasp the tube between the thumb and forefinger of your left hand. Rest the blowing end lightly in a V made by pressing together the thumb and forefinger of your right hand. When the tube softens, suck gently on the mouthpiece. A constriction will form around the tube in the softened area. Try to make the constriction about two millimeters deep. Anneal and cool the glass.

You now have an ampoule for holding liquids or other specimens. Place the specimen inside the ampoule. To seal the container first tilt the propane torch so that the flame burns horizontally. Hold the ampoule vertically and rotate the constriction in the flame. When the glass softens, insert one point of the tweezers inside the open end to prevent the glass from drooping. After the glass reaches a distinct red color close the tweezers and pull the solid end away while continuing to rotate the ampoule. The thin thread will melt in the flame. Gradually lower the closed, tapered end out of the flame and, while maintaining the ampoule in the vertical position, coat the hot glass with soot and anneal in cotton. If the ampoule contains a liquid that would be altered by heat, the lower half of the glass can be kept in a container of ice water throughout the sealing operation.

It is easy to join two glass tubes of equal diameter or to make a T joint, particularly between tubes of unequal size when the vertical leg of the T is the smaller tube. First close one end of each tube to be joined by the procedure outlined for making a test tube. Then, instead of annealing the hemisphere, heat it to a bright yellow, remove the glass from the fire and blow quickly and strongly into the open end [*see top illustration on page 130*]. A large bubble of glass will form and burst into fragments so thin that they glow with the iridescence of a soap bubble. Brush the fragments from the end thus flared. Prepare one end of the other tube in the same way. Close the nonflared end of one tube with a cork and fit the second tube with the blowing cork. Rotate both flared ends in the fire until the ragged edges heat to redness. Remove from the fire, quickly lift the ends to eye level and move them into contact as a matching joint. The redness need not extend more than a sixteenth of an inch into the glass.

Some workers prefer to hold the tubes at the angle of a shallow V so that initial contact is made at one point on the rim of each tube. This point of adhesion then serves as a hinge for guiding the ends together. Both tubes must be grasped and rotated synchronously at their respective balance points. This too may sound difficult. It is not. Hot glass behaves like heavy glue. It is just as sticky and strong. If the tube tends to bend at the joint, a slight pull, together with a corrective bending force, will put it right.

The straight joint is now rotated in the fire. As the glass heats, the joint will tend to shrink and thicken. When the glass becomes plastic, remove the work from the fire, allow the thinner portions to cool and then blow until some part of the joint expands to the diameter of the unheated wall. Now inspect the joint for the lowest, most shrunken portion. Without rotating the tube, heat this portion, remove the work from the fire, let the thin portions cool, then blow to expand this portion to the uniform diameter of the tube. Continue to work around the joint locally in this manner until its size and shape match that of the tubing. If a ragged accumulation of glass from the flared ends appears at any point, heat it locally and, while the glass is in the flame, alternately suck and puff gently while inspecting the heated portion. The hot glass will alternately shrink and expand, an action that will cause the ragged portions to merge with the neighboring glass. When the joint is complete, carefully anneal the work.

To make a T joint, stopper one end of the piece that will serve as the cross of the T and fit the blowing cork into the other end. Heat the middle of the tube gradually all around in a four-

## The generation of intense magnetic fields by superconducting magnets which operate with

low power was—as recently as five years ago—little more than an intriguing possibility.

Today Varian offers commercial superconducting systems which combine high field intensities and high homogeneity over large usable volumes. Indeed, our efforts in this burgeoning field have been directed toward the *practical application* of this new magnetic technology to basic research instrumentation.

Here's a chronology of some important milestones in our progress to date:

April 1962—First known observation of NMR proton resonance in a superconducting solenoid. Resonance obtained in 12 kG solenoid operating at 40 mc (9,400 gauss).

November 1962—Operation of 25 kG end-corrected solenoid for NMR applications.

February 1963—The three chemically-shifted proton resonances of ethyl alcohol were resolved at 40 mc (9,400 gauss), demonstrating field homogeneities of the order of parts per million attainable with this end-corrected 6th order solenoid design.

June 1963—First commercial delivery of compensated solenoid—55 kG with 1″ bore. (In operation, fields in excess of 60 kG have been consistently achieved with training.)

February 1964—Varian solenoid produced first known 200 mc (47,000 gauss) proton resonance signal. As a laboratory experiment at this high field, high resolution NMR was obtained in ethyl alcohol with an ultimate resolution sufficient to clearly resolve the proton spin-coupling.

March 1964—Operated large volume, high field solenoid—85 kG with 1″ bore.

While continuing research will undoubtedly produce additional significant developments in the future, superconducting solenoid systems and accessories available now from Varian offer scientists extraordinary new research capabilities. For more information about superconducting solenoids, or our line of precision iron magnets, please write Bob Abler, Magnet Products Manager.

## Biophysicists and biochemists have been trying for years to pinpoint the precise role that the free radical plays in the processes of metabolism.

Thirty years ago, Leonor Michaelis hypothesized: "It will... be shown that all oxidations of organic molecules in biological systems, although they are bivalent, proceed in two successive univalent stages, *the intermediate being a free radical.*"

Like many other brilliant hypotheses, Michaelis' conclusions could not be verified at that time with existing equipment. Highly sensitive EPR spectrometer systems developed by Varian scientists provided the means for showing that Michaelis was, indeed, correct. The unique feature of EPR spectroscopy is, of course, that it responds only when free radicals are present. Quite recently, biochemists have been using EPR spectroscopy to study free radicals in biological systems. A growing reservoir of information is being formed.

One very promising application of this technique has been to study the mechanism of action of certain psychotropic drugs, the type used in treating mental illness. EPR shows that free radical intermediates are formed in the oxidation of these important drugs. It is possible that continued EPR study will delineate the exact role these intermediates play in the clinical activity of the drug.

This study of psychotropic drugs is but one application of EPR techniques to the field of biochemistry. Other areas of research in biology, physics, and chemistry have applied this powerful analytical technique with equally dramatic results. We are interested in discussing with you the ways EPR spectroscopy might assist your present research. Please address your letter to Dr. William Landgraf, EPR Applications Laboratory, Analytical Instrument Division.

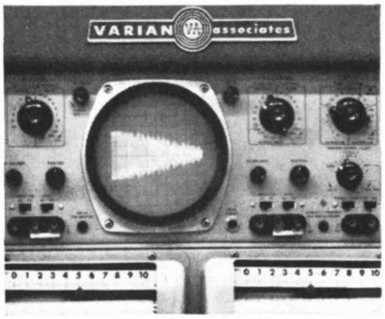
## Oceanography is the chemistry and physics of the sea. It matches in scientific intensity of pur-

