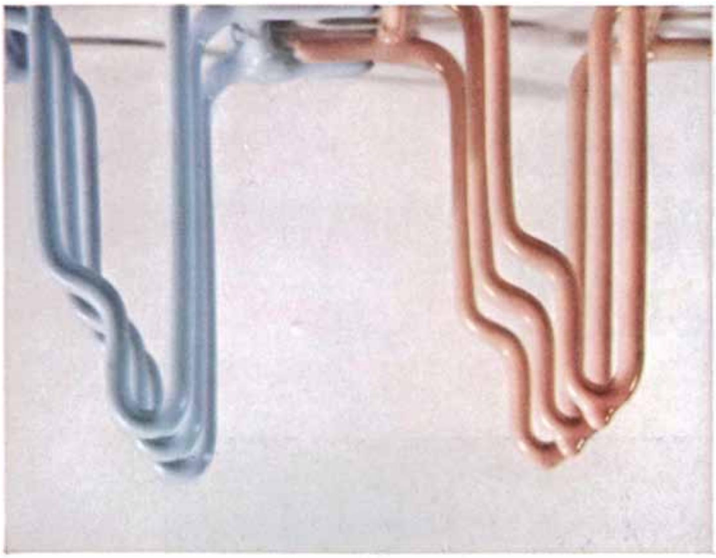
SCIENTIFIC AMERICAN

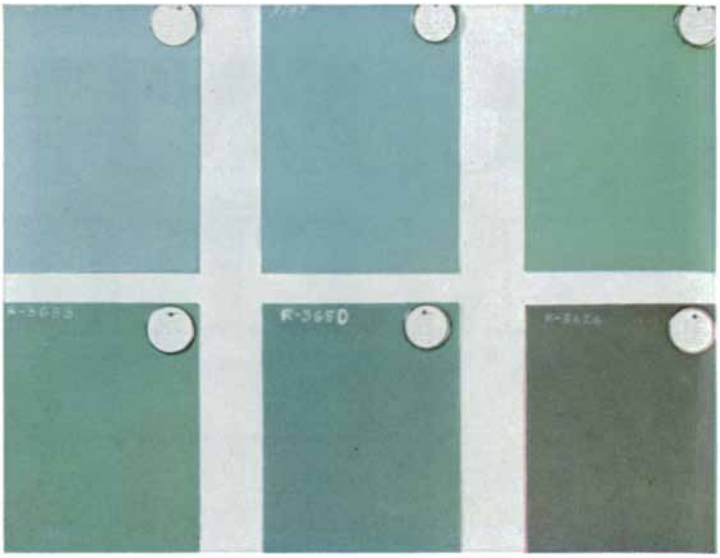
BOWERBIRD DISPLAY

FIFTY CENTS

August 1963



Change of color changes properties: Spectrophotometers and color computers help to control color in M&T vinyl coatings to within one McAdam unit. But change colors significantly and you often change physical properties, as indicated above. Here human capability comes in. Putting experience to work, M&T chemists often come up with entirely different formulations for two colors to have the same physical and chemical properties.



Which panel has the most color pigment?: The answer: they all contain the same amount. And that's the basis for the current M&T work with antimony-based flame retarders. Our chemists have developed six types to match color requirements. Each one has high flame retardancy. Main difference is in amount of tinctorial strength. Result: users of M&T flame retarders save on costly color pigments for deep colors or improve translucency in others.

How to keep color under strict control: Only the most skilled color matcher can detect color variations of less than 1 N.B.S. unit in ceramic tile. Nevertheless, control to 1 N.B.S. unit isn't good enough for many tile producers. To meet standards such as these, M&T completely controls the uniformity of its Ultrox® ceramic opacifiers so that test glazes checked by colorimeter will have color variations of less than 0.5 N.B.S. units. This minute variation is well below the normal levels of visual perception.

M&T works with chemical and physical properties, such as color, in many materials. M&T capabilities may help solve your problems in chemistry, ceramics, plating, organic coatings, minerals and welding. Write M&T Chemicals Inc., General Offices, Rahway, New Jersey.

M&T Chemicals Inc.

FORMERLY METAL & THERMIT CORPORATION

"Why we chose the NCR 390 Computer."

Bridgeport Metal Goods Mfg. Co., Bridgeport, Conn.

"Even though we are not an industrial giant, compared with many of the firms installing computers today, we had urgent need for what has come to be called a 'total system.' After evaluating the many systems available, we chose the NCR 390 computer as the one most suited to our particular needs.

"With the 390 we are able to continue using hard copy accounting records which have proven to be so essential to us over the years. Of importance, however, is the fact that now these records are also able to store data electronically, and to act as their own input to the computer.

"Basically, our NCR 390 has enabled us to integrate our accounting and reporting procedures. Because of the comparative simplicity of the 390, we have not had to hire professional electronic programmers. We accomplish all systems and programming functions within our own organization.

"In summary, our new tool — the NCR 390 computer — is providing new capabilities, enabling us to do a more efficient accounting job, to upgrade our reporting procedures, and to obtain a significant return on our investment."

William H. Beach, Vice President & Treasurer

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THROUGH ACCOUNTING MACHINES, CASH REGISTERS OR ADDING MACHINES, AND DATA PROCESSING
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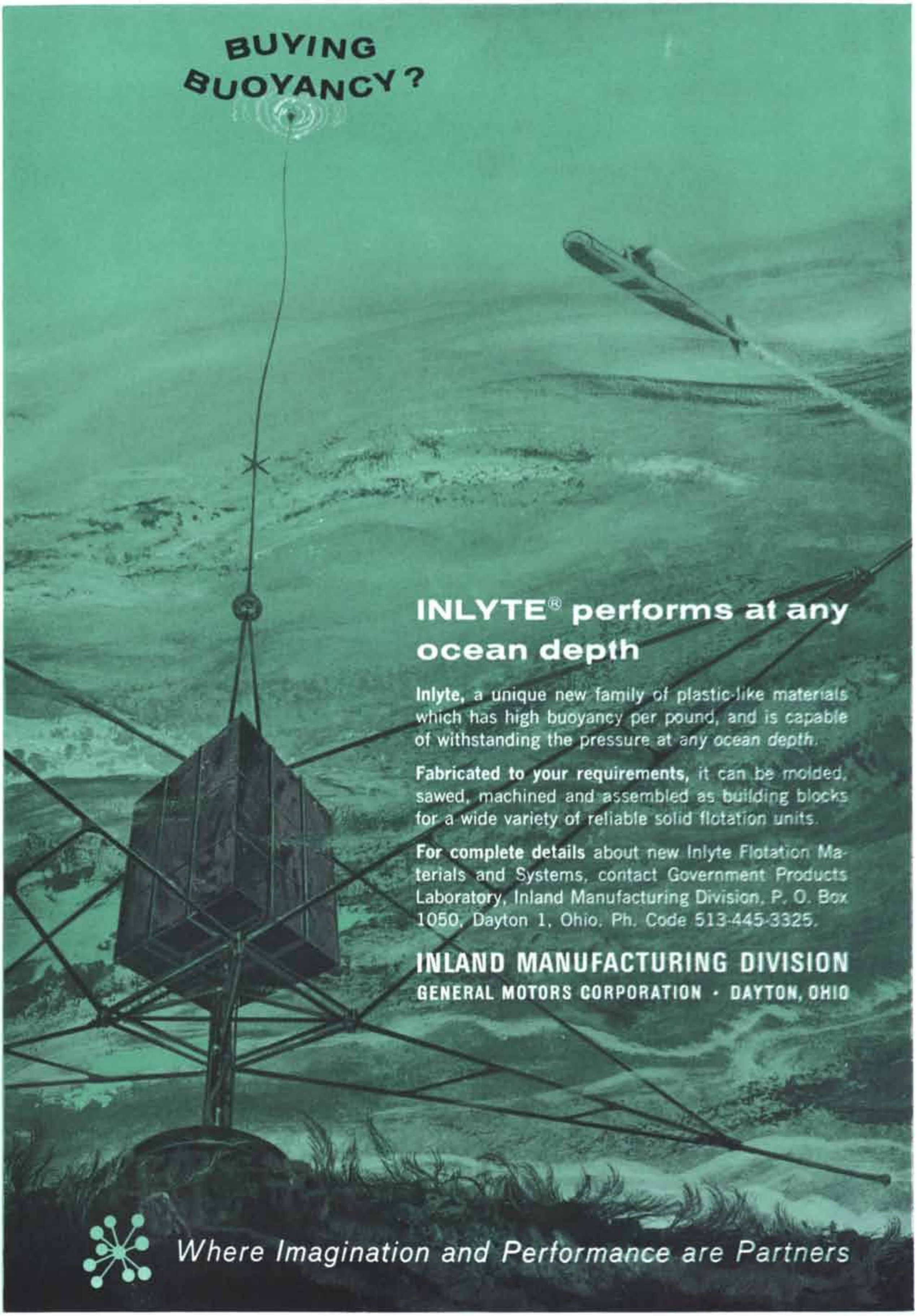
NCR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Established 1845 **SCIENTIFIC AMERICAN** August 1963 Volume 209 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows a male bowerbird in the course of its courtship display. The bird is displaying to the female by holding in its beak a colorful berry. Among the bowerbirds complex mating stations, built of sticks and often lavishly decorated with colorful objects, and elaborate courtship behavior incorporating natural objects often substitute for male sexual plumage in attracting females (see "The Evolution of Bowerbirds," page 38). The bird depicted on the cover is a Lauterbach's bowerbird (*Chlamydera lauterbachi*), a New Guinea species that builds four-walled bowers by inserting thousands of sticks into a foundation mat. The bower-builders are arena birds: the males live in bachelor clans and establish their individual breeding courts within a zone known as an arena.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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New generation of Shaped-Beam Tubes makes

by: A. H. Wisdom,
Manager of Research and Engineering for Data Products

CHARACTRON® Shaped-Beam Tubes produced nearly 10 years ago, many of which are still being used in the display consoles of the SAGE program, have achieved 20,000 hours or more of reliable performance. Today's CHARACTRON Tube represents a new generation of development, offering dozens of major improvements over the original tube. The principle, however, remains essentially the same.

HOW IT WORKS

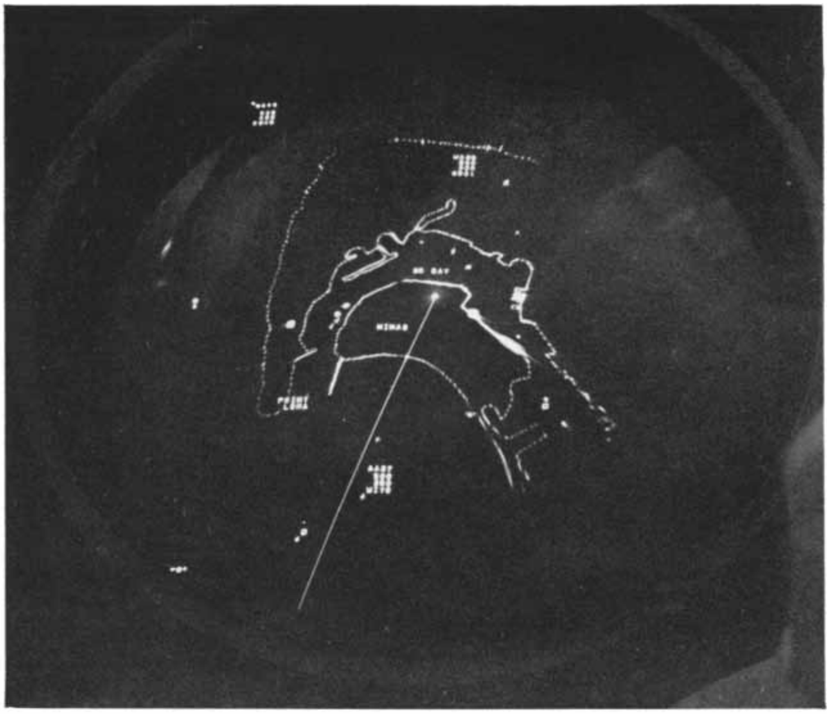
Heart of the CHARACTRON Shaped-Beam Tube is the stencil-like matrix, a thin disc with alphanumeric and symbolic characters etched through it. This matrix is placed within the neck of the tube, in front of an electron gun. The stream of electrons emitted from the gun is extruded through a selected character in the matrix. When the beam impinges on the phosphor-coated face of the tube, the character is reproduced.

The standard matrix carries 64 characters. However, matrices have been made with 88, 128, and 132 characters. Coupled with new variable character size capabilities, the CHARACTRON Tube offers a wide latitude in symbol generation. The beam is passed through one of the characters by applying the proper voltage to the selection plates. Electrostatic reference plates and/or magnetic deflection are then used to position the beam at any tube face location. In more compact tubes, the entire matrix is flooded with electrons generating a complete array of characters, while only the desired character is allowed to pass through a small masking aperture. A small diameter beam can be used to display data from analog inputs simultaneously with the characters.

NEW GENERATION OF TUBES

Today's CHARACTRON Tube is *not* the same tube built ten years ago. While all major improvements cannot be discussed, following are some of the more significant:

Earlier tubes had some deformation of the characters at the screen edge. The modern tube is sharp to the edge, with much greater resolution. New bright phosphors have been developed including a pastel green which eliminates spot size variation or "blooming". When necessary, tube length can now be dramatically decreased. A tube 25 in. long now achieves the same results once requiring a tube 45 in. long.



Time-share version of CHARACTRON Shaped-Beam Tube.

SPEED

Many optimistic goals have been claimed regarding the speed of character writing tubes. Frequently, however, these claims do not delineate the time required for the positioning of these generated characters but simply state the time necessary for generation. It is a simple matter to blink a character at tremendous speeds at the same place on the tube face. Generating different characters and positioning them in different places on the tube is something else. The shaped-beam principle generates characters in a period of time independent of the complexity of the character. Complex symbols can be generated as simply as a dot. With high speed circuitry, selection can be accomplished at rates equivalent to oscilloscope deflection frequencies.

For example, characters could easily be generated at a million each second. However, today's magnetic deflection yokes require a minimum 5 to 8 micro-seconds to settle the magnetic domain in the core and this is the limiting factor in positioning speeds. Using a high speed selection system and allowing five to ten micro-seconds for unblanking, CHARACTRON Tubes can provide realistic writing rates of 50,000 characters per second or more, even using random deflection. Electrostatic deflection tubes now under development promise writing speeds of up to 200,000 characters per second.

ECONOMICS

A CHARACTRON Tube by itself appears to be relatively expensive, but a system using this tube can economically justify itself easily. This is true because the CHARACTRON Tube replaces both the necessary character generator and much of the circuitry required by other systems.

In recent models, alignment procedures have been simplified, and the tube holds alignment longer than other character writing systems. A CHARACTRON Tube can be set up by an experienced man in less than one hour. Tubes are available in a wide range of phosphors with practically any desired color or degree of persistence. Resolution of 1800 TV lines can

advanced techniques possible in data display

be provided, the only limitation being the grain size of the phosphor. CHARACTRON Tubes are no more fragile than any other cathode ray tube. They have been exposed to a 32G shock for 52 milliseconds without harm, and can take just about any shock that does not fracture the glass. In one application, the tube was used in a portable battlefield display console.

PICTURE WINDOW TUBE

Frequently, it is necessary to continuously repeat certain data on the face of a tube while changing other data.

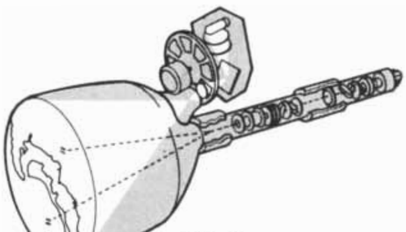


FIG. I

This may be done easily with a new development called the "picture window" concept. In the "window" tube, changing data from computer, radar, or communications link, is presented in the usual manner. Repetitious data are projected through the "window" onto the faceplate using a slide or film projector (Figure I). In a typical application, a geographic map of the area is projected on the face while the computer presents changing data. As the area under surveillance changes, the operator pushes a button to select another map. In another application, business or engineering forms are projected on the tube and filled in with data from the computer. Included in this option is a recording camera. By means of a beam splitting half-silvered mirror, the camera maintains optical access to the entire tube face. A button actuated solenoid operates the camera, recording all data being displayed.

TIME-SHARE TUBE

A new "time-share" version of the tube produces alphanumeric data and at the same time performs beam writing to draw curves and vectors. In the drawing mode, electrons pass through a special large aperture so that none of the beam is blocked. Brighter beam drawings result. The name "time-share" is derived from the fact that both the alphanumeric and drawing mode share the beam from one cathode for part of the time. This tube is ideal for applications such as long range radar where the antenna may turn at a relatively low speed of six times a minute.

TWO-GUN TUBE

On short range radar requiring high rotation speeds of perhaps 25 times a minute and many hits on small targets to build up an image, there may not be enough time left for forming alphanumeric symbols. With these applications, a two-gun tube (Figure II) is suggested. This tube retains the beam shaping electron gun for producing characters and employs another gun to accomplish the video writing. This second gun, when coupled with video driving circuitry, can be used to generate high resolution TV images including scan converter readout or

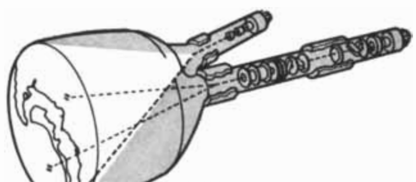


FIG. II

raw radar data. These images, of course, can occur at the same time as and without any effect on the alphanumeric data supplied from the shaped-beam gun.

SYSTEMS

General Dynamics|Electronics designs and produces a number of custom and standard display, printing and film recording systems which utilize the CHARACTRON Shaped-Beam Tube.

Custom installations include direct-view consoles as well as film recorders which automatically process and project large-screen displays for group viewing.

The S-C 1090 Display console (Figure III) presents alphanumeric, symbolic and graphic data from computers

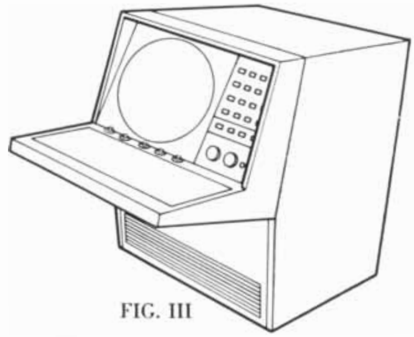


FIG. III

or other sources. It is a complete, "off-the-shelf" display unit. Optional equipment includes internal test routine, input register, level converters, internal storage of complete display frame, vector generator, expansion and off-centering, category selection and various data channel buffers. The console is 66 in. long, 32½ in. wide, and 47 in. high. It is recommended for a variety of applications, including command and control systems, air traffic control, computer readout and data display for any automated process.

The S-C 4020 records the output of large scale computers on film and/or paper at equivalent speeds. Combinations of drawings and alphanumeric data may be recorded in fractions of a second.

The S-C 3070 provides high-speed asynchronous printing without impact on paper for communications or computer output applications.

WRITE FOR MORE INFORMATION

For technical information on the S-C 1090 Display, the S-C 4020 Computer Recorder, the S-C 3070 Electronic Printers, or the new generation of CHARACTRON Shaped-Beam Tubes, write to General Dynamics|Electronics, Department D-26, P. O. Box 127, San Diego 12, California.

GENERAL DYNAMICS | ELECTRONICS GD SAN DIEGO

LETTERS

Sirs:

I am haunted by the thought that the author of the fascinating article "Early Experience and Emotional Development" [SCIENTIFIC AMERICAN, June] may have indulged in circular reasoning. In gauging emotional development in rats Victor H. Denenberg used as a measure of flexible and adaptive behavior a rat's activity in running about and exploring the floor of an empty four-foot-square box. Per contra, he took as being emotionally disturbed those rats that cowered in corners of the box, crept about timidly and defecated frequently.

Can we be certain those standards are correct and not reversed? Presumably there is in the experiment and its findings some implicit analogy with other mammals and their behavior. So the question arises whether, in a world ever more dangerous and uncertain for both mice and men, the mother and her pups that proceed with caution and take what meager protection the environment affords are emotionally disturbed or, alternately, are really adapting to their conditions as well as could be expected.

Keeping the bowels open and the flanks covered in these hostile times may well be as good a way to adapt to unfamiliar situations as any other—better, perhaps, than hyperactive, constipated

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ERRATUM

In the article "Machine Translation of Chinese," by Gilbert W. King and Hsien-Wu Chang [SCIENTIFIC AMERICAN, June] the statement is made: "Perhaps the most important feature of [the] system is a photographic 'memory' containing hundreds of thousands of dictionary-like entries, any one of which can be found in a twenty-thousandth of a second." The correct figure is not a twenty-thousandth of a second but 20 thousandths of a second.

scuttling in aimless search for an unknown goal.

ALFRED FRIENDLY

The Washington Post
Washington, D.C.

Sirs:

Alfred Friendly's question concerning the validity of the measure of emotional reactivity is quite cogent. Both observation and experimental data help to supply an answer. A common observation with laboratory rodents is that they "freeze" and defecate when placed in a strange and frightening situation.

The experimental data relating stimulation in infancy to open-field performance and other patterns of behavior, and to physiological measurements, are too lengthy to detail here. Briefly, animals who are stimulated in infancy are more active and defecate less in the open-field test than nonstimulated controls; such animals also learn an avoidance response more rapidly, have a lower ratio of adrenal weight to body weight following chronic stress and are better able to survive a severe environmental stress.

The patterns of behavior suggested by Friendly in his last paragraph may be appropriate for humans, but it is doubtful that they would be of any adaptive value to rats. And whether or not these patterns would be adaptive for humans would be determined in the long run by the adequacy of the plumbing and the efficiency of the sanitation system.

VICTOR H. DENENBERG

Department of Psychology
Purdue University
Lafayette, Ind.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1913: "Dr. Alexander Graham Bell recently announced that F. C. Baldwin, one of his assistants, seriously thinks of crossing the Atlantic in an aeroplane, in an effort to win the *London Daily Mail's* $50,000 prize. According to the newspapers, Dr. Bell proposes that the flight be made at an altitude of five miles, where an atmospheric density one-third that at sea level would permit a great speed. However, the altitude record held by Legagneux is only 17,878 feet, which means that Baldwin will have to go about 8,500 feet higher. There is trouble enough with motors, not to mention the human breathing apparatus at a height of three miles."

"The camp of biologists is divided. There are those who hold that the phenomena of life involve a separate principle which does not operate in nonliving matter. Another school seeks to interpret all actions or functions of the living organisms in terms of the general laws of nature which are known to apply to all matter living or dead. To us it appears premature to take any side in this dispute. There is a very wise principle current among scientific men, that the aid of a new hypothesis shall not be invoked so long as a given set of phenomena can be explained without it. It is therefore clearly the best policy in the investigation of life phenomena to press forward as far as we can by the application of the methods and principles with which we are familiar in the physical world in general, and to see just how much of the remarkable phenomena presented by living matter we can explain in terms of such general laws, before we attack the question whether, after all has been done in the way indicated, there still remains a certain residuum of facts which cannot be accounted for in this way, and for the explanation of which we must postulate some special 'vital principle,' or whatever we may like to call it."

"Air currents at a height of 50 miles above the earth are discussed by J. Edmund Clark in the *Quarterly Journal of the Royal Meteorological Society,* on the basis of observations made at many places in southern England and northern France of the drift of a particularly bright and persistent meteor train seen on the night of February 22, 1909. Mr. Clark himself saw the train for 104 minutes. The most remarkable conclusions drawn by the writer relate to the velocity of the upper winds at various levels, as indicated by the movement of the train. Thus it appears that between 49½ and 51 miles' altitude the streak lay in a west wind of more than 170 miles an hour, whereas at 51½ miles the current was almost from the east with a velocity approaching 200 miles an hour. These conclusions hardly agree with the prevailing conception of the stratosphere as a region of gentle winds."

"The scientist H. Molisch finds that radium rays have the effect of interrupting the repose of winter buds of different woody plants and thus give rise to a precocious budding."

"It has been conjectured that excessive atmospheric precipitation might favor the occurrence of earthquakes by increasing the supply of subterranean water, leading to a washing away and collapse of portions of the earth's crust. Count de Montessus de Ballore has published in the *Comptes Rendus* the results of a painstaking comparison between 4,136 earthquakes and the rainfall conditions preceding them. He concludes that there is no relation of cause and effect between these phenomena."

"By making the circuit of the world in 35 days, 21 hours and 35 minutes, J. H. Mears, representing the New York *Evening Sun,* has reduced the record by nearly four days below that made by A. Jaeger-Schmidt in 1911."

Scientific American.

AUGUST, 1863: "The manner in which the armor of the *Ironsides* has thrown off the rebel shot at Fort Sumter causes general satisfaction, although she has not yet been closer than 1,800 yards to the rebel batteries. Most of the heavy shot have crumbled to pieces on her solid sides, and the rifled shot have only made indentations without doing the slightest damage. She has received two 10-inch shot on her port stoppers, and even there they only made indentations without doing any harm to them. The steel-pointed shot have made cuts about an inch deep. She will, however, be tested within 800 yards when the great assault is made."

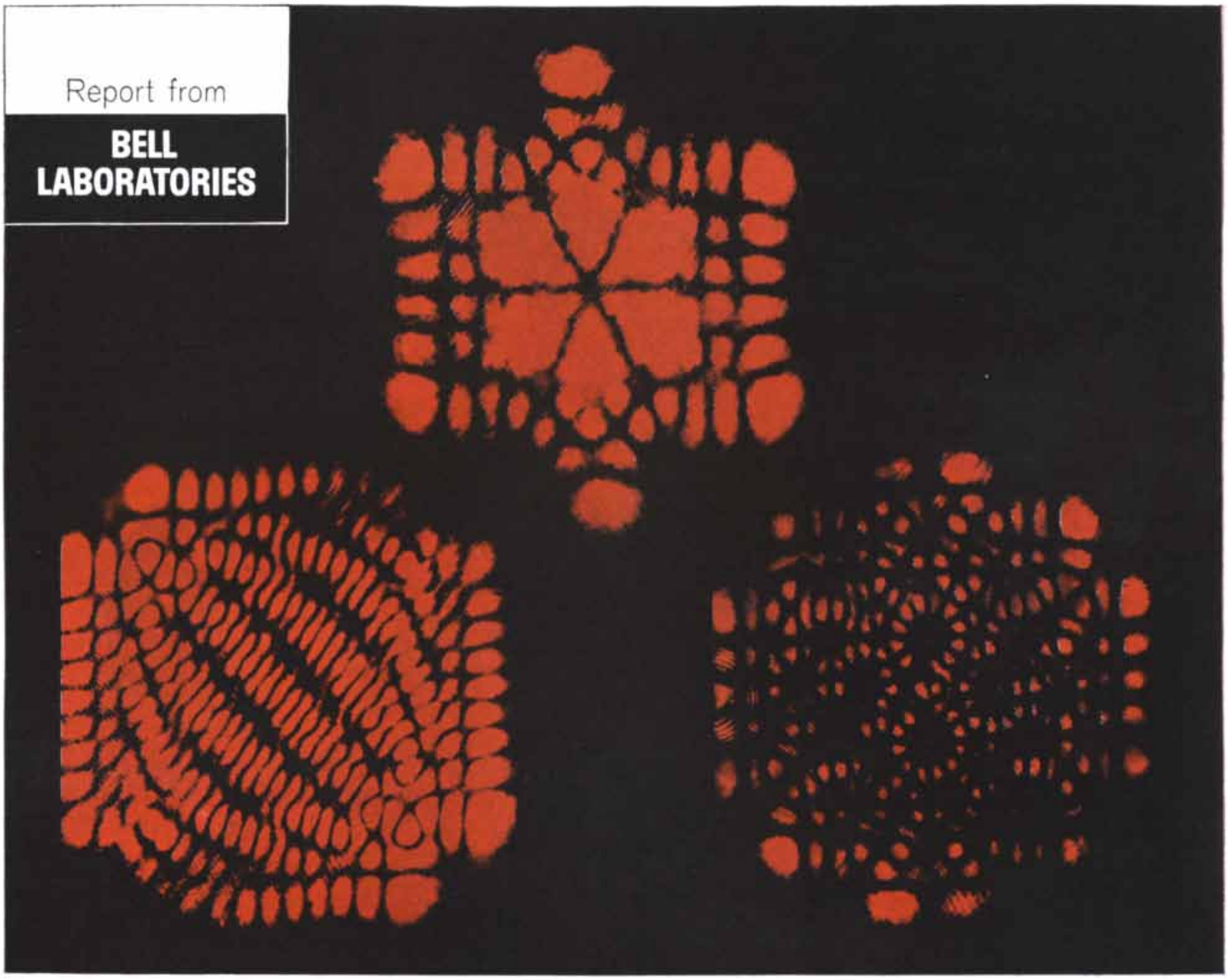
"Oscar H. Kratze of Leipsic has invented an engine that uses petroleum for the purpose of giving motion to the piston of an ordinary cylinder without the use of a furnace. The invention consists in the employment, for the purpose of producing a direct motive power, of petroleum, naphtha or other hydro-carbon, in the form of vapor, mixed with a sufficient quantity of atmospheric air to sustain combustion in such a manner that, by igniting said vaporized hydrocarbon liquid in the cylinder with an electric current, the desired reciprocating motion of the piston is effected."

"We learn that Mr. D. L. Miller, Jr., of Philadelphia is loading a cargo of crude petroleum in bulk for Liverpool, which is the first ever carried in that way. The vessel is fitted up with an exclusive view to carrying oil in bulk (of which it is expected she will take 50,000 gallons) and provided with 12 immense iron tanks. The barrels of oil are emptied directly into the tanks, and when the vessel is unloaded, the tanks are pumped out. Of course the peculiar construction of the vessel unfits her for any other than the petroleum trade."

"Professor Roscoe, in a paper on the spectrum produced by the flame evolved in the manufacture of cast steel by the Bessemer process, states that during a certain phase of its existence the flame exhibits a complicated but most characteristic spectrum, including the sodium, lithium and potassium lines. He expresses his belief that this first practical application of the spectrum analysis will prove of the highest importance in the manufacture of cast steel by the Bessemer process."

"A genius in New Bedford is fitting up a steamer for the purpose of towing icebergs to India, where ice sells for six cents a pound. Another proposes to do still better—to fit a screw in the iceberg itself and thus avoid the expense of shipbuilding."

"The greatest capture of men in modern history has hitherto been that of Napoleon at Austerlitz, where he took 20,000 prisoners. Gen. Grant at Vicksburg took 31,000. The spoil at Austerlitz was 150 pieces of artillery; that at Vicksburg is set down at 238."



To produce these mode patterns, the normal operation of a helium-neon optical maser is perturbed by placing a pair of wire cross hairs in the cavity. These wires interact with the mode structure of the unperturbed cavity, suppressing some modes and, in certain cases, coupling others together. By changing the angle between the cross hairs, this interaction can be altered and different mode patterns, as shown, can be produced.

A STEADILY GROWING FAMILY OF OPTICAL MASERS

Scientists at Bell Telephone Laboratories are continuing extensive research programs to gain increased knowledge about optical maser (laser) action. The immediate goal of these investigations is more complete understanding of the phenomenon itself. In the long run, however, this knowledge will help us to evaluate better the communications applications.

One aspect of optical maser research is the study of the mode structures in laser cavities. The modes excited in a particular experiment can be identified by mode patterns, shown above, produced by directing the emergent beam onto a photographic plate.

Optical maser research at Bell Laboratories has resulted in a broad new field of radiation science. For instance, discovery of gas lasers also provided the first continuously operating laser. The active medium in this device is a mixture of helium and neon; its operation depends on the excitation of neon atoms by collision with excited helium atoms. Originally, this system emitted infrared light, but recently it has been made to produce visible red and yellow light.

More recently, in another significant advance, our scientists have discovered two other new mechanisms for creating maser action in gases. One depends on the dissociation of oxygen molecules in mixtures of oxygen and neon or argon. The other takes place in pure noble gases—helium, neon, argon, krypton and xenon—and depends on a direct transfer of energy from accelerated free electrons to the gas atoms.

With these mechanisms and various gases or gas mixtures, we have achieved maser action at approximately 150 different wavelengths extending from 0.594 microns in the yellow region of the spectrum to 34.5 microns in the far infrared—and more are in prospect.

BELL TELEPHONE LABORATORIES

World center of communications research and development

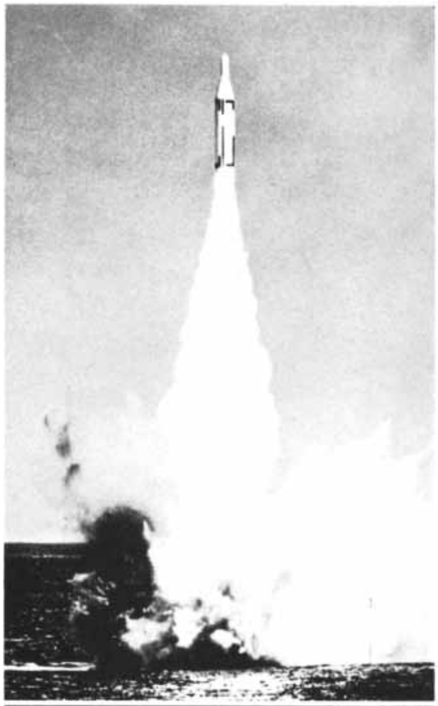
Turning theory into hardware

Technological breakthroughs are almost an everyday occurrence in electronics. Everywhere we see many new scientific discoveries being turned to the service of man.

Hughes is one of those companies whose obligation is not only to form these theories, but also to visualize how they might be applied. And then to make that application — both in man's defense and in the betterment of his life.

Today, Hughes technology is being applied in over 500 projects, programs and studies. A few are shown to illustrate: Completely new technologies which are creating new devices... Major improvements in existing technologies... Advanced manufacturing technologies which produce more reliable hardware for duty in this world — and out of it.

More than 5,000 Hughes engineers help create

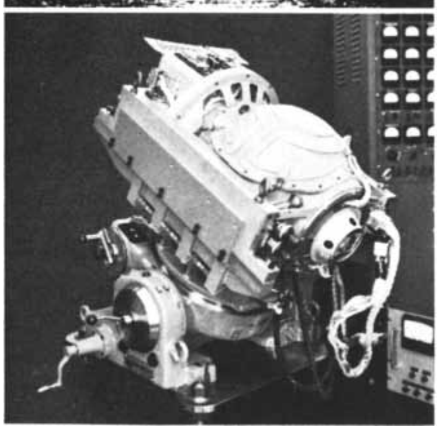


Enterprise "Eyes"

Like giant billboards, Hughes detection and 3-D tracking radar on the 4 sides of the Enterprise tower scan hundreds of miles of air space to track great numbers of supersonic targets. Utilizing Hughes *frequency scanning* invention, these antennas position beams electronically— eliminate mechanical movement and complexity— are "hardened" against damage.

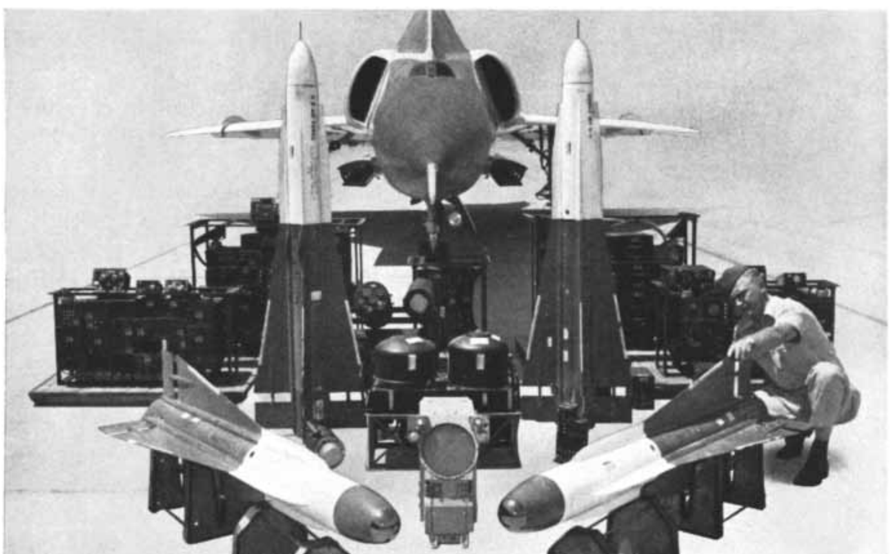
Surveyor

Hughes Surveyor is designed to give information on conditions in flight and "soft land" instruments which will report information about the moon back to earth. The first of seven Surveyors being built by Hughes for NASA under Jet Propulsion Laboratory technical direction is scheduled for launch early in 1964.