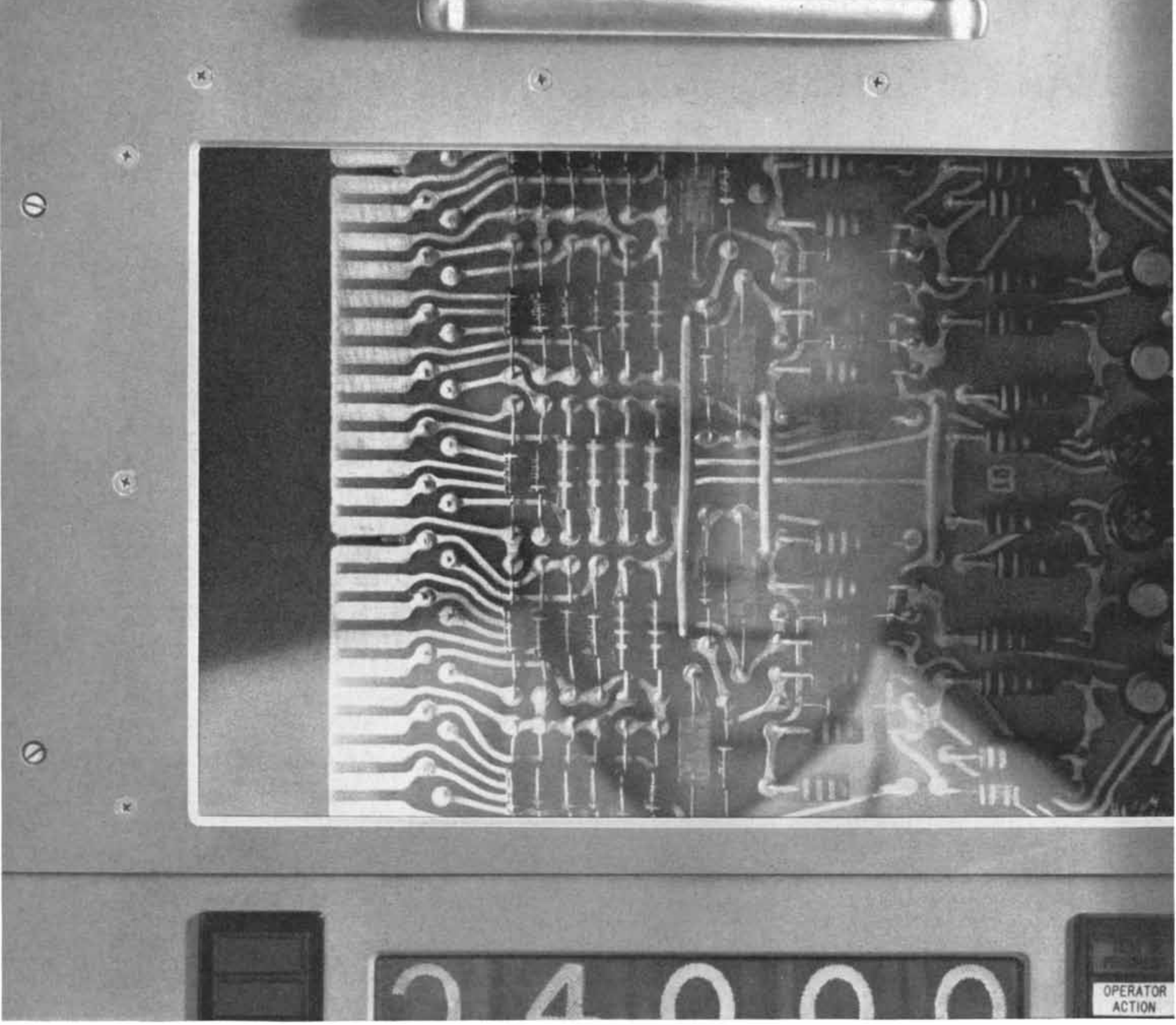
pose, if not in public glamor or funding, the quest for complementary data from space.

Magnetism, along with such natural phenomena as gravity, depth, current, temperature, salinity, turbidity and others, is a basic variable sensed. And proton free precession magnetometers have become the oceanographer's accepted standard since Russell Varian's discovery of the principle.

The invariant natural relationship between ambient magnetic field and proton precession (23.4874 gammas per cycle) is harnessed in these systems to give rapid, absolute field data to ±1 gamma from a simple, rugged transducer virtually insensitive to orientation. Designed for 750-foot cables to reduce the anomaly created by the towing ship, some systems have been modified in the field under emergency circumstances to deliver original one gamma sensitivities through *four miles of cable.* This feat gains stature when you consider that the decaying proton precession signal (see oscilloscope trace) is at microvolt levels in the transducer—no pre-amplification is used except in the on-board console itself!

Varian proton magnetometers are mapping spatial variations of the earth's field in oceanographic vessels all over the world. The new higher-sensitivity, optically pumped magnetometers are opening research into magnetic-field time variations at sea. To learn more about either technique, for oceanography or other geophysical applications, write Lee Langan, Instrument Special Products.





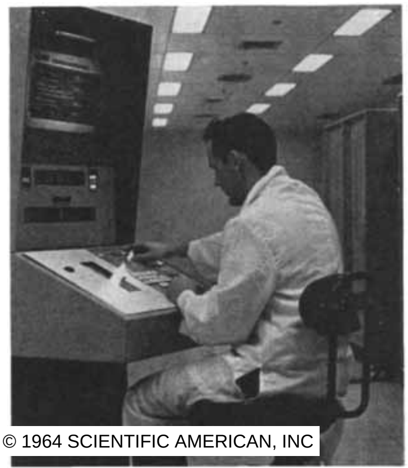

# How to look into a "bird brain"

This is a picture of a circuit from the "brain" of an intercontinental ballistic missile. It is part of one of the most complex devices ever created, capable of guiding the giant "bird" over vast distances.

To give this kind of guidance system a regular checkup—making sure it will be ready for its vital mission—is a massive job. Until now, each type of "brain" had to have a custom-made tester to give it a checkup.

This was expensive. People had to be specially trained. And when a new system came along, a new tester was needed.

So the U. S. Air Force asked Hughes engineers to look at the problem. The assignment was to apply their unique experience in digital computers to build a tester which would automatically diagnose malfunctions in many different types of systems. It would be easy to operate. Self-testing. Easy to repair. And require fewer and less highly-trained operators.



The answer, now in operation, is VATE—Versatile Automatic Test Equipment. This is a combination of digital computers and associated equipment in "building block" form. It can be programmed to do several tests simultaneously on a wide variety of systems. Because the computers can easily be re-programmed and the modules replaced, VATE will not go out of date. It can be inexpensively adapted

**Now in operation** at the Newark Air Force Station, Heath, Ohio, VATE "knows" so much it can predict a breakdown before it happens by sensing minute changes in performance which might ordinarily escape notice.

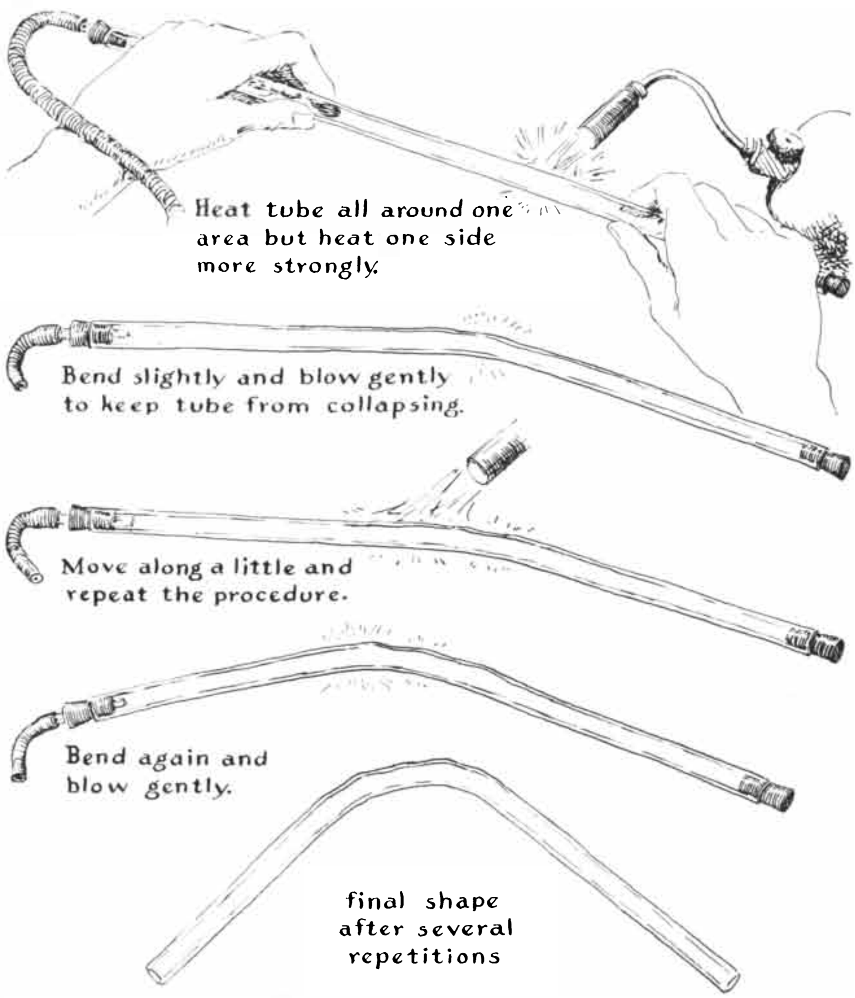
*Creating a new world with electronics*

**HUGHES**

HUGHES AIRCRAFT COMPANY

inch flame by the combined motions of stroking and rotating the glass in the flame. Experience will now enable you to judge when the glass approaches the plastic state. Immediately before this state is reached reduce the flame to about two inches and hold the glass still to heat a point at the middle of the tube. The heated spot should just make contact with the tip of the inner cone of the flame. When the glass begins to color the flame yellow, remove the tube and blow gently until the softened glass bulges slightly at the heated area [*see bottom illustration on page 130*]. Do not wait for part of the area to cool. When a slight bulge forms, return the glass to the fire, reheat and blow again. The object is to blow a bulge equal in height to the radius of the tube. The width of the bulge at the level of the unheated portion must equal the diameter of the tube that will form the leg of the T. These proportions are easily judged by eye. The novice is advised not to try to form the bulge with a single heating of the glass. Puff it out in easy stages.