Polaris missile brain

Through the application of its advanced manufacturing technology, Hughes is now a prime contractor in inertial guidance systems (illustrated above) for the U.S. Navy's Polaris missile. It is one of the world's mightiest, most reliable forces for freedom.



Modern Falconry

In the late 1940s, airborne electronics was in its infancy. Yet, in a few years, U.S. Air Force jets were equipped with Hughes advanced weapons control systems armed to fire Falcon missiles. Together (and vastly improved) they have become our most potent air defense weapon. Hughes—the leading builder—has delivered thousands of control systems and well over 30,000 infrared and radar-guided Falcons.

at Hughes

the theories. More than 25,000 other skilled Hughes people help translate their work into practical hardware. Together they are helping create a new world with electronics.

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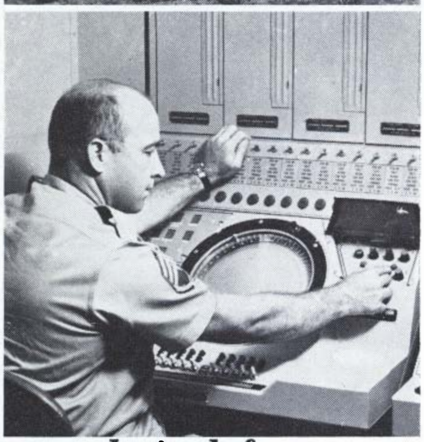

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THE AUTHORS

OSLER L. PETERSON ("Medical Care in the U.S.") is visiting professor and acting chairman of the Department of Preventive Medicine at the Harvard Medical School. He is also Assistant Director for Medical Education and Public Health for the Rockefeller Foundation. He received his medical degree from the University of Minnesota in 1939 and studied internal medicine for several years at Boston City Hospital before joining the Rockefeller Foundation Virus Laboratory in 1943. Shortly afterward he became attracted to the problem of medical care, his interest arising, he writes, "from the contradiction presented by the almost explosive growth of medical knowledge and the remarkable lack of information about how effective or ineffective is our application of medical science to any given population." From 1944 to 1952 he made several extended trips abroad as the Rockefeller Foundation's representative to South America, Italy and England, taking time out to obtain a degree in public health from Johns Hopkins University in 1947. He returned to this country in 1952 to do research on medical care at the University of North Carolina and in 1956 took up his post at the Rockefeller Foundation. He joined the Harvard faculty in 1959.

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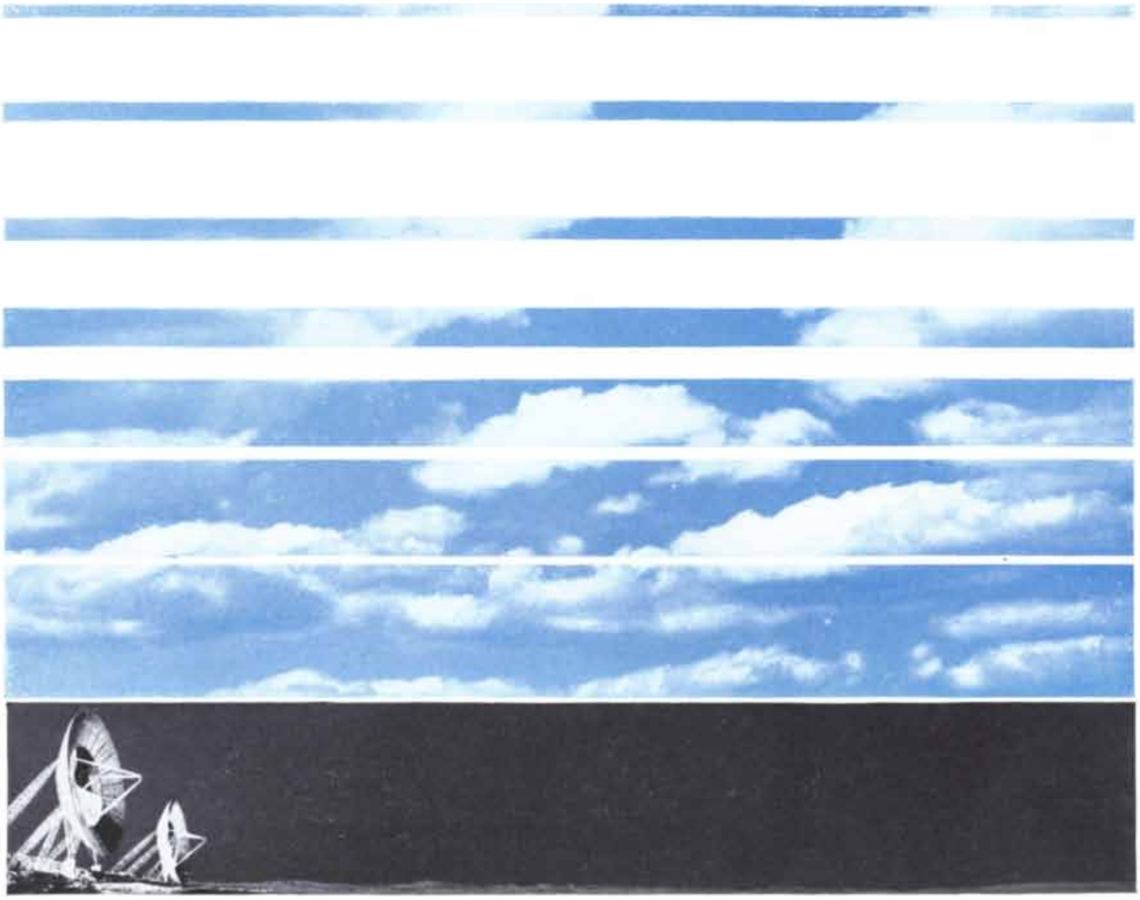
the Aero Medical Laboratory at Wright Field and afterward was a junior fellow at Harvard before joining the Princeton faculty in 1947. He is presently on leave of absence from Princeton and working at the University of Cambridge.

MAURICE A. GARBELL ("The Sea that Spills into a Desert") is president of the firm of Maurice A. Garbell, Inc., consulting aeronautical engineers and meteorologists, and president and director of research of the Garbell Research Foundation, both in San Francisco. He received the degree of Doctor of Mechanical and Industrial Engineering from the Institute of Technology in Milan, Italy, in 1938. As a graduate student he was instrumental in the introduction of powerless gliding as an Olympic sport by giving a soaring demonstration in Berlin in 1936 and by acting as chairman of the International Design Committee for the standard Olympia sailplane. His stall-safety wing, invented in 1939, is currently used on many propeller-driven and turbojet aircraft. As a consultant in aeronautical engineering and meteorology since 1942, he has served various Government agencies, military services and private industries. He and his associates at the Garbell Research Foundation are engaged in work on air-traffic control, theoretical studies of relativity and gravitation, and research in the fields of cloud modification and air pollution.

RENATO BASERGA and WALTER E. KISIELESKI ("Autobiographies of Cells") are respectively medical consultant and research chemist at the Argonne National Laboratory. Baserga was born in Milan, Italy, and received a medical degree from the University of Milan in 1949. From 1943 to 1945 he served with the Italian partisan forces supporting the Allies in northern Italy. Since 1958 he has been on the faculty of the Northwestern University Medical School, where he is assistant professor of pathology. Kisieleski is a veteran of 20 years at the Argonne National Laboratory, where he is currently in charge of the radioisotope laboratory. He received his undergraduate degree from James Millikin University and did graduate work in chemistry at the University of Chicago.

A. RUPERT HALL, who in this issue reviews *The Scientific Intellectual: The Psychological & Sociological Origins of Modern Science* by Lewis S. Feuer, is professor of the history and logic of science at Indiana University.



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Medical Care in the U.S.

The revolution in medical science during the past three decades has brought great changes in the way medicine is practiced and is creating urgent problems in the organization of medical care

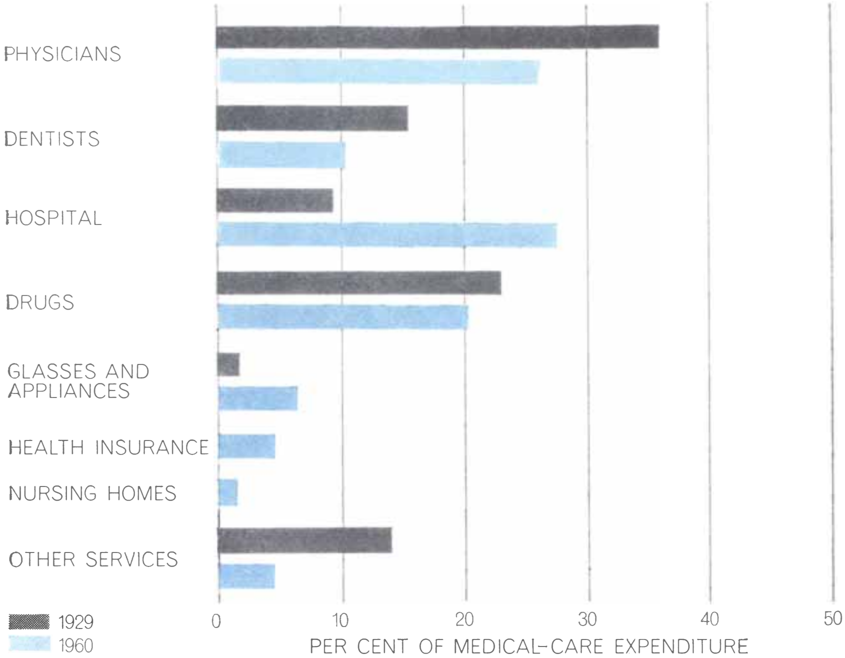
by Osler L. Peterson

A generation ago the late Lawrence J. Henderson of Harvard University remarked that a random patient with a random disease consulting a random doctor had a 50–50 chance of benefiting from the encounter. The advance of medical science in the intervening years calls for some amendment of this judgment. Without doubt the sharper tools available to the modern doctor have increased the probability of benefit. Fully half of the private practitioners in the U.S. today are specialists, compared with only 16 per cent in 1931. They are provided with a constantly increasing number of active and specific medications. In the remarkable interplay of knowledge, skill, organization and equipment—represented so dramatically in modern heart surgery—they may with confidence quite literally take the patient's life in their hands.

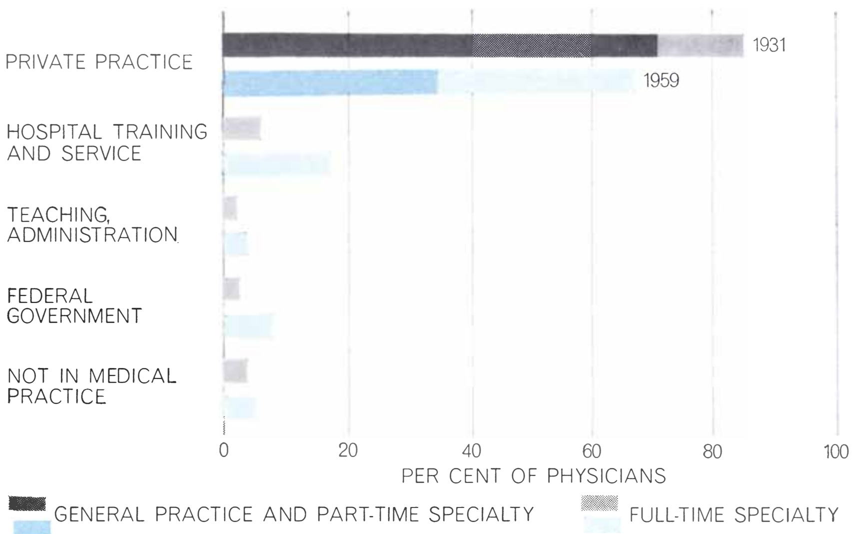
At the same time it must be conceded that progress in knowledge and technique has also increased the possibility of complication from treatment. There are increasing numbers of specialists, but the patient's problem is how to select and use them; the pain in the back that he takes to an orthopedist may well require the attention of a urologist or cardiologist, and his mistaken self-diagnosis may prove costly to health as well as expensive. Modern drugs are occasionally toxic; they are certainly not home remedies for casual prescription or use. Quite apart from cost, the question of how many institutions can be staffed and equipped to render safely such services as heart surgery demands consideration on a scale wider than that of a single hospital or community.

In the resolution of the difficult issues that are suggested here third parties have joined the relationship of physician and patient. Because health insurance has become a major perquisite of employment—an important, tax-free mode of compensation—the Blue Cross and insurance companies, commissioners of insurance, employers and, most important, labor unions are making policy with respect to medical care. The insurers require information about diagnosis, the treatment procedure, the number of patient-visits and similar items. Unions sponsor studies of the "adequacy" and "quality" of the care purchased for their members. Lay groups, such as the Health Insurance Plan of Greater New York and the Kaiser Foundation Medical Care Program in California, undertake to provide "comprehensive care of high quality" and promote the institution of group practice by a diversity of specialists as well as prepayment by the consumer. Among the interested critics there looms also the Federal Government: Congress responds with alacrity to public concern over the reliability of tests prescribed for the certification of drugs and the executive department acquires increasing regulatory power along with its increasing role in the underwriting of medical facilities, not to mention the provision of care for millions of veterans and prospectively for the aged. Finally, the press seems to have developed mixed feelings about doctors: the wonderful new developments of medical science are standard fare, but the discontent of patients, fee-splitting and unnecessary surgery also provide topics for featured articles.

The adjustment of medicine to its technical growth has thus had heavy repercussions in the profession and in society. When social institutions must adapt to change of this kind, the difficulties they experience are not unlike those of the growing child, whose adjustment to a new level of competence and skill provokes tensions that upset the whole family as well as make the child unhappy. It is not surprising that the doctor of medicine should feel beleaguered and irritated and that he should become uncompromising when political leaders propose instituting major changes in the method of paying for care. The adjustment that is causing so much general irritation involves three interrelated questions: the quality of medical care—how to make increasingly effective medical care available to the patient; the organization of medical care—how to organize the institutions necessary to deliver such care; and the financial aspect of medical care—how to pay for care that at its most effective is also at its most expensive. No physician would dissent from this agenda or the order of priority implied, but most phy-



PRIVATE MEDICAL-CARE EXPENDITURES in 1960 were distributed quite differently from those in 1929. Hospitals' share has tripled, physicians' has dropped and new items have appeared. Total expenditures, public and private, rose from $3.6 billion to $30 billion.



TYPE OF PRACTICE by physicians has changed greatly in past three decades. There are now many more specialists and more doctors in hospital service and working for the Government. Information is from American Medical Association and U.S. Public Health Service.

sicians would argue that the answers to all three must respond also to a fourth question: how to preserve the character of a liberal profession and the freedoms that sustain it.

As for quality, one must perhaps accept the fact that variation in human capacity is inevitable. Nevertheless, what can be done must be done because the consequences of variation in medical skills, unlike those in other professions, can be pronounced. Enormous variation in the fervor, erudition and ability of the clergy, for example, may not be incompatible with the goals of the ministry. A fundamentalist preacher who is long on fervor and short on erudition might be highly successful in inculcating faith in one congregation, whereas he might be found intolerable by another. The educated and the ignorant, the rich and the poor may not always suffer the same diseases, but their ills all require the same medical care.

In theory and in hope the diminishing numbers of general practitioners, who exemplified the virtues of the personal doctor, could provide the continuity and discriminating guidance to the confusing multiplicity of specialist services that lie beyond the scope and judgment of the patient. The medical schools are often blamed for the disappearance of the general practitioner, and unfairly. The expansion of medical knowledge has forced the schools to precede the profession into specialization. Against this pressure many schools have experimented with comprehensive patient-care clinics to help the student to integrate the training he receives piecemeal from specialists representing fields as diverse as biochemistry and psychiatry.

Medical students, in spite of the attractions of other careers in the sciences, are still a highly selected group. In facing the challenge of medical education, however, they run the gamut from brilliant to plodding. The able and promising are welcomed into the ladder-like training programs of the university hospitals that lead to certification in one or another specialty. As a study by Fremont J. Lyden of the Harvard Medical School has shown, students of higher rank obtain teaching-hospital internships more frequently than poorer students and go on to further postgraduate training with substantially greater probability than those who have interned in nonteaching hospitals. The least able must be content with more modest institutions that provide shorter training with more meager educational resources. Although theory would dictate that the less able need the longer and better training, the conflicting interests of education result in the recruiting by the teaching hospitals of the best for themselves. This is a practice that is not exclusive to medicine.

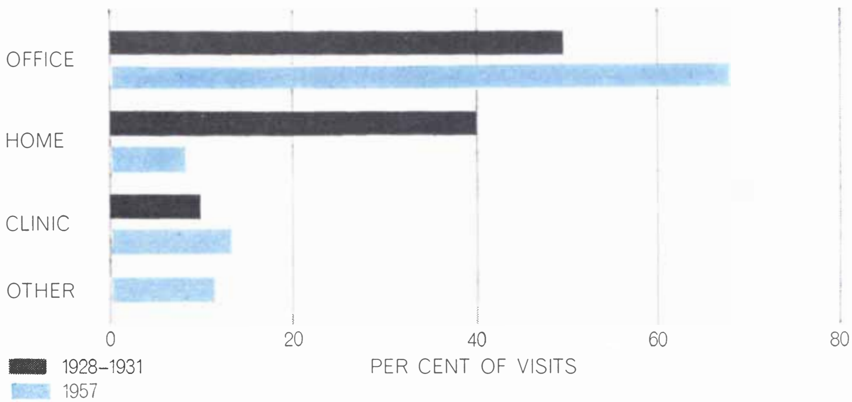
Several years ago a general study of general practitioners was undertaken at the University of North Carolina by Leon P. Andrews, Bernard G. Greenberg, Robert S. Spain and myself. We expected to find variations in skill, but we were entirely unprepared for the extremes we found. The best of the practitioners performed at a level that would have been acceptable in the outpatient clinic of a university hospital. Many were not conspicuously skillful but were adequate. At the other end of the scale there were some whose practices would have been unsatisfactory in a senior medical student.

Since the general practitioner daily sees a variety of diseases, trivial and serious, his major problem is to make a diagnosis or at least to recognize a dangerous illness when it is present. In the study we observed randomly selected doctors at their work over a period of three and a half to four days to see how often and how well a clinical history was taken, a physical examination was given and a few common laboratory procedures were used when patients presented such potentially serious complaints as chest pain, bleeding or weight loss. Description and classification of these procedures, made in many cases independently by more than one of us, proved to be highly reproducible. Furthermore, the doctors' performances turned out to be markedly consistent from day to day and from technique to technique. If we observed a doctor taking the clinical history of a patient in a thorough fashion, we could predict that he would make a good physical examination and order a sound laboratory procedure. This made it possible for us to classify the doctors by their skill and to study the elements in their background significant to their performance.

We found that a number of variables were related to excellence. The doctor's record as a medical student proved to have some prognostic value, although there were enough exceptions to make it perfectly clear that a poor student could become a good doctor and vice versa. The extent of hospital training in internal medicine proved to be one of the most important determinants of skill; the average performance was consistently better and the variation less in those whose training was the most prolonged. Some observations could not be correlated with performance on a quantitative scale. Among these were the depth of a doctor's interest in clinical medicine; this seemed to vary, in individual physicians, from intensity to boredom. One of our more significant quantitative findings, on the other hand, was that a doctor's success, as measured by the number of patients he saw during the course of the week, bore no relation to his knowledge and skill. The choice of a physician by the patient would seem to depend on factors other than these, which are obviously difficult for the layman to judge.

Kenneth F. Clute of the School of Hygiene at the University of Toronto has applied the techniques developed in our study to an evaluation of the work of general practitioners in several areas in Canada. He found the same marked variation in performance, with good performance plainly correlated to internship and residency in teaching hospitals and poor performance to postgraduate experience in nonteaching hospitals. What is more, the duration of training in the teaching hospital showed a clear positive correlation to the doctor's skill. No such connection could be detected where training had been secured in nonteaching hospitals—an indication of the relative ineffectiveness of these institutions.

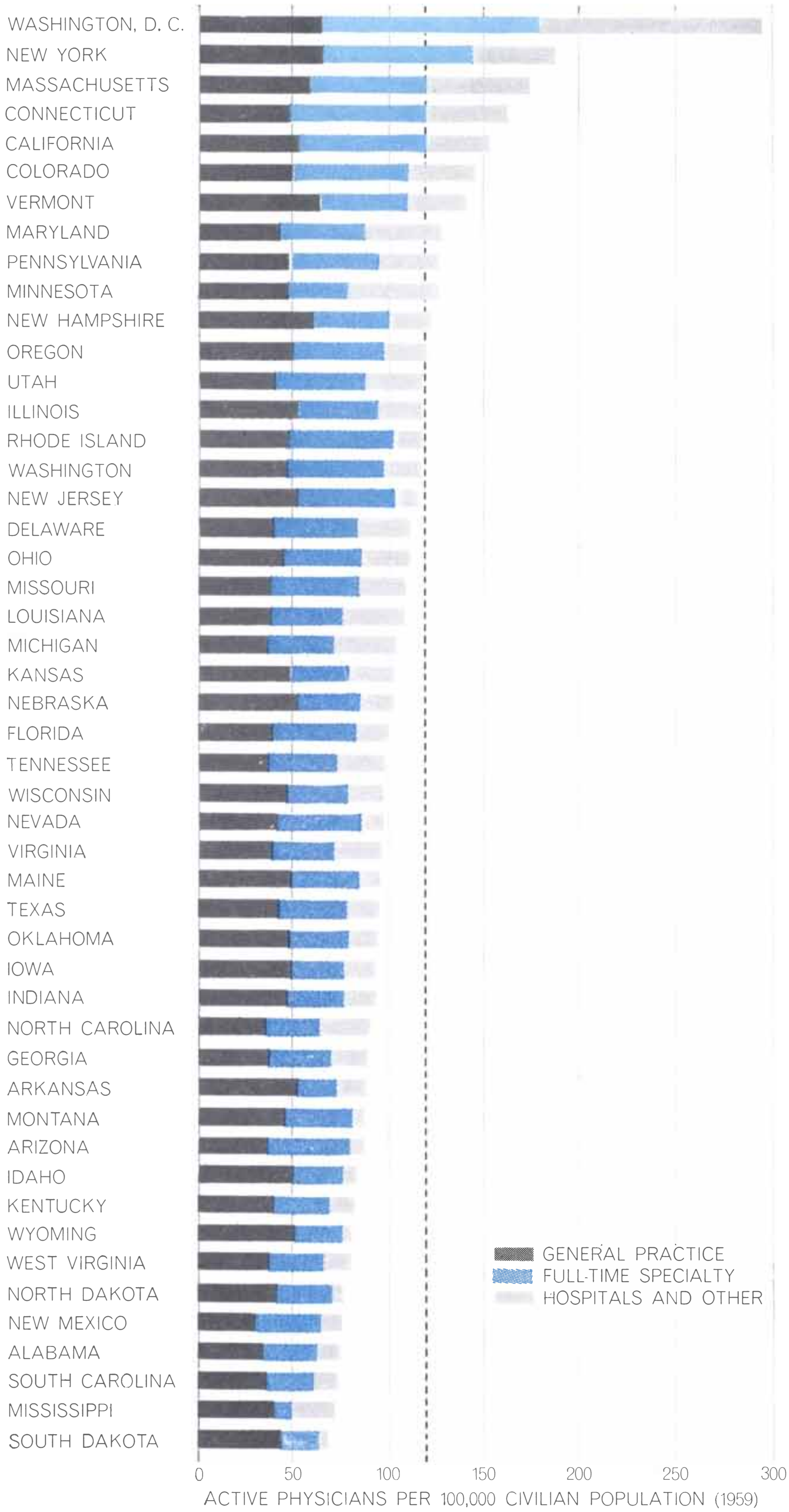
The public meanwhile has been working out its own adjustment to the disappearance and decline in the status of the general practitioner. H. Jack Geiger, formerly in the Department of Preventive Medicine at the Harvard Medical School, has conducted a study of the doctor-patient relationship in an economically mixed suburb of the type in which Americans are living in increasing numbers. He found that the family doctor who delivered the baby, set the bone, removed the tonsils and gave comfort where he could do no more had ceased to



PLACE PATIENT IS SEEN has also changed. Chart shows sites of visits by or to the doctor outside hospitals. Decline of home visits reflects greater efficiency in medical practice.

	EXTENT OF SURGICAL SPECIALIZATION	PROCEDURES (PER CENT)	
SPECIAL CREDENTIALS IN SURGERY	AMERICAN BOARD OF SURGERY	18	49
	AMERICAN BOARD OF ORTHOPAEDIC SURGERY	4	
	AMERICAN BOARD OF PLASTIC SURGERY	1	
	AMERICAN BOARD OF NEUROLOGICAL SURGERY	1	
	BOARD OF THORACIC SURGERY	1	
	AMERICAN BOARD OF UROLOGY	2	
	AMERICAN BOARD OF OBSTETRICS AND GYNECOLOGY	4	
	AMERICAN BOARDS OF OPHTHALMOLOGY AND OTOLARYNGOLOGY	12	
	AMERICAN BOARD OF PROCTOLOGY	1	
	FELLOW OF AMERICAN COLLEGE OF SURGEONS BUT NOT BOARD CERTIFIED	9	
NO SURGICAL CREDENTIALS	FULL OR PART SPECIALTY IN SURGERY	21	51
	GENERAL PRACTITIONER	22	
	SPECIALTY THAT DOES NOT INCLUDE SURGERY	3	
	OTHER PHYSICIANS	5	

PROFESSIONAL QUALIFICATIONS of physicians who performed surgery were studied in 1957–1958 survey of nearly 3,000 families representing a sample of U.S. population. Study was made by Health Information Foundation. Forty-nine per cent of the surgical procedures performed on these people were done by physicians having the special credentials indicated. (The sum is less than the parts because some doctors are certified by two boards.) Of physicians claiming some surgical specialization, 21 per cent had no special credentials.



PHYSICIAN-POPULATION RATIO for each state in 1959 shows that only 11 states are above the national average (*vertical broken line at 119*). Chart includes all active physicians not working for the Federal Government. The states with the more favorable ratios also tend to have a larger proportion of specialists and of physicians who are employed in hospitals.

exist in the experience of most of the population. Working-class families still have a "family doctor" in the sense that they secure most of their medical care from general practitioners. The remainder of the population seek in their own way to obtain the best of modern medicine by employing specialists in internal medicine, pediatricians, obstetricians, orthopedists and others—each to treat a pain or problem the patient believes to be "in his field."

Good medical care requires ample physician time. Under the combined pressures of eagerness on the part of the patients and the economic arrangement of payment by the visit, however, general practitioners see between 25 and 35 patients per day on the average in different settings. Clearly the number must reach a point where the carefully detailed history and examination necessary to make a diagnosis becomes impossible. That the number is excessive is suggested by comparison with other countries. The U.S. citizen visits a doctor 5.3 times per year on the average, in contrast with the British and Swedish figures, which are 4.7 and 2.5 respectively. The lower death rates and the greater longevity of the British and the Swedes suggest that health need not be at hazard.

Studies conducted by Vergil Slee of the Commission on Professional and Hospital Activities and Paul A. Lembcke of the University of California Medical Center in Los Angeles provide an objective index of the variation in the quality of care obtainable from the assemblage of general practitioners and specialists available in the community. Slee examined the records of 15 hospitals to determine how many operations for appendicitis had been justified by the finding of diseased tissue in the pathology laboratory. The percentage of diagnoses thus confirmed varied from about 70 per cent in one hospital to less than 20 per cent at the other extreme. Needless to say, 20 per cent correct diagnosis is not good. Lembcke, taking the same disease as a criterion, found that the number of people operated on for appendicitis in more than 20 different hospitals varied from 2.9 to 7.1 per 1,000 population per year. It is, of course, unlikely that the incidence of the disease is so variable. He has also shown that a study of surgery in hospitals sharply reduced the frequency of operations that can be criticized as too extensive, too restricted or unnecessary.

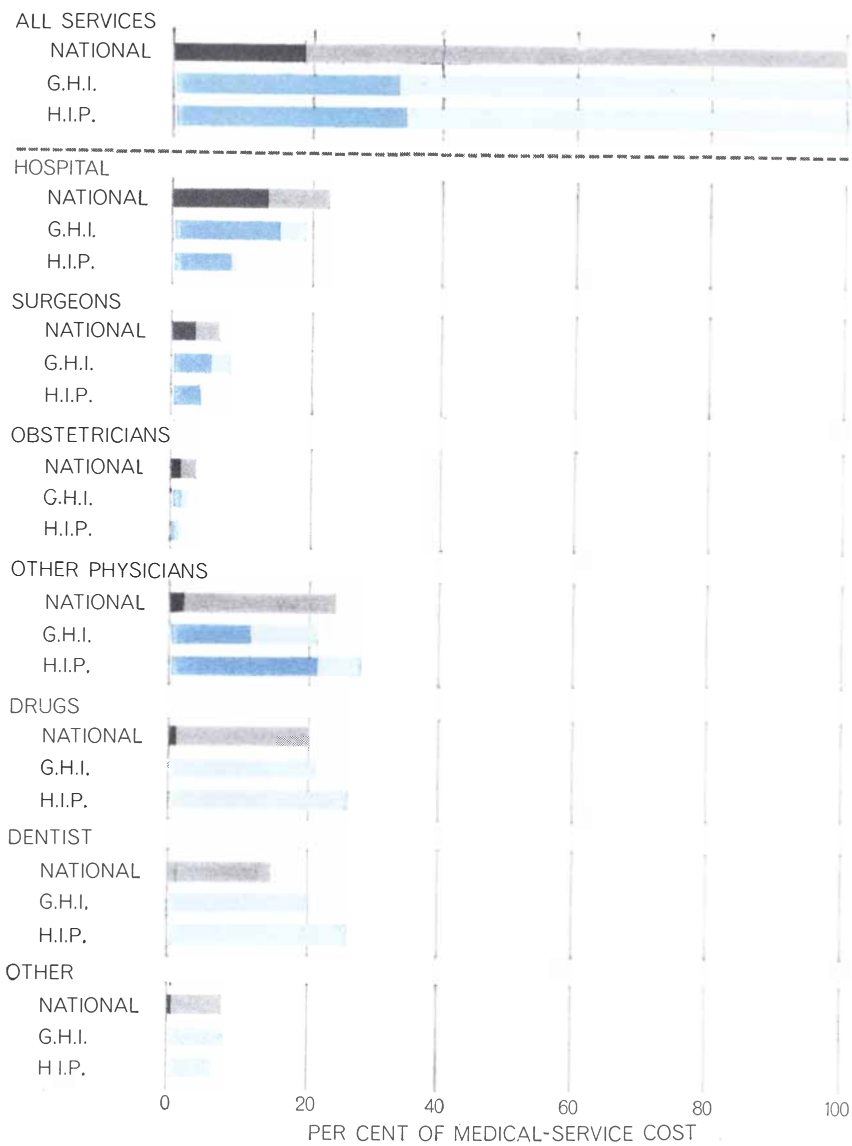
Other studies show that the quality of care depends not only on the native ability and training of the doctors but also on the organization of medical services, the availability of facilities and the intellectual stimulation of colleagues. One of the most pertinent of these studies was conducted by Ray E. Trussell, now Commissioner of Hospitals of the City of New York, with his associates at the Columbia University School of Public Health and Administrative Medicine. Their findings were the subject of local controversy that drew attack on their methods; they are supported, however, by other data. Trussell and his associates concluded that about 80 per cent of patients who are cared for in hospitals affiliated with medical schools receive good or excellent treatment. At the other end of the scale, in hospitals that have no internship or residency programs and are not accredited to give such training, only a third of the patients receive such care. Significantly these investigators also found that specialists certified by appropriate boards and societies and working in good hospitals give good care, whereas similarly accredited specialists working in poor hospitals give care no better than that rendered by doctors with no evidence of such training.

These conclusions are supported by the work of Odin W. Anderson of the Health Information Foundation and Jacob J. Feldman of the National Opinion Research Center. About half of the surgery in the U.S., they estimate, is done by doctors who are neither certified as specialists nor members of the societies that require evidence of competence or training. Doctors who have qualifications show up more frequently in accredited or large hospitals. Anderson and Feldman found a similar distribution of obstetrical talent and training. In the nation as a whole 38 per cent of the deliveries are performed by obstetricians who are certified or who give sufficient time to their practice to be classified as specialists. "The larger the hospital," these authors observed, "the more likely that a specialist attends the obstetrical case."

One of the most persuasive pieces of evidence for the link between organization, quality of medical care and health comes from a study of the Health Insurance Plan of Greater New York conducted by Sam Shapiro, Louis Weiner and Paul H. Densen. In this plan obstetric and pediatric care are provided by specialists brought into close collaboration by well-organized group-practice units. Their patients proved to have a lower perinatal mortality than patients of similar means who obtained their care from the generality of physicians in New York City. Perinatal mortality—the rate of stillbirths plus infant deaths in the first months of life—is the accepted indicator of the effectiveness of care given to mother and child in the period of late pregnancy, delivery and early life.

If one compares the organization of medical care in the U.S. with that in Great Britain, Sweden or Germany, its most obvious characteristic is its fractionation, or, as some would say, atomization. Many, if not most, doctors are engaged in "solo" practice, working alone in their own offices and caring for their patients as best they can, both in and out of the hospital, without the formal collaboration or consultation of colleagues. The hospitals too are fractionated; many small cities have two or more small hospitals. If medicine demands specialization and the frequent collaboration of specialists, clearly it is illogical for physicians to practice alone out of offices with duplicated and often inadequate facilities and to place their patients in ill-equipped small hospitals.

The physicians themselves in recent years have advanced a uniquely American solution in the form of group practice. In addition to the representation of two or more specialties, the group must have an agreed-on income distribution.



INSURANCE BENEFITS (*darker parts of bars*) **in 1957 covered only 19 per cent of all private medical costs in national sampling survey by Health Information Foundation. A 1957 New York City survey studied two local programs, Group Health Insurance (G.H.I.), which pays bills of the participating and other practitioners, and Health Insurance Plan (H.I.P.), a prepayment, group-practice program. Under H.I.P. there is considerably less hospitalization.**

If there is no plan to cut the cake, it is not a group, because the income-distribution plan serves the function of facilitating the referral of the patient from one specialist to the other. Group-practice units offer rather formidable competition to singlehanded physicians; where they exist side by side, groups and individual physicians usually have separate clienteles. Except for a few well-known examples, such as the Mayo Clinic in Rochester, Minn., group physicians deal with the humdrum as well as the more complicated medical problems their members are trained and organized to meet.

That a group can provide more and better technical facilities is self-evident. Through this and other economies the group probably makes care more efficient as well as more effective. Even more than a hospital, it puts its members in a goldfish bowl, in which each physician carries on his work under the scrutiny of his fellows. A group of sufficient size and diversity can sustain its own intellectual life and provide day-to-day education. Most important, from the patient's point of view, it provides an internist who fills the role of personal physician and whose informed diagnosis directs the patient to the specialist. When a group is organized in relation to a prepayment plan, it will have boxed the major problems of quality, organization and finance. In the circumstances of practice prevailing in the U.S. today, however, the group will have isolated itself even further from the generality of medicine.

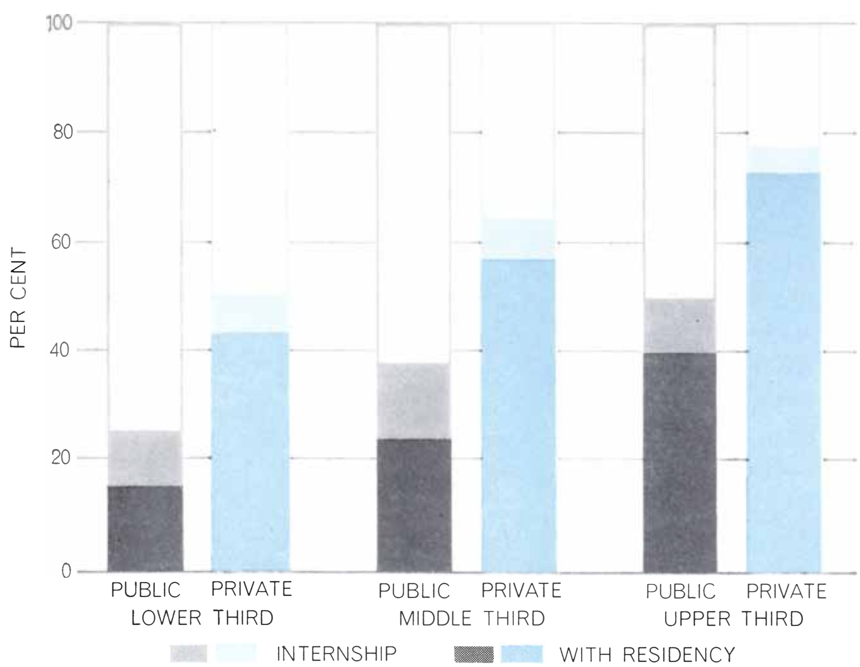
The tendency of medical practice in this country to organize itself around the hospitals presents a different and seemingly more significant development. Most physicians are already affiliated with one or more hospitals; this makes the hospital a focal point for the planning and provision of the services, facilities and educational programs so badly needed to keep practice in step with science. The hospital is the one institution that has real influence on the generality of doctors in so far as it can require that they meet universal standards of training and can demand responsible performance.