When the desired size has been achieved, return the bulge to the flame and heat it strongly in the middle until the spot of red-hot glass is slightly smaller than the inner bore of the tube that will become the leg of the T. Then remove the work from the fire and blow off a bubble. Brush the glass fragments from the edges of the hole thus formed. Gradually reduce the temperature of the heated portion by moving the glass in and out of the hot region beyond the colored part of the flame, but do not anneal. Next similarly flare one end of the tube that will serve as the leg of the T. The flared end is then joined to the flared hole by much the same procedure as was used for making the straight joint. The edges are heated, one on each side of the flame, until the glass becomes red all around to a depth of about a sixteenth of an inch. The mating edges are then pressed together lightly and the joint is returned to the fire. Allow the flame to play on the solid neighboring portions of the glass occasionally so that they




*Procedure for bending a tube*

will not become appreciably cooler than the joint.

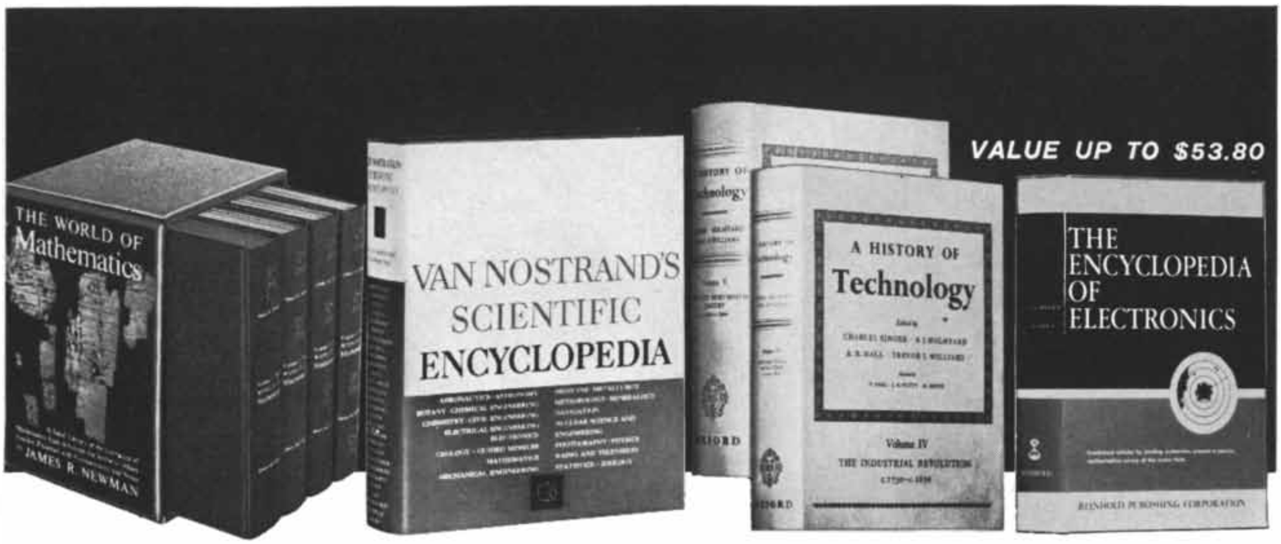
The object now is to heat the joint locally and blow the mating faces slightly outward into a conical fairing. During this operation the leg of the T must be supported at right angles with respect to the crosspiece. Only a slight force need be applied because the glass is fairly solid except at the heated area. Local heating and blowing are continued until the fairing is complete. With experience you will find that glass becomes plastic enough for blowing curves like this before it reaches a red heat. Use the lowest temperature that will accomplish any desired result. Working at minimum temperature not only makes the job easier but also avoids a destructive effect known to glassblowers as devitrification. Devitrification occurs when glass is maintained above a certain critical temperature for extended periods. The ingredients of the glass tend to separate from one another and clump in the form of crystalline masses. Devitrified glass loses its transparency and other desirable physical properties; it looks frosted and burned.

Occasionally experiments require electrical connections to be made between the inner and outer portions of a sealed glass vessel. They are easy to install after the beginner has made a few T joints. First, flare the end of a piece of tubing by exploding a bubble; then heat and flatten the other end slightly, as shown in the accompanying drawing [*page 132*]. For the conducting leads I frequently salvage the filaments from old vacuum tubes or discarded lamp bulbs. The bulb is placed in a strong paper bag and squeezed between the jaws of a vise until the glass breaks from the leads. The wires are then arranged in the flattened glass stem as illustrated. The stem is first brought gradually up to temperature to prevent cracking. The wires are next heated to a bright yellow by concentrating the hottest part of the flame on the metal at the point where it enters the tube. The glass is now heated to redness and squeezed in contact with the wires by means of the tweezers. Heating is continued until the glass reaches an orange color and "wets" the metal. If the wires are not first heated to a bright yellow, the metal will react with the molten glass to produce tiny bubbles: literally a froth that ruins the glass-to-metal seal.

When completed, the seal must be carefully annealed. I am told that filament from lamps and vacuum tubes is not recommended for use with soda-lime or lead glass because its coefficient of expansion differs from that of the glasses enough to invite cracks and leaks, but I have experienced no difficulty when the glass has been fully annealed. Incidentally, copper will seal to soft glass splendidly when the metal is reduced to a foil on the order of .005 inch thick. Suitable lengths of wire thick enough to carry the anticipated current are simply pounded flat with a hammer over the length that comes in contact with the glass and heated to the same temperature as the glass when the seal is made. The worker must be careful not to overheat and melt the copper. The copper takes on a distinctive and easily recognized color along the portions that are wetted by the molten glass. I have used copper seals successfully for firing barium getters: devices that evaporate a thin film of metallic barium onto the internal surface of the vacuum tube for absorbing unwanted gases. Getters are customarily fired by induction heating, which requires a source of high-frequency current. Sealed leads enable the amateur without access to induction-heating equipment to accomplish the same result with an automobile storage battery or a doorbell transformer.

What about bending glass tubes and blowing large bulbs? Simple bends are no problem, particularly in the case of tubes less than eight millimeters in diameter. To make bends, fit the torch with the burner that produces a broad, bushy flame. If possible, add a batwing attachment to spread the flame in a fan-shaped pattern. Then, supporting the tube at positions about a quarter of its length from each end, bring the center portion slowly up to temperature; let the glass sag in the form of a natural bend that can be stopped at any angle. If the bend is desired at some point other than the center, judge the approximate balance points for supporting the glass and proceed in the same way. When bending tubes, as in most operations with hot glass, the heat must be evenly distributed by rotating the glass. Tubes of greater diameter are bent by gradual steps. The glass tends to buckle along the inner radius of the bend or, conversely, to flatten along the outer radius, particularly in the case of large tubes with thin walls. These imperfections are continually corrected by local heating and blowing [*see illustration on preceding page*].

As for blowing large bulbs, my advice is: Do not try unless you really can trace your ancestry to Venice. If you need a large bulb, make one from a round-bottomed flask.

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# BOOKS

## *An anthropologist's criticism of contemporary U.S. society*

by Marshall D. Sahlins

CULTURE AGAINST MAN, by Jules Henry. Random House ($7.95).

The first sentences of this otherwise uncommon book are tried and true prefatory cliché: a view from the academic window. As I gaze down from my study I see it's spring out there, the earth is good, the dogwood "gray with a foam of new buds." This sort of looking-through-the-glass prefacemanship customarily warns he who enters here that he is about to lose contact with the Outside. Having glanced up distractedly to discover it's spring or something, and having duly remarked on the contrast with his book's concern, the author usually gets on with important things, such as, in anthropology, an archaeology of the living. Not Jules Henry. Combining the field experience of an ethnologist—which includes living among *The New York Times*—with the insight of a dissenting intellectual, he gets on with a book about what's wrong with the U.S. today. The trouble with the U.S. is both an institutional malaise and a consequent disease of character. These find a common expression—the U.S. has too much of a goods thing.

The tribe is different but the anthropologist remains the same. Indeed, Henry has not exactly forsaken primitive peoples: he brings them in didactically, as contradictions and exaggerations, to highlight various Americanisms. Moreover, he has retained the traditional commitment of U.S. anthropologists to investigate at the same time big structural events and the relations of these to people, to their workaday lives, their homebred concerns and their selves as human beings. Henry's particular synthesis of big cultural things with little contingent lives is an unusual tour de force, worthy of independent elaboration as social theory. Yet the appeal of the book as social theory is overshadowed by its thrust as social criticism.

Part One, about a quarter of the book, is Henry's critique of the political economy. In certain respects it is the weakest section: historically shallow, debatable as to some economic propositions and, where it does not transcend Vance Packard, occasionally presenting the spectacle of an anthropologist discovering America. Here too the book is most seriously marred by such compulsions of the academic style as the capricious footnote and the italicized metaphor. Nevertheless, Henry carries it off. Perhaps because he is fundamentally right. Or perhaps just because he is on the right side, the people's side, bravely disestablishmentarian as he cunningly dissects the premises of Madison Avenue "pecuniary logic" or comments sardonically on nonprofit military-strategy firms such as the Rand Corporation, the "most famous casino of fun-in-death games in the country."

Of the structural conditions that have victimized us, one is from Henry's vantage decisive. Other aberrations of "the system" that he draws in are functionally related to this one, if not actually subordinate expressions of it. Productivity has got out of hand: it threatens the nation's capacity to turn over the output—at the usual profits. A confined market is under intense pressure to absorb a surpassing amount and variety of things, which is also to say that people are under continuous bombardment by merchants of the good thing.

To speak of the overproductive society is not to neglect the acquisitive society. Acquisitiveness figures as an underlying condition of American life, inherent not only in competitive production, where Henry confronts it as "technological drivenness," but also and necessarily in the mode of consumption, where it appears as "the high-rising standard of living." No less than the profit-hunger of producers, consumer-hunger seems a historic consequence of market arrangements. A system of markets brings within a man's reach, but not yet his grasp, the manifold products of a great division of labor. Thus is "scarcity" instituted and eternalized. It is not simply that one never has enough to buy everything but that each acquisition is simultaneously a deprivation—of something virtually as good or something better that just could not be swung. And so "needs" expand in some proportion to the growth of production. However, "needs" today (not even to consider incomes) are sluggish compared with the flood of products. In the sanguine view of old-time economists everything would turn out all right—"tend toward equilibrium," they were pleased to say. Yet as Henry observes, productivity is out of phase with markets; indeed, imbalance among products, machines, wants, consumers, workers and resources is the current American plan.

In the train of this disjunction come the massive institutional distortions against which Henry scores in a series of brilliant ripostes. There is advertising, of course, bequeathed by the prevailing industrial capacity with the critical function of training people "to heroic feats of consumption." There is "dynamic obsolescence" of products, processes and business, and in the ensuing flux an instability of employment that completes the classic alienation of the worker from his product and his job by disengaging him as well from his co-workers and his ambition. As for the cold war, presumably it and its several perversions such as fun-in-death games are sustained for their salutary effects on the Gross National Product; moreover, in Henry's view the cold war exacerbates the internal imbalance by restrictions it imposes on external trade. Things are a mess.

Above all, people are a mess. The bulk of *Culture against Man* is a documentation of the human casualties, as recorded by Henry and his students on various battlegrounds of character. We look inside families, both through records of children's attitudes toward parents and through participant observation of home lives that have produced child psychosis. We are ushered into the teen-age turmoil of a high school—called "Rome" for the ironic contrast. We get inside elementary schools too, there to see drill in such subjects as reading, writing and arithmetic also become systematic training in absurdity, hate and fear. Then we are taken on a tour of old-age homes, one of which, a private establishment for social security pensioners, is appropriately introduced by a passage from *The Inferno:* "...do you see that one/ scratching herself with dungy nails...?" Here again Henry operates in the good anthropological tradition. He does the natural history of man: he goes to the trouble of finding out what's happening in the world. There is not even the pretense of a random sample, and indeed no attempt at statistical understanding. But before the social scientists among us protest, let them consider if the kind of insights that came to Henry could have been developed statistically.

Every society, the book suggests, gets the sort of people it deserves. Whether, under the institutions that beset us, Americans are more, less or just otherwise misshapen than other peoples is not clear; different passages support different conclusions. Henry does, however, consider the human material subject to two general kinds of disintegration under present circumstances. First, people are not what they used to be morally; second, as joyless, soulless and selfless beings, people amount to little these days as people.

The great and good traditional virtues have been eroded: love, generosity, self-denial, truthfulness, honesty, loyalty, friendship, kindness to children. That many of these traits of good character have been banalized by advertising seems incidental. The main thing is that a comprehensive subversion of old-time morality is a necessary condition of new-time economy. It is not the old virtues but their opposites—deceit, disloyalty, impulse release, exploitation of naïve minds—that are capitalized by "the cultural demand for epic deeds of consumption." "Let us remember," Henry writes, "that though some may consider the exploitation of children immoral, in the world view of pecuniary philosophy the sin would consist in letting the market go untapped.... What should businessmen do, sit in their offices and dream, while millions of product-ignorant children go uninstructed?" Or again: "Only a people who have learned to decontrol their impulses can consume as we do." The collective superego is apparently gone; but then, as Henry says, in a consuming culture the unbridled id-energy is the greater national resource anyway.

To free human energies for the great work of the Gross National Product the cultural cyclotron does not merely smash traditional moralities. It attacks human capacities for life and joy. The strictly American tragedy involving the disintegration of traditional morality is in Henry's treatment only the fraction of a greater human tragedy. In a sensible and well-argued way he traces exigent pressures of the cultural system as they insinuate themselves in homes, schools and the other milieus of everyday life, ultimately to express themselves in people as progressive moronization, self-renunciation, other-direction, self-contempt, grim bacchanals of fun and poignant dreams of failure. Providing the energy of cultural advance, people are left dissolute, not only morally but also humanly. On this contradiction—the paradox of a cultural order built on human disorder—Henry spends his best talents, developing such subcontradictions as these:

Our sadness in the midst of material enjoyments. The persistent feelings of deprivation without which the world's richest and most secure technical arrangements do not function—for "without constant discovery and exploitation of hidden cravings, all of us would starve under the present system." The reliance of a great economic success on a profound fear of failure, a nightmare so carefully implanted in the first grade as to be internalized for life. The spectacle of a rational economy being sustained by human stupidity: "The *stupefied* TV audience is the natural and necessary complement to the *alert* advertiser; and the merchants of *confusion* on Madison Avenue are a necessary complement to hard-pressed industry, pursuing economically *rational* ends." The renunciation of personal needs so often involved in taking a job, a selflessness that is, "paradoxically, a product of the most successful effort in human history to meet on a mass basis an infinite variety of material needs." And so on. *Culture against Man* is a long exegesis of the classical text with which it is prefixed: "No event can be beyond expectations, fear contradiction, or compel surprise, for Zeus, father of Olympians, has made night at full noon, darkness mid the brilliance of the sun."

This contraposition of culture and people is in my opinion Henry's best contribution to the study of social character. That man in the U.S. has been made "hostage to the GNP" may not seem a novel piece of information. But in viewing character formation as a historic task of main institutions Henry has not been content simply to show that distortions in people parallel the going biases in culture. Many studies of social character present the self-evident truth that people who live by the market find their happiness in acquisitiveness, or that those who live by war are violent types, or that those who live under dictatorship fulfill their own submissiveness. Henry refuses to engage, however, in the easy assumption that people are molded by the institutional machinery so as to come out small-scale human impressions created in culture's likeness. Henry sees the human upshot of cultural processing as functional to the system; people like this make a world like this go round, but they are not necessarily crazed in the same way that the system seems crazy. Social character complements cultural order without duplicating it. If we insist that a people mirror their culture, let us also recall that a mirror image is reversed. As the trouble with a miser is not that he wants too much but that he does not have enough, so it seems eminently sensible that Americans engage in heroic material acquisition not because they enjoy many things but because they cannot enjoy any thing. The propensity we have for reading directly from the qualities of a culture to the character of a people, and vice versa, is probably ancient beyond myth, so deep does it lie in the tissues of vulgar philosophy, not to mention social science.