That the quality of a hospital will vary with size is perfectly obvious, but it is a surprise to discover how great the differences can be. The hospitals in the U.S. are only slightly less atomized than practice itself. Of the nearly 6,800 general hospitals in the country, some 1,600 have fewer than 25 beds and only 2,300 have more than 100 beds. It is clear that 25 beds cannot justify the diverse services demanded of modern medicine and that even 100 beds fall below the border line of some of the most significant services.

Hospitals of the same size may vary considerably in quality, but there are variations in quality that correlate directly with size. The large hospital will obviously have a wide range of facilities because size makes such a range both necessary and possible. It is in this group, even outside of the university-affiliated hospitals, that one finds an occasional research program, a full-time director of medical education and an active educational program, a relatively complete laboratory and range of treatment services, many and varied specialists and an administrator of distinction. These for the most part are the "accredited" hospitals—accredited for the training of nurses and for the postgraduate internships and residencies that now take as many years of a young doctor's life as his medical school education. Accreditation is conferred by a joint commission of the American Medical Association and other professional societies. This is a powerful lever for setting and elevating standards of performance. Although accreditation is a much desired minimum qualification, fewer than half of the eligible voluntary hospitals have won it. On the other hand, since withdrawal of accreditation carries such heavy sanctions, it is a police power that is difficult to exercise.

Few hospitals in the middle range of size are able to provide training for residents and interns. Many of them, however, maintain a nursing school because this provides important services to the hospital itself. In the small and very small hospitals the pathologist may be only on a part-time basis or may be replaced by a direct-mail service, and there is a corresponding dearth of other facilities. The generally lower charges of such institutions reflect a poverty of resources rather than of efficiency. In fact, hospitals with 25 or fewer beds have average occupancy rates of only about 50 per cent, whereas an 80-per-cent rate prevails in hospitals of 200 beds or more.

The voluntary—as distinguished from Government or proprietary—general hospital of the U.S. is an institution *sui generis;* it is rare elsewhere in the world. It is usually the property of a lay board of trustees; the lay administrator to whom the trustees delegate the management of the institution has great power over every aspect of the institution but one: the medical service rendered within it. The hospital in the end is the doctors' workshop and, barring misbehavior or incompetence, they are free to use it with few restrictions. From their own number the doctors elect such important officers as chief of staff and the chiefs of the various services. Because this democratic procedure often reflects considerations other than excellence—the doctors in a community inevitably develop mutual interests and conflicts as they live and



TRAINING IN MAJOR TEACHING HOSPITALS is more readily available to graduates of private medical schools and to those in upper ranks of their classes. The graduates with poorer academic standing, who need the most training, usually get the less rigorous internships. Study of graduates was made by Fremont J. Lyden, formerly of Harvard Medical School.

NUMBER OF HOSPITAL BEDS per 1,000 people varies with section of country. The information was gathered in 1960 by the American Hospital Association and the Health Information Foundation. The range of variation by area was much greater in a 1946 study.

work together, refer patients to one another and so on—the quality of medical administration is variable and may amount to inaction. In one small hospital, for example, the surgeons have never elected one of themselves chief of surgery but rotate what has become a medically meaningless office among the more numerous general practitioners. Fortunately doctors tend to be conscientious and responsible men, so that results are not so bad as the process suggests.

This scheme of organization is almost unknown in hospitals abroad. In the western European countries, where the practice of medicine as reflected in vital statistics achieves results comparable to our own, the hospitals normally have salaried staffs with full-time chiefs of service. The rationale for this is that the patient sick enough to be admitted to the hospital needs specialist care. The system also provides a means for more careful discrimination in the admission of patients to the hospital in the first place. In the U.S. this arrangement is often described as tantamount to "socialized medicine." It prevails, however, in the Netherlands, where health insurance is voluntary; in Denmark, where voluntary insurance is subsidized by the government; and in Great Britain, where medical care is almost completely socialized. The system is found also in the Henry Ford Hospital in Detroit and in the Mary Imogene Bassett Hospital in Cooperstown, N.Y., respectively a distinguished large hospital and a distinguished small one.

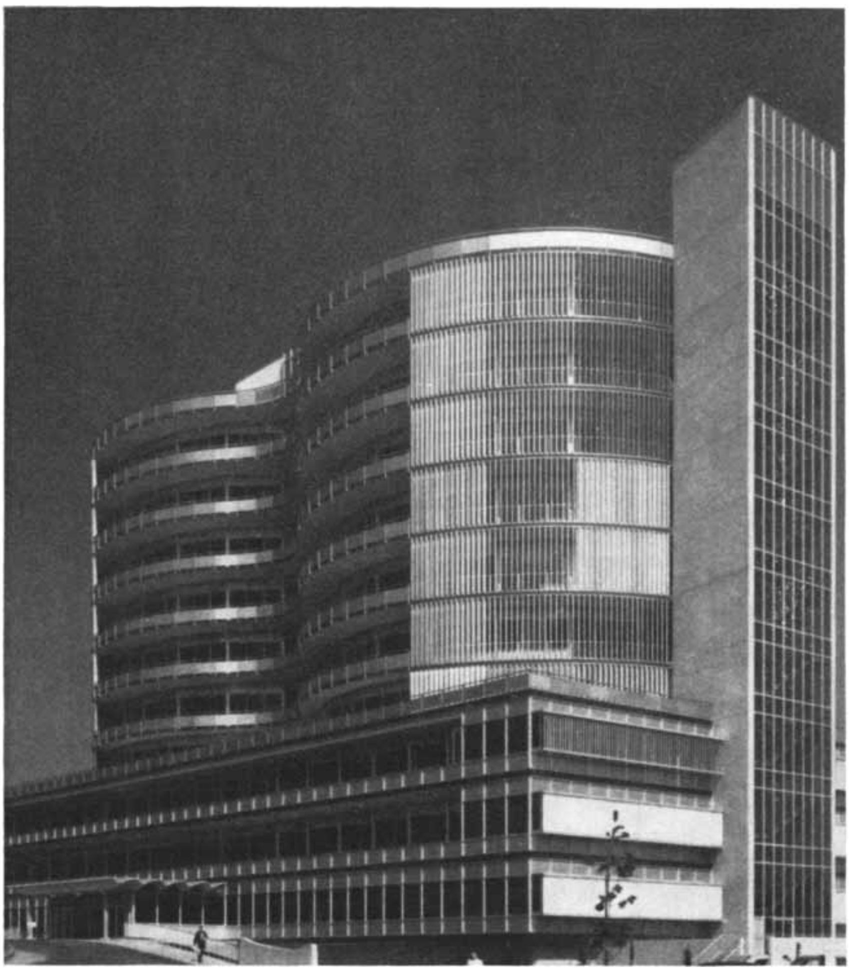
Perhaps the most significant single trend in the organization of medical care in the U.S. in recent years has been the rapid increase in the number of physicians—representing all the medical specialties—who practice or are employed full time as members or chiefs of hospital staffs all over the country. Their numbers, which include trainees as well as practicing physicians, have increased from 8 per cent of the profession in 1931 to 22 per cent in 1959. In this respect U.S. medical care is moving toward the European pattern. Radiologists and pathologists were among the first to make the transition, and more recently members of all the other specialties have followed suit.

A measure of the trend is the degree to which it has complicated the debate on using Federal Social Security funds to pay hospital bills for the aged. Physicians have clearly seen that, if the Government begins to participate in paying for hospital care, it may later help to pay doctors' bills. If this happens, the Government may ask if Doctor A is qualified to hospitalize Patient B—as it already does in connection with admissions to Veterans Administration hospitals. University hospitals have already sought to protect their excellence by careful recruitment and selection of staff, so that there is ample precedent for such action.

As hospitals have been strengthened under the medical direction of full-time staff members, they have tended to specialize in the treatment and care they afford. Even the smallest hospital must be prepared to care for a variety of common medical, surgical and obstetrical problems. There are, however, rarer problems—such as those requiring the skill of a cardiac-surgery team—that can be cared for only in very large medical centers. The differential need for various types of service has given rise to the concept of, if not a trend toward, regional organization of smaller satellite hospitals around larger medical centers and university hospitals. In the Hill-Burton Hospital Survey and Construction Act, Congress expressly called for the development of regional plans as a prerequisite to obtaining the Federal funds the act made available for the vast expansion of hospital facilities during the past two decades. One notable attempt was made in this direction in western New York, centering on the university medical center in Rochester. At this point the net result seems to be the achievement of a small measure of co-operation among the hospitals in purchasing and other services but no significant regional planning for the use of medical services and facilities. It is naturally easy to blame the system of fee-for-service payments and the economic ties that go along with the referral of patient to specialist. It was probably unrealistic, however, to expect doctors who believe they are doing the best they can for their patients to exhibit any interest in a regional organization that would, by implication, contradict that belief, particularly when the regional plan had neither stick nor carrot to encourage a change of habit.

The questions of the quality and organization of medical care in this country ultimately invoke the financing of medical care—the methods by which the patient pays for care received and by which the physician is paid for services rendered. For the period 1929 to 1932 the famous Committee on the Costs of Medical Care, headed by the late Ray Lyman Wilbur, president of Stanford University and a member of President Hoover's cabinet, found that 10 per cent of the population incurred 40 per cent of all medical-care bills in any one year. A recent survey by the Health Information Foundation found an almost identical figure: 11 per cent of the population in 1956 was burdened with 41 per cent of the total personal expenditure for medical care. The fact that medical costs are unevenly distributed within the population, that illness and its costs cannot be predicted for any one individual and that the need and therefore the expense for medical care is, in any case, unevenly distributed throughout the individual's lifetime—these are the factors that have made medical insurance popular as well as logical. About three-quarters of the population now carry some form of medical insurance, the principal outlay being made to insure hospital costs.

During the 30-year period since 1930 the medical bill has grown with respect to other costs. The rate of hospitalization per capita has more than doubled; the demand for physicians' services has nearly doubled; and the expense for medication has increased proportionately. As a result the share of the national income going to medical care has risen from 3.5 to 5.2 per cent in this period. This compares with 4.7 per cent in both Sweden and Great Britain. The extensive investigations of the Health Information Foundation have shown that a "large bill"—in excess of $200—may be due to such varied causes as the purchase of drugs, physician services and hospitalization. It seems likely, however, that the truly major problems of paying for medical care are most often those related to episodes of hospitalization that, in addition to hospital bills, also involve larger fees paid to the doctor.



MODERN HOSPITAL, controversial in some respects, was built by the Kaiser Foundation at Panorama City in San Fernando Valley of California. It has 133 beds and is a medical center as well, providing care for 60,000 members of prepaid, group-practice medical-care plan. Rectangular three-story base has medical offices and diagnostic facilities. Twin seven-floor, circular columns above hold the hospital. Stair wells are at the ends of the columns. Several other circular hospitals have been built previously in various parts of the country.

Americans today receive a large amount of hospital care. About 125 persons per 1,000 are hospitalized each year. This is not only twice the rate of 30 years ago but also is substantially higher than the rate of 86 per 1,000 in England and Wales. The availability of insurance funds to pay for hospitalization has undoubtedly played a part in this development. Among the uninsured the rate of admission is 90 per 1,000 per year, compared with 140 among the insured.

The part that is also played by the organization of medical practice is illustrated by a study of the much studied Health Insurance Plan of Greater New York. Enrollees in this plan have a lower rate of hospitalization than other New Yorkers with the same hospitalization insurance provided by the Blue Cross. The implication is that the group-practice units caring for the enrollees in the Health Insurance Plan are able to care for their patients more effectively outside the hospital or that they are more selective in prescribing admission of their patients to the hospital. It is also worth observing that the group-practice units are paid a flat annual capitation for rendering comprehensive care to their subscribers and do not receive a fee for the service that happens to involve sending the patient to a hospital. A parallel study shows that steelworkers cared for in California by the Kaiser Foundation Medical Care Program—a prepaid medical-care plan that also provides comprehensive services through group-practice units paid through a combination of capitations and salaries—show a correspondingly lower rate of hospitalization

NURSING STATION at center of hospital floor is in area closed to the public. The typical patient floor contains 23 beds in each circular unit, every bed only a few steps from the nurse. Visitors' lobby is in another service area between circular patient units.

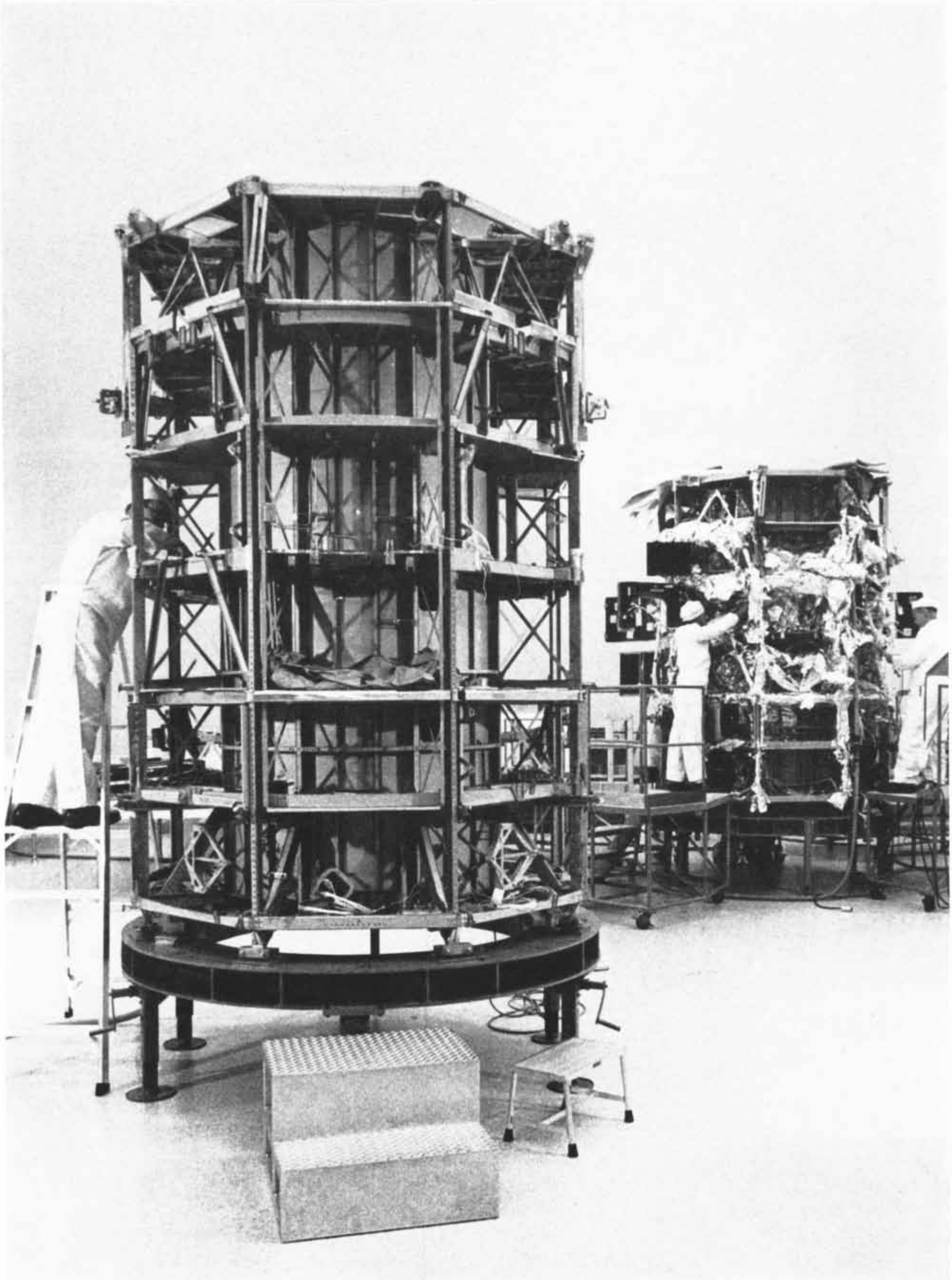
than steelworkers elsewhere in the country who are covered by Blue Cross hospitalization insurance and a variety of insurance plans that pay the doctors on a fee-for-service basis.

The differing rates of hospitalization may be due to many factors other than those cited. But one thing is clear: there can be great latitude in the rate of hospitalization without danger to health. European experts cite the U.S. experience as evidence of the need for control of admissions by well-paid, well-trained, full-time specialists on hospital staffs.

The growth of health insurance in the U.S. evidently reflects the consumer's prudence in the face of his exposed position in relation to the costs of illness. Several investigations have shown the popularity of comprehensive insurance. In the State of Washington physicians provide a remarkably all-inclusive insurance plan to cover doctors' bills. George A. Shipman and his colleagues at the University of Washington have found that the purchasers' satisfaction is tempered only by their desire for still more comprehensive prepayment.

The most intriguing unanswered question is why physicians, who are so concerned about Government intervention in health insurance, have not tried to forestall it by imitating more widely the successful precedents established by their colleagues and by nongovernmental lay institutions. Even though all the costs of illness probably should not be insured, the fact is that only about a fifth of personal medical-care expenditures are now covered. Because the best of medical care, such as heart surgery, is often expensive, our present rather limited provision for insuring medical care must be much improved if the best of medical care is to be available.

PLAN OF OBSTETRICAL FLOOR shows nursing stations at convenient places near every room. Some infants room in with mothers. Clarence W. Mayhew was the architect and H. L. Thiederman associate architect. Sidney R. Garfield was the medical consultant.



ORBITING ASTRONOMICAL OBSERVATORY is shown under construction at the Grumman Aircraft Engineering Corporation in Bethpage, N.Y. A prototype is visible in the background. The 3,300-pound craft, scheduled for launching next year, will carry into orbit one 16-inch and four eight-inch reflecting telescopes. They will provide the first view of the sky from above the atmosphere.

OBSERVATORIES IN SPACE

The best view man has ever had of the universe should be obtained from telescopes placed above the atmosphere. The first of several Orbiting Astronomical Observatories will be launched next year

by Arthur I. Berman

The year 1946, when the first astronomical observation was made from outside the earth's atmosphere, will take its place with two other memorable dates in astronomy: 1609 and 1932. In 1609 Galileo opened the age of optical astronomy with a crude telescope of his own construction. Although the instrument had been invented by the Dutch, they did not perceive its astronomical use. Galileo's observations of mountains on the moon, the phases of Venus and the satellites of Jupiter overturned centuries of philosophical speculation. In 1932 Karl G. Jansky of the Bell Telephone Laboratories opened the era of radio astronomy with an antenna mounted on the wheels of a Model T Ford. In the course of trying to identify the source of radio noise that was disrupting transatlantic radiotelephone communications, he discovered that a small part of it emanated from the center of our galaxy. If the sun had not been in one of its quiet periods in 1932, Jansky would surely have detected radio emission from the sun as well. Jansky's discovery enabled astronomers to observe a far greater range of electromagnetic radiations than could be detected by optical instruments, thereby opening a new window on the universe.

All windows were opened in 1946 when a group at the U.S. Naval Research Laboratory under Richard Tousey mounted a small spectrograph in one of the V-2 rockets that had been captured from the Germans. The rocket, launched at White Sands, N.M., soared far above the stratosphere. During the flight the spectrograph made the first recordings of the sun's radiation in the ultraviolet region of the spectrum that is blocked by the earth's atmosphere. Even in 1946 few would have predicted that only 11 years later the first artificial earth satellite would present the possibility of sustained astronomical observations from a space platform. Just a month before the launching of *Sputnik I* a different sort of high-altitude platform, the *Stratoscope I* balloon, conceived by Martin Schwarzschild of Princeton University, produced superb photographs of the sun from an altitude of more than 15 miles [see "Balloon Astronomy," by Martin and Barbara Schwarzschild; SCIENTIFIC AMERICAN, May, 1959]. Early this year *Stratoscope II* made observations of the water-vapor content of the Martian atmosphere and in future flights will carry a 36-inch telescope to photograph the Martian surface. Balloon astronomy is relatively inexpensive, and for some purposes it should be able to supply results almost as good as those that can be obtained from an observatory in space.

The first true space observatory was launched on March 7, 1962, under the direction of John C. Lindsay of the Goddard Space Flight Center. The spacecraft, known as the Orbiting Solar Observatory, or OSO, was the first of a series of vehicles designed to make observations over the full 11-year cycle of sunspot activity. During 77 days of almost perfect operation, the OSO transmitted nearly 1,000 hours of data on solar radiation and related phenomena.

Scheduled for launching in a few months is the Orbiting Geophysical Observatory (OGO), being built by the Space Technology Laboratories, Inc. The first of a family of spacecraft, the OGO is designed to be continuously oriented toward the earth from an eccentric orbit in the upper atmosphere and exosphere. It will record the flux of charged particles, the strength of magnetic fields and radiation of various wavelengths.

The OSO and OGO, neither of which carry image-forming telescopes, are forerunners of a series of spacecraft designated Orbiting Astronomical Observatories (OAO), which will carry reflecting telescopes of various sizes. The first OAO, a 3,300-pound craft, is nearing completion at the Grumman Aircraft Engineering Corporation [*see illustration on opposite page*]. It is being built under the supervision of James E. Kupperian, Jr., for the Goddard Space Flight Center. If all goes well, the OAO will be launched next year and will provide the first optical views of the sky from outside the earth's atmosphere. The craft will carry four eight-inch reflecting telescopes with which the Smithsonian Astrophysical Observatory will attempt a complete sky survey of ultraviolet radiation. The craft will also carry a 16-inch reflector with which workers at the University of Wisconsin plan to study several hundred selected stars and other objects in the ultraviolet region between 1,100 and 3,000 angstrom units. In 1965 *OAO II* will carry a 36-inch reflector, which should provide ultraviolet spectograms of extremely high resolution.

The increased knowledge and understanding of the universe promised by space astronomy can justify much of the monumental cost of the nation's space program. An observing platform in space will overcome at a stroke four fundamental limitations placed on earthbound instruments. First, a telescope on the earth—whether optical or radio—can record only a small part of the electromagnetic spectrum, because most of the spectrum is blocked by the atmosphere. Second, background sky radiation—light scattered by the atmosphere or radiated by processes within it—fogs photographic plates, thereby limiting exposure times and as a result making it impossible to record objects below a certain magnitude. Third, the atmosphere is a turbulent fluid that blurs the images of everything observed. Finally, the earth's gravity, by bending and distorting optical systems, sets a practical limit to the size of earth-based instruments. The orbiting telescope surmounts all these limitations. It introduces a few problems of its own, but they are technological ones, not fundamental.

Let us consider each of these four limitations in somewhat greater detail. Except for the optical window, a narrow infrared window and the radio window, the atmosphere forms a solid wall against much that is of interest in the electromagnetic spectrum of celestial objects [*see illustration below*]. The optical window admits the visible spectrum and some radiation of shorter and longer wavelengths. The admitted wavelengths shorter than those of light are in the near ultraviolet: from about 4,000 angstroms down to 3,000. The ultraviolet wavelengths below 3,000 angstroms are strongly absorbed by ozone in the stratosphere and by oxygen at higher altitudes. The admitted optical wavelengths longer than those of light are in the near infrared: from about 7,000 angstroms up to 10,000 angstroms, or one micron. At longer wavelengths carbon dioxide and water vapor strongly absorb incoming radiation; the atmosphere is fairly opaque between one and 24 microns, except for a narrow but important window that lies roughly between eight and 12 microns. This window enables earthbound instruments to sample the infrared radiation emanating from other planets, thereby providing a good indication of their temperatures.

Between 24 microns and several millimeters the electromagnetic window is tightly shut. Then it gradually opens between one centimeter and about a meter. It shuts tightly again at about 15 meters, at which point free electrons in the ionosphere begin to reflect the incoming radiation.

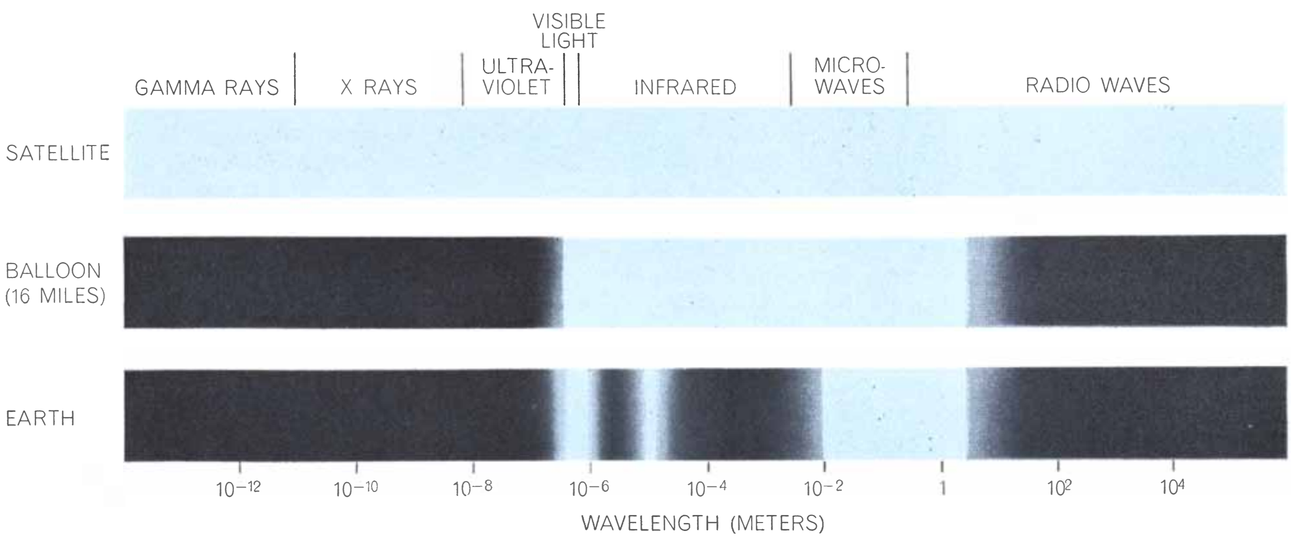
Thus all the wavelengths below 3,000 angstroms—the far ultraviolet, the complete X-ray and gamma-ray spectrum—and the long radio waves above 15 meters are blocked completely even at balloon altitudes. Balloons, however, can float to a point where 97 per cent of the mass of the atmosphere lies below them, including all the water vapor and carbon dioxide, so that at least the infrared-microwave region is accessible to balloon-based telescopes.

The second obstacle—background radiation—consists of airglow in the upper atmosphere and scattered light in the lower regions. If there were no light-scattering, one could see stars even during the day. At night the scattered light from cities and towns has been a growing problem at most observatories. Even at the most secluded sites, however, the scattering of starlight contributes to the fog on photographic plates. Fortunately light-scattering is not serious at balloon altitudes, but airglow, the steady emission of light by the air itself, remains to plague the balloon astronomer.

The next problem is the constant thermal wavering of the atmosphere, which causes stars to twinkle. The same shimmering effect is produced by air rising from a fire or from a hot pavement. It is largely to minimize atmospheric shimmer that observatories are often built at high altitudes. Anyone who has looked at Mars through a large telescope will recall his disappointment. Instead of a sharp, clear, cloudless surface all that can be seen are diffuse patches of light and darkness. Suddenly there may be a momentary clearing and one can almost imagine catching a glimpse of Schiaparelli's canals, but whether or not it has all been an illusion one will never know.

In spite of these three limitations, it would still be worthwhile to have a telescope two, three or 10 times the size of the 200-inch Palomar telescope, which was built almost two decades ago. The extra light-gathering power of a larger instrument would produce a gain in image-to-fog ratio and allow photography (and spectrography) of stars and galaxies fainter than any yet recorded. Why, then, has no one sought to build a telescope much larger than the 200-inch? The answer is gravitational flexure. The mirror must be capable of movement in many directions, yet the sag across the entire mirror must never exceed two millionths of an inch—a tenth of the wavelength of light. The task of properly supporting even the 200-inch mirror is near the limit of engineering capability. The U.S.S.R. is now building a telescope with a 236-inch mirror, but it seems unlikely that anything larger will ever be attempted on the earth.

Gravity can be eliminated as a problem if a telescope is placed in orbit, where its weight simply vanishes. There still remain limitations on size, but they are of a totally different nature. The decision to put a 36-inch telescope in one of the orbiting astronomical observatories was an audacious one. The OAO mirror must be polished to a higher degree of optical perfection than any other mirror of comparable size if it is to exploit fully the opportunities pre-

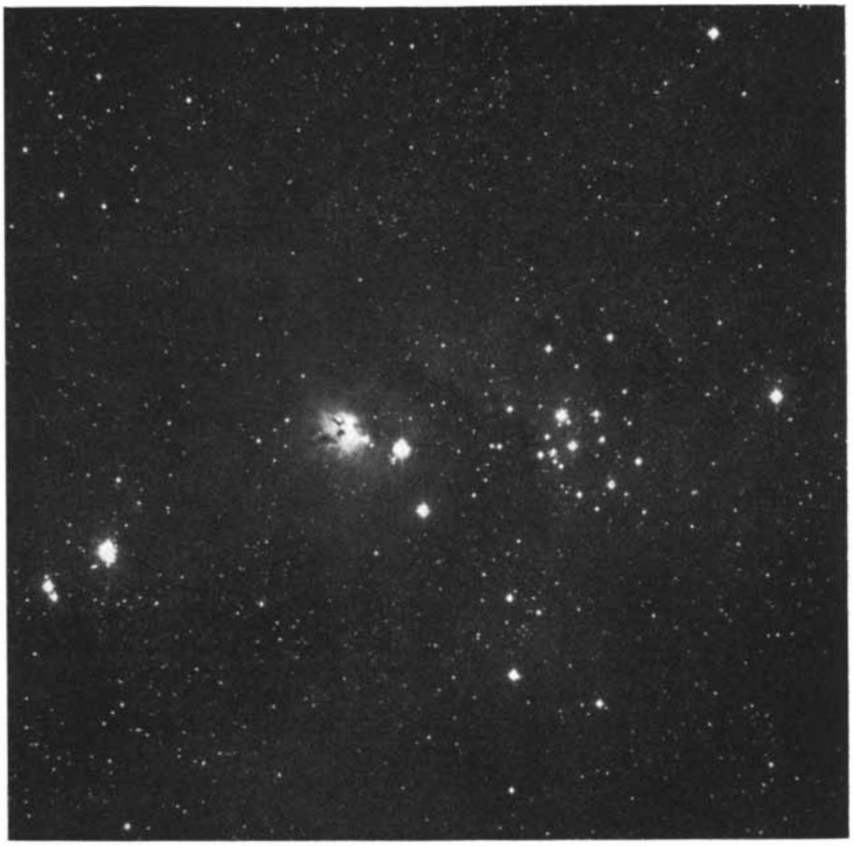


RADIATION FROM SPACE is heavily absorbed by the earth's atmosphere. The colored areas in the bottom band show how little of the electromagnetic spectrum can reach earth-based optical and radio telescopes. At balloon altitudes (*middle band*) the full infrared region becomes accessible. At the altitude of space observatories (*top band*) the entire electromagnetic spectrum is visible.

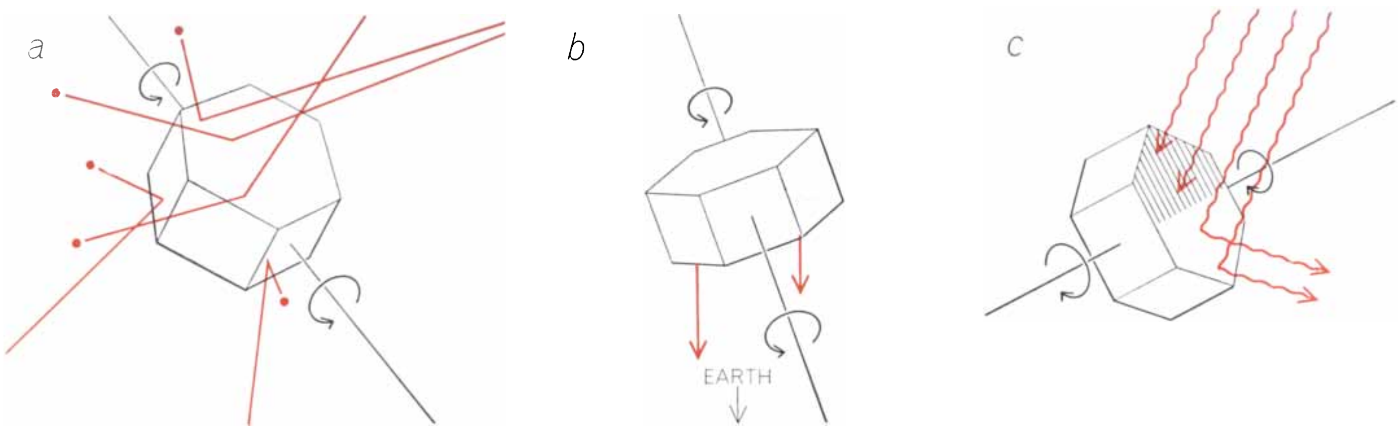
sented by a location in outer space.

A 36-inch mirror has only about a thirtieth of the area, and hence only about a thirtieth of the light-gathering power, of a 200-inch mirror. But in actual practice the OAO telescope should not require exposures 30 times longer than the Palomar telescope in order to obtain images of stars and galaxies never recorded at Palomar. The reason is twofold: the absence of plate-fogging radiation and the higher resolving power of the space telescope. The angular resolving power of the largest earth-based telescopes for photographic work is about .3 second of arc, which is no better than the theoretical resolving power of a 12-inch telescope. No gain is realized in larger instruments because the theoretical improvement is canceled by the shimmering of the atmosphere. The 36-inch reflector to be placed in the OAO—as well as the similar instrument in *Stratoscope II*—should be able to attain an angular resolution of .1 second of arc. The task of maintaining guiding accuracy within this limit is severe but has already been achieved in the guiding mechanism designed for *Stratoscope II* by the Perkin-Elmer Corporation. If the same accuracy can be attained in the OAO telescope, it should be able to record faint stars and galaxies that are smeared into the background fog in plates made by the 200-inch telescope. The gain in resolution alone should make it possible to reduce exposures considerably because the star image will be concentrated in a much smaller area and show up more readily against the fog. The virtual absence of fog should allow a further significant reduction. Thus in order to record objects in the visible-wavelength range the exposures required with the 36-inch space telescope should compare well with those of the 200-inch reflector.

The success of an orbiting observatory will depend largely on the accuracy of its guidance. The altitude of 500 miles was chosen for the OAO in an effort to minimize two major disturbing influences. The altitude is below the magnetosphere, the region of the Van Allen radiation belts, and yet within the exosphere, where molecules are so widely separated that they should normally interfere little with the satellite's course. Even at 500 miles, however, aerodynamic drag can become significant as an aftermath of solar flares, which can suddenly expand the atmosphere by radiation heating. The orbit of *Echo I*, originally about 1,000 miles above the earth, was perturbed by such flares.



TWO VIEWS OF STAR CLUSTER M 8 in the constellation Sagittarius were taken in yellow light (*top*) and in the near-ultraviolet region of the spectrum (*bottom*). The latter exposure was made with wavelengths between 3,100 and 3,850 angstrom units, barely within the optical window in the atmosphere. The difference in the two views illustrates what can be expected when celestial objects are observed in regions of the spectrum blocked by the atmosphere.



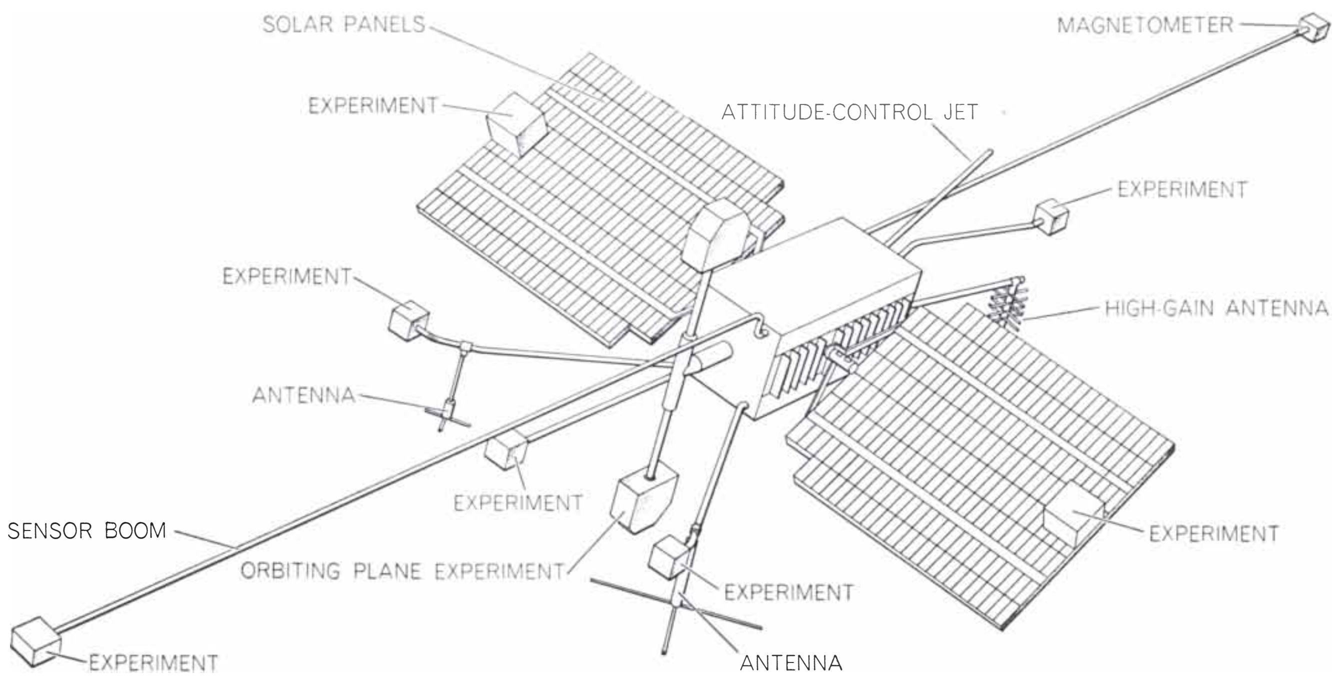
PERTURBING FORCES of several kinds can interfere with the guiding accuracy of a satellite. Simple aerodynamic drag is supplanted at higher altitudes (*a*) by bombardment with individual molecules of gas. Gravity-gradient torque (*b*) arises because all parts of a satellite are not the same distance from the earth. Radiation torque (*c*) can occur if different parts of the satellite reflect

Future observatories may be placed in a synchronous orbit above the Equator, that is, a circular orbit 22,300 miles high where the satellite's period of revolution will coincide with the rotational period of the earth. At this altitude an observatory will be above most of the magnetosphere as well as above the atmosphere, and it will have the additional advantage of continuous direct communication with a single data-receiving and control center on the earth. Furthermore, observatories in synchronous orbits will be able to keep a given celestial object in view longer than observatories closer in, where occultation by the earth is frequent.

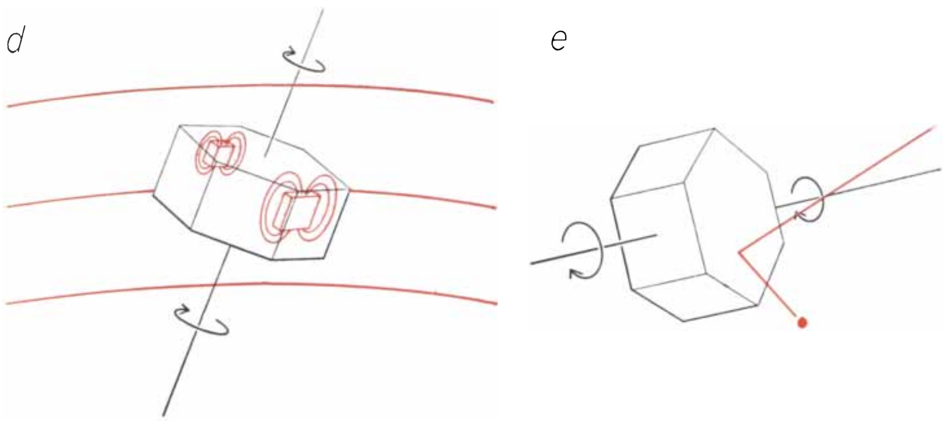
Another factor interfering with steady guidance is gravity-gradient torque, or, as it is sometimes called, tidal torque. This develops because the parts of a satellite that are at varying distances from the earth are attracted unequally by the force of gravity. Unless the satellite is symmetrical about a line passing through the earth's center, the unequal attraction will tend to rotate the satellite around its center of mass. The effect decreases with the cube of the distance from the earth's center, thereby providing another argument for placing an observatory in a high synchronous orbit.

The pressure of solar radiation can also exert a torque on satellites, particularly those with extended solar panels, unless the center of pressure coincides with the center of mass. In the case of the Orbiting Solar Observatory, the solar radiation torque was nullified by making the satellite symmetrical around an axial line that was kept pointing toward the sun. The Orbiting Geophysical Observatory, which is designed to face the earth, will be subjected to a small radiation torque. The Orbiting Astronomical Observatory, on the other hand, is so massive and compact that solar radiation will have only a small effect.

Another perturbing torque is produced when the earth's magnetic field interacts with various current loops in the satellite's electrical system. An in-



ORBITING GEOPHYSICAL OBSERVATORY (OGO), built by the Space Technology Laboratories, Inc., will be launched this year. It will stay pointed continuously toward the earth from an eccentric orbit carrying it through the upper atmosphere and exosphere. It will record the fluxes of charged particles, the strength of magnetic fields and the intensity of electromagnetic radiation.



sunlight unequally. Magnetic torque (*d*) is produced by the interaction of current loops inside the satellite with the earth's magnetic field (*color*). Such torques can be deliberately induced to provide stabilization. Meteoroid bombardment (*e*) can also upset guidance.

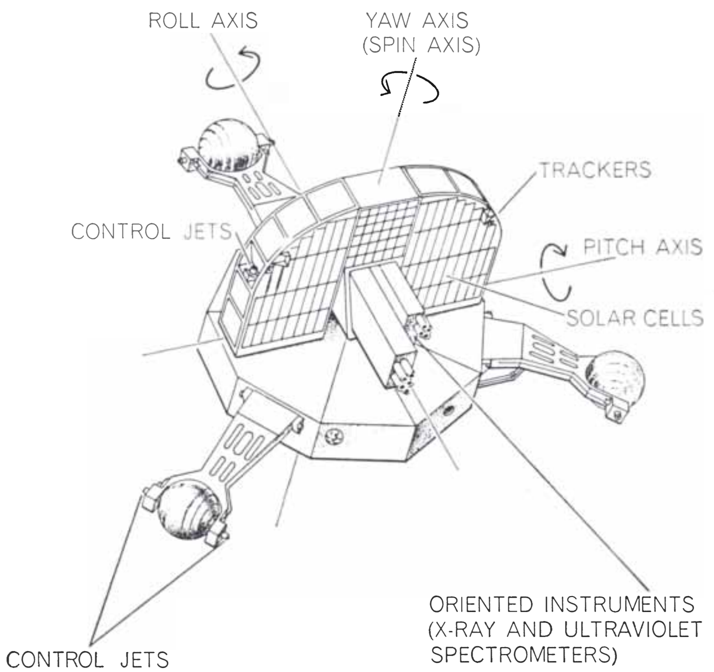
tensification of this effect can occur in satellites, such as the Orbiting Solar Observatory, that are spun for stability. The spinning produces eddy currents that can damp out the spin and destroy pointing accuracy. To reduce magnetic disturbances satellites are sometimes provided with dual circuits that generate canceling torques. Magnetic torques would be negligible at the altitude of a synchronous orbit, which is above most of the magnetosphere.

Little can be done in satellite design to prevent the disturbances caused by meteoroid bombardment. The only recourse is to install fast-acting mechanisms that can restore orientation by providing a compensating torque.

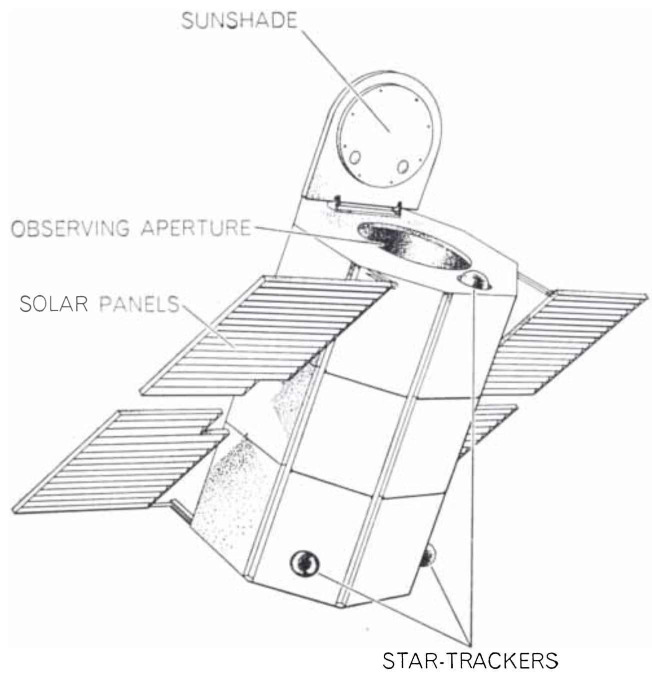
Neither the Orbiting Solar Observatory nor the Orbiting Geophysical Observatory (which has still to be launched) requires exceptionally precise aiming systems. The maximum pointing accuracy achieved with the Solar Observatory was ± 1 minute of arc. The pointing tolerance for the Geophysical Observatory will be only ± 2 degrees. For the Orbiting Astronomical Observatory, however, the designers hope to maintain a pointing precision of at least .1 second of arc, equal to the resolving power of the telescope in the visible region of the spectrum. Fine guidance will be provided by the variable turning of three "inertia" wheels oriented along each of the three perpendicular axes. In the absence of an external torque the turning of a wheel would force the satellite to turn in the opposite direction. If an external torque were present, the appropriate wheel or combination of wheels would turn just enough to keep the satellite in a fixed orientation. In the OAO containing the 36-inch mirror the optical system of the telescope itself will be used to detect any change in orientation. If there is sufficient movement to displace the image even minutely, an appropriate signal will be fed at once to the inertia wheels.

To cope with torques too large for the wheels to handle, the Astronomical Observatory will have two additional correction systems. One will use gas reaction-jets. The other will employ electric currents and coils to create a magnetic field that will react against the earth's magnetic field. The initial stabilization against tumbling will be achieved by means of gas jets, and the orientation in particular directions will be achieved with another set of inertia wheels that are larger and less sensitive than the guidance wheels. A set of co-ordinate axes fixed in galactic space will be provided by a star-tracking system.

Strict temperature control is of critical importance in an observatory intended to produce focused images. In the Astronomical Observatory temperature gradients of more than one degree centigrade in the optical components can shift and



ORBITING SOLAR OBSERVATORY (OSO), built by the Ball Brothers Company, transmitted almost 1,000 hours of solar data last year. Instruments in wedges were aimed toward sun sequentially.



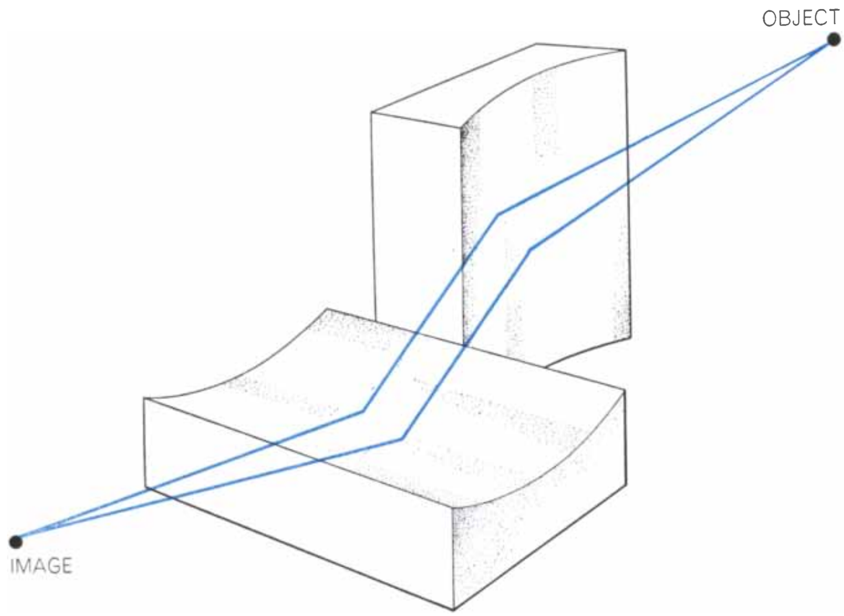
ORBITING ASTRONOMICAL OBSERVATORY (OAO) will need the most precise guidance system ever designed for a satellite to exploit the high resolving power of its reflecting telescopes.

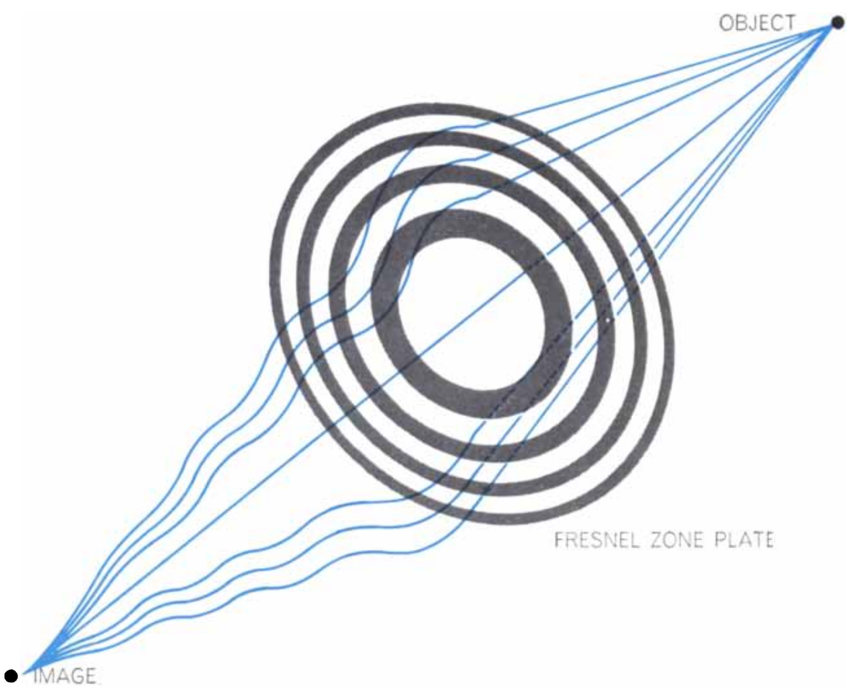
blur the image. The satellite is being designed so that internal temperatures will not fluctuate more than one degree whether the OAO is in brilliant sunlight or in the earth's shadow. This will be accomplished by reflecting sunlight (and earthlight) away from the coated aluminum skin and by insulating the skin from the interior. The electronic equipment will similarly be insulated from the telescope structure. In addition, two radiating surfaces will help to maintain the interior heat balance.

It is difficult to predict the advances in astronomy that will follow the orbiting of telescopes. The possibilities seem limitless. A great many stars, including young blue stars and white dwarfs, have surface temperatures far in excess of the sun's relatively cool 6,000 degrees C. Much of their radiation is in the ultraviolet region obscured by the earth's atmosphere. Even for studies of cool stars, the small sample of their radiation that passes through the optical window provides only a rough indication of their absolute energy emission and precludes detailed knowledge of their energy processes. Many of the chemical elements emit or absorb radiation at specific frequencies between 1,000 and 3,000 angstroms; these resonant lines cannot be observed from the earth, and as a result virtually nothing is known of the abundance of many elements in the sun and other stars. Conceivably the ability to record ultraviolet radiation, which provides most of the energy absorbed by interstellar matter, may show that interstellar space contains large amounts of hydrogen in molecular form. At present there is no way to detect it. The existence of interstellar atomic hydrogen, in amounts comparable to the total mass of the stars, has been established only within the past dozen years by radio astronomy.

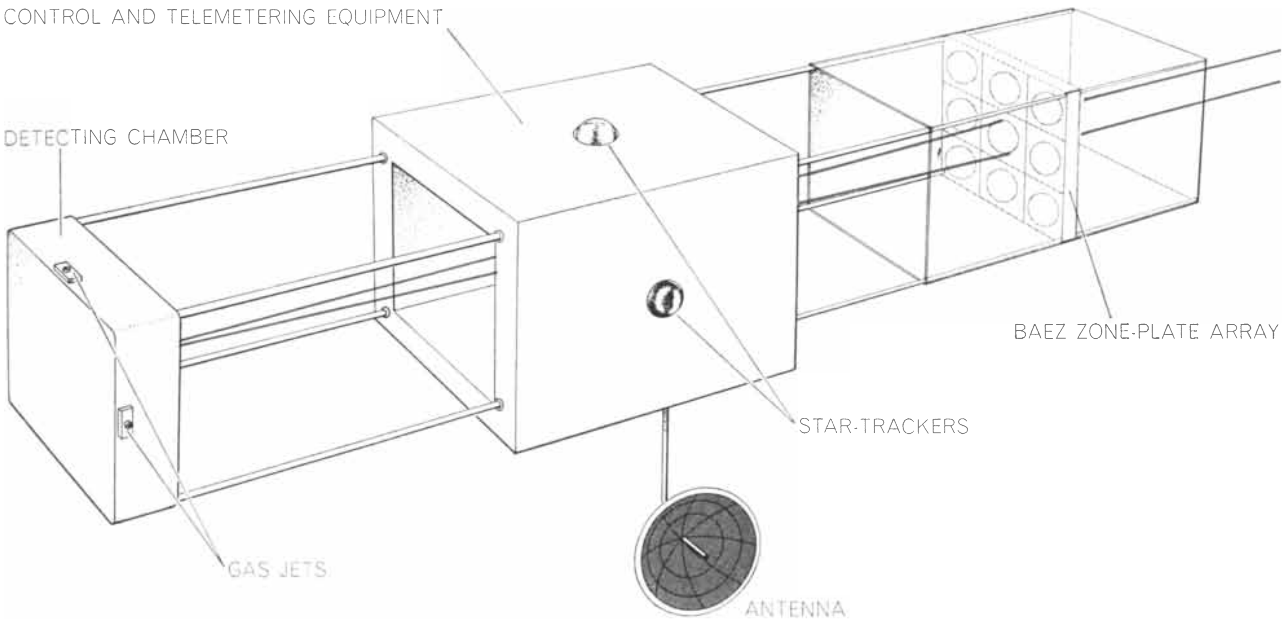
Many of the phenomena taking place in the sun's chromosphere and corona, where temperatures reach a million degrees and more, emit short-wavelength ultraviolet radiation and "soft" X rays: radiation with a wavelength of between five and 100 angstroms. Radiation associated with solar flares, a serious hazard to manned space flight, is rich in penetrating, or "hard," X rays, which have wavelengths shorter than five angstroms. X-ray studies will not only be invaluable in determining the absolute spectral intensity of stars; they should also shed light on the complex interactions of magnetic fields and charged particles within stars and within our galaxy as a whole. These interactions are the province of magnetohydrodynamics. Many of the X rays that reach the solar system are thought to be generated by the acceleration of charged particles in space, in much the same way that X rays are generated within a synchrotron.

One can safely predict that the Crab nebula, the remains of a supernova that flared up in A.D. 1054, will be a prolific source of X rays. Last year a strong X-ray source was found near the center of our galaxy in one of the first X-ray surveys of the night sky carried out by rocket. The discovery was reported by Riccardo Giacconi, Herbert Gursky and Frank Paolini of American Science and Engineering, Inc., and Bruno B. Rossi of the Massachusetts Institute of Technology. The nature of the source remains to be determined. It is expected that interstellar matter will extinguish much of the soft X radiation produced by the stars and other sources, but certainly a great





FOCUSING OF X RAYS is difficult but can be achieved. In one method (*top*) a narrow beam of X rays from space comes to a focus as a result of having grazed off two cylindrical mirrors placed at right angles. In a second method (*bottom*) the rays pass through openings in a Fresnel zone plate, an arrangement of opaque rings and annular passages each of which has the same area as a small central aperture. Wavelets of a given wavelength constructively interfere to produce a pointlike image. Both methods still need much development.



ORBITING X-RAY OBSERVATORY (OXO) is hypothetical. It would focus X rays by means of an array of zone plates, which would continue to provide useful images even if some plates were damaged. The multiple images formed in the detecting chamber would be combined electronically. If each zone plate were one centimeter in diameter and brought X rays of 50-angstrom wavelength to a focus at a distance of 25 feet, its theoretical resolving power would exceed that attainable with any terrestrial telescope.

deal of the hard and near-hard X radiation will penetrate to the solar system.

Much study is being given to the problem of transmitting back to the earth the high-resolution images that will be produced by telescopes in orbit. One possibility is to record the images on high-resolution photographic plates, to develop the plates automatically and to transmit them to the earth by a high-resolution television scanning system. A far more profitable and direct method would be to transmit not images but numbers indicating intensity readings of points throughout the image. Such digital data would comprise all the information in a photographic (or spectrographic) plate and would present it in a form that could most readily be used. If desired, of course, the digital data could be used to reconstruct a photographic image.

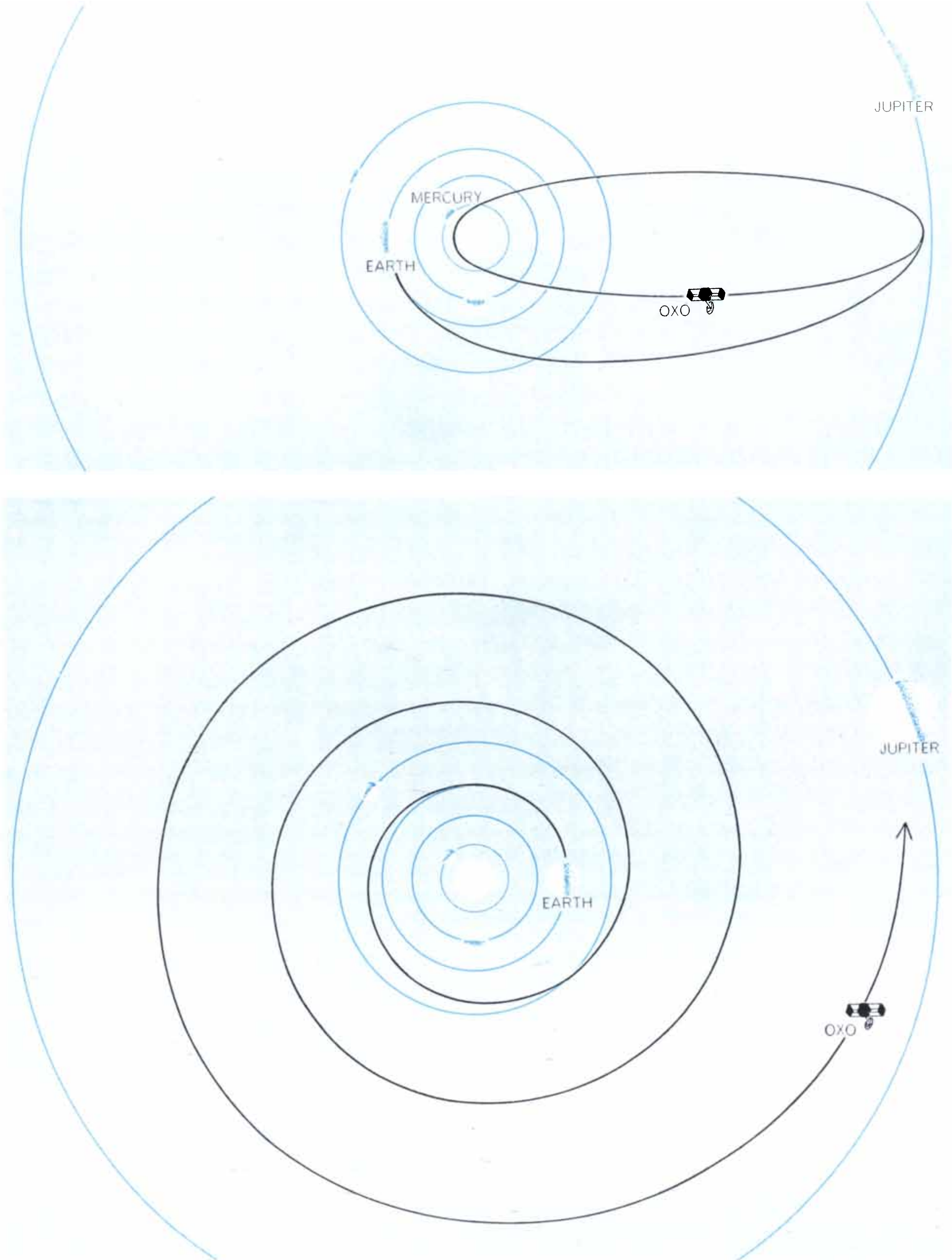
The sharp star images obtainable with a 36-inch reflector in orbit, combined with the elimination of much background radiation, should lead to a gain of many stellar magnitudes over photographic images recorded on the earth. It is expected that stars as much as 100 times fainter than those discernible with the 200-inch telescope can be recorded by the space telescope. Whole galaxies should suddenly appear where none have been seen before. If this expectation is realized, the "edge" of the visible universe may be pushed beyond the present estimate of six billion to eight billion light-years. In addition, many objects that now appear to be single stars should be resolved into double stars. The centers of some star clusters and parts of many galaxies should be resolved into individual stars, leading to a more accurate estimate of the distance scale of the universe. It may even be possible to detect surface detail on some of the nearest and largest stars.

If a way can be found to produce X-ray images of stars and galaxies, the gain in resolution should be even more striking than it is in the optical region. In theory, the resolution improves as the wavelength decreases. Thus a point source of X rays with a wavelength of five angstroms will yield an image disk having only a thousandth of the diameter of the disk made by yellow light of 5,000 angstroms. This thousandfold improvement assumes that the instruments making the images have the same focal length and the same aperture, or radiation-gathering power. Conversely, one can reduce the aperture for X rays by a factor of 1,000 and achieve the same angular resolution attainable with visible radiation.

But how can X rays be focused? Certainly not by conventional optical systems. Paradoxically the X rays of greatest interest to astronomers have such low penetrating power that they are absorbed even by the gelatin in photographic emulsions. There is, therefore, no hope of bending them by passing them through lens systems. In any case the refractive indexes of X rays are so close to unity that many feet of optical path would be needed to produce significant bending. Reflection of X rays by conventional mirror systems is equally out of the question. Only a few materials (for example, platinum) will reflect a high-incidence beam of X rays shorter than 400 angstroms and even then nearly all the rays striking the surface are absorbed rather than reflected. Gigantic mirrors would be required to produce usable images from the weak flux of X rays originating in space.

All is not hopeless, however. When X rays strike a polished surface at grazing incidence—that is, at an angle of less than a few degrees—they are totally reflected. The phenomenon is the same as the total reflection that occurs when light strikes the internal surface of water or glass at a low angle. In the case of light the reflection takes place at the dense-to-rare interface; in the case of X rays the reflection is external, at the rare-to-dense interface.

An X-ray focusing system can therefore be constructed, at least in principle, by allowing a beam of divergent rays to graze two surfaces in succession. The surfaces must be concave cylinders placed at right angles, as shown in the top diagram on the opposite page. The use of such a system for an X-ray microscope was proposed some years ago by Paul H. Kirkpatrick of Stanford University [see "The X-Ray Microscope," by Paul Kirk-



X-RAY OBSERVATORY ORBITS ideally should take the craft away from the sun, for stellar and galactic studies, and then back to its vicinity for solar observations. An initial large thrust from the earth would send the craft directly out to the region of Jupiter's orbit (*top*), where a small reverse thrust would send it back within Mercury's orbit. If the craft were continuously powered by a small ion rocket, the orbit would be a spiral (*bottom*). The trip to Jupiter's orbit would take about two and a half years by the first propulsion method and less time by the second. Long exposures may be needed to record the X radiation from stars and galaxies.

patrick; SCIENTIFIC AMERICAN, March, 1949].

One of Kirkpatrick's former students, Albert V. Baez (whose daughter Joan is the well-known folk singer), devised a somewhat similar crossed-mirror system at the Smithsonian Astrophysical Observatory to produce a long-focus X-ray image of a distant object. His device consists of multiple crossed reflectors, resembling two sets of slightly curved Venetian blinds crossed at right angles, one in front of the other. The system was successfully tested in visible and ultraviolet radiation and the results are expected to be equally good for X rays. The reflected X rays passing through the array of openings converge at a single point. The effective aperture that determines the resolution is unfortunately fairly small, a square pinhole a few tenths of a millimeter on a side. It can be increased by increasing the plate width. The radiation-gathering power, however, depends on the total number of pinhole openings. Since all wavelengths obey the same law of reflection, this system brings X rays of different wavelengths to a common focus.

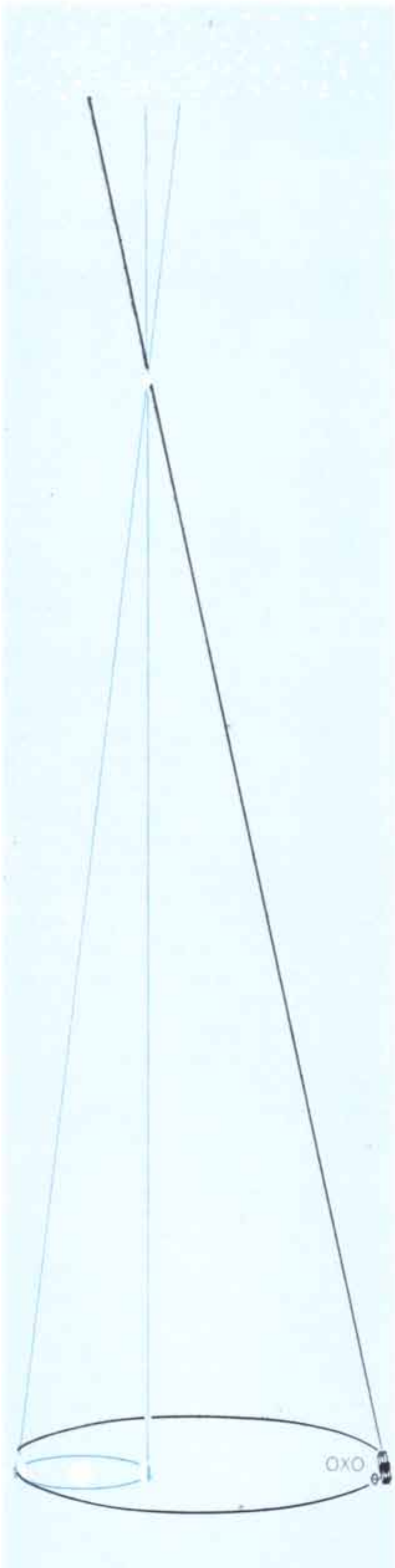
Baez has also experimented with a second system for imaging X rays, which may or may not prove easier to construct. The principle, which has long been known for light rays, is based on diffraction by means of a Fresnel zone plate, a series of annular openings separated by opaque rings. At the center is a pinhole opening that establishes the area for each of the openings and rings. This means that the openings and rings grow progressively narrower the farther they are from the center [*see bottom diagram on page 34*]. Baez designed a zone plate of thin gold foil held together by radial struts. The X rays pass through the annular openings but are absorbed by the gold foil rings. After passing through the openings the wavelets of a given wavelength reinforce each other in such a way as to create a disk image at a common focal point. Since the focal length is inversely proportional to wavelength, sharp images can be obtained only by limiting the converging radiation to selected wavelengths. In spite of this limitation the aperture can be 10 to 100 times larger than it is in the crossed-plate system, with a corresponding increase in resolution.

If either of Baez' two methods were to lead to a practical X-ray telescope, one might consider building an OXO–Orbiting X-Ray Observatory. For maximum usefulness its orbit would have to be carefully selected. First, it should be placed in an orbit far beyond the range of the Van Allen radiation belts, which contain a high flux of energetic electrons as far as 40,000 miles from the earth. If such energetic electrons were to strike the spacecraft, they would generate a shower of X rays. Second, an X-ray observatory designed to make stellar and galactic studies must be well shielded from the sun's X rays and from solar charged particles that could generate additional X rays. Third, long exposures must be planned, since the flux of stellar and galactic X rays will probably be fairly low. Such exposures present guidance problems at least an order of magnitude more severe than have been faced in designing the Astronomical Observatory.

These requirements point to an orbit that would carry the OXO far out into the solar system for stellar and galactic studies and close to the sun for solar observations. Fortunately both X-ray imaging systems described are light and compact, so that it should not be too difficult to place them in wide-ranging orbits. An orbit with many advantages is one that would take the X-ray telescope almost as far out as the orbit of Jupiter, or about 450 million miles from the sun, but not necessarily near the planet itself. When the observatory had reached aphelion, a small reverse thrust would send it back to a point inside Mercury's orbit, or to within 20 million miles of the sun. The observatory would take about two and a half years for the outbound flight and another two years to return. If the observatory were continuously powered by an ion rocket, it could reach Jupiter's orbit somewhat faster.

During the leisurely interplanetary voyage long exposures could be made without the perturbing influence of tidal torques, planetary magnetic fields or earth occultations. (The hazard of meteorite collisions must be reckoned with, however, when the observatory crosses the asteroidal belt between Mars and Jupiter.) One of the most important assignments of such an observatory would be to make precise parallax measurements of the nearer stars, using a base line two or three times longer than is possible from the earth.

It is easy to see why most astronomers are looking forward more keenly to the launching of space observatories, beginning next year with the Orbiting Astronomical Observatory, than to a manned flight to the moon. As the oldest science, astronomy has learned that new tools are crucial to a deeper understanding of the universe. The observatory in space is such a tool.



STELLAR DISTANCES could be measured with unprecedented accuracy by an X-ray observatory. The job requires a telescope of high resolving power and a long base line from which it can observe nearby stars against a background of more distant stars.

The Evolution of Bowerbirds

It now seems that the complex mating stages these birds maintain and their specialized sexual displays constitute an advanced form of avian behavior that tends to speed up evolutionary processes

by E. Thomas Gilliard

A 19th-century naturalist once suggested that just as mammals were commonly divided into two groups—man and the lower forms—all birds should be split into two categories: bowerbirds and other birds. No one who has observed the behavior of these remarkable creatures of Australia and New Guinea and examined their artifacts can scoff at this proposal. The males of some species build elaborate walled bowers of sticks and decorate them with bright objects and even with paint. Others construct towers up to nine feet high, some with tepee-like roofs and internal chambers, on circular lawns that they tend carefully and embellish with golden resins, garishly colored berries, iridescent insect skeletons and fresh flowers that are replaced as they wither. The bowers are stages set by the males on which to perform intricate routines of sexual display and to mate with the females of their species. The bowerbirds' architectural, engineering and decorating skills and their courtship displays constitute behavior that, as G. Evelyn Hutchinson of Yale University has said, "in its complexity and refinement is unique in the nonhuman part of the animal kingdom."

The student of evolution inevitably asks how such extremely specialized behavior came about. The answer, I suspect, can be unmasked if one steps back to survey all the birds with behavioral affinities to the bowerbirds, that is, those birds that practice the pattern of courtship behavior known as arena behavior. There are only 18 species called bowerbirds, at least 12 of which actually build bowers, but there are in all some 85 species that have been described as arena birds. This is still a small proportion—about 1 per cent—of the avian species of the world. But arena birds are a world-wide assemblage including species in such disparate families as sandpipers, grouse, bustards, blackbirds, small tropical manakins and the bizarrely beautiful birds of paradise.

It has fallen to my lot to be able to make comparative ethological investigations of many of these species in the tropics of New Guinea and South America. As a result I have been able to reach some conclusions that seem to be new. I believe that arena behavior, wherever it appears, probably has a common origin and that it represents an advanced stage in avian development. Once set in motion, I think, it has a predictable evolution leading rather quickly to the development of the highly specialized combinations of structure and behavior found in all the far-flung arena species. The bowerbirds are at the pinnacle of arena evolution. They have gone a step beyond the most richly ornamented arena birds, substituting fancy houses and jewelry for colorful plumage.