As Henry proceeds, explicitly developing paradox after paradox, he constructs a transcendent but concealed contradiction that one does not recognize intellectually so much as feel in the form of mounting uneasiness. The ostensible message of the book, implied in its title, is that circumstances ("the system") brought us to this tragic end. Although concessions in principle are made to the "feedback" between people and their institutions, the main drift is clearly that Americans are casualties of their time and culture. Yet the way Henry goes about telling this says something else entirely. The structure of the book completely confounds its content.

Consider this. There are only certain people whose sufferings the reader of this book is privy to. The tragic protagonists are babies, schoolchildren, adolescents and finally the ancient, spent wreckage of "the system": it is overwhelmingly people of *these* life grades whose duress we are given to see.

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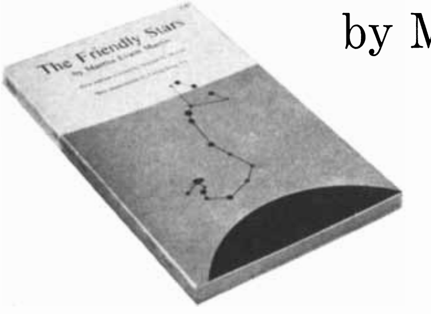


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Even as our own disfigurement under "the system" goes practically undocumented, Henry gives the most intimate and poignant details of what we culture-movers have wrought on those we are charged to love, and our guilt is not lessened by such of his idiosyncratic usages as "children" in reference to teen-agers as nearly adult as anyone he describes. The drift of the book is that the fault is in cultural circumstances. Yet reading it one is conscience-stricken.

The contradiction does not weaken the book. On the contrary, the reader's subjective unhappiness lends impact to the objective content. At the beginning and again in conclusion Henry makes the customary critic's apologies for failing to prescribe remedial measures. But surely he would not consider his readers' dismay meaningless for what shall go on in the world. He might have argued, in a consummate regress of paradox, that he need not apologize —precisely because he troubles people.

## Short Reviews

HYPNOSIS & SUGGESTION IN PSYCHOTHERAPY, by H. Bernheim. University Books ($10). Hypnosis has had its ups and downs. Under Franz Anton Mesmer in the 18th century it attracted wide attention. It suffered when his theories of animal magnetism were demolished, enjoyed a revival because of its possible use as an anesthetic, and then lost this claim to attention when ether and chloroform were introduced. In the second part of the 19th century the techniques of hypnosis were mustered against psychological disorders, particularly hysteria, by two highly respected French neurologists, Jean Martin Charcot and Hippolyte Bernheim. Early in his career Sigmund Freud was intensely interested in hypnosis. He studied under Charcot in Paris and translated his work, as well as two books by Bernheim, into German. When Freud turned away to introduce his own system, hypnosis again had a sinking spell; those who might have been attracted to it because of their belief in the psychogenesis of mental illness were influenced by his disaffection.

Within the past quarter-century, as Ernest R. Hilgard points out in his introduction to this classic volume, experimental studies by Clark L. Hull that led to the book *Hypnosis and Suggestibility*, published in 1933, made the method "a promising field for scientific inquiry." This trend was strengthened during World War II, when hypnosis was reintroduced as a useful adjunct to psychotherapy. There is now widespread activity and interest in the subject; the republication of Bernheim's celebrated book, which first appeared in the 1880's and was translated into English in 1888, will be welcomed.

In his clinic at the University of Nancy, Bernheim attempted to hypnotize some 10,000 of the hospital patients and succeeded, it is said, with more than 80 per cent of them. With exceptional lucidity, and without a trace of flummery or mystification, he explains his empirical theories of hypnosis, which he equates with suggestion. He gives an admirable account of a large number of his cases and reports the abatement of a wide variety of symptoms—at least temporarily. (Since there was little follow-up study, one has no way of knowing if the symptoms recurred.)

In his description of the workings of hypnosis Bernheim dispels stereotypes and misconceptions still prevalent even among the educated. These include the notion that one cannot persuade a hypnotized subject to do what is fundamentally abhorrent to him. Without difficulty Bernheim induced law-abiding, timid patients to perpetrate mock murders, which, however, they believed to be real; afterward they felt the most profound remorse until the suggestive spell they were under was dissolved by the hypnotist.

JOHN VON NEUMANN, COLLECTED WORKS: VOLUMES II THROUGH VI, edited by A. H. Taub. The Macmillan Company ($14 each). This gathering, the first volume of which was reviewed in this department last year, is now complete. It contains all of von Neumann's published articles, some of his Government reports and miscellaneous items such as addresses and reviews. His amazing range of mathematical interests and skills were a byword during his lifetime; even so, one's admiration is renewed in this presentation by this assemblage of tracts on continuous geometry, quantum logic, group theory, set theory, topology, the philosophy and foundations of mathematics, the ergodic theorem, the design of computers, the theory of automata, numerical analysis, hydrodynamics, meteorology, astrophysics, the theory of games and so on and on.

The set will be prized by mathematicians, physicists and philosophers of science, but it misses being a proper tribute to von Neumann in several respects. There is not even a brief biographical note. The typography is a mishmash; the papers are simply photographed from the journals and other sources in which they first appeared. The editor has not favored us with any orienting introductory material, and in many instances the articles are poorly identified. Typographical and other errors are evident. It would have been better if care had been given to these matters rather than to such absurdities as repeating von Neumann's portrait, the bibliography, the table of contents and the preface in each of the six volumes.

THE STRUCTURE OF SCIENTIFIC REVOLUTIONS, by Thomas S. Kuhn. The University of Chicago Press ($4). Also issued as a monograph in the *International Encyclopedia of Unified Science* (Vol. II, No. 2), this book is a critique of positivistic analyses of the nature of science as well as of the familiar image of the scientific enterprise as a cumulative progression of knowledge. Kuhn's argument rests heavily on the notion of the scientific paradigm, a "model" of acceptable scientific practice. A paradigm involves a distinctive way of seeing the world, and its adoption by a scientific community initiates and dominates a period of "normal" science. During such a period scientific inquiry is said to be essentially a mopping-up operation of solving problems or puzzles prescribed by the paradigm, rather than a search for evidence to test it. Indeed, in spite of manifest incongruities that may arise between paradigm-based expectations of normal sci-

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ence and observed fact, scientists allegedly resist fundamental changes in the paradigm and will at most merely patch it up to eliminate glaring discrepancies. Nevertheless, incongruities may pile up to the point where a patch job no longer suffices; the ensuing period of crisis and revolution is terminated only when the scientific community is converted to a new paradigm that is "incommensurable" with the old one, and that marks the beginning of another period of normal science in which the facts and problems of earlier periods are generally discarded as lacking significance. Kuhn therefore maintains that progress can be intelligibly based only on individual periods of normal science, since scientific progress consists simply in the solution of problems set by a given paradigm. According to him no sense can be made of the assertion that the history of science as an ongoing sequence of normal periods is a progressive enterprise.

Kuhn presents these claims as if they embodied startlingly new revelations about the nature of science. The central idea and sound core of the book, however, is the hardly novel point that scientific conclusions are not free gifts of nature but answers to questions put to nature in the light of assumptions and hypotheses that scientists bring to their inquiries, although Kuhn distorts this idea by using it to support a version of the skeptical "relativism" that has long been fashionable among historians and sociologists. In any event, the term "paradigm," which carries the burden of his argument, is so loosely defined that it covers not only well-articulated theories and vague conceptual schemes but also single scientific laws and specialized instrumental techniques. As a result almost any discovery or innovation can be considered the beginning of a new period of normal science or the occasion for a scientific revolution. On the other hand, it is difficult to see how, in view of Kuhn's claim that a paradigm determines the way scientists perceive their subject matter and thereby completely controls their interpretations of observed data, paradigm-based expectations can ever be defeated or periods of crisis ever arise. Nor is it easy to understand why so much of the science of preceding centuries (e.g., Newtonian mechanics) should continue to be studied and used in later ones if successive paradigms are as radically incommensurable as he declares them to be. These claims are at best wild exaggerations. Moreover, Kuhn is attacking a straw man when he criticizes the notion of scientific progress but construes it as the belief that "science draws constantly nearer to some goal set by nature in advance." And although he maintains at the outset that the notion is strictly applicable only when individual periods of normal science are under discussion, he eventually admits in so many words that even successive periods of normal science can properly be said to exhibit cumulative progress. Accordingly the book succeeds in presenting sound but familiar reflections on the nature of science; it is also much ado about very little.