Arena behavior was defined by the ornithologist and student of evolution Ernst Mayr as a pattern of territorial behavior in which the males establish a mating station that has no connection with feeding or nesting. I would add that it is a rather rare form of courtship behavior involving a group of males usually living in an organized band on or about a long-established mating space: the arena. Each arena is composed of a number of courts, the private display territories of individual males. To establish their right to a territory the males go through ritualistic combat routines, fighting, charging, displaying their plumage or brandishing twigs, singing or producing "mechanical" sounds. Once territories are established there is little fighting for mates because the females do the choosing. The sexes live apart for long periods of the year and are often so dissimilarly dressed as to look like different species. Since there is no true pair bond, the males play no part whatever in building or defending the nest or in rearing the young.

This advanced courtship pattern is in sharp contrast to the less advanced behavior of the other 99 per cent of the world's birds. For them the central event is the establishment of a pair bond between a male and a female, with the pair proceeding to share the work of raising the young. (The word "advanced" is not intended to imply a value judgment on the state of matrimony. Ornithologists simply assume that pair-bonding and work-sharing habits represent the less advanced evolutionary condition in birds because these habits are so nearly universal.) The pair-bond pattern is found regularly not only in the phylogenetically recent passerine (perching) order of songbirds, which is currently the most numerous and highly differentiated avian group, but also in the older nonpasserine birds; it is a "conservative" behavioral pattern that has resisted modification. Yet the breakthrough to arena behavior seems to occur, apparently at random, just about anywhere in the world and at scattered points on the family tree of birds [*see illustration on page 42*].

The characteristics that define arena behavior and argue for its common origin and line of evolution emerge from the study of a fairly large number of arena birds. The pattern is most evident when the arena is small, as in the case of the ruff, a sandpiper of northern Europe and Asia whose behavior has been described in detail by C. R. Stonor. The males and females apparently live apart except for a few minutes in the breeding season. Each spring the males gather in isolated clans, each of which populates

MALE COCK OF THE ROCK (*Rupicola rupicola*) perches above its court in a British Guiana forest. Like the bowerbirds, this member of the cotinga family is an arena bird: the males live apart from the females in clans and establish individual breeding stations.

THREE COCKS occupying adjacent courts in a small arena were watched by the author for 20 days as they defended their territories and displayed to visiting females. The cock at left is posturing on its terrestrial court; the others perch above their courts.

CRESTED BOWERBIRD (*Amblyornis macgregoriae*) of New Guinea is a member of a remarkable genus that builds high towers of sticks surrounded by courtyards. *A. macgregoriae*, the most colorfully plumed of the genus, builds the least complex bower.

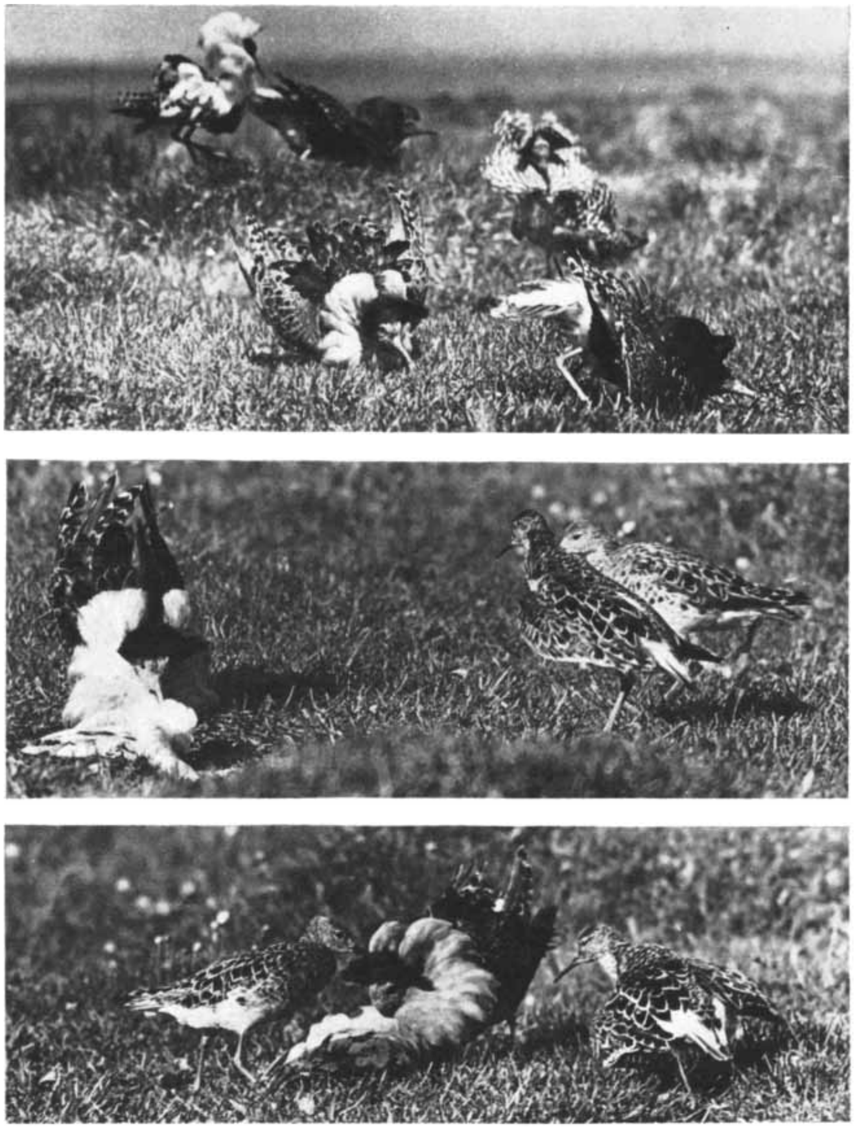
GREATER BIRD OF PARADISE (*Paradisaea apoda*) is native to the New Guinea region. This bird is a member of a breeding colony established in 1909 on Little Tobago in the Caribbean Sea. Photographs on this page and preceding one were made by author.

a small, grassy hillock in rolling meadowland. After a period of fighting and display among themselves the males learn to recognize one another as individuals, and arrange themselves on the mound in a social order that presumably remains fairly fixed throughout the breeding season. Each male's territory is a private court about two feet in diameter that he defends vigorously against other males. The clan waits day after day for the visits of occasional females in search of mates. When one appears, the males go to their courts and assume strangely stiff postures, extending the colorful plumage of their neck ruffs. Displaying in this manner they reminded Stonor of a bed of flowers. The female wanders through this cluster and pecks at the neck feathers of the bird she prefers. Mating occurs immediately—whereupon the rejected males immediately collapse on their courts as if in a fainting spell.

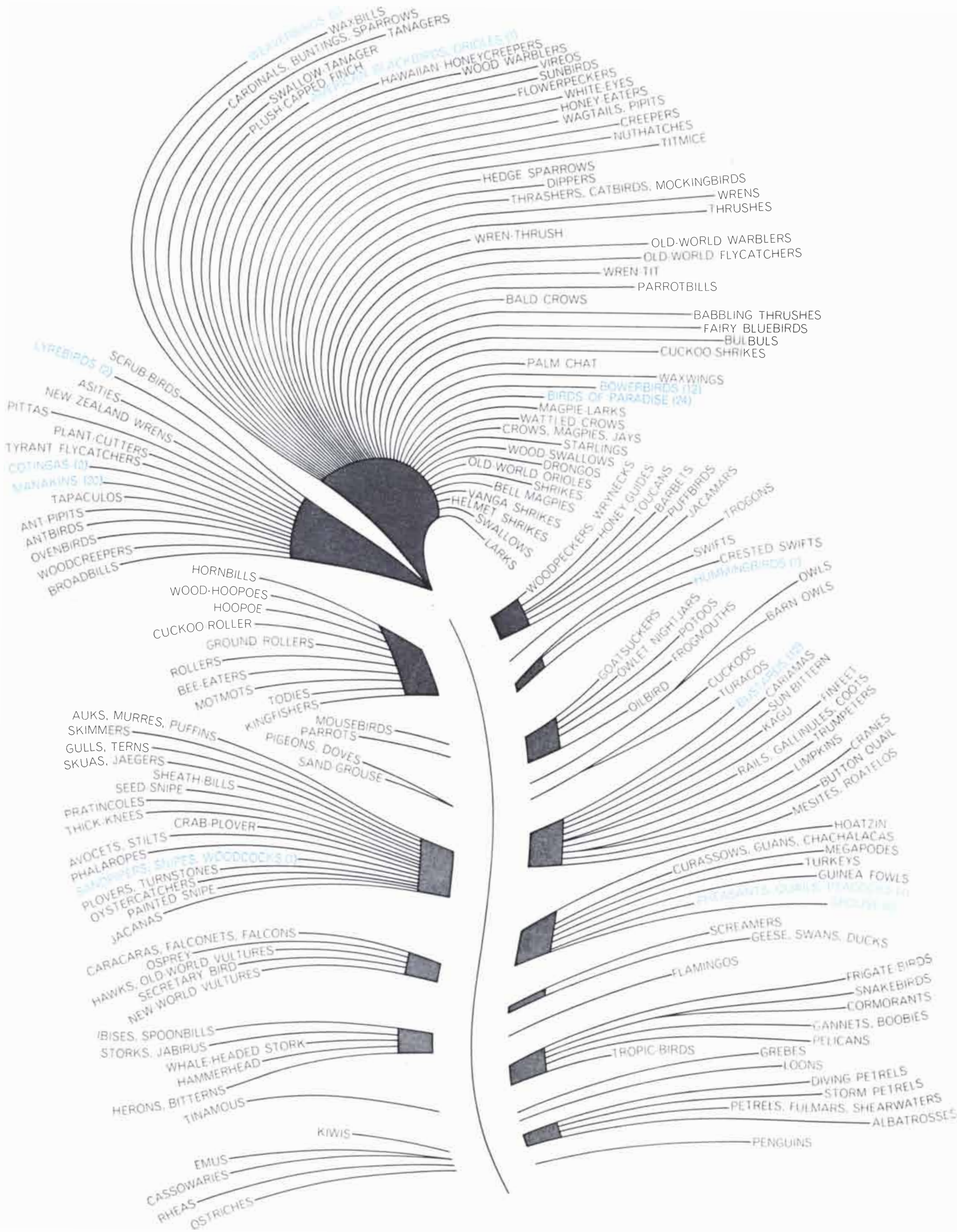
Arena behavior of a similar sort but on a larger scale is practiced by the sage grouse and prairie chicken of North America. The grouse's arena may be half a mile long and 200 yards wide, with 400 males within its boundaries, each standing 25 to 40 feet apart on its private court. The zoologist John W. Scott was able to study the breeding hierarchy in a clan of these grouse. He found that the great majority of matings went to four "master" and a few "submaster" cocks with courts located along the center line of the long, narrow arena. Of 114 observed matings involving males whose place in the hierarchy had been determined, 74 per cent went to the four master cocks. Only after these birds had become satiated did 13 per cent of the matings go to the submasters, and the few remaining matings went to scattered owners of peripheral courts. These and other observations make it clear that arena matings are not random: the coordinated clan activities that serve to establish the territorial hierarchy, and thus the breeding rights, are of primary evolutionary importance.

Some years ago on an expedition to South America I studied arena behavior in a very different bird, a cotinga called cock of the rock (*Rupicola rupicola*). I found a clan of these brilliant orange birds, which wear a great semicircular crest resembling that of a Roman helmet, in the Kanuku Mountains of British Guiana. The males held and defended an arena some 40 by 80 feet in extent including about 40 small courts—cleared areas on the ground under saplings and vines that provided convenient perches. For 20 consecutive days I watched three members of the clan, readily recognizable as individuals, that held adjacent courts in one part of the arena. I was struck by the silence and deliberateness of movement that characterized their behavior on the courts; it was reminiscent of the behavior of a pair-bonded male at its nest. During the period of observation females visited the arena several times. Whenever a female arrived, the three males, if they were not already on the ground, would fall almost like stones from their perches to their courts. There, with bodies flattened and heads tilted so that the crests were silhouetted against the bare ground, they would posture stiffly for many minutes. Again there was a resemblance to the attitude of a male attending a nest. The three birds jealously defended from one another their own courts and a cone-shaped space above them. But when a wandering nonclan male visited them, they would fly up and attack him as a team with violent chasing displays, wing-buffeting, strange cries and whinnying sounds.

The 24 species of birds of paradise in which arena behavior is seen vary widely in physical characteristics and in the details of their displays. Some clear courts on or near the ground, some inhabit the middle levels of tropical forests and some display high in the treetops. In many of them the arena is so large that it has not usually been considered an arena at all. The distances between the individual courts can mislead one into believing that each male is operating in solitude, but this is almost cer-



MALE RUFFS display on small private courts close to one another in a tight arena. When reeves (female ruffs) are in the vicinity, the males posture stiffly on their courts, extending their colorful plumage (*top*). Two reeves approach (*middle*); one selects a mate by pecking at its neck feathers (*bottom*). The photographs were made by Arthur Christiansen.


WAXBILLS
CARDINALS, BUNTINGS, SPARROWS
TANAGERS
SWALLOW-TANAGER
PLUSH-CAPPED FINCH
HAWAIIAN HONEYCREEPERS
WOOD WARBLERS
VIREOS
SUNBIRDS
FLOWERPECKERS
WHITE-EYES
HONEY-EATERS
WAGTAILS, PIPITS
CREEPERS
NUTHATCHES
TITMICE
HEDGE SPARROWS
DIPPERS
THRASHERS, CATBIRDS, MOCKINGBIRDS
WRENS
THRUSHES
WREN-THRUSH
OLD-WORLD WARBLERS
OLD-WORLD FLYCATCHERS
WREN-TIT
PARROTBILLS
BALD CROWS
BABBLING THRUSHES
FAIRY BLUEBIRDS
BULBULS
CUCKOO-SHRIKES
PALM CHAT
WAXWINGS
BOWERBIRDS (12)
BIRDS OF PARADISE (24)
MAGPIE-LARKS
WATTLED CROWS
CROWS, MAGPIES, JAYS
STARLINGS
WOOD-SWALLOWS
DRONGOS
OLD-WORLD ORIOLES
SHRIKES
BELL MAGPIES
VANGA SHRIKES
HELMET SHRIKES
SWALLOWS
LARKS
LYREBIRDS (2)
SCRUB-BIRDS
ASITIES
NEW ZEALAND WRENS
PITTAS
PLANT-CUTTERS
TYRANT FLYCATCHERS
TAPACULOS
ANT-PIPITS
ANTBIRDS
OVENBIRDS
WOODCREEPERS
BROADBILLS
HORNBILLS
WOOD-HOOPOES
HOOPOE
CUCKOO ROLLER
GROUND ROLLERS
ROLLERS
BEE-EATERS
MOTMOTS
TODIES
KINGFISHERS
MOUSEBIRDS
PARROTS
PIGEONS, DOVES
SAND GROUSE
WOODPECKERS, WRYNECKS
HONEY GUIDES
TOUCANS
BARBETS
PUFFBIRDS
JACAMARS
TROGONS
SWIFTS
CRESTED SWIFTS
OWLS
BARN OWLS
GOATSUCKERS
OWLET-NIGHTJARS
POTOOS
FROGMOUTHS
OILBIRD
CUCKOOS
TURACOS
CARIAMAS
SUN BITTERN
KAGU
FINFEET
RAILS, GALLINULES, COOTS
TRUMPETERS
LIMPKINS
CRANES
BUTTON QUAIL
MESITES, ROATELOS
HOATZIN
CURASSOWS, GUANS, CHACHALACAS
MEGAPODES
TURKEYS
GUINEA FOWLS
SCREAMERS
GEESE, SWANS, DUCKS
FLAMINGOS
FRIGATE BIRDS
SNAKEBIRDS
CORMORANTS
GANNETS, BOOBIES
PELICANS
TROPIC-BIRDS
GREBES
LOONS
DIVING PETRELS
STORM PETRELS
PETRELS, FULMARS, SHEARWATERS
ALBATROSSES
PENGUINS
AUKS, MURRES, PUFFINS
SKIMMERS
GULLS, TERNS
SKUAS, JAEGERS
SHEATH-BILLS
SEED SNIPE
PRATINCOLES
THICK-KNEES
CRAB-PLOVER
AVOCETS, STILTS
PHALAROPES
PLOVERS, TURNSTONES
OYSTERCATCHERS
PAINTED SNIPE
JACANAS
CARACARAS, FALCONETS, FALCONS
OSPREY
HAWKS, OLD-WORLD VULTURES
SECRETARY BIRD
NEW-WORLD VULTURES
IBISES, SPOONBILLS
STORKS, JABIRUS
WHALE-HEADED STORK
HAMMERHEAD
HERONS, BITTERNS
TINAMOUS
KIWIS
EMUS
CASSOWARIES
RHEAS
OSTRICHES

tainly not the case. Apparently these species have "exploded" arenas; the birds' calls and mechanisms for the production of other sounds are always highly developed and powerful, so that the males can interact in spite of their seeming isolation. Strong evidence in favor of the exploded-arena hypothesis is the fact that in many of these species the courts have been found to be concentrated in certain areas of the forest year after year.

I have studied two of the species that clear courts on or near the ground beneath low branches, vines and saplings: the magnificent bird of paradise (*Diphyllodes magnificus*) and Queen Carola's bird of paradise (*Parotia carolae*). For both species the court is the property of a single male that remains in attendance many hours a day, probably for several months a year. Austin L. Rand of the Chicago Natural History Museum has described how the magnificent bird of paradise spends countless hours trimming away the forest leaves above its court, thereby enabling a shaft of sky light to enhance the bird's iridescent coloring. Similar but less well developed court-clearing is practiced by other arena birds. In an arena of blue-backed manakins on Tobago in the West Indies I saw that much of the foliage had been cut around the arboreal courts. Frank M. Chapman of the American Museum of Natural History studied clans of Gould's manakins located miles apart in Panama that had cleared many small, platelike clearings in 200-foot-long strips of the rain-forest floor. The cock of the rock clears its court with violent wing-thrashing, whereas most other arena birds use their bills for this purpose. However it is done, the court of many arena birds is swept clean of fallen debris if it is terrestrial, and stripped of many leaves and twigs if it is arboreal.

It seems not too big a step from the court-clearers to such elementary bower-builders as Archbold's bowerbird (*Archboldia papuensis*). These are clearly arena birds: the males and females apparently live apart most of the year. The males spend the breeding season on or close to table-sized stages on the ground in high mountain forests of New Guinea. Each stage is owned and defended by a single male who carpets it with ferns, decorates it with shafts of bamboo, piles of resin, beetle skeletons, snail shells and lumps of charcoal. Each is within audible range of other stage-tending males. On one slope of Mount Hagen I found five stages concentrated in a zone about two miles in diameter, and my native hunters reported others I did not see. Although the species seemed rather common, a number of expeditions failed to find any of these birds elsewhere on Mount Hagen; however, a similar group was discovered on another mountain some 20 miles away. In my opinion each of these groups represents a clan, and its gathering place is the clan's arena. The males within each clan maintain contact with one another by uttering mighty whistles and harsh, rasping notes, and it seems likely that they all know when a female is in the arena and act in concert as many other arena birds do.

I watched one male receiving a visit from a female. As soon as the female arrived near the court the male dropped to its colorful stage and began to act in a manner resembling that of a young bird begging food. With its wings outstretched and its tail spread, it crawled tortuously toward the female, which perched at the edge of the court and kept moving around its periphery. The male held its head up like a turtle, made gasping movements with its bill and kept up a deep, penetrating "churr" song. In spite of the vigor of this display the ceremony was apparently not consummated by mating. After 22 minutes something disturbed the birds and the female flew off. Soon the male began rearranging the piles of ornaments and resumed its long, solitary wait.

Another New Guinea bowerbird with an exploded arena is the extraordinary gardener bowerbird (*Amblyornis*). A male of this genus builds its bower by piling sticks against a sapling on the floor of a mountain rain forest and clearing a mossy saucer around the tower. Some species build large towers with roofs and internal chambers and decorate the moss court with snail shells, insect and spider silk and fresh flowers changed daily for months on end. Others build only a small roof and use fewer ornaments, and still others merely maintain a clearing around a modest tower of intertwined sticks.

Some years ago I noticed that there is an inverse ratio in the three known *Amblyornis* species between the complexity of the bower and the plumage of the male bird (the three females are virtually indistinguishable). In the species *A. macgregoriae*, which builds the simple bower, the adult male wears a long golden-orange crest [*see top illustration on page 40*]. In *A. subalaris*, which builds the somewhat more complex bower, the male wears a shorter crest. And in the aptly named species *A. inornatus*, which builds the most elaborate bower (with a broad roof overhanging a court decorated with berries, shells and piles of flowers), the male wears no crest at all and cannot be distinguished from any of the females!

I believe that in these birds the forces of sexual selection have been transferred from morphological characteristics—the male plumage—to external objects and that this "transferral effect" may be the key factor in the evolution of the more complex bowerbirds. This would explain the extraordinary development and proliferation of the bowers and their ornaments: these objects have in effect become externalized bundles of secondary sexual characteristics that are psychologically but not physically connected with the males. The transfer also has an important morphological effect: once colorful plumage is rendered unimportant, natural selection operates in the direction of protective coloration and the male tends more and more to resemble the female.

Further evidence of this sort came from observations of Lauterbach's bowerbird (*Chlamydera lauterbachi*), a grassland and forest-edge species of New Guinea. In an area several miles in diameter I once found 16 bowers of this "avenue-building" species hundreds to many thousands of feet apart. One bower I examined contained almost 1,000 pale pebbles weighing nearly 10 pounds. More than 3,000 sticks and 1,000 hairlike strands of grass had gone into the four-walled structure. The sticks were interlocked to form a rigid structure and the grass was used to line the vertical walls facing the inner court. Three times during the many days I watched a female entered a bower. The male became highly excited and began to dance. The female jumped quickly within the walls and then stood still and alert. Almost as soon as she was in the bower the male picked up with its bill a marble-sized red berry, held it high and displayed it to the female much as it would have displayed its bright crest feathers—if it had had any [*see painting on the cover of this issue*]. *C. lauterbachi*, like *A. inornatus*, is the most advanced builder of its genus. It is also a species in which the male and

ARENA BEHAVIOR has developed at a number of apparently unrelated points on the tree of avian evolution. Families that include arena birds are shown in color, together with the number of known arena species in each, a number that is subject to upward revision. In this highly schematic diagram the major families have been grouped into 28 orders of birds, from the oldest (*bottom*) to the most recent (*top*).

INVERSE RATIO was noted by the author between the complexity of gardener bowerbirds' bowers and the brilliance of their plumage. The most complex bower, seen at left in a photograph made by S. Dillon Ripley of Yale University, is built by the crestless *Amblyornis inornatus.* The simplest bower (*right*) is that of the orange-crested *A. macgregoriae* [*see top illustration on page 40*].

female cannot be told apart except by dissection. The transferral effect seems to be operating in this case too.

It appears that once the female has selected a bower-owner she stays for several days. (This has also been reported in some arena birds, such as the argus pheasant.) These stays may be responsible for the assumption made by many investigators that there is a pair bond in bowerbirds. Pair-bonding cannot be proved or disproved except by marking and observing females; my investigations indicate that at least most of the bower-building bowerbirds are polygynous, with exploded arenas like those of their close relatives, the birds of paradise.

One further observation bearing on the transferral effect should be mentioned. In the Finisterre Mountains of New Guinea I watched and filmed the courtship behavior of the fawn-breasted bowerbird (*Chlamydera cerviniventris*), in which both sexes are an identical drab brown. When a female entered the two-walled avenue bower and squatted on the floor, the male immediately approached. On the ground several feet from the bower the male suddenly appeared to be overcome by a spasm. Its head seemed to turn involuntarily away from the female again and again. Finally the bird appeared to regain control, seized a sprig of green berries in its bill, faced the female and waved the berries up and down as it slowly approached the bower. I saw several more such visits by a female, and each time the male went through the curious twisting motions that presented the back of its head to the female.

Later, watching the films I had made of these movements, I was struck by the thought that the head-screwing might constitute crest display—except for the fact that *C. cerviniventris* has no crest! But many males closely related to this species do have glittering violet-to-pink crests at the nape of the neck and the Australian ornithologist John Warham has described how they twist their necks to display the crest to a female in the bower. I concluded that the head-twisting of *C. cerviniventris* is a relict movement dating from the time when the species had such a crest. With the later incorporation of the berries as ornaments in the courtship ceremony, I postulated, the crest became unimportant. Since it was now simply a liability in terms of protective coloration, it was lost through natural selection—but the movement associated with it persists. This I consider a strong second line of evidence for the transferral effect.

Again it must be emphasized that the courtship behavior of this species and probably that of all other ground-displaying bowerbirds, even though complicated and camouflaged by refinements of ornamentation and stick architecture, follows the basic pattern of

COURTSHIP BEHAVIOR of avenue-building bowerbirds is shown in this sequence of drawings. The male builds a walled bower by inserting thousands of sticks into a foundation mat (*left*) and decorates it with pebbles and berries (*second from left*).

arena behavior the world around. It is the behavior of a clan of males interacting in an arena, each on its own territory and competing with the other males for itinerant females. Many arena species clear courts and some do it more effectively than others; some build stages or erect walls, towers or houses. All these actions, I believe, are merely levels of refinement of the same basic behavior.

Is the history of the bower, then, the same as the history of the arena bird's court? I think so. Arena behavior, I suggest, can develop fortuitously at any period in the history of any bird group as a result of a shift in the work load shared by a pair-bonded male and female. The division of labor in nest construction and care and the rearing of the young varies from species to species. In extreme cases the males may be completely released from all nesting duties—perhaps because natural selection favors a stock in which brightly colored males stay away from the nest. Emancipated from the pair bond, the males can live apart from the females in bachelor clans. Now sexual selection can operate freely, tending in the direction of brighter plumage and more complex display behavior that will attract more females.

The next step, from elementary arena behavior to bower-building, may not be so great as it seems at first. I have pointed out that most arena birds clear some sort of display space for themselves. In the species that have come down from the trees to the ground, such as the cock of the rock and some birds of paradise, the males spend much of their time clearing away twigs and leaves and perhaps berries, stones and shells, if there are any about. A. J. Marshall of Monash University in Australia and Erwin Stresemann of the Berlin Natural History Museum have speculated that the handling of these objects may accidentally have become incorporated in and important to the courtship ceremony for which the court is maintained, and so have led to bower-building. I think it likely that both court-clearing and bower-building are deeply rooted in the nesting impulses of the male birds. Nest-building and the actions associated with it by each species constitute fixed behavioral patterns that are not easily abandoned and are more likely to be diverted into new directions. Other investigators have noted actions in arena birds, and particularly in bowerbirds, that reminded them of nesting behavior. V. G. L. van Someren remarked some years ago that in shaping its court the male of the weaverbird species known as Jackson's dancing whydah "creates recesses resembling the early stages of a nest, butting into the grass and smoothing it down with his breast." Edward A. Armstrong commented in his classic book on bird behavior that "this performance would seem to be due to the survival of the nest-building impulse."

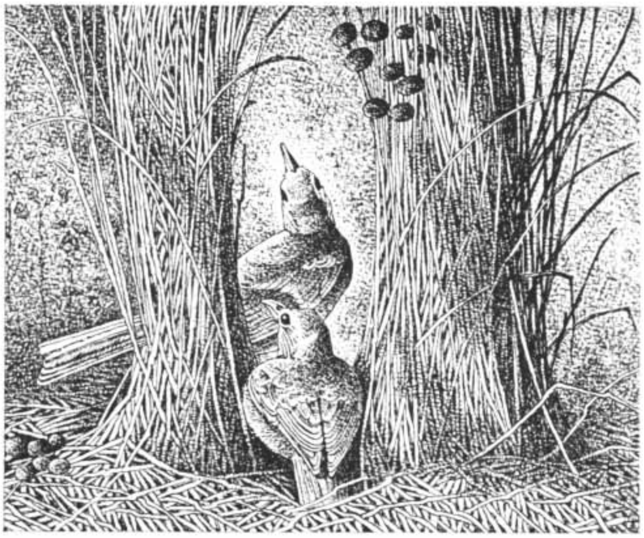
Marshall, a leading student of the bowerbirds, has called attention to many activities he believes stem from displaced nesting habits. Certainly as one looks at a New Guinea stick bower, particularly that of Lauterbach's bowerbird, one cannot but feel it is some sort of monstrous nest. The wall of sticks, the lining of grass, even the way the male places egg-sized berries or pebbles near the center of the basket-like structure—all suggest aspects of nest-building that still survive in males that have had no nesting responsibilities for tens of thousands of years and probably much longer. In other bowerbirds and arena birds this impression of a physical nest is, to be sure, not so vivid. But, as noted in the case of the cock of the rock, I have often been impressed by the male's strangely quiet and attentive manner when it visits its court or bower, a manner that reminds an ornithologist of a parent bird arriving at its nest.

To sum up, I would define arena behavior as courtship behavior reshaped by emancipated males to include their nondiscardable nesting tendencies. I would further suggest that bower behavior has developed in certain arena birds under the influence of natural and sexual selection, that some of the ground-clearing arena birds are even now on the way to becoming builders of bowers, and that the dully dressed bowerbirds that build the most complex and ornamented structures are at the leading edge of avian evolution.

This hypothesis does not in itself explain the great variety and variability of bowers or the complexities of behavior and plumage in arena birds, all of which seem to imply that these birds are evolving at an accelerated rate compared with other birds. The biological advantage of arena behavior may be precisely that it does speed up evolution. Because of promiscuous polygyny a few males in each generation are enough to propagate a species. Losses by predation can be very acute (and indeed must be in the case of terrestrially displaying males), and both natural and sexual selection can operate more severely than usual.

An indication that some such process may be at work is the fact that "intergeneric hybrids," although extremely rare in all animals, are rather more common in arena birds. Since a species—a limb-tip on the avian tree of evolution—is identified as such by its "reproductive isolation" from the other limb-tips, it is difficult to explain even one case of interfertility between genera, the main limbs of the tree. Yet in our collection at the American Museum of Natural History

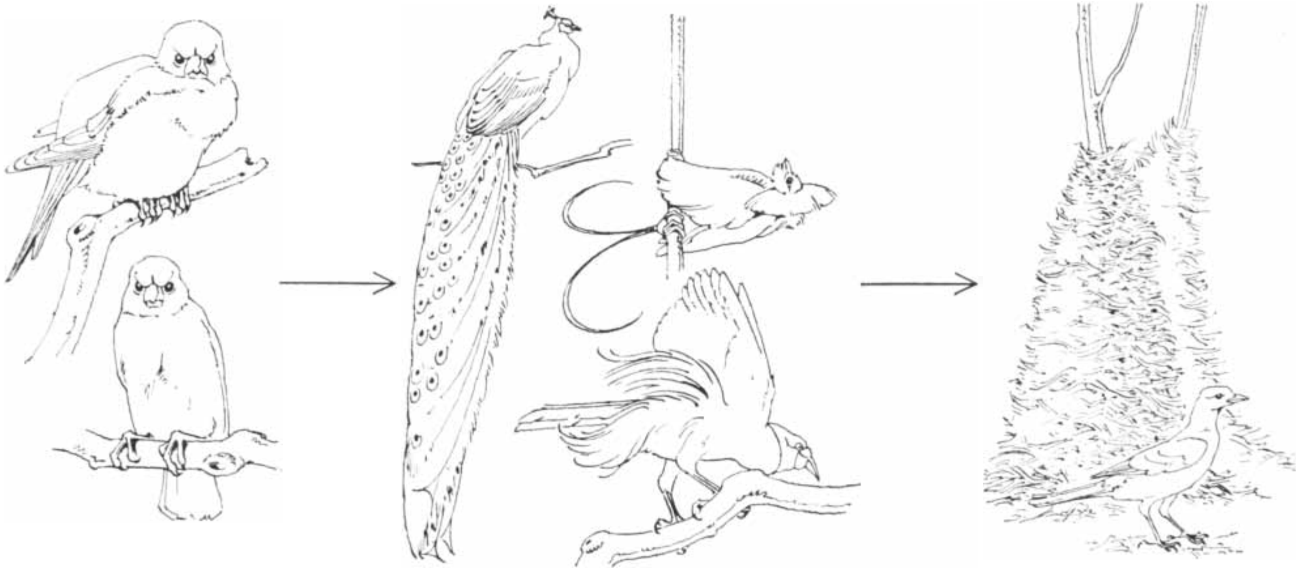
With the male in attendance, a female enters the bower (*third from left*) and, after the male displays, sits on the floor (*third from right*). The two birds mate (*second from right*). Then the female leaves to build a nest and rear her young by herself (*right*).



"TRANSFERRAL EFFECT" is illustrated by a relict head-turning movement in a bowerbird. *Chlamydera nuchalis* (*left*) displays to the female a bright pink crest at the nape of its neck. *C. cerviniventris* (*right*) makes a similar movement although it has no crest. This bird's use of berries as ornaments made the crest unnecessary and it disappeared, but the turning motion persists.

we have no less than 11 adult male intergeneric hybrid offspring of the magnificent bird of paradise (*Diphyllodes magnificus*) and the king bird of paradise (*Cicinnurus regius*), which were long ago classified in different genera. The number of hybrids occurring between these birds leads me to suspect that *Diphyllodes* and *Cicinnurus* may not be nearly so distantly related as their fundamental structures seem to indicate. Perhaps arena behavior, once it takes hold of a species, fashions structural changes (body form) more rapidly than it does genetic changes (reproductive barriers). Such uneven radiation might explain the hybrids between arena birds so different in size, shape and color that any taxonomist would accept them as distinct genera. Is there perhaps a correlation between such birds and the many varieties of domestic dogs, in the case of which man has acted as the agent of rapid selection and has bred such different but interfertile forms as the Pekingese and the great Dane?

This idea is probably premature and may be fanciful. Keeping to firmer ground, it is safe to say that the highly specialized combinations of structure and behavior seen in arena birds argue most eloquently that these birds are evolving at a faster rate than most birds and that this accelerated evolution is due to their behavior. One has only to consider the magnificent plumage of the argus pheasant, the great inflatable bibs of the bustard, the radiant orange paraphernalia of the cock of the rock and the lacy plumage of the birds of paradise to be seized by the notion that some rapidly operating mechanism is directing the evolution of these birds. The same holds true for the even more wonderful arena birds called bowerbirds, with their houses and ornamented gardens and their courtship displays that replace plumage with glittering natural jewelry.



EVOLUTION OF BOWERBIRDS is diagramed here according to the author's hypothesis in highly simplified form. "Ordinary" birds (*left*) develop a pair bond, with a male and female mating and then tending the nest. If that pair bond is broken, there is a breakthrough to arena behavior (*center*) and a consequent proliferation of specialized plumage and courtship behavior. A few arena birds go one step further, to bower-building (*right*). With sexual selection transferred to objects, males may become dully colored.

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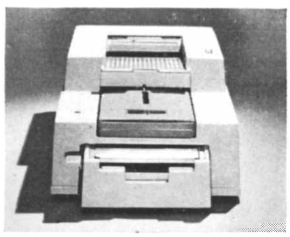

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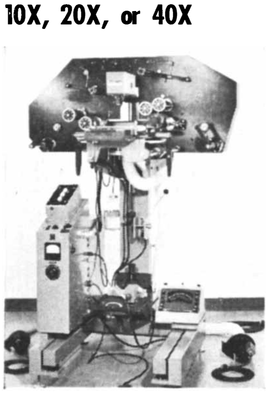

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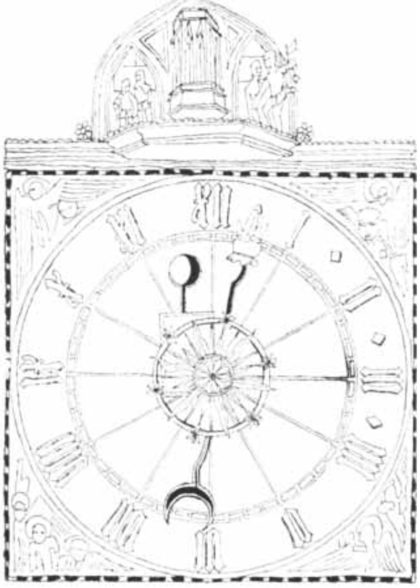


Test Ban and Overkill

As U.S., British and Soviet negotiators assembled in Moscow in mid-July for a renewed effort to negotiate a ban on further testing of nuclear weapons, comments by officials in the U.S. and U.S.S.R. suggested that advances in military technology may have facilitated the task of arriving at an agreement. Unnamed U.S. officials, according to *The New York Times*, have said that the Administration has begun to explore the possibility of curtailing the production of nuclear weapons. In the U.S.S.R. Premier Khrushchev stated that his country had stopped producing surface warships and long-range bombers.

Behind the U.S. discussions lies the belief that the nuclear arsenal may have reached the point of "overkill." As one official put it to the *Times:* "We have tens or hundreds of times more weapons than we would ever drop even in an all-out war." Another official estimated that it might be possible to cut $1 billion from the Atomic Energy Commission's $1.8 billion annual budget for the production of nuclear weapons.

Premier Khrushchev made his disclosure to Harold Wilson, British Labor Party leader, during the latter's recent visit to Moscow. Wilson quoted Khrushchev as saying that the U.S.S.R. had decided to stop making surface warships and long-range bombers "because of their total vulnerability" in the missile age. The plain implication was that Moscow regards itself as adequately armed with submarine-borne and intercontinental ballistic missiles. Earlier this year U.S. Defense Secretary Robert S. McNamara had declared in the same vein that "our forces today could still destroy the Soviet Union without any help from the deployed tactical air units, or carrier task forces, or Thor or Jupiter intermediate-range ballistic missiles."

Doubled Fallout

Nuclear tests by the U.S. and the U.S.S.R. during 1962 doubled the quantity of radioactive debris in the atmosphere. As a result the level of strontium 90 in the U.S. diet this year will rise to 50 strontium units (micromicrocuries of strontium 90 per gram of dietary calcium), a fourfold increase over 1962 and a twelvefold increase over the low reached in 1961 after the moratorium on atmospheric testing.

The forecast was made by the Federal Radiation Council in a summary of atmospheric nuclear tests by the U.S. and U.S.S.R. last year. The U.S.S.R. exploded 39 devices with a total energy yield of 180 megatons; the U.S. set off 36 with an energy yield of 37 megatons. The Soviet explosions were bigger but "cleaner." Only a third of their yield, or 60 megatons, came from radioactive-debris-producing fission reactions, compared with 43 per cent, or 16 megatons, for the U.S. explosions. No immediate threat to health was foreseen, although the council predicted that the amount of strontium 90 deposited in new bone in infants and children would now rise to a quarter of the level set by the council as acceptable.

Supersonic Transports

Stimulated by a 20-month-old British-French plan to build a supersonic commercial jet transport, the Administration has asked Congress to authorize up to $750 million for the development of such an aircraft by U.S. manufacturers. It is felt that the cost of development, estimated at $1 billion, would be too great for private industry. This would be the first time the Government has provided a direct subsidy for the development of a commercial airplane.

Najeeb E. Halaby, head of the Federal Aviation Agency, envisions a 1,500-to-2,000-mile-per-hour transport in operation before 1971. The craft would have a range of approximately 4,000 miles, would weigh 350,000 pounds and would have a payload of 35,000 pounds. It would carry up to 163 passengers and a ton of cargo and mail. In addition, Halaby told a Congressional hearing, the plane should be capable of operating at airports designed for today's jets and should produce no more noise on landing and take-off than the subsonic jets. Halaby believes it will be possible to produce a craft that is faster than the British-French Concorde and to introduce it at about the same time.

The first step in the development of the plane would be a design competition during the rest of this year. Next, the companies that produce the best designs for airframe and engines would spend 1964 on detailed designs; the Government would invest $60 million in this phase. In 1965 the building of the aircraft would start.

Among the difficulties to be overcome, according to Halaby, are the high temperatures that the aircraft will generate in flight: 306 degrees Fahrenheit at Mach 2.2 (2.2 times the speed of sound), 600 degrees at Mach 3 and 882 degrees at Mach 3.5. Here U.S. experience with supersonic military aircraft will be helpful. Two other problems are sonic boom and whether or not supersonic transports are economically sound. (The Government does not plan to offer operating subsidies.) Halaby believes that both problems can be solved.

An airline that wishes to obtain one of the aircraft will have to meet the manufacturer's price and also pay to the Government a royalty and perhaps 1.5 per cent of the revenue produced by the craft for 12 years. If an order for an airplane is placed within six months after the detailed design is completed, the royalty will be $200,000; if the order is placed later, the royalty will be $500,000. The payments to the Government would be applied to amortize its investment in the development of the transport.

Nongenetic Genetic Code?

Evidence is rapidly accumulating that all living organisms use the same "language" in making protein molecules from instructions coded in the giant molecules of DNA (deoxyribonucleic acid). This in turn introduces the surprising possibility that the translation of the genetic code may not be genetically determined. The possibility was put forward by I. Bernard Weinstein of the Columbia University College of Physicians and Surgeons at the recent Symposium on Quantitative Biology in Cold Spring Harbor, N.Y.

The first major step in the decipherment of the genetic code was taken late in 1961 by Marshall W. Nirenberg of the National Institutes of Health, who employed the protein-synthesizing machinery of the colon bacillus in his studies [see "The Genetic Code: II," by Marshall W. Nirenberg; SCIENTIFIC AMERICAN, March]. Nirenberg and other workers, notably Severo Ochoa and his colleagues at the New York University School of Medicine, eventually worked out a "dictionary" in which the incorporation of a given amino acid into the chain of a protein molecule is related to a genetic code "word" (or words). The words, or codons, are sequences of the chemical units called bases found in "messenger" RNA (ribonucleic acid), the molecule that transcribes the genetic code from DNA and carries it to the site of protein synthesis. Each of the 20 amino acids is specified by at least one codon, and most of the amino acids are specified by more than one. This causes no confusion, however, in the construction of proteins. It simply means that messenger RNA can use more than one "word" in calling for a particular amino acid. Each of the 20 amino acids is delivered to the site of protein synthesis by a specific form of "transfer" RNA, which must perform a dual function. It must recognize both an amino acid and its particular codon, thereby bringing about the pairing specified in the code-word dictionary.

It is generally believed that the codons are sequences of three bases, but this has not been fully established. There are four bases: adenine, uracil, guanine and cytosine. Taken three at a time, the four bases can be arranged in 64 different combinations. In the colon-bacillus system more than 40 of the 64 possible codons have now been found to have a meaning, that is, to specify the incorporation of some amino acid.

From the outset of the coding work it was a matter of great interest to discover whether or not a given codon would have the same meaning in an organism other than the colon bacillus. It was generally thought that the dictionaries would differ among species and that the difference would be greater the greater the evolutionary gap between organisms.

At Cold Spring Harbor, Weinstein reported results in protein-synthesizing systems obtained from several kinds of cells, including the protozoon *Chlamydomonas*, rat liver cells and mouse tumor cells. All the amino acids tested so far (six) are identified by the same groups of codons in all the systems.

If the code is indeed universal, as these and other results suggest, it implies that it has been fixed throughout most of organic evolution, in other words, that it is not subject to mutation. This may mean either that no change can produce an improvement, which seems rather unlikely, or that transfer RNA's can make only certain fixed associations. It had been thought, for example, that a transfer RNA that delivers amino acid A to codon *A* in the colon bacillus might in another species, as a result of genetic modification in the transfer RNA, deliver amino acid A to some other codon, say codon *D*. If such a modification cannot take place, the pairing of amino acid and codon must be subject to constraints for which there is no provision in present theory.

Plant-Human Virus Family

A virus that infects plants has been shown to be closely related to a virus that infects human beings. The plant virus is the wound-tumor virus, which causes a tumor to grow at the site of a wound on a previously infected plant. The human virus is a reovirus, formerly known as the ECHO Type 10 virus, an agent of infection that causes upper respiratory and gastrointestinal diseases.

Immunological studies showing that the two viruses share certain antigenic characteristics established that they are closely related, although not identical. The work was done by Gert Streissle and Karl Maramorosch at the Boyce Thompson Institute for Plant Research in Yonkers, N.Y. The study was suggested by André Lwoff and his associates at the Pasteur Institute in Paris, who observed that the plant virus and the reovirus bear a strong structural resemblance to each other. It has since been found that the genetic material of both is ribonucleic acid, not deoxyribonucleic acid.

It has been known for some time that certain viruses can infect both plant and animal cells. Insects often carry such viruses from plant to plant [see "Friendly Viruses," by Karl Maramorosch; SCIENTIFIC AMERICAN, August, 1960]. The wound-tumor virus infects several species of plants and at least three species of leaf hoppers.

In their paper in *Science* Streissle and Maramorosch say that the discovery of the close relation between the reovirus and the plant virus will have "far-reaching implications in the study of virus reservoirs, virus survival in nature, fundamental aspects of virus-host interactions and in public-health problems." Maramorosch and his associates are now investigating the possibility that the plant virus can infect mice, perhaps causing tumors. They are also trying to find out if the reovirus can infect plants, either by direct injection or through an insect vector.

Primordial Adenine

Adenine, one of the celebrated four repeating subunits of DNA and RNA, has been made from simple starting materials under experimental conditions approximating those believed to have prevailed on the earth four billion years ago. The synthesis, accomplished by a group of workers at the University of California at Berkeley, shows how a key constituent of the genetic material might have originated on the primitive earth and thus fills an important gap in efforts to reconstruct the origin of life. Adenine is also a subunit of compounds involved in the energy-yielding reactions of the cell: adenosine triphosphate (ATP), triphosphopyridine nucleotide (TPN) and coenzyme A.

The synthesis was carried out by bombarding a mixture of gases—methane, ammonia, hydrogen and water vapor—believed present in the primitive atmosphere with electrons from a 4.5-million-volt linear accelerator. Electrons with comparable energies are released by many natural radioactive elements. Chromatography and other analytical techniques confirmed the appearance of adenine in the irradiated mixture.

The experiment was performed at the Lawrence Radiation Laboratory of the University of California by Cyril Ponnamperuma, Ruth Mariner, Richard M. Lemmon and Melvin Calvin and was reported in *Proceedings of the National Academy of Sciences.* In 1951 Calvin, who in 1961 won a Nobel prize for his work on photosynthesis, and several colleagues initiated modern experimental investigation of the origin of life by exposing a primitive-atmosphere mixture to alpha particles from a 60-inch cyclotron. The irradiation yielded simple organic compounds such as formic acid, malic acid and lactic acid. Two years later Stanley L. Miller, working under Harold C. Urey at the University of Chicago, synthesized amino acids with a laboratory analogue of a lightning storm on the primitive earth: an electric discharge passed through the primitive-atmosphere mixture. Numerous other biological molecules, including fatty acids, hydroxy acids and amines, have since been produced by similar procedures. In all these experiments the yield of biological molecules is small. Calvin and his associates note, however, that adenine is resistant to destruction by radiation and could have accumulated on the surface of the earth until enough of it was available for the synthesis of more complex molecules.

Parched Planet

The first direct proof that the atmosphere of Mars contains water vapor has been secured with a large spectrograph and the 100-inch telescope on Mount Wilson, with an assist from nearly perfect atmospheric conditions. The observation also demonstrated why the Martian water vapor has been so difficult to detect: its concentration is between 1,000 and 2,000 times lower than that of water vapor in the atmosphere of the earth. Indeed, if all the water vapor in the atmosphere of Mars were to condense, it would cover the planet with a film of water only a three-thousandth of an inch thick.

The observation was reported in *The Astrophysical Journal* by Lewis D. Kaplan and Hyron Spinrad of the Jet Propulsion Laboratory of the California Institute of Technology and Guido Münch of the Mount Wilson and Palomar Observatories. The measurements were made by projecting a magnified image of Mars, formed by the telescope, into the spectrograph. The infrared portion of the spectrum revealed absorption bands for water vapor and carbon dioxide in light passing through the Martian atmosphere. The Martian bands could be distinguished from those due to water vapor and carbon dioxide in the earth's atmosphere because the earth was moving away from Mars at the time. This produced a Doppler shift in the Martian bands and separated the two sets of spectra.

The spectra also revealed that the concentration of carbon dioxide in the atmosphere of Mars is considerably higher than has been thought. As on earth, the carbon dioxide participates in the "greenhouse" effect: it passes the light that enters the atmosphere but traps the reradiated infrared wavelengths. Although this slightly warms the Martian atmosphere, its maximum temperature at the equator is 70 degrees Fahrenheit. The new observations reinforce the view that if life exists on Mars, it does so under the extreme conditions of a cold, dry desert.

IDEALIZED PORTRAIT of Chingis Khan was made by a Chinese artist sometime after China overthrew the Mongol rule in 1368. The painting, which hangs in Peiping, is reproduced from a photograph owned by L. Carrington Goodrich of Columbia University.

Chingis Khan and the Mongol Conquests

The storied conqueror of the steppe was no simple savage warrior. He manipulated tribal politics to organize the nomad world before launching his light cavalry against the citadels of civilization

by Owen Lattimore

In the year 1240 Matthew Paris, a monk of St. Albans near London, recorded in his *Chronica Majora* testimony of Europe's dread of the Mongol cavalrymen who were then ravaging the settlements and cities of Russia. It was said that the Mongol horses were so huge they ate branches and even trees and the Mongols had to carry around three-step ladders in order to mount the beasts. In 1242 the chronicler got hold of a letter from an unnamed bishop in Hungary, whose country the Mongols had now overrun. The bishop was able to give a more accurate account of the Mongol remount system: "Many horses follow them, entirely without being led, so that if one man is riding, 20 or 30 horses follow him." This was the system that gave the Mongol invasions their wide-ranging rapidity. The bishop's report also indicated that the Mongol cavalrymen were still riding the tough little horses with which they had started from faraway Mongolia and were not dependent on local remounts.

Down to the very present two themes, foreshadowed in these reports, have never been disentangled in attempts to explain the Mongol conquests of the 13th century. On the one hand, they were a convulsion of nature, a manifestation of the wrath of God; the name Tatar, by which the Mongols were known for centuries in Russia, became "Tartar" in Europe, from Tartarus, the Latin name for Hell. This theme has been resurrected most recently by Arnold Toynbee; in his *A Study of History* Toynbee attributes the irruption of violence from Asia to a supposed period of climatic desiccation, in which the drying up of the pastures forced the Mongols into migration and conquest. On the other hand, the "great man" theories of history have tended to explain the whole Mongol outburst by clothing Chingis Khan, the first in this line of conquerors, in a kind of "cult of personality." Even B. Ya. Vladimirtsov, the Soviet scholar who pioneered the sociological analysis of the primary source materials, summed up Chingis Khan as "a savage of genius."

The persistent mystification of history as written in the West may perhaps be explained by the fact that the Mongols disappeared from Europe (although not from Russia) as suddenly and inexplicably as they had come. In 1241 they had won a great battle at Liegnitz, in the present Oder-Neisse territory of Poland, against forces that included the heavily armed knights of the Teutonic Order. They had despoiled Hungary and Bohemia and sent raiding columns into Austria and the Balkans. Then the news reached them of the death of Ögedei, the son and first successor of Chingis Khan. The Mongol commanders immediately turned around and rode home to Mongolia. For them a new conquest was something they could organize at any time; they had not met any troops they could not beat. The election of a new khan was urgent business, however, demanding the presence of all the great men.

The West was again saved in 1260. In that year the Mamelukes of Egypt defeated a "Mongol" army by the shores of the Sea of Galilee. Although this has been celebrated as a feat of arms, the truth is that the Mongol army was far below strength and was composed mostly of Turkish auxiliaries. Its commander, Hülegü, a grandson of Chingis Khan, had already turned back toward Mongolia with his best troops on learning of the death of Möngke Khan, the third in succession from Chingis Khan.

It was at this moment that the great Mongol conquest-empire began to break up into a cluster of states: the Golden Horde that held the Russian kings and princes in vassalage until 1487; the House of Chaghadai in Central Asia; the Il Khans, of whom the first was Hülegü; and the Yüan dynasty of China. The decisive moment came in 1260, when Qubilai Khan decreed that his capital would be at Peking in China instead of at Kharakhorum in Mongolia. The Mongol domains then ceased to be centrally controlled from Mongolia, and there was never a new, concerted drive toward the West.

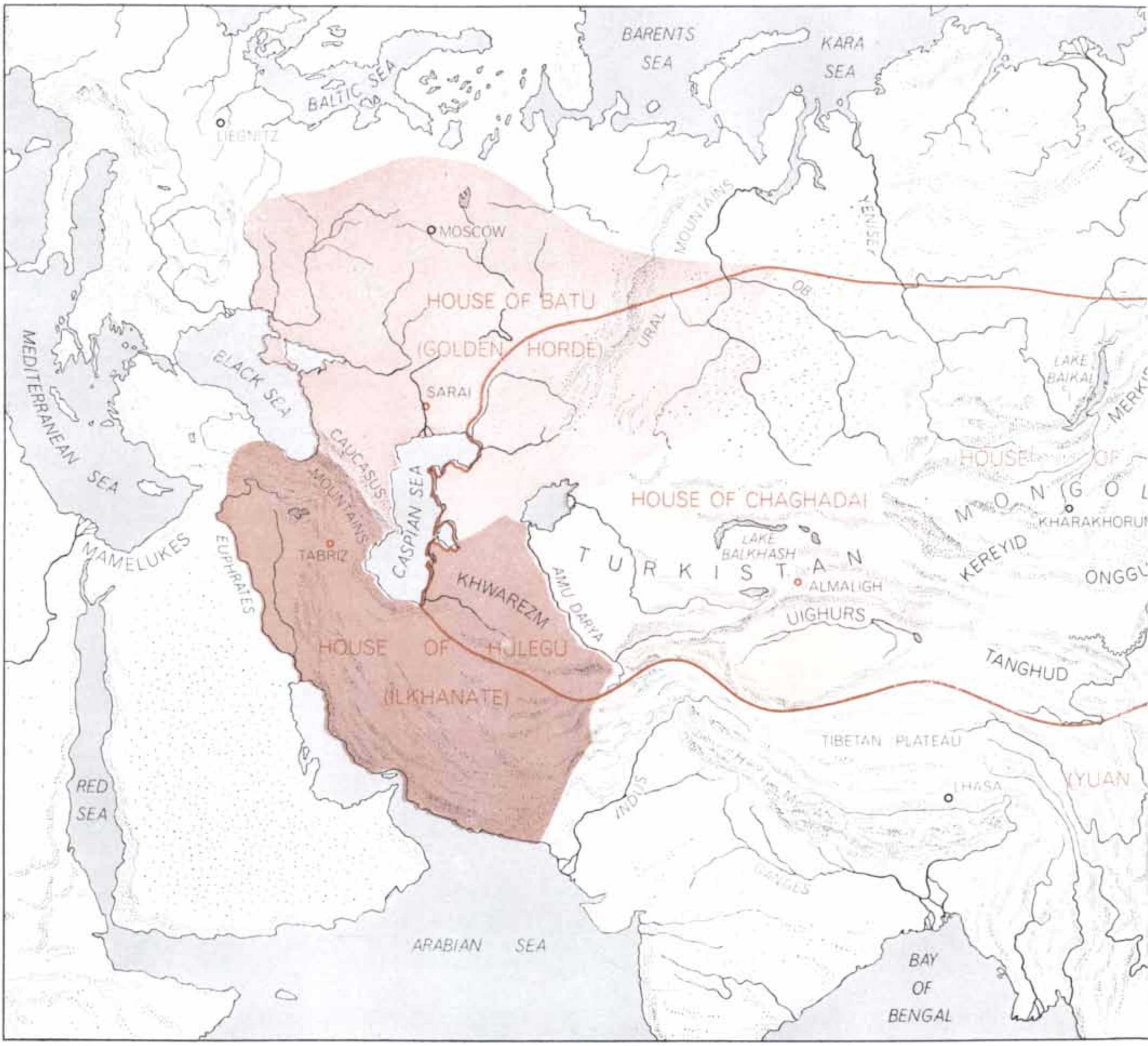
The Historical Record

Since Europe had done nothing to bring about these changes, it is no wonder Europe did not understand what it was all about. The Middle East knew more. Persian historians, such as Juwaini in the 13th century and Rashīd al-Dīn in the 14th, served as high officials under the Mongol sovereigns. Juwaini visited the Mongol capital at Kharakhorum. Both he and Rashīd al-Dīn knew the Mongol language and had access to written records, now lost, in the libraries of their royal patrons. Moreover, a large part of their Moslem world had been ruled by Turks of nomadic origin before the Mongols came and conquered both Turks and Persians. They understood the tribal politics of the great steppe world of the nomads, stretching from southern Russia to Manchuria, in its interaction with the politics of the civilized states to the south.

In addition to what the Moslem historians have preserved, parts of the original Mongol record are quoted, paraphrased or reflected in Chinese sources, and there is material also in Tibetan chronicles and relatively later Mongol ones that contain excerpts from earlier documents now lost. At the very heart of the tradition stands the noblest survivor of them all: the *Secret History of the Mongols*. It was written down in Mongolia in 1240, when many who had served under Chingis Khan were still alive. It survived, however, only in a version transcribed in Chinese characters together with two Chinese translations, one following the Mongol word order and the other written in conventional Chinese. Because a Chinese "character" represents a Mongol sound only approximately, and because many of the sounds in both languages have changed in the intervening centuries, the restoration of the Mongol text calls for the skills of a code-breaker as well as those of a philologist [*see illustration on page* 68].

This unique crossword puzzle was rediscovered in Peking less than a century ago by the Russian Archimandrite Palladii. Since then scholars of many nations—Russia, China, Japan, Turkey, Germany, France and Belgium—have worked and reworked the material. One of the most valuable editions is a rendering from medieval Mongol into modern Mongol by Ts. Damdinsüren. The conspicuous gap has been the lack of an English edition; this is now being bridged by Francis Woodman Cleaves of Harvard University, whose work is awaited nowhere more eagerly than in Mongolia itself.

The word "secret" in the title shows the influence of China, where it was the custom to keep "classified" records, setting down the discreditable incidents and details as well as conduct more appropriate to imperial dignity. Emperors



MONGOL CONQUESTS of the 13th century are mapped. Chingis Khan began by unifying the tribes in the area labeled Mongolia. The extent of his empire is shown by the heavy colored line. His successors pushed on to the west and the south, as shown by the colcould thereby be recalled to proper humility and made to ponder how much their predecessors owed to the favor of heaven—a heaven that might withdraw its mandate and let the dynasty fall. Thus the *Secret History* records that when Chingis Khan was a boy he joined with one of his brothers to murder one of his half-brothers. It also records the suspicion that the eldest son of the conqueror was a bastard, begotten when the conqueror's bride Börte was for a time the captive of tribal enemies.

The great lesson to be learned from the *Secret History* and the related source material is that the career of Chingis Khan was the recognizable outcome of an intelligible historical process. Chingis Khan was a genius but not a savage; illiterate but not ignorant. He was born into a tradition that embraced war as a profession and also included a sophisticated knowledge of the political and economic uses of power. All his natural talent would not have got him very far, however, if he had not been born into this tradition at a propitious moment and in just the right geographical region.

ored areas. The Mongol domains split into four separate empires beginning in 1260.

Chingis Khan had a clear idea of the structure of power in his time. The backbone of that structure in the politics of the nomad tribes on the frontier of civilization was supplied by the system of blood relations of the extended patrilineal kinship system that, among the nomads, had replaced the matrilineal system found so universally among the preagricultural peoples of the world [see "Primitive Kinship," by Meyer Fortes; SCIENTIFIC AMERICAN, June, 1959]. This kinship system also supplied the occasions for blood feuds that sharpened the mettle of the nomad warriors in recurrent fratricidal wars. Across tribal alliances and tribal feuds alike there lay the shadow of great-power politics. Alliances by marriage and by oath were counterpoised against blood feuds and the inherited duty of revenge, and both were manipulated by whatever dynasty happened to be ruling the seats of settled agricultural civilization in China on the other side of the Great Wall.

Some of the tribes fighting one another out on the steppe were always available for service in the defense of the imperial frontier. This was exactly the Roman formula of *Divide et impera*. The Chinese put it just as succinctly: *I i chih i*—"Use barbarians to control barbarians." When the formula worked, it worked very well indeed. When it failed, the seats of civilization in China came under the domination of a new dynasty established by barbarian conquerors.

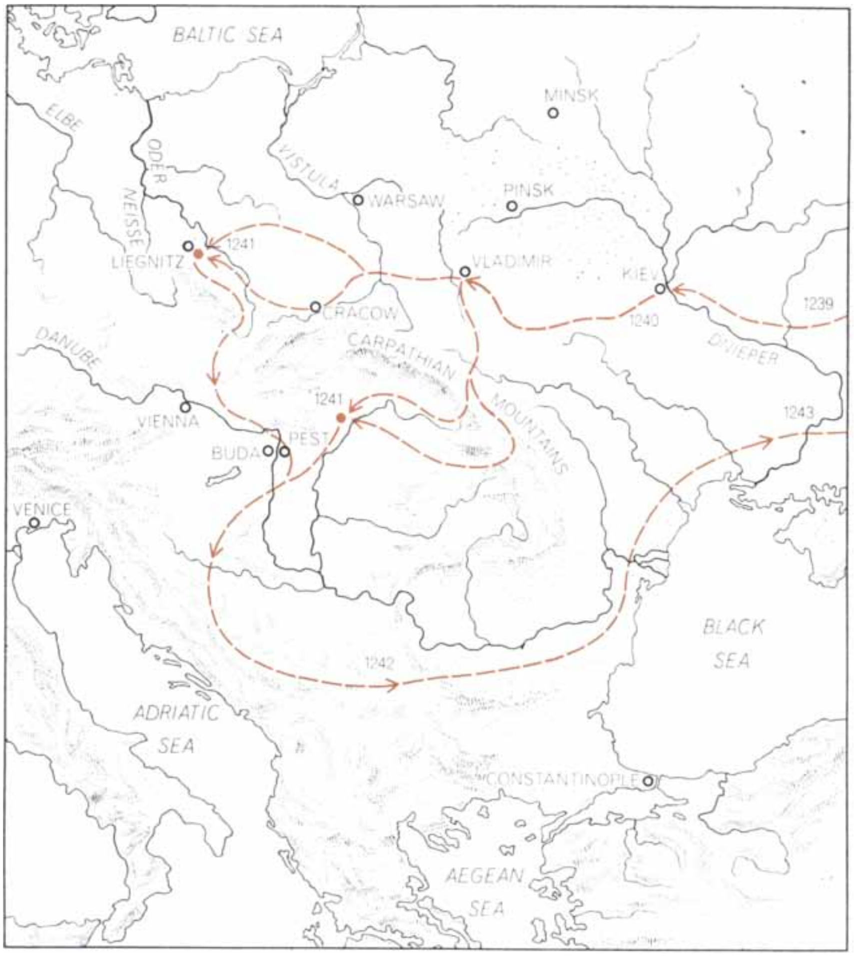
Thus in 937 the Khitan tribe had established a dynasty that held sway in northern China for nearly 200 years. This dynasty is known in Chinese history as that of the Liao. The tribal name Khitan explains why Marco Polo called northern China Cathay and why the Russians, Mongols and others still use one or another variant of the name Khitan. In the decade 1115 to 1125, half a century before the birth of Chingis Khan, there came another "time of troubles," when the Khitan were overthrown by a tribe called the Jurchid, which took the Chinese dynastic name of Chin. On each occasion the new dynasts inherited the problems and techniques of the old and turned to holding the frontier by setting tribe against tribe.

The *Secret History* is packed with indications that Chingis Khan comprehended the theory, propounded in the 19th century by the Prussian general Karl von Clausewitz, that "war is the continuation of policy by other means." To become attached to the frontier service of a great empire was to gain an illusion of power. Those attached to the frontier could always be attacked from the front by the great power and from the rear by rival tribes. For a man born on the steppe the only true road to power was first to unite "all the people of the felt-walled tents" and then to turn against the civilized states. Both the ancestors of Chingis Khan and their rivals had made the mistake of leaving nomad powers in their rear. He would never do that.

Chingis Khan left the conquest of northern China to subordinate generals and the conquest of southern China eventually to his grandson Qubilai Khan, whereas he himself relentlessly sought out and brought under his control every nomad tribe all the way to the Dnieper River in the southern plains of Russia. Even his conquests of the rich oases and cities of Khwarezm (modern Uzbekistan) on the northern edge of Persia were secondary to his conquest of the rulers of nomad Turkish origin who had until then ruled them. His principle, from which his successors departed (but less in Russia than elsewhere), was to stay outside "civilization," exact tribute and maintain a cavalry army of nomads to enforce it. Although he transformed the tribal institutions to the service of his imperial, feudal aims, he anchored his power in the self-sustaining and self-renewing vitality of the nomad culture from which he sprang.

The Early Life of Chingis Khan

Chingis Khan was probably born in 1167, the son of Yesügei Baghutur, chief of the minor Kiyad tribe in northeastern Mongolia. At the moment of his birth his father was returning from a revenge campaign against the numerous and powerful Tatars. The Tatars were also Mongols, but the name "Mongol" remained to be established as a collective, all-inclusive tribal name by the ultimate triumph of the future Chingis Khan. Typically the occasion for this blood feud had been supplied a generation earlier, when the Tatars had betrayed a Mongol chieftain to the imperial Chin dynasty. Yesügei had captured a Tatar chief, Temüjin, a name that means



TWO BATTLES in 1241 (*colored dots*) in which the nomad cavalrymen defeated heavily armed knights were the high points of a four-year foray into eastern Europe some 15 years after Chingis Khan's death. The Mongol commanders swept on through the Balkans. Then, on receiving word of the death of Ögedei Khan, they suddenly turned and rode for home.

"ironworker." (This is the origin of the legend that Chingis Khan himself began life as a smith.) On reaching camp he found that his wife had given birth to a son. Following an ancient custom he gave his son the name of the captured chief: the "virtue," or strength and courage, of the killed or captured enemy was supposed to pass on to the newborn son.

When Temüjin, the future Chingis Khan, was only eight years old, he was betrothed to Börte, daughter of a chief of the Onggirad tribe, and was left to grow up in her father's camp. Börte was several years older than Temüjin, as was quite common. It was assumed that an aristocrat, if he became a successful war leader and tribal chief, would later have other wives and concubines, but it was considered a good thing for the first wife to be a few years older. She would reach puberty earlier, would be ready to initiate her husband sexually and also be able to guide and counsel him in worldly matters.

No later favorite ever displaced Börte as Temüjin's trusted adviser. His love for her is described in the passage of the *Secret History* that tells how, after she had been captured from him and given to another man, Temüjin and his allies made a night attack on the camp of the Merkid, her captors. She was being carried away in a cart, but "Temüjin went seeking her in the midst of the panic-stricken people, calling out 'Börte, Börte!' And Börte, in the midst of the panic-stricken people, hearing and recognizing the voice of Temüjin, jumped down from the cart . . . came running, and caught the reins and halter-cord of Temüjin's horse. In the moonlight night Temüjin looked, saw that in truth it was Börte, and caught her to his breast."

Marriage had a great deal to do with politics. Under the Mongol system a man could not marry a girl whose father was descended from the same clan ancestor as his own father. He could not marry a girl cousin who was the daughter of one of his father's brothers, but he could marry one who was the daughter of one of his mother's sisters (if that mother's sister had not been married to one of his father's brothers). In this way marriage alliances grew up. Generation after generation Clan B would give its daughters in marriage to the sons of Clan A, but it could not take the daughters of these women as wives for its own sons, because this was called "the mother's flesh returning to the mother's clan" and was considered incestuous. Clan B therefore had to look for wives from Clan C or Clan D, so that the circle of marriage alliance included more than two clans or tribes.

On the other hand, marriage also led to war, because if a man captured a woman who was betrothed or married to someone else, it was the duty of that man's tribe to back him up in taking revenge. Temüjin's father, in fact, had captured the bride of a Merkid, and in the next generation the Merkid captured Temüjin's bride!

Mongol Feudalism

Contemporary Mongol historians regard the early career of Temüjin as "progressive" in the Marxist sense because, they say, feudalism is a higher form of organization than a loose dispersion of eternally warring tribes, and Temüjin imposed a feudal unity on all the Mongol tribes. In doing so he had to undermine, destroy and replace many tribal institutions. One of these was the oath of *anda*, a form of "naturalization" by which warriors were sworn to alliance with one another as if they were descended from a common ancestor. There was pressing need for such devices when chronic war and feuding were constantly upsetting the standards of theoretically "pure" blood loyalty. By the oath of *anda* young Temüjin was sworn to one of his earliest close and powerful allies, a chief named Jamukha. Artificial blood brotherhood, however, like true brotherhood, introduced questions of seniority and standing that in military alliances sometimes clouded the title to leadership. In a later contest for leadership Temüjin and Jamukha were to become bitter enemies. For his purposes Temüjin found the institution of *nükür* more useful than that of *anda*. The word *nükür* means "friend," and Mongol Communists now use it in the sense of "comrade." In Temüjin's time it meant a warrior who freely declared himself "the man" of a chosen leader, even to the repudiation of his own tribe or origin. The loyalty of a *nükür* was thus unmistakably chivalric, if not feudal. Temüjin, when he became Chingis Khan, used his *nüküd* (plural of *nükür*) as generals and governors; he could trust them more than his own relatives.

Temüjin acquired his first *nükür* when he was still only a boy. Raiders had stolen the small herd of horses belonging to Temüjin's family. The only one left was a horse that one of Temüjin's brothers had taken to go hunting marmots. When he returned, Temüjin took the horse and set out to track the horse thieves. Far from home in strange country he encountered a youth named Bo'orchu and asked him if he had seen the stolen horses. Not only had Bo'orchu seen them but also on the spot he gave Temüjin a fresh mount, volunteered to accompany him and declared himself Temüjin's *nükür*. Stressing this new loyalty, the *Secret History* says that Bo'orchu did not even stop at his own camp to tell his father he was leaving; the new loyalty superseded even filial piety. In a later, embellished version of the story, a further symbol is added: When Temüjin asks about the stolen horses, Bo'orchu thinks his manner is too haughty and angrily challenges him to wrestle. Temüjin throws him and Bo'orchu, getting up, says that he has never before met his match at wrestling and declares himself Temüjin's *nükür*. The two boys ride on and recover the horses, and Bo'orchu refuses all reward—he is not a mercenary but a free-sworn *nükür*.

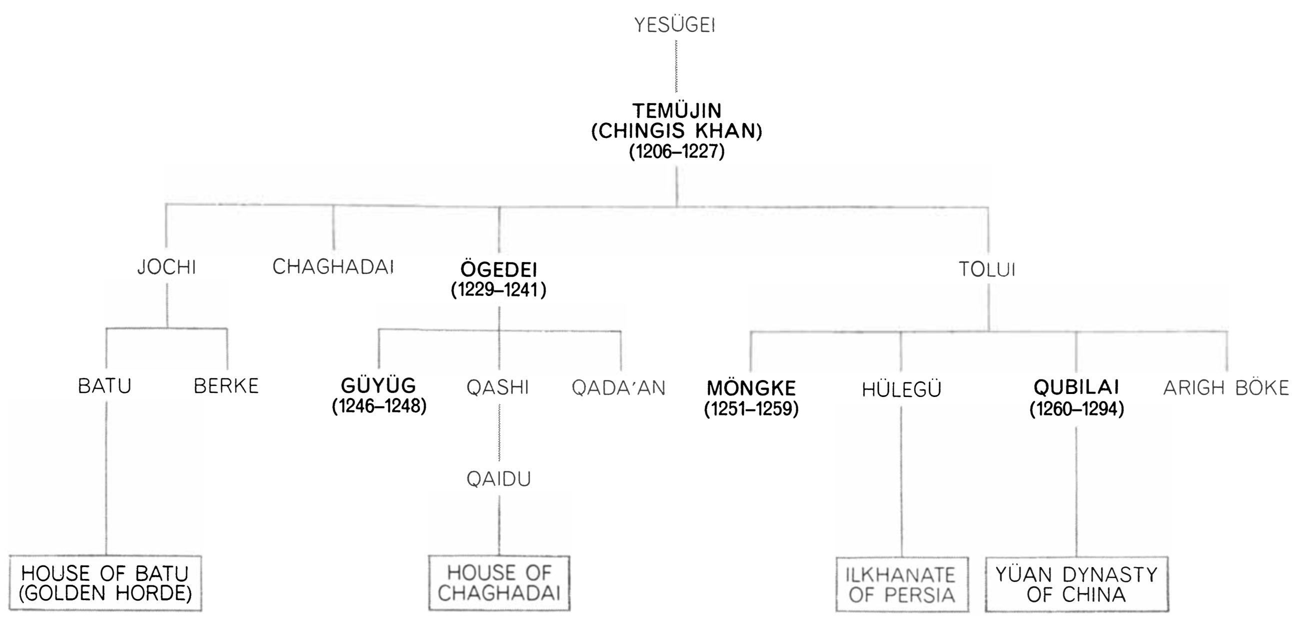
The history of two other institutions reflects the methods by which Temüjin made himself Chingis Khan. One was tribal in origin but was easily and advantageously incorporated into his emergent feudal system. The other was so purely tribal that it had to be destroyed in order to make a feudal system possible.