HANDBOOK OF MATHEMATICAL PSYCHOLOGY: VOLUMES I AND II, edited by R. Duncan Luce, Robert R. Bush and Eugene Galanter. John Wiley & Sons, Inc. ($10.50 and $11.95). In these two volumes 14 authors in 14 jam-packed chapters assist at the birth of what they proclaim the newest kind of psychology. It is a branch of applied mathematics that shows how theoretical models can be formed mathematically for the analytical description of such major psychological functions as choice, detection, recognition, discrimination, psychophysical scaling, learning, language and social interaction. (A discussion of visual and auditory functions and of utility and preference is still over the horizon in a third volume.) Only six of the 14 authors have entire chapters to themselves. The others pair off in different combinations, but the books speak with one voice, avoiding the redundancy characteristic of such a congeries by referring back explicitly a few hundred pages to what has been said by someone else and what the reader is thus supposed to know already.

The chapters are divided into 85 sections of about a dozen pages each, and each section has some contribution to make to the main enterprise, which is described by one editor as being the "estimation of parameters" rather than the now old-fashioned psychologist's hobby of testing hypotheses. Mathematical psychology, say these tough revolutionaries, is young, but it finds an ancestor in Gustav Theodor Fechner, the 19th-century German physician, philosopher and psychologist, and even earlier in Johann Friedrich Herbart, the philosopher who pioneered scientific pedagogy. If psychology is ever to become a mature science, psychologists must know much more mathematics than they have in the past, argue these prophets, predicting that the mathematics will have been learned and maturity achieved in perhaps five years.

There can be no question about the rigor of mathematics and how it polices loose thinking, and these books reveal many errors of the past, such as assuming that Weber's law can hold generally when the scales of the various stimuli for which it is supposed to hold are reduced to a common invariant. One wonders, however, whether mathematiphiles can be trusted to toughen psychology. The discipline will begin to be what they want it to be when its models are confirmed after conception and are used to predict other models that are eventually confirmed.

AN INTRODUCTION TO CYBERNETICS, by W. Ross Ashby ($1.65). MINERALS AND HOW TO STUDY THEM, by Edward Salisbury Dana ($1.45). THROUGH SPACE AND TIME, by Sir James Jeans ($1.45). REALMS OF WATER, by Ph. H. Kuenen ($1.95). SCIENCE AWAKENING, by B. L. van der Waerden ($2.65). THE CLINICAL METHOD IN PSYCHOLOGY, by Robert I. Watson ($2.45). John Wiley & Sons, Inc. An edifying crop of paperback reissues of well-established books about science. Ashby's *Cybernetics,* first published in 1956, is a sound introduction to a difficult subject, and although the treatment is by no means elementary, much of the material can be followed by a reader who is not expert in mathematics and has no other background in the field. Dana's mineral handbook is a thoroughly revised edition of a guide that first appeared in 1895. It is suitable for field use or home study. Jeans's *Through Space and Time,* based on the 1933 Royal Institution Christmas Lectures, is in the characteristic vein of this famous astronomer and popularizer. One now reads him with some caution and skepticism, and certain of his scientific descriptions and conjectures are outmoded, but his writing is an unalloyed delight. The Kuenen is a fine beginner's book about water, particularly some aspects of its cycle in nature; the volume is fully and effectively illustrated. Egyptian, Babylonian and Greek mathematics are the subjects of van der Waerden's history. It is a survey by an eminent mathematician who is able to relate mathematical development to philosophy, astronomy and the general life of the times. Watson's treatise is a standard reference on clinical psychology originally published in 1951.

CLIMATES OF THE PAST, by Martin Schwarzbach. D. Van Nostrand Company, Ltd. ($10.75). The irrepressible 18th-century German wit, sat-

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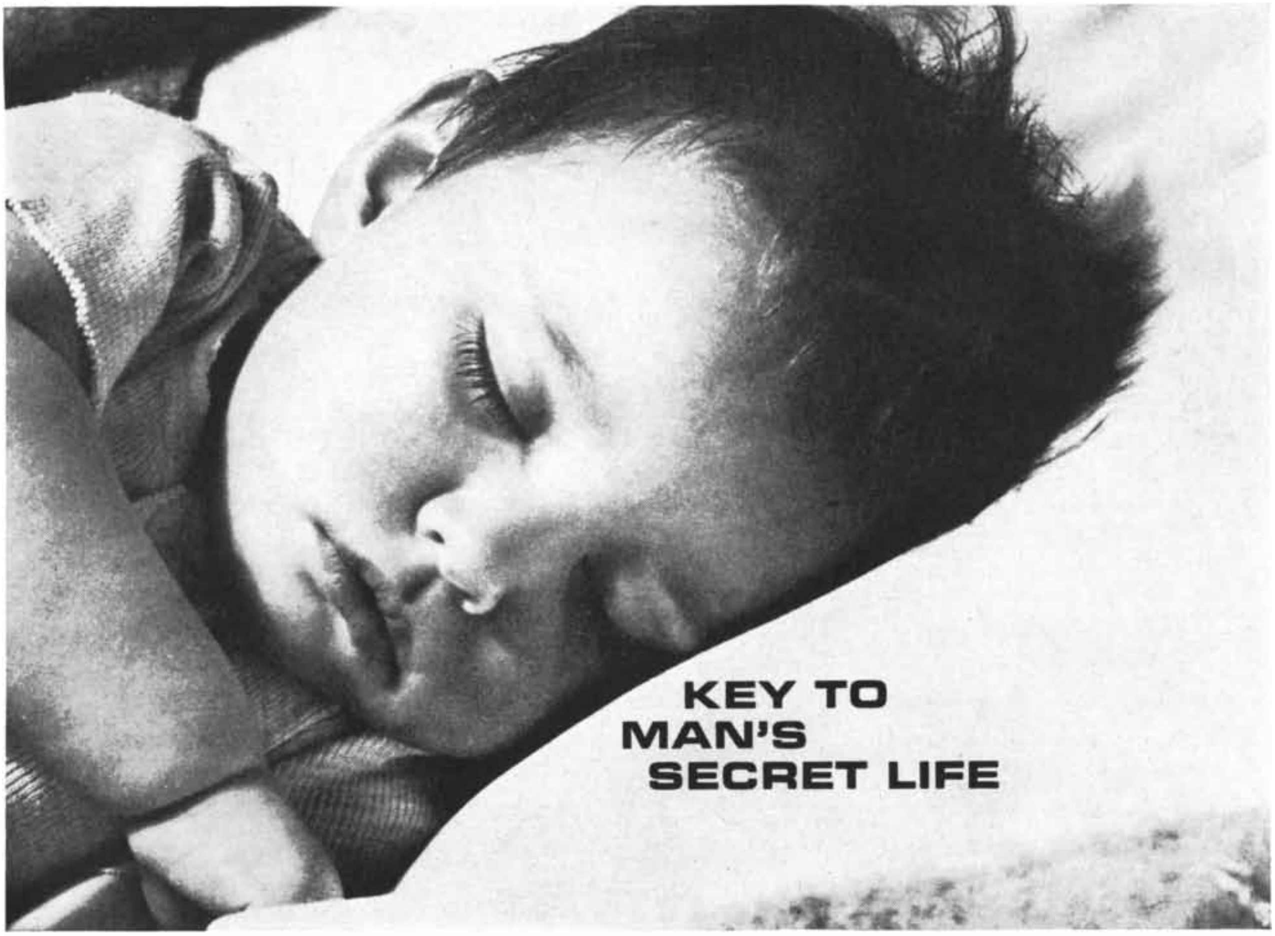


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THREE HUNDRED YEARS OF PSYCHIATRY: 1535–1860, by Richard Hunter and Ida Macalpine. Oxford University Press ($13.45). An extensive compilation of selected texts in English pertaining to the history of psychiatry. This large body of material is rich, as a British reviewer has remarked, "in cautionary tales"; as the authors themselves point out, the history of psychiatry is not so much "a chronicle of feats, facts and discoveries...[as] a record of perennial problems, recurrent ideas, disputes and treatments, trailing in the wake of medicine and exhibiting paradoxically—as medicine did of old—a mixture of as many false facts as false theories." One has only to look at some of the methods of psychiatric treatment still in vogue to realize that this observation is as applicable to present-day psychiatry as it is to the period covered by Hunter and Macalpine's collection. A valuable and often absorbing book, with more than 200 illustrations.