The first was the subordinate tribe. Such tribes have been called "slaves," but this is a mistake. They were not "property." They were collectively under the protection of and simultaneously exploited by a stronger tribe. They could own property consisting of cattle and horses; they had their own clans and families, and their daughters could marry "upward" into the patron tribe. Their chiefs, of course, were not on the same footing as the chiefs of ruling tribes, but they had a kind of headman status. Although some subordinate tribes had been conquered and forced to submit, others sought the protection of an overlord of their own accord.

The existence of a margin of choice is interesting. Undoubtedly in medieval Europe too some men were reduced to serfdom by force, whereas others became serfs as a way of seeking protection in the incessant feudal wars. There is a great difference, however, between peasants and nomads. If a peasant serf tried to run away from an oppressive lord to seek the protection of someone with a better reputation, he had nothing to offer. He could not carry with him his plow and other farming tools. Everything favored a gentleman's agreement among the lords to return one another's runaway serfs. Nomad "serfs," however, if that is the right word for them, were in charge of four-footed property. In a well-organized escape they could take livestock with them. Most tempting of all, they could offer themselves to a new lord. If they had horses fit for military use, he might well decide not to send them back to their old lord.

Maintenance of the integrity of the subordinate tribe helped to block defection. Its members collectively and its headman individually could be made responsible for mutual loyalty. The conditions of life, however, sometimes made this safeguard ineffective. In fluid, rapidly moving nomadic warfare there were times when the subordinates could tip the scale by abandoning a detested lord and going over to an admired new leader. The *Secret History* shows that Temüjin knew this. He was once captured by his kinsmen and bitter enemies, the Tayiji'ud. He hit his guard on the head, escaped and (leaving out some of the exciting details) took refuge with a man who was a kind of subordinate headman under the Tayiji'ud. This man had decided "by the fire in his glance and the radiance of his face" that Temüjin was a coming leader, and so he was willing to take risks. He hid him in a cartload of wool, and when the searchers came and started to prod the wool he said casually: "On a hot day like this, anybody would suffocate under all that wool." The searchers agreed and left.

Temüjin got back safely to his own people. Later he fought an indecisive battle with the Tayiji'ud. The two sides camped on the field. Everything depended on whether, when the fighting began



GENEALOGICAL TABLE traces the house of Chingis Khan. The rulers of a united Mongol empire are shown in bold type, together with the dates of their reigns. When Qubilai moved his capital to Peking from Mongolia, the empire broke up into four domains.

TEMÜJIN, having triumphed in a series of tribal wars, is proclaimed Chingis Khan, "all-encompassing lord," in 1206. He is seated on a throne before his tent. At the left are three of his sons: Chaghadai, Ögedei and Jochi. This illustration and the next two are reproductions of prints in the *History of the Mongols*, by the great Persian historian Rashīd al-Dīn.

IMPERIAL AUDIENCE is depicted in this print. Chingis Khan (*seated*) is receiving homage from tribal leaders, one of whom prostrates himself and grasps the emperor's sleeve.

again, someone on one side or the other would lose heart. With fate in the balance, Temüjin's liberator deserted the Tayiji'ud and came over to Temüjin. "Why not sooner?" Temüjin asked him. "In my heart," the man replied, "I recognized you as my lord. But why hurry? If I had moved too soon, my lords the Tayiji'ud would have scattered like ashes my wife and sons, my herds and possessions, that I would have had to leave behind." In other words, it required nerve and good timing to elude the obligations of collective responsibility imposed by the institution of the subordinate tribe. To this explanation Temüjin laconically replied: "*Dzöb*" ("Right").

The tribal institution that Temüjin had to destroy, on the other hand, in order to create a new kind of imperial-feudal unity was that of the double tribe, or, to use later Mongol terminology, "right hand" and "left hand." Among those who may be called in anticipation the "Mongols proper" the main division was between the Tayiji'ud and the Borjigid line, to which Temüjin belonged. Each of these had many subdivisions down to the closest kinship groups, such as Temüjin's own Kiyad clan. Among the Tatars, with whom Temüjin had a hereditary blood feud, there was also a main double division with many subdivisions. In tribal mythology and genealogy such divisions were typically accounted for as lines of descent from two brothers.

The same structure and the same problems existed in the West. Romulus and Remus were brothers—and let us not forget that Romulus killed Remus. There is a key to the explanation in the fact that in the later Roman system there were two consuls. If one consul was away on a campaign, the other had to be in Rome. This suggests that the original structure of the Latin tribes alternately assigned half of the tribe to a tour of duty for war and protection, and the other half to production, by farming or herding as the case might be. It is easy to see how antagonisms could arise ("We did a better job of protecting you than you did when it was your turn"). In the case of Temüjin the leadership had belonged to his line until the death of his father, when the other line, the Tayiji'ud, tried to take over. This illustrates a problem inherent in the system. There had to be a supreme command. Normally it alternated between the two, but inevitably there was a tendency to usurp and dominate.

In his feud against the Tayiji'ud, Temüjin for a while set up an alternative two-line alliance with Jamukha, his brother by the oath of *anda*. The breakup

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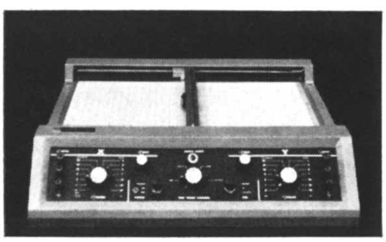

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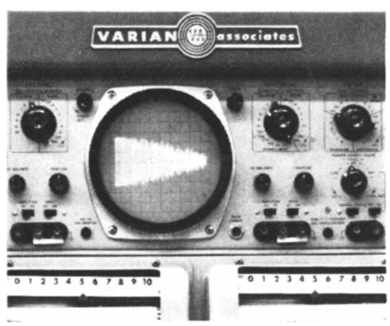


of this alliance shows what was involved in nomadic warfare, which demanded more than normally frequent movement of the herds. Moving the herds too often and too far wore them down and weakened the economic strength of the tribe. There were bound to be crises of leadership. Had the tribe won enough victories to make it safe to rest for a while and build up the condition of the flocks and herds? Or was it necessary, even at the cost of weakening them, to win a few more battles?

The break between Temüjin and Jamukha is described in the *Secret History* as follows: One day on the march Jamukha said to Temüjin: "Let us camp near the hills and there will be tents for the horse-herders. Let us camp near the stream, and there will be food for the shepherds and the watchers of the lambs." Temüjin, without answering, dropped back toward the end of the line of march, where the carts with the womenfolk were coming along, and started to ask his mother if she could guess the meaning of this riddle, but before she could answer Börte broke in—a mark of the "un-Oriental" independence of women among the nomads. She said that the question boded no good; they must break with Jamukha immediately; instead of camping with him that night they must march on through the whole night. This they did, and a new feud began, to end only when Temüjin—who by then was Chingis Khan—sentenced Jamukha to death.

This passage was the occasion for controversy between Vladimirtsov and his colleague V. V. Barthold. Both these distinguished scholars lived their formative years in the tsarist period, but both published some of their most important work in the Soviet period. The issue that divided them was whether or not favoring the warriors—that is, the horsemen—would be more "feudal" and favoring the shepherds more "democratic." Damdinsüren, one of the greatest of living Mongol scholars, has made another suggestion: Jamukha was proposing that they divide their force, half camping by the hills and half by the stream. I think the key to the riddle lies in the conditions of nomadic warfare: should they rest and build up the livestock or should they go on fighting? Jamukha was forcing a crisis of leadership. Had Temüjin answered, Jamukha would have opposed him, whatever his answer.

Unifying the Tribes

It was by maneuvering in and out between the conventions and oppositions of the tribal system that Temüjin was able to make himself the supreme chief, strong enough to destroy the tribal system and create something new. With him policy always came first, and war was never anything but "the pursuit of policy by other means." His order of priority is interesting. The most dangerous feud was with his closest kinsmen, the Tayiji'ud. Then came the Tatars, his remoter kinsmen. Then came what may be called the "outer tribes," the Kereyid and Naiman of western Mongolia. Then the Turks of Central Asia, particularly those who were nomads like the Mongols. Only then came the great civilized states—Khwarezm in Central Asia, the Tanghud, or Hsia, in northwestern China, the Chin, or Jurchid, in northern China.

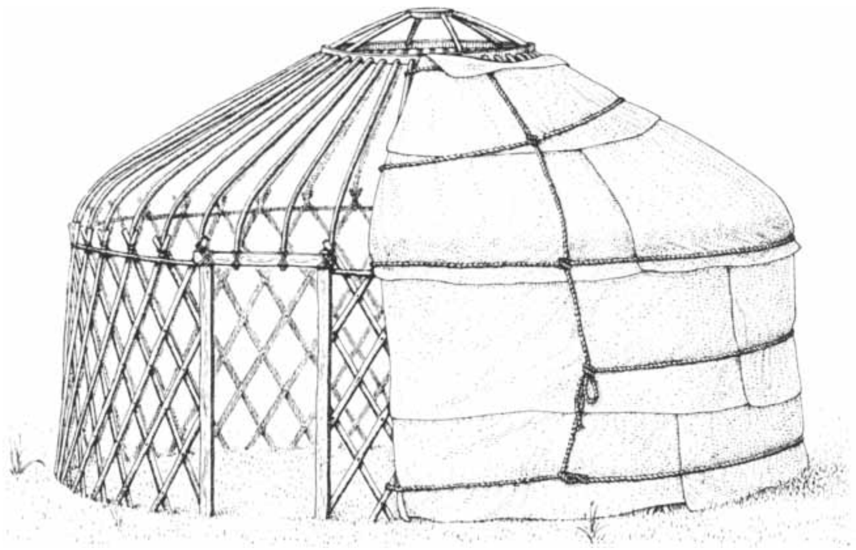
Nothing could be more different from the conventional picture of the savage warrior, blindly ferocious and conquering for the sake of plunder. It is true that Chingis Khan contributed to this legend himself when he said, in words attributed to him by Rashīd al-Dīn, that the best things in life were to conquer, to despoil the defeated, to ride their best horses and to possess their women. This is the conventional "ideology," to use a modern word, of the barbarian warrior.

Against the words must be set the pattern of action. Temüjin, on his way to making himself Chingis Khan, was not blinded by either greed for booty or lust for women. All his moves were politically calculated, and the calculation, from early in his career, was directed toward the building of a structure of power that would be capable of extension in both time and space.

At first he was dealing with men whose outlook was completely tribal. To induce them to transfer to him personally their hereditary tribal loyalties, he took care always to be able to justify each move "morally," by the standards of the very system he was going to destroy and supplant.

He would not turn against a former ally, therefore, just because the oppor-

SIEGE OF BAGHDAD by the army of Hülegü, grandson of Chingis and the founder of the house of the Il Khans of Persia, is depicted in this detail from a large print in the Persian history. The battle is almost won and the Mongols are about to enter the city.



TRADITIONAL SHELTER of the Mongols was—and still is—the yurt, a tent made by stretching sheets of felt over a wooden frame. These light "felt-walled tents" were carried by Chingis' troops on campaigns and are still the standard dwelling of Outer Mongolia.

tunity looked good. He would first let the situation develop, and if possible help it to develop, in such a way that the other man could be accused of disloyalty in act or intent, and if there remained any shadow on his own loyalty, he would make out a case that what he did was "for the common good." The politically valuable victories were those that enabled him to divide defeated enemies by winning some of them over to his own side.

A famous example is that of the warrior who on surrendering admitted that he was the man, fighting to the last, who had loosed the arrow that wounded the horse Temüjin was riding, but who now offered him single-minded loyalty. Praising his forthrightness, Temüjin gave him the new name Jebe, meaning arrowhead, and accepted him as a *nükür.* Jebe became a famous general. There are other stories of this kind. Twice Temüjin praised men who defected to his side but who told him that, although they could have captured and brought to him a chief who was his enemy, they thought it wrong to appear before him as men disloyal to their tribal chief. Once when men came to deliver his most personal enemy, Jamukha, and again when a man reported that he had abandoned his chief in the desert but knew where he could be found, he accepted delivery of the men betrayed but put to death the betrayers. He knew that in creating new standards of loyalty and "morality" he could not put himself under obligation to men who, "by raising their hands against their rightful lords," had made treachery their main recommendation.

Temüjin triumphed in his tribal wars when in 1206 he was "elevated," to use the Mongol term, to be supreme chief of all the Mongol tribes with the title of Chingis Khan. In this title Khan means simply "chief." Temüjin seems never to have used the title "khaghan," although his successors did. There is no precise explanation of the difference between "khan" and "khaghan," but in a general way they seem to correspond to the Chinese *wang* and *huang,* usually translated "king" and "emperor," and to the Iranian *shah* and *shah-in-shah,* "king" and "king of kings." As for Chingis, it is from the Turkish *tengiz,* "a large body of water, the ocean." In the cosmology of the time the earth was flat and surrounded by an ocean, so Chingis Khan meant "the all-encompassing lord." Later the Mongols began to use their own word for "ocean": *dalai.* This is why the title conferred on the chief prelate of Tibet by his Mongol overlord was Dalai Lama and not Tengiz or Chingis Lama.

Even before he was completely supreme over the tribes Temüjin began to invent new institutions to supersede the tribal structure. His first innovation was an imperial guard composed of Day Guards and Night Guards. This created a new elite—privates of the guard outranked officers of the regular army—whose loyalty was based not on blood and tribe but was, so to speak, "professional." Membership in the imperial guard opened the path to glory and power for promising young warriors; a guardsman could suddenly find himself appointed the governor of a province. At the same time it provided a hostage system, because the sons of important generals also served in the guard.

As a further step away from tribalism and toward feudalism Chingis Khan began to break up conquered tribes, "conferring" them as vassals on various relatives and favorite followers. He also came to bestow "appanages" on men of his own blood and on important commanders. These were regions, plainly in the feudal mold, in which the descendants of the first appanage-holder were to be hereditary rulers, bound to furnish military contingents to the successors of Chingis Khan. The new standard of discipline required a man to be obedient to the local ruler, who was usually not of his own tribal blood, and to perform his military service and pay his tribute within a geographically defined region from which he was not allowed to move.

As a result of these assignments, although there have been reversions toward tribalism in times of war and change of dynasty, Mongol "tribes" have not been truly tribal for many hundreds of years. Within a so-called tribe it will be found that there are a number of clan or family names, that many of these clan names were once tribal names and that they are found widely scattered in various parts of Mongolia. They preserve the evidence of the breaking up of tribes by Chingis Khan and similar redistribution in later centuries.

Mongol Diplomacy

With the development of a new structure of Mongol society went the development of institutions for conducting diplomacy and international relations. Although there is no explicit statement in the documents, it is clear enough that Chingis Khan was wary of the great civilization geographically nearest to him, that of the Chinese: it was too protean, too absorptive; it had undermined the conquering dynasties of the Khitan and the Jurchid, which loomed so large in recent centuries of Mongol history. He needed and employed a few Chinese, but he kept a careful balance. An adviser who had great influence on him was Yeh-lü Ch'u-ts'ai, a Khitan who knew the Chinese culture thoroughly but who, as a Khitan, was felt to be a tribal kinsman. Chingis Khan also employed many Uighur Turks from the oases of Sinkiang and Önggüd Turks from the fringe of Inner Mongolia. He was quick to see the uses of the Uighur-Nestorian script written by these peoples and ordered that his sons be instructed in it. A great advantage of such a script was that it was independent of the Chinese writ-

ing—one of the most important cultural weapons used by the Chinese in establishing psychological ascendancy over the barbarians of the north. Tribe after tribe attempted to evade this domination by inventing or adapting a script of its own, and the Mongol attempt succeeded better than most.

A particularly interesting part was played by Moslems in the service of Chingis Khan. It is not always possible to be sure whether they were Turks, Iranians or Arabs, but most of them began as merchants, traveling about the vast regions between the Near East and China, dealing in all kinds of goods and getting to know what was going on in many countries. It was through them that Chingis Khan learned about the power of the Turkish nomads far to the west of Mongolia. This intelligence probably was influential in shaping his conviction that he must establish complete domination over all the nomad peoples, Turks as well as Mongols, before getting involved too deeply in invasion of the great agricultural and urban civilizations. He used these merchants first as intelligence agents, then as go-betweens and finally as more formal ambassadors. As his power increased he appointed some of them governors and administrators—just as Marco Polo and his father and uncle, coming to China as merchant adventurers, were given appointments by Qubilai Khan. In the Moslem world at this time wealthy merchants were more often well-traveled, well-educated men of the world than they were in China, where the merchants were despised by the landowners. Certainly the use of these men as administrators helped the Mongols to win over many of the upper class in western Central Asia and northern Iran.

The Khan as a General

As a military genius, able to take over new techniques and improve them, Chingis Khan stands above Alexander the Great, Hannibal, Caesar, Attila and Napoleon. In 1206 he became the khan of a group of tribes whose only skills in war were the use of the horse and the bow; the long, rapid march; the swift raid; and the discipline—like that of the ancient Parthians—that enabled them to pretend defeat so that the enemy would break ranks in order to pursue them, then wheel, close ranks and annihilate the dispersed enemy. Yet when Chingis Khan set out to campaign in Turkistan and Khwarezm 13 years later, he was able to co-ordinate the use of his cavalry with elaborate siege weapons—powerful catapults, battering-rams and sappers who tunneled under walls and blew them up with gunpowder—against strongly fortified cities.

He certainly recruited his first engineers in northern and perhaps northwestern China, where the originally "barbarian" military power of the Jurchid, or Chin, state and the Tanghud, or

MONGOL HORSES, tough little range-bred animals, were an essential element in Chingis' conquests. The same stock of horses is still ridden by Mongol herdsmen. This group, approaching the capital city of Ulan Bator, is on the final stretch of a 50-mile race.

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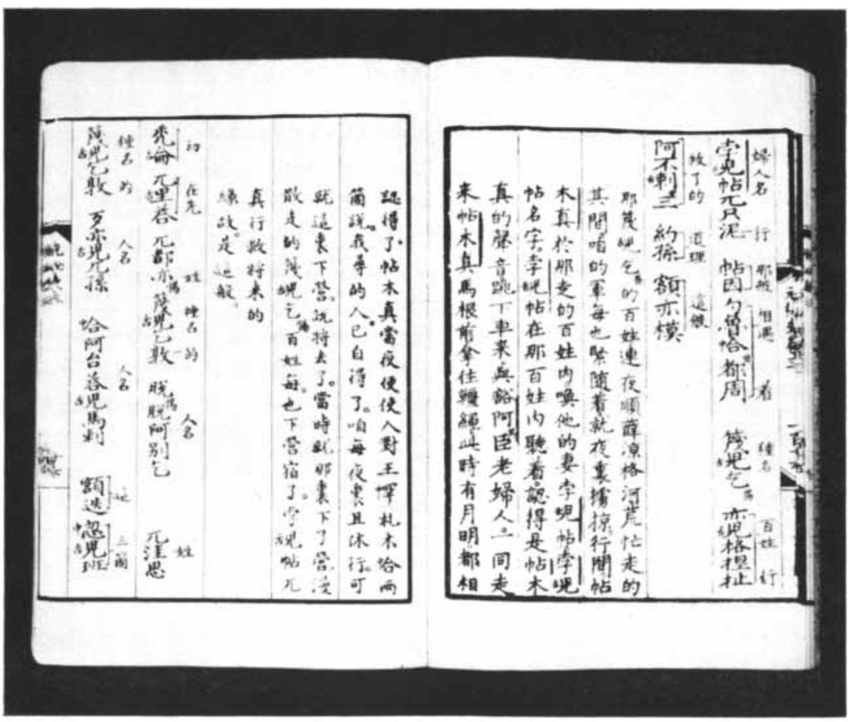
Hsia, state had acquired Chinese techniques. When he took these men westward with him, he brought about a cross-stimulation of Chinese and Iranian engineering and technology. This in turn almost certainly had something to do with the development of the cannon from the use of gunpowder in sapping operations. Unfortunately we do not know the step-by-step details. At any rate the use of cannon both as siege weapons and as field weapons followed very quickly the Mongol conquest.

Although Chingis Khan used the technology of civilization to overpower the walled cities of civilization, his cavalry remained always his main arm. The peculiarity of this cavalry has never yet, it seems to me, been fully appreciated. Throughout history, all across the steppe zone from the Black Sea to the Yellow Sea, there was an alternating dominance of tribal cavalry and feudal cavalry. This alternation is explainable. A horse that grazes only on the open range, with no shelter in the bitter winter and no hay or grain for supplementary feed, becomes a very tough animal. Its growth is stunted, however, to roughly the size of a small polo pony; its endurance is great but limited. Even today a Mongolian horse that can be lassoed on the range, saddled and with no further preparation ridden nonstop for more than a 100 miles is typical, not exceptional. But it cannot be ridden again the same way the next day; it has to be allowed several days of grazing. So the warriors of pastoral tribes that had little or no agriculture had to have large herds of remounts, and any warrior, if he had enough remounts, was about as good as any other warrior.

The alternation came when a tribe of this kind became strong enough to draw in toward the oases of Central Asia or the Great Wall of China and establish itself on a new kind of footing, exploiting trade and subsidiary agriculture—often by importing Chinese or Central Asian peasants to irrigate a suitable stretch of territory. In this phase a kind of feudalism or protofeudalism developed (the terms are approximate), in which an elite of nobles and a class of free warriors were distinguished from the subject classes of herdsmen and cultivators. To maintain their superiority over the commoners, the elite wore heavy body armor and used heavy swords and lances in addition to the bow and arrow; for this they needed bigger, weight-carrying horses. They developed the horses they needed partly by selective breeding but more by feeding them well with hay and grain.



PASSAGE FROM *SECRET HISTORY* is reproduced from a modern printed version of a Yüan dynasty manuscript. In each of the four outer columns the Mongolian original is transcribed into Chinese characters at left, with a word-for-word Chinese translation at right. The six middle columns give a full Chinese translation of the story of Börte's recapture.

We know of these alternations from the burying of horses with both "tribal" and "feudal" chiefs, and from documents. In the famous inscriptions of the Orkhon Turks in Central Mongolia the elite and their horses are singled out; in the inscription to the warrior Kül Tegin each war horse he rode is identified, and its fate is mentioned if it fell in battle. Particularly curious and suggestive is the story that about 2,000 years ago the Chinese were obsessed with reports about the fine horses of the oases in Turkistan. At last an ambassador-explorer succeeded in bringing some back to China. When he did, he also brought with him the seeds of lucerne, or alfalfa, until then unknown in China. Presumably the people from whom he got the horses told him that they had to be given this special fodder.

Although Chingis Khan, in founding an empire and making the Mongols into the elite of that empire, began to change the structure of Mongol society from tribal to feudal, and although he replaced the tribal system with regiments and divisions under professional commanders, he did not limit the mobility of his armies by trying to equip them with big horses that needed hay, grain and winter shelter. He drew the essence of his power from archers riding tough little range-bred horses, with plenty of remounts.

And so we return to the beginning of our story and the Hungarian bishop's report on the Mongol remount system. At this point we can also sum up the characteristics of the Mongol conquest: the manipulation of the tribal politics of alliance and feud to destroy the tribal system and replace it with a feudal-imperial pyramid—an emperor at the top and regional appanages below, sustained by tribute in kind and taxes paid in money; the use of the engineers and machines of civilization, combined with mobile cavalry, to destroy the strongholds of civilization; and, after the conquest, the quartering of the main Mongol forces as a mobile reserve in the steppes of Mongolia, Turkistan and southern Russia, rather than the dispersing of them in garrisons in the conquered countries. At least this last was Chingis Khan's intention. It was when his successors—notably Qubilai Khan in China—turned their backs on the steppe and began to concern themselves primarily with civilization that the old nemesis of civilization began to erode the empire of the great barbarian genius, as it had the empires of many similar but lesser barbarian conquerors.

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NaK—Designed the SNAP-8 heat exchanger for operation at 1300°F. Determined corrosiveness of NaK in columbium-stainless steel bi-metallic capsules at 700°F for 1000 hours.

MERCURY—Designed zero gravity boiler and radiator for SNAP-8; operated boiling Hg condensing loop to determine flow stability and heat transfer; determined solubility of containment alloys in Hg up to 1150°F; determined compatibility of alloys in Hg at temperatures up to 1250°F over a 10,000-hour period.

- For further information on AGN's progress in liquid metal technology, write for AGN Active Files #3 and #6.

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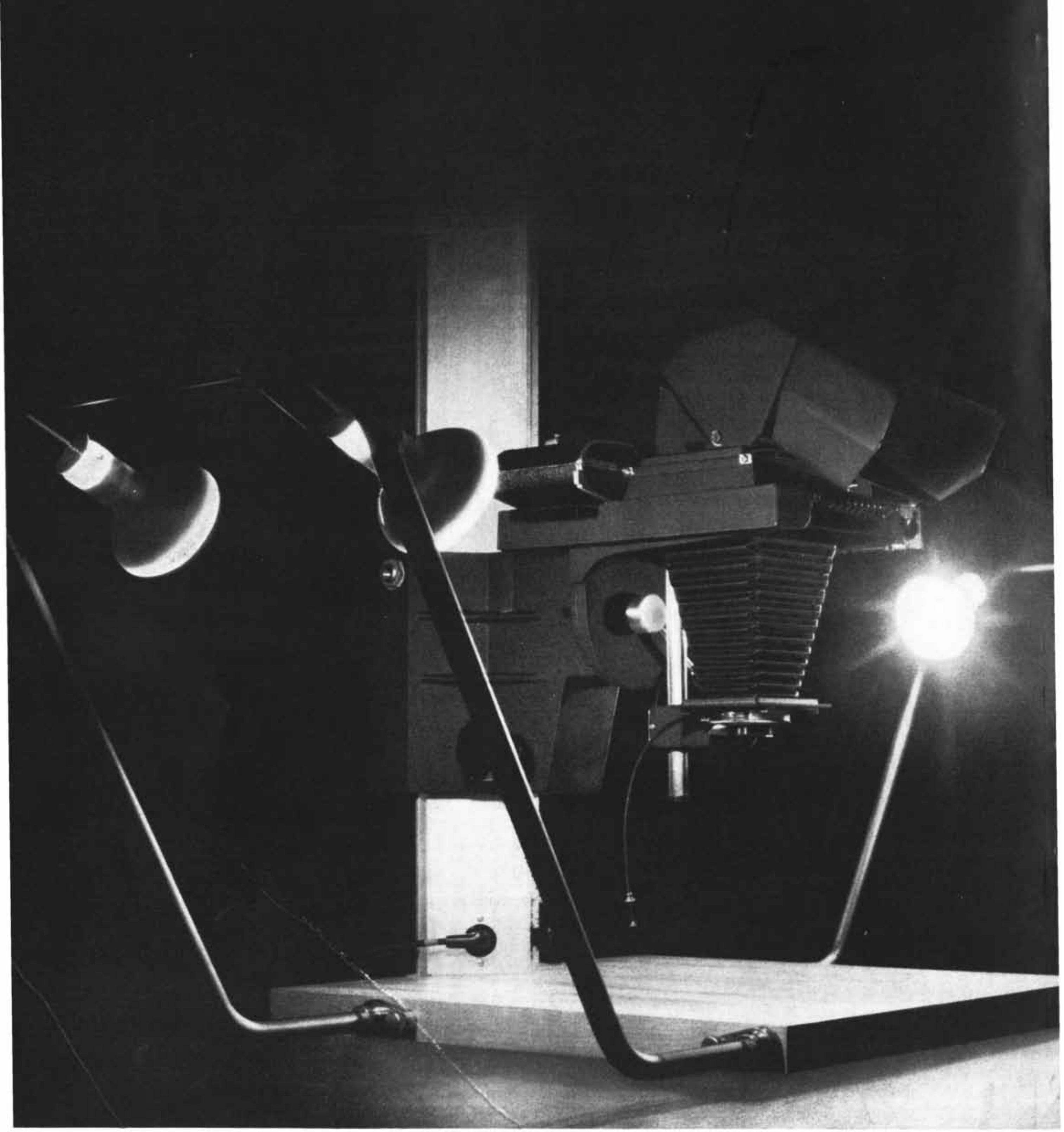

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THE STRENGTH OF STEEL

Control of strength-producing mechanisms is closing the great gap between the attainable strength of steel and the theoretical value. The traditional strengthener, carbon, is missing from one new alloy

by Victor F. Zackay

The difference between the actual tensile strength of a crystal of pure iron and the theoretical strength of the crystal is represented by a factor of about 1,000. The actual strength is some 1,500 pounds per square inch; the theoretical strength is about 1.6 million pounds per square inch. Long before these figures were known—indeed, before anything was known of the composition and intimate structure of steel—artisans little by little discovered ways to increase the strength of iron alloys to about 150,000 pounds per square inch. This approximates the strength of the finest sword blades made in Damascus and Japan. Ordinary low-carbon, or structural, steel, which accounts for most of present production, has a tensile strength of between 45,000 and 60,000 pounds per square inch. Tool steels go up to about 300,000 pounds per square inch, and cold-drawn fine steel wire—the strongest commercial steel product—goes up to about 600,000.

Within the past few years, as a result of slowly developing insight into the factors that strengthen steel, new processes have been developed for producing a steel in bulk form that has a tensile strength of more than 400,000 pounds per square inch. Almost as strong as the steel in cold-drawn wires, the new material is being tested for a variety of automotive, aircraft and other applications in which the utmost in strength-to-weight ratio is required.

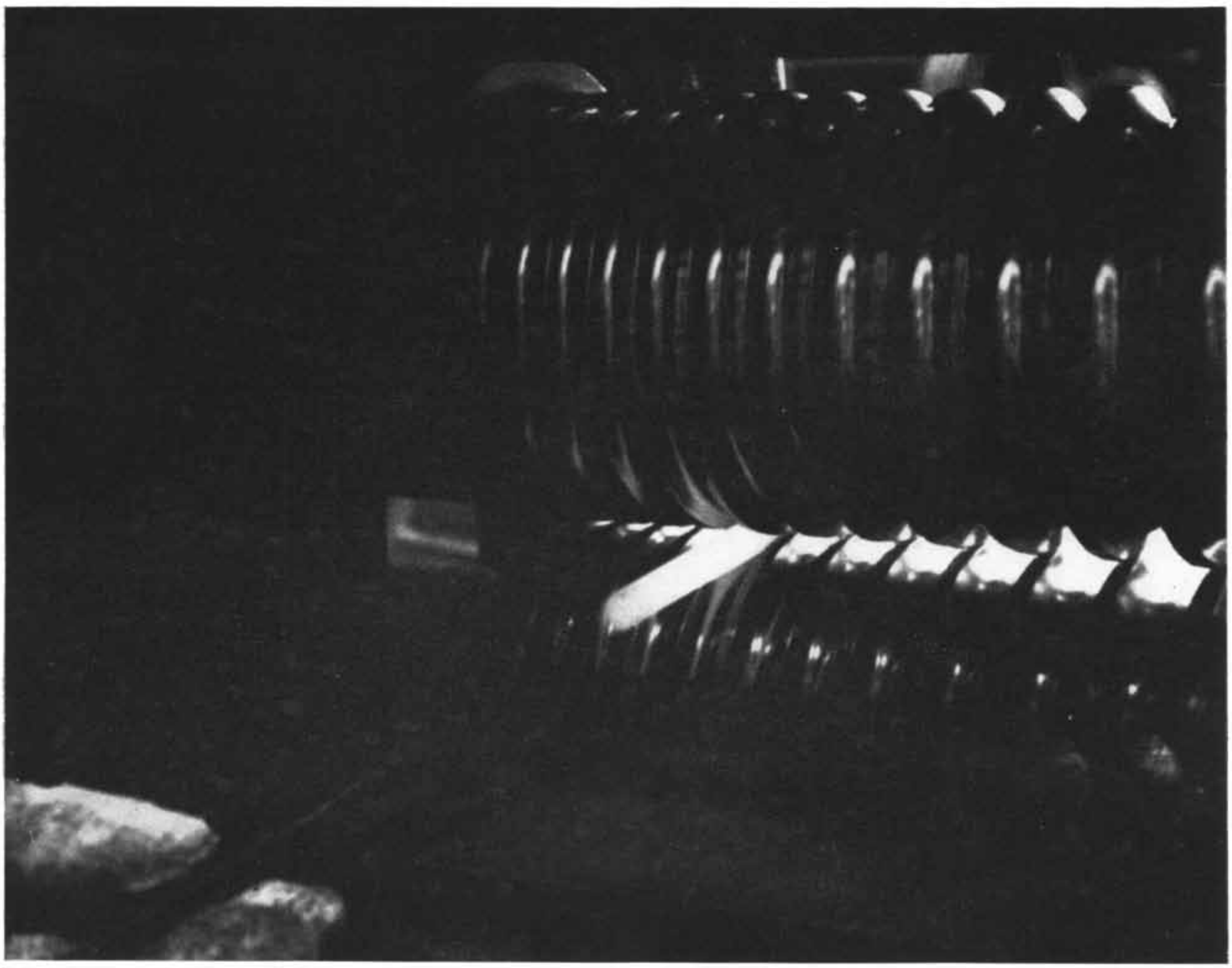
One of the tough new steels is made by the Ausform process, developed in the Scientific Laboratory of the Ford Motor Company. The process is an extension of concepts introduced by Dutch metallurgists. A second new process, called Maraging (a contraction of "martensite aging"), was developed by the International Nickel Company, Inc. The unique feature of Maraging steels, which are almost as strong as Ausform steels and even tougher, is an almost total absence of carbon. Historically the strength of steel has been related to carbon content. In the Maraging alloys the role of carbon is taken over by substantial percentages of nickel, cobalt and molybdenum, amounting to more than 25 per cent of the total alloy. The discovery that carbon is not essential to high strength should encourage the design of a whole new class of ductile alloys, both ferrous and nonferrous, free of an element known to cause embrittlement.

Increased understanding of the strength of steel and other metals has gone hand in hand with the development of instruments for seeing finer and finer details of physical structure. The first indication that steel and cast iron are crystalline solids came from the examination of their fractured surfaces with a hand lens. Later, when the surfaces were examined under the microscope, it was found that much greater detail could be seen if the samples were polished and etched to increase the contrast between crystals having different phases, or structural states. Such studies showed that metals are a composite of crystalline grains within which reside other crystalline phases varying greatly in shape, size and distribution. Today the electron microscope is widely used for studying metallic structure just above the level of the atom. And with X-ray diffraction methods and the field-ion microscope the probing can be carried down to the atomic level.

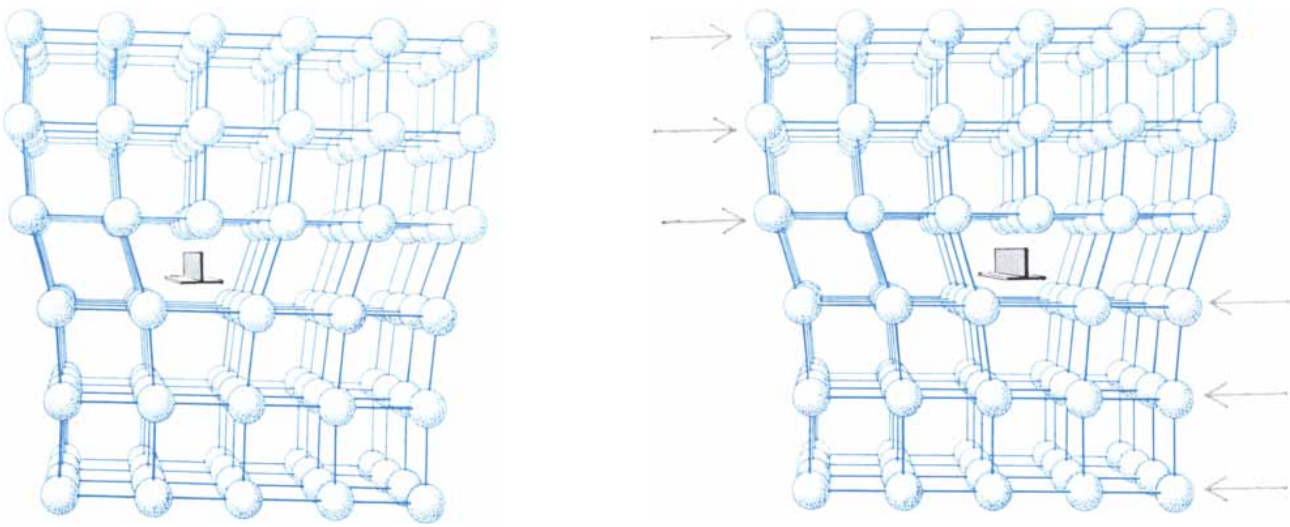
Early in this century it became possible to make a rough approximation of the theoretical strength of metals, based on the binding forces between the atoms in a crystal lattice. For iron the computed values were between a million and two million pounds per square inch. The problem then became one of explaining why real metals are so weak. The answer was suggested independently in 1934 by Geoffrey I. Taylor, Egon Orowan and Michael Polanyi. They postulated that metals contain dislocations, or linear defects, that move easily when extremely small stresses are applied [see "Observing Dislocations in Crystals," by W. C. Dash and A. G. Tweet; Scientific American, October, 1961]. The commonest form of dislocation occurs when a plane of atoms is missing from a crystal lattice, as shown in the top illustration on pages 74 and 75. (The dislocation can also be thought of as being produced by an extra plane of atoms.) When a small stress is applied, the missing plane (or the extra plane) slips freely through the lattice. The theory explained satisfactorily why real metals are far weaker than ideal, or defect-free, crystals. The theory also explained why "whiskers," or single-crystal fibers, of many metals have strengths equal to the theoretically calculated values. Either there are few dislocations in whiskers or those present are almost completely immobilized.