BIOCHEMICAL LESIONS AND LETHAL SYNTHESIS, by Sir Rudolph Peters. The Macmillan Company ($10). A group of essays about various topics on which the author, a British biochemist, has worked with his colleagues for many years. The term "biochemical lesion" means "the initial biochemical change in tissue cells that precedes any damage visible with the light microscope"; the term "lethal synthesis" was proposed by Peters for a special phenomenon in which a substance that is itself nontoxic is converted into a substance that will then cause a biochemical lesion. Illustrations.

THE THREE CHRISTS OF YPSILANTI, by Milton Rokeach. Alfred A. Knopf ($5.95). A report by a social psychologist of a research project involving three men, each of whom believes he is Jesus Christ. These three men, a farmer, a clerk and an electrician, are patients in a state mental hospital in Ypsilanti, Mich., and for a period of two years (1959–1961) they were brought together daily, encouraged to converse, to argue, to assert their identity and to live together fairly peaceably. How each man responded to these circumstances, learned how to cling to his own delusions while accommodating himself to those of the others, is recounted in these pages, most of which are transcripts of the patients' own recorded words. As a case report for clinicians the book may be of considerable value; as a book for the general reader, even though portions of it are moving and at times engrossing, it is much too long.

FORD: DECLINE AND REBIRTH, 1933–1962. Allan Nevins and Frank Ernest Hill. Charles Scribner's Sons ($8.95). The third and final volume of this history of the Ford Motor Company is notable for its vivid account of the struggle between Henry Ford and the labor unions. As Ford grew older his prejudices and his inability to adjust to the changes in the social and economic scene gained an almost complete ascendancy over his actions. No better evidence can be found of this deterioration than in the increasing reliance he placed on his sinister lieutenant Harry Bennett. The result of enlarging Bennett's powers was to bring about bitter and bloody strife and almost wreck a vast industrial empire. The death of Henry Ford's son Edsel, who both as a human being and as an administrator was vastly superior to his father, was the final blow, from which it seemed the company would never recover. It was not until Henry Ford II came to power that the company began to rebuild and to rise once more to industrial eminence. The three volumes of this history are of high interest and present a remarkable picture of an important side of American life for more than half a century.

THE BIRDS OF THE BRITISH ISLES: VOLUME XII, by David Armitage Bannerman. Oliver & Boyd Ltd (63 shillings). The 12th volume of Bannerman's survey, which brings this admirable work to an end, deals with the skuas, auks, guillemots, razorbills, puffins, rails, crakes, coots and game birds such as the grouse, the pheasant and the partridge. In its amplitude, its details and its readable and leisurely style this volume attains the standards of its predecessors. There are 31 plates by George Lodge and a complete index to the entire work. It is gratifying to see a labor of so many years completed, but anyone who has tasted of these books and looked forward to the appearance of each new volume will regret that there are no more to come.

CURIOSITIES OF MEDICINE, edited by Berton Roueché. Little, Brown and Company ($5.95). An anthology of essays on unusual medical cases or phenomena: Samuel Hopkins Adams on the black widow spider and the unpleasant effects of its bite, John Caius on the sweating sickness, René and Jean Dubos on consumption and the Romantic Age, Niels Dungal on the reasons for stomach cancer in Iceland, William Beaumont on his celebrated experiments on digestion, Kinder Wood on the dancing mania, John Snow on cholera and the infamous "Broad Street pump," Ashley Montagu on yawning, Philip Marshall Dale on the tragic effects of cerebral arteriosclerosis on Immanuel Kant, and so on. An entertaining assortment.

WORLD ARCHITECTURE: A PICTORIAL HISTORY, by Seton Lloyd, David Talbot Rice, Norbert Lynton, Andrew Boyd, Andrew Carden, Philip Rawson and John Jacobus. McGraw-Hill Book Company ($17.95). An ably written conspectus of great buildings from antiquity to the present, with more than 1,000 illustrations, many in color. The pictures tend to be jumbled, but the photographs can be resolved even when they are small. The captions are informative and relatively free of the usual critic's rubbish. No other single volume gives a comparable overview of the main themes and trends of architectural history.

CHINESE CERAMICS, BRONZES AND JADES IN THE COLLECTION OF SIR ALAN AND LADY BARLOW, by Michael Sullivan. Faber and Faber Limited (eight pounds eight shillings). A strikingly handsome annotated and illustrated catalogue of one of the finest private collections of Chinese art in Great Britain. Sullivan, a noted student of Asian art who has lived and studied in China, describes each of the figurines, wares, jades and archaic bronzes and prefaces each section of his book with an essay that draws on recent research and excavations in China. The illustrations are first-class.

THE ECOLOGY OF NORTH AMERICA, by Victor E. Shelford. The University of Illinois Press ($10). A comprehensive description of the communities of flora and fauna in North America as they existed around 1600, that is, before European settlers changed the land, sometimes for the better, often for the worse. Shelford, who has been called the father of modern animal ecology, spent more than 30 years preparing this study by extensive field trips, culling the literature and initiating and supervising the research of his students. Copiously illustrated.

## Notes

EARTH, MOON, AND PLANETS, by Fred L. Whipple. Harvard University Press ($6.50). A revised edition of a nontechnical survey of the solar system by the director of the Smithsonian Astrophysical Observatory. Relaxed and informative, suitable for young readers as well as grownups. Many illustrations.

INTRODUCTION TO FUNCTIONAL ANALYSIS, by B. Z. Vulikh. Addison-Wesley Publishing Company, Inc. ($10). A translation from the Russian of an introduction to the methods of functional analysis, a comparatively young discipline with extensive applications in mathematical physics and other fields.

LIGHT AND HEAT SENSING, edited by Harrison J. Merrill. The Macmillan Company ($20). Papers presented at a 1962 Paris symposium on instruments and methods of light and heat detection, mostly in space science and technology.

THE DIPLOMATS: 1919–1939, edited by Gordon A. Craig and Felix Gilbert. Atheneum ($3.30). A reissue of a collaborative work that affords a remarkable survey of the main figures and events of the diplomatic history of the fateful period between the two world wars. Two paperbound volumes.

AMERICAN SCIENTIFIC BOOKS 1962–1963, edited by Phyllis B. Steckler. R. R. Bowker Company ($5). A supplement to *American Scientific Books 1960–1962,* continuing the cumulation of titles from the monthly issues of the *American Book Publishing Record.*

INTRODUCTION TO MODEL THEORY AND TO THE METAMATHEMATICS OF ALGEBRA, by Abraham Robinson. North-Holland Publishing Company ($8.50). A much-expanded version of the author's *On the Metamathematics of Algebra* published in 1951 and now out of print, this book is concerned with the relations between "the properties of sets of axioms and of their systems of models and more particularly with the analysis and development of algebra by the methods of mathematical logic."

CONJECTURES AND REFUTATIONS, by Karl R. Popper. Basic Books, Inc., Publishers ($10). A collection of philosophical essays and lectures dealing with such topics as the theory of knowledge, the history of philosophy and science, and social and political questions.

AMERICAN INSTITUTE OF PHYSICS HANDBOOK, edited by Dwight E. Gray. McGraw-Hill Book Company ($29.75). This second edition of a standard working tool has been updated in several departments and has fresh material on, among other things, computers, solid-state physics, high- and low-temperature physics and the magnetic properties of materials.

THE COMPLETE PLAIN WORDS, by Sir Ernest Gowers. Penguin Books Inc. ($1.25). A paperback reprint of Gowers' delightful and delightfully instructive guide to the writing, choice and arrangement of words in such a way "as to get an idea as exactly as possible out of one mind into another."

LINEAR OPERATORS. PART II: SPECTRAL THEORY, by Nelson Dunford and Jacob T. Schwartz. John Wiley & Sons, Inc. ($35). The second volume of this treatise on linear operators deals largely with operations in Hilbert space.

FOUNDATIONS OF DIFFERENTIAL GEOMETRY: VOLUME I, by Shoshichi Kabayashi and Katsumi Nomizu. Interscience Publishers, Inc. ($15). The first of two volumes of an introduction to differential geometry, intended to be sufficiently comprehensive to serve as a reference book.