Conversely, the weakest form of a metal should be one containing dislocations that are not immobilized. A very pure single crystal that has been grown to bulk size meets this specification; it contains neither grain boundaries nor impurity atoms to impede the movement of dislocations. Thus very pure single crystals and metallic whiskers represent the floor and the ceiling of the strength of a given metal.

With the insight provided by dislocation theory, metallurgists have gained a better understanding of the traditional methods used to strengthen steel. They are effective to the extent that they impede or block the movement of dislocations. Five particularly effective methods



AUSFORM PROCESS, developed by the Ford Motor Company, creates a steel of great strength by deforming, or cold-working, suitable alloys. Top photograph shows an experimental billet being heated preparatory to quenching and deforming. Bottom photograph, taken on infrared-sensitive film, shows the billet being deformed in a rolling mill. To the eye the billet is not luminous.



MOVEMENT OF DISLOCATION accounts for the weakness of iron and other metals. The dislocation, represented by the black T-shape, occurs where a plane of atoms is missing from the lattice of a crystal. When a small shearing force is applied, a sim-

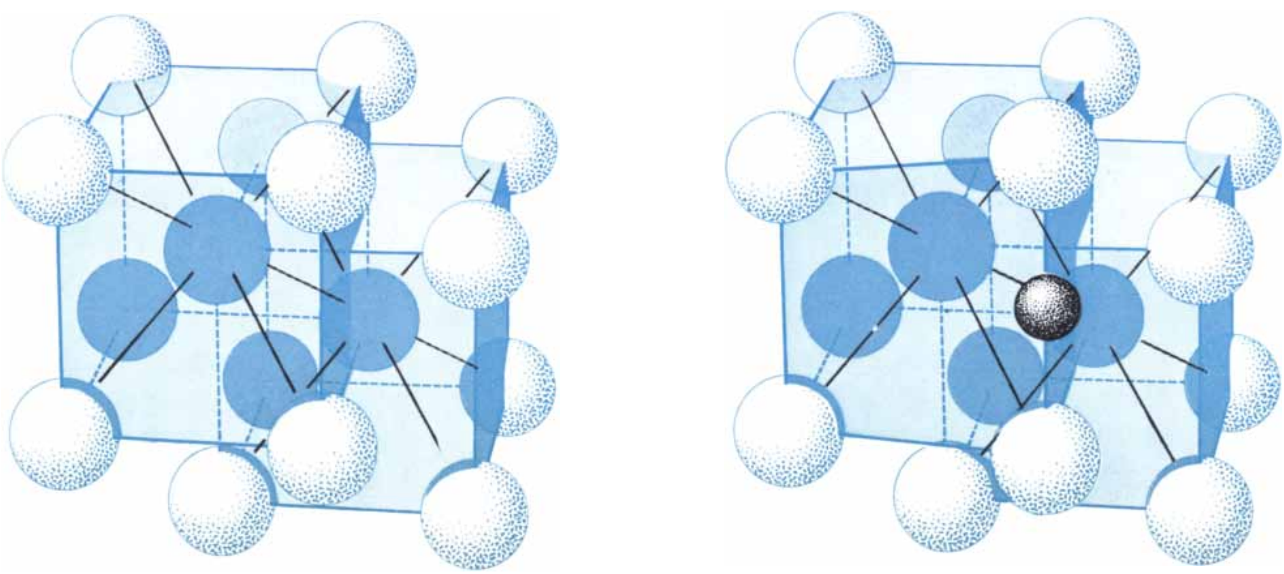
for increasing the strength of steel are: (1) addition of carbon, (2) reduction of grain size, (3) deformation of structure by "cold-working," (4) inclusion of hard particles or precipitates, (5) quenching, or quick cooling, to produce a structure whose strengthening mechanisms are only partially understood. Each of these will be discussed in turn.

Increasing the amount of carbon dissolved in very pure iron from .0001 to .005 per cent increases the strength of the metal by a factor of four. The carbon dissolves in the crystals of iron, which are in the form of ferrite, cubic crystals with an atom of iron in the center. The potent strengthening is thought to be related to the position of the carbon atoms in the iron lattice. The carbon may either be squeezed into the interstices of the lattice or clustered around the dislocations [*see bottom illustrations on these two pages*]. In either event the dislocations tend to be immobilized and a greater stress has to be applied to make them move.

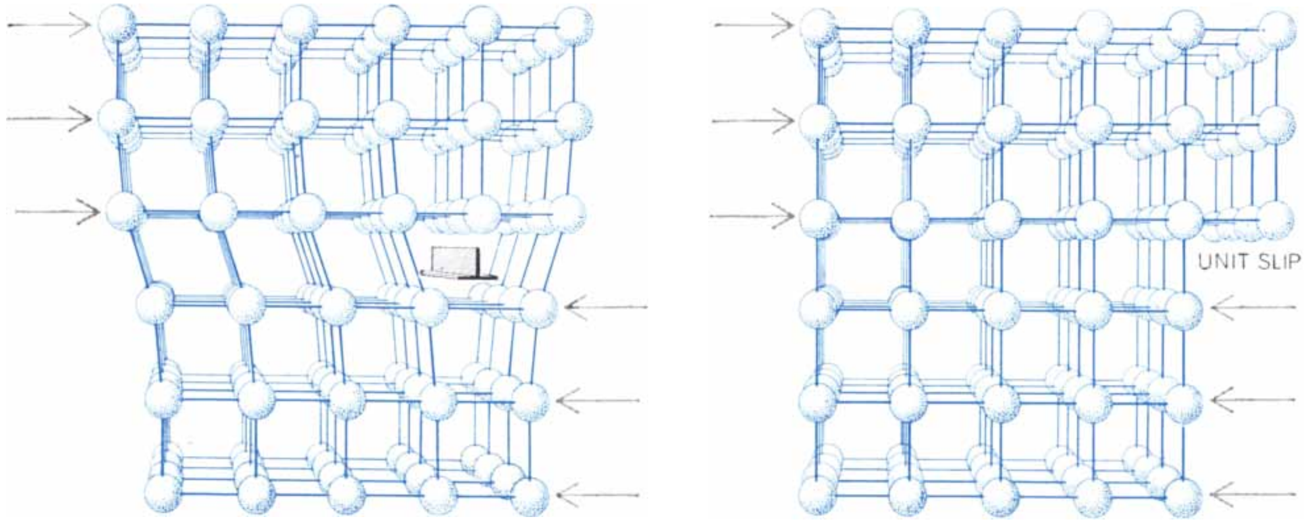
The second method for limiting the movement of dislocations is to decrease the size of the crystal grains in the metal. Although a dislocation can move through the crystal in which it originates, it cannot jump across a grain boundary and propagate itself in an adjacent crystal. By decreasing the grain size tenfold, thereby presenting many more barriers to dislocation movement, the strength of iron can be tripled. Grain size is established by the combination of thermal and mechanical processing that the metal has undergone. The upper electron micrograph on page 78 shows how dislocations have piled up at a grain boundary in stainless steel.

The third way to raise the strength of steel is to hammer, roll, forge, extrude or otherwise deform it. If the deforming is done at a temperature at which the metal is not in the plastic state, it is called cold-working. Severe deformation of iron at room temperature doubles its strength. The deformation produces complex tangles of dislocations that impede the motion of other dislocations [*see lower illustration on page 78*].

The fourth method of blocking dislocations is to disperse hard particles or precipitates in alloys. Steel normally con-



CRYSTAL OF FERRITE, one form of pure iron, consists of interlocking cubes, producing a "body-centered" structure (*left*). Carbon can dissolve in ferrite to a small extent (*right*). A dissolved atom (*black*) occupies a site along the edge of a cube.

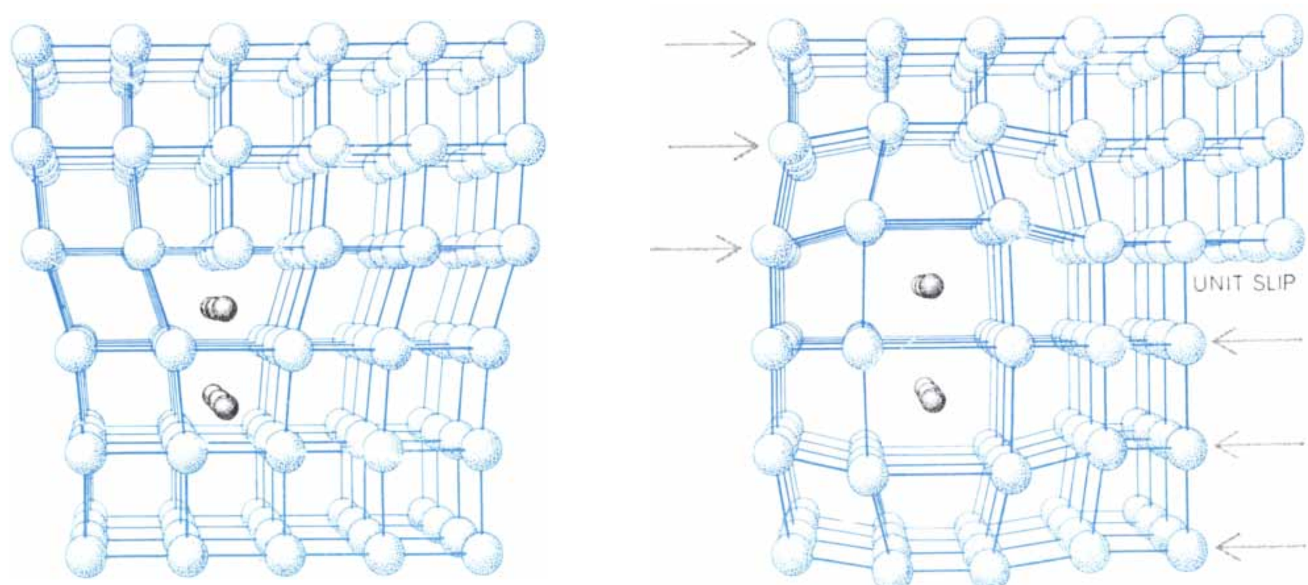


ple flip in atomic bonding allows the dislocation to jump one cell to the right (*second panel from left*). Ultimately the dislocation reaches the edge of the crystal, producing a unit of slip. Many such slips will lead to a visible change in the shape of the metal.

sists of hard and brittle iron carbides dispersed in a relatively soft matrix of cubic ferrite. The closer the spacing of these carbides and, to some extent, the smaller their size, the stronger the steel. Two of the most important forms of steel, pearlite and bainite, owe their strength to the particular shape and distribution of hard iron carbides. Pearlite contains alternating plates of hard carbide and soft ferrite. Bainite has a more complex structure in which the individual carbide and ferrite phases can be plate-like, needle-like or feather-shaped. The strength of both pearlite and bainite can be raised by decreasing the distance between carbide particles by alloying and heat treatment. Pearlite and bainite are included in the class of plain carbon steels in which the carbon content runs between .1 and .8 per cent. Their usable strength is between 30,000 and 150,000 pounds per square inch.

To obtain still greater strength one must resort to the fifth method of treatment, in which steel is quenched from a high temperature. The rapid cooling prevents the formation of carbide-ferrite microstructures like those of pearlite or bainite and yields the structure known as martensite. As a result of this type of heat treatment all or most of the carbon is retained in a supersaturated solution. Martensite can contain tens or even hundreds of times more carbon in solution than ferrite can. The strength of martensitic steels is directly proportional to the dissolved carbon. When the carbon is .4 to .6 per cent, the strength runs as high as 300,000 pounds per square inch.

The various types of steel mentioned —pearlite, bainite and martensite—are simply names for particular microstructures that arise spontaneously as a consequence of carbon content, temperature treatment and one other factor: time. These relations are diagramed at the top of page 79. The black curve (*a*) in the diagram shows how a medium-carbon steel can exist in various phases, depending on temperature and time. Above 1,450 degrees Fahrenheit the steel is in the form of austenite. If it is cooled quickly, it becomes metastable austenite and, below 450 to 650 degrees F., martensite. If it is not cooled quickly but is held at a temperature between 750 and



CARBON-STRENGTHENING OF IRON may take place in two steps. Carbon atoms dissolve at the site of a dislocation (*left*). After a unit slip occurs, the carbon atoms create a stressed region (*right*), which interferes with the passage of other dislocations.

1,450 degrees, it decomposes spontaneously into ferrite and carbide. If the decomposition takes place near the higher temperature, the ferrite and carbide take the form of pearlite; if it occurs near the lower temperature, they become bainite.

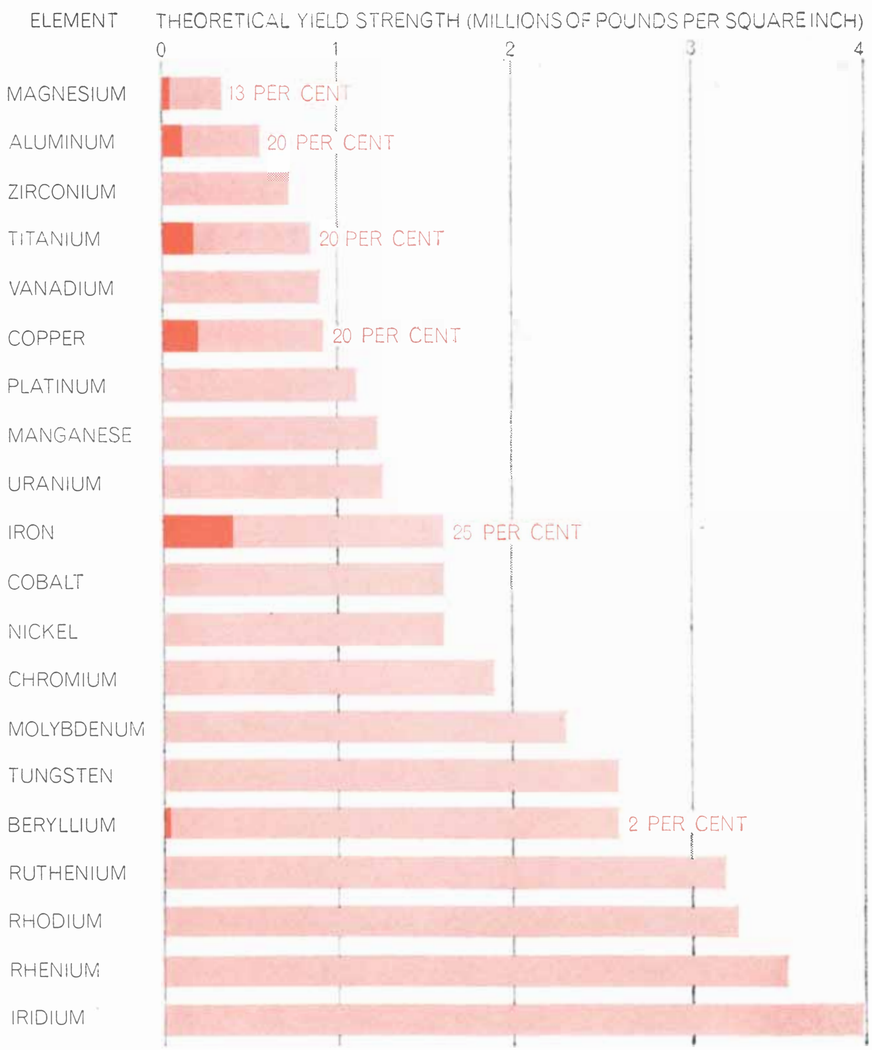
In making martensitic steel the austenite must be cooled fast enough to avoid decomposition into ferrite and carbide. Yet the quenching rate must not be so fast as to crack the hard but brittle martensite. Ductility is achieved later by a tempering operation, in which the steel is reheated to a temperature below 1,000 degrees and held there for about an hour [*see first panel in top illustration on page 80*]. Tempering sacrifices some of the strength and hardness of martensite for additional toughness. It is little wonder that in ancient times truly good swords were priceless and exceptional ones became the source of legends.

In 1954 two Dutch metallurgists, E. M. H. Lips and H. van Zuilen, announced a process for raising the strength of martensitic steel a full third over the previous values of 300,000 pounds per square inch. In their process austenite is either continuously deformed as it is cooled from about 1,700 degrees or it is deformed at a constant temperature just above the point at which martensite starts to form. When the metal is cold-worked above this temperature, an entirely new variety of soft, strain-free grain is created. This produces a stronger austenite from which the martensite subsequently arises. The deformed austenite is then quenched and tempered as in the conventional heat treatment of martensitic steels. The Dutch process is shown in the second panel in the top illustration on page 80.

A major difficulty in the Dutch process was that the cold-working of austenite at comparatively low temperatures caused the austenite to decompose rapidly, so that the final product was usually a mixture of ferrite, carbide and martensite of low strength. The initial encouraging results reported by Lips and van Zuilen were achieved with wires and thin sheets, in which quick deformation and quick quenching did not give the decomposition reactions time to take place. It therefore was clear that a new process was required if this technique of strengthening were to be employed in bulk steel parts having cross sections larger than those of wire, foil and thin sheet.

A search for such a process was begun about 1954 by a group of us at the Ford Scientific Laboratory, and after an intensive six-year effort the Ausform process was developed. Applicable to a wide variety of steel alloys and fabrication techniques, it solves the problem that frustrated the Dutch process. In the Ford process the decomposition of austenite is delayed by certain alloying elements, notably chromium. It had been known for many years that when chromium is used in a suitable alloy, a "bay" develops in the curve marking the decomposition boundary between austenite and martensite. This bay, shown by the colored curve (*b*) in the top illustration on page 79, indicates that the decomposition of austenite to ferrite and carbide is strongly suppressed over a wide region in the neighborhood of 600 to 1,000 degrees F. Once this region had been identified there was no great problem in confining the cold-working operations to it. The deformation is carried out under close temperature control so that no decomposition into pearlite or bainite takes place [*see third panel in top illustration on page 80*]. The cold-worked austenite is quenched to martensite and tempered. Many commercially available high-strength steels have compositions that lend themselves favorably to the Ausform process. One such steel, known as Type H-11, responds particularly well. In addition to iron it contains 5 per cent chromium, 1.3 per cent molybdenum, .5 per cent vanadium and .4 per cent carbon.

The principal factors controlling the strength of Ausform steels are the amount of deformation, the temperature at which the deformation is done and the carbon content. Lesser variables are the tempering temperature and the alloy content. The strength of any cold-



THEORETICAL STRENGTH is shown for 20 metals. The currently attainable bulk yield strength for six of them is indicated by dark color; the numbers indicate per cent of the theoretical value. The theoretical strength represents the atomic binding forces in a crystal.

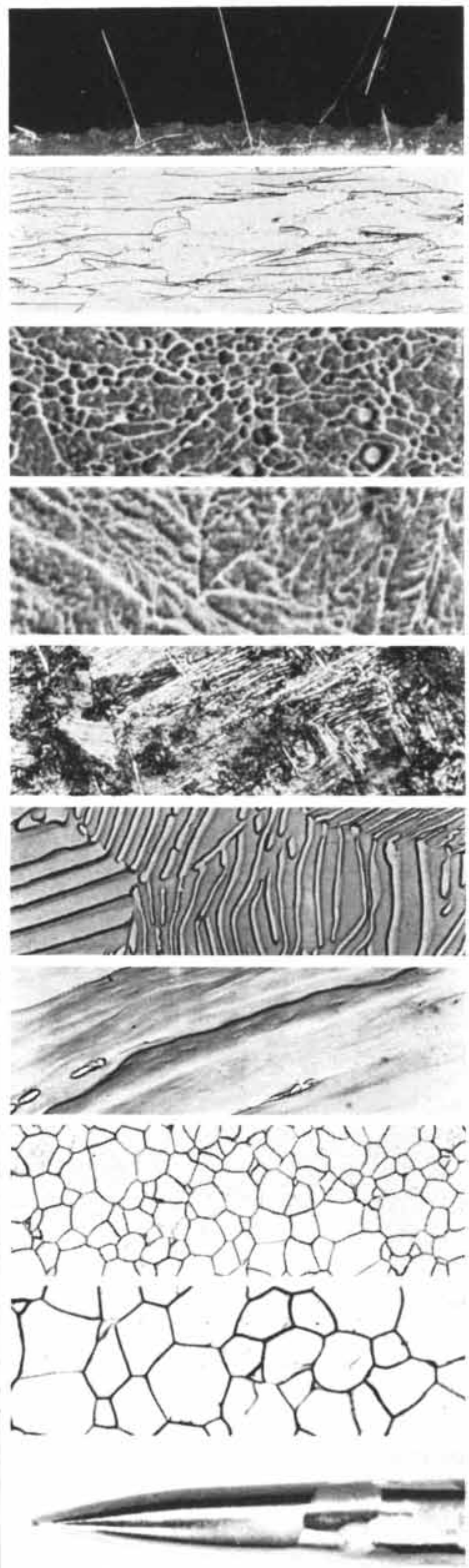
worked metal or alloy increases with the amount of deformation and decreases as the temperature of deformation rises. In other words, the lower the temperature at which the cold-working takes place, the better.

These general principles have been found to hold for Ausform steels [*see bottom illustration on page 80*]. It is quite clear that the strength of the martensite of the Ausform steels directly reflects the increased strength of the cold-worked austenite from which it forms. An increase of 100,000 pounds per square inch in strength without a concomitant loss in ductility can be observed in Ausform steels in which the austenite has been severely deformed.

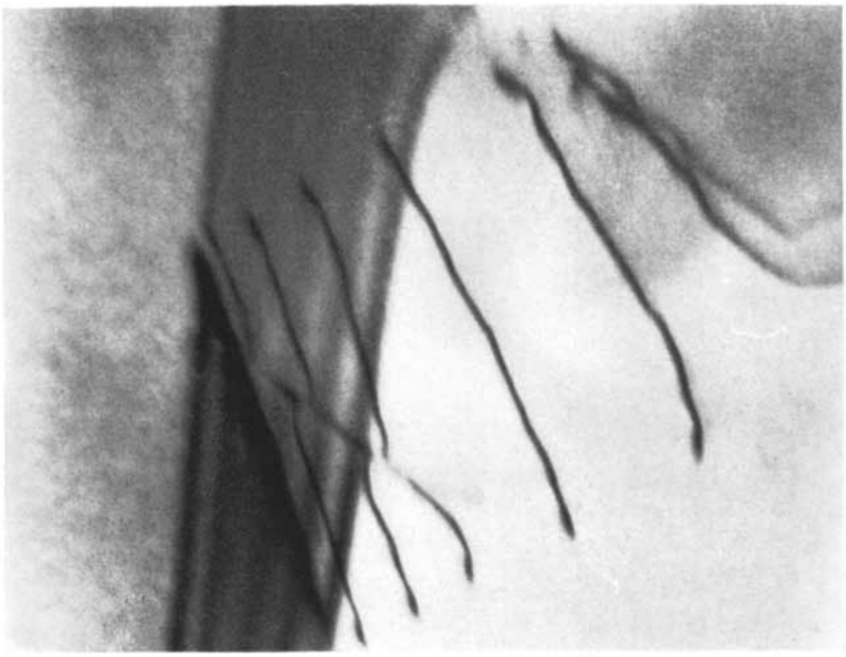
The highly distorted and deformed structure of the austenite of Ausform steels can be seen by deliberately allowing austenite decomposition to take place. This is most conveniently done by allowing the cold-worked austenite to cool slowly instead of quenching it. The decomposition products of ferrite and carbide precipitate preferentially on the slip bands, or flow lines, of the deformed austenite grains [*see illustration at top left in the group of four at bottom of page 82*]. Slip bands marked by such precipitates are said to be decorated. When only a few martensite plates are allowed to form, the interaction of these plates with decorated slip bands can readily be seen, as shown in the illustration at top right in the group of four on page 82. Conventionally formed martensite is observed within the undistorted grain in the bottom third of the photomicrograph. Several badly distorted martensite plates are seen in the deformed grain in the upper portion of the photomicrograph. Careful examination reveals that the forming martensite plates are offset each time they intersect a decorated slip band.

The strength and hardness of Ausform steels is maximized in a highly alloyed high-carbon steel that has been severely deformed in the austenite condition at a relatively low temperature. The mechanical properties of such a steel (Vascojet MA), containing .55 per cent carbon and a total of 12 per cent alloying elements, are shown as a function of tempering temperature in the top illustration on page 82. The strength (equivalent to that of a metal-cutting tool) is remarkably insensitive to tempering temperature. The yield strength of this steel is more than 400,000 pounds per square inch and its tensile strength is more than 475,000 pounds per square inch, over a wide range of tempering temperatures. The ductility is equal to or better than

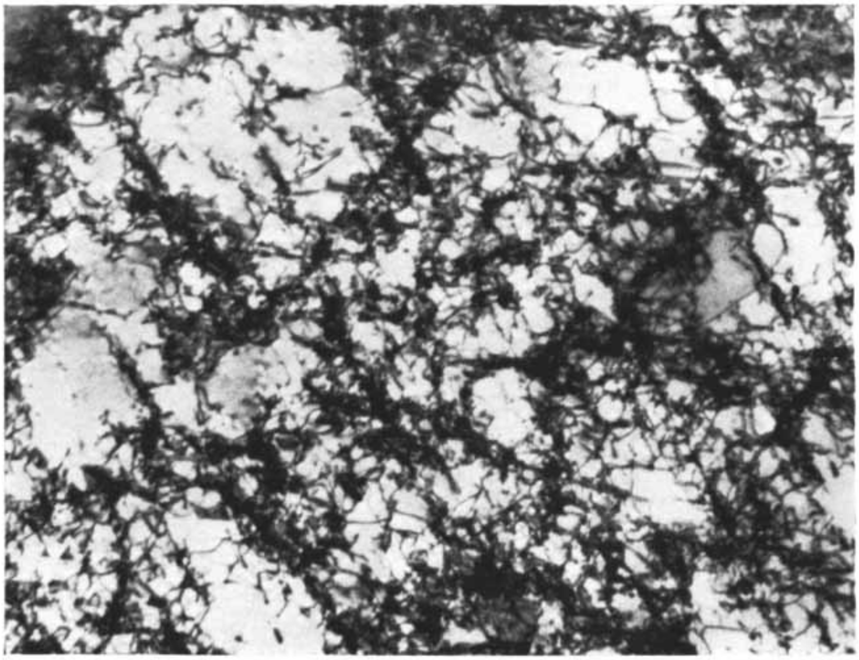
STRUCTURE	STRENGTH
IRON WHISKERS	1,600,000
COLD-DRAWN STEEL WIRE	600,000
AUSFORM STEEL	425,000
MARTENSITIC STEEL	300,000
BAINITIC STEEL	200,000
PEARLITIC STEEL	175,000
COLD-WORKED IRON	100,000
IRON OF SMALL GRAIN SIZE	50,000
IRON CONTAINING DISSOLVED CARBON	20,000
SINGLE CRYSTAL OF PURE IRON	1,500



STRENGTH OF IRON, given in pounds per square inch, can be raised by introducing various obstacles to the movement of dislocations. Such obstacles include dissolved carbon, grain boundaries and hard precipitates. Pictures are by U.S. Steel Corporation and Ford.



PILEUP OF DISLOCATIONS is shown by the series of lines that bunch up at a grain boundary (*dark vertical region*) in stainless steel. The boundary limits dislocation movement. Micrograph is by W. Roser and G. Thomas of the University of California, Berkeley.



TANGLE OF DISLOCATIONS is produced when a metal is cold-worked. The tangles themselves provide an obstacle to the movement of other dislocations, which are not visible. This micrograph of nickel was made by R. Nolder and Thomas of the University of California.

that of its conventionally heat-treated counterpart.

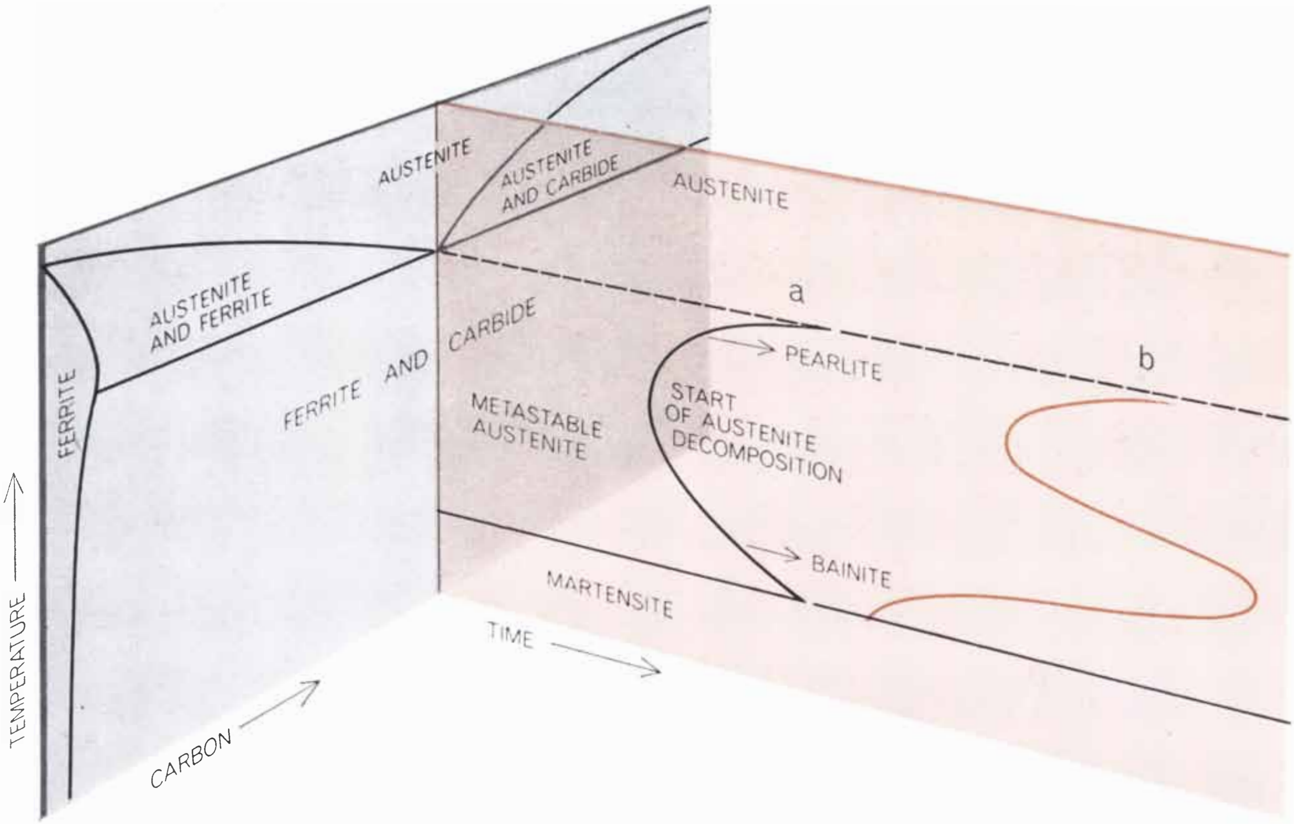
The Ausform process combines fabrication and heat treatment in one operation. This is its source of both strength and weakness. The requirement that the steel be cold-worked at or below the comparatively low temperature of 1,100 degrees F., and that this be done over a limited temperature range, currently poses some manufacturing limitations on the process. At this temperature the steel becomes stronger as it is cold-worked, and equipment must be rugged to deform it. There is also a need for fast-acting temperature-sensing devices to maintain the steel at the proper temperature. Steps are presently being taken to meet both needs

Because Ausform steels are strong, hard and ductile they should be useful for making tools such as punches, dies and shears. Great strength, coupled with excellent resistance to fatigue failure, also recommend their use in automotive suspension systems, aircraft landing gear and high-strength bolting. Several of the highest strength experimental bolts ever tested were made of Ausform steel. Other applications of interest include the manufacture of missile cases and vehicle armor.

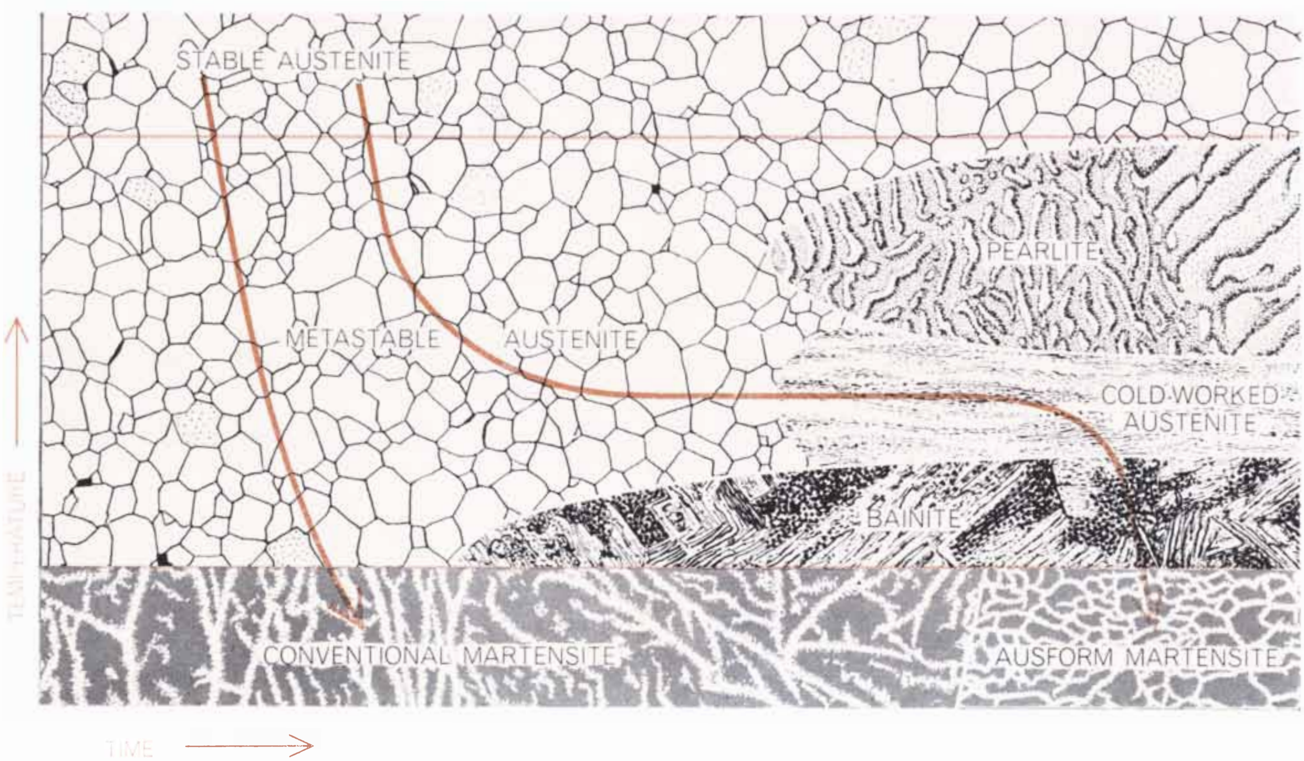
Where extreme toughness and ductility are required, Ausform steels have now been surpassed by International Nickel's Maraging alloys—the alloys that surprised metallurgists by containing virtually no carbon. A typical Maraging steel