BACTERIAL PHOTOSYNTHESIS, edited by Howard Gest, Anthony San Pietro and Leo P. Vernon. Antioch Press ($6). Papers presented at a symposium on bacterial photosynthesis held in Yellow Springs, Ohio, in 1963.

THE ELOQUENT LIGHT, by Nancy Newhall. Sierra Club ($20). The first of two volumes of a biography of the distinguished photographer Ansel Adams. Fully illustrated with many of his superb pictures.

DYNAMIC ASPECTS OF BIOCHEMISTRY, by Ernest Baldwin. Cambridge University Press ($7.50). The fourth edition of this excellent elementary text on the chemical basis of metabolic activity.

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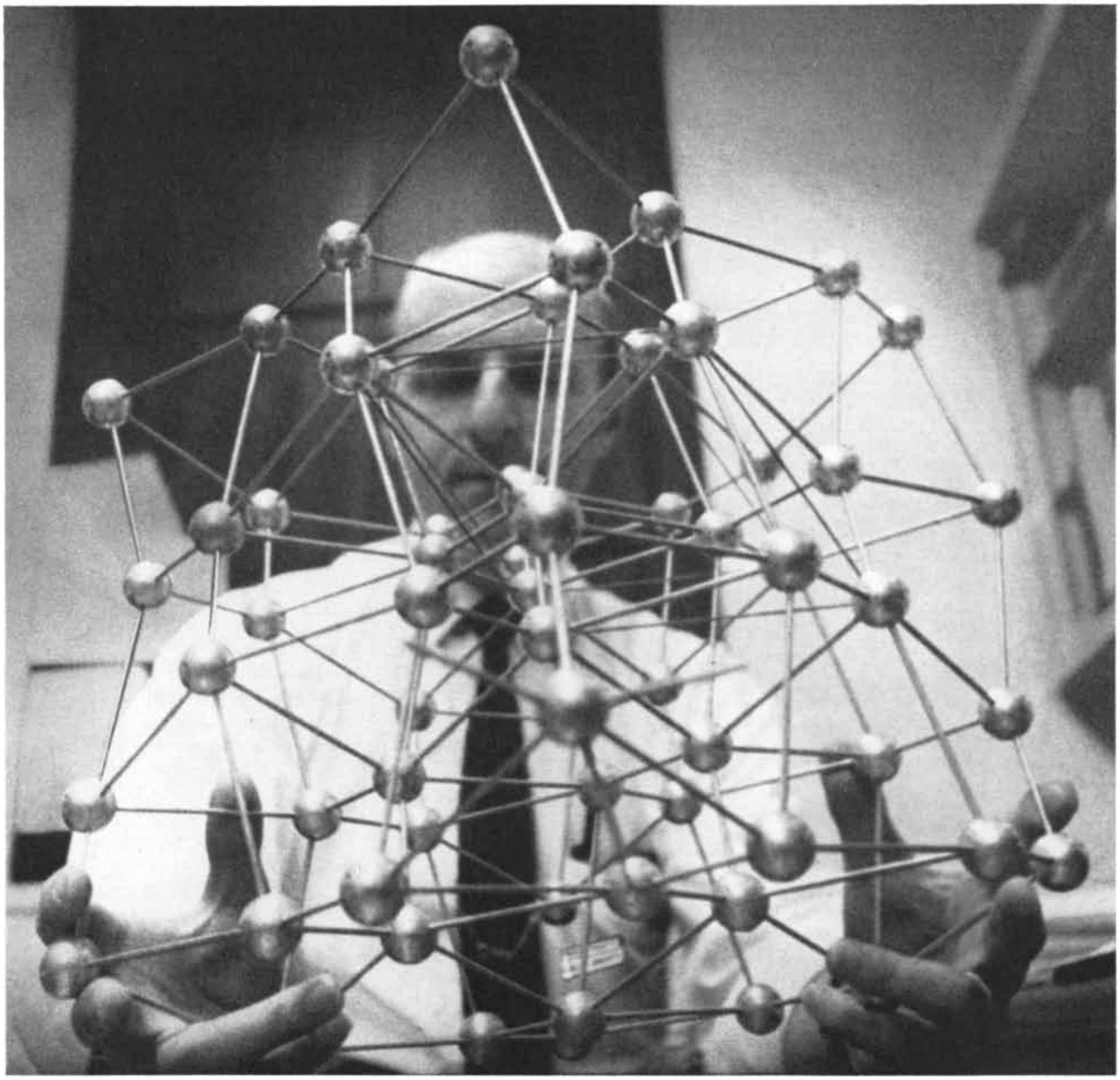
EXPERIMENTAL EVALUATION OF POTEN-



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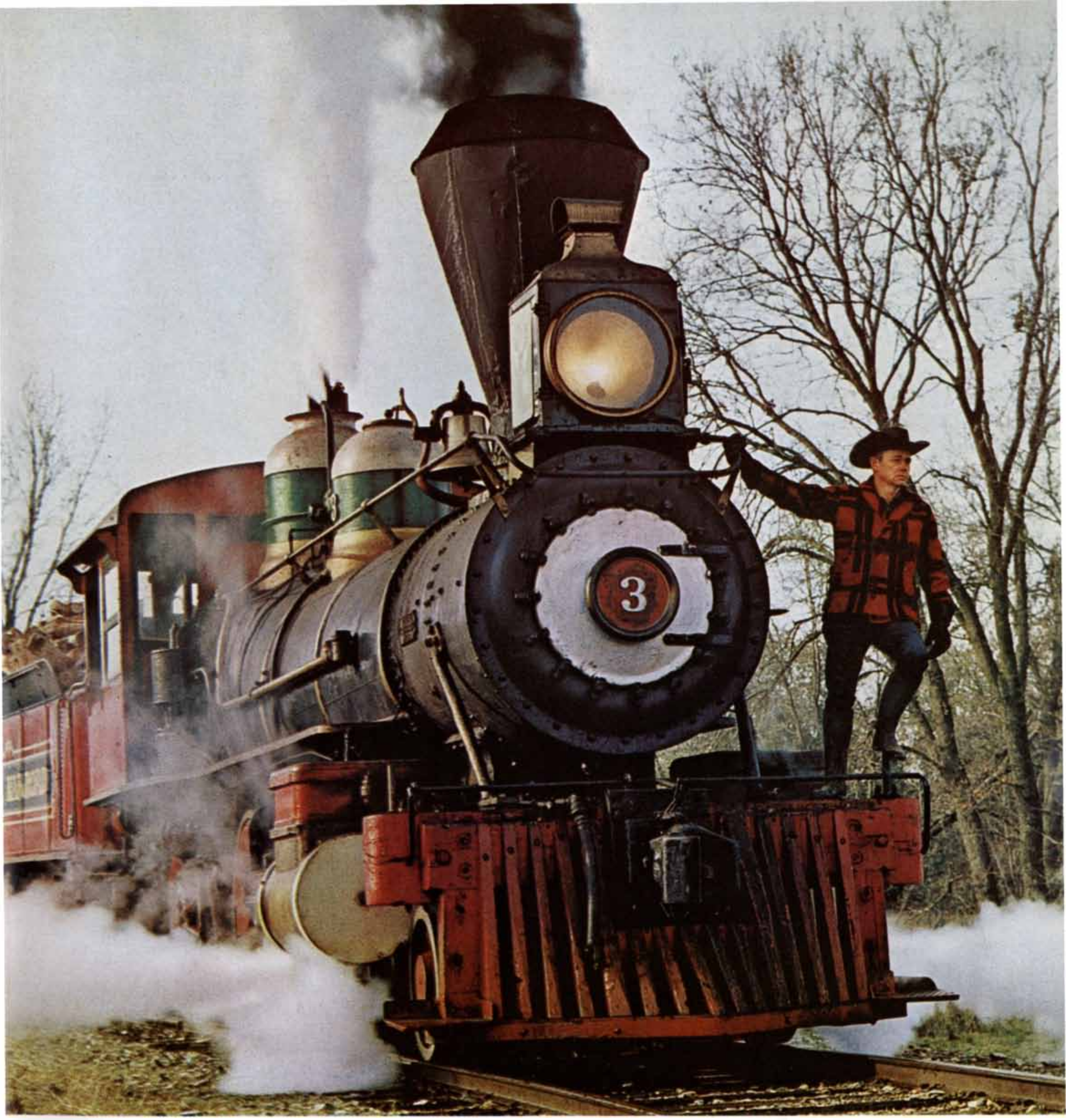


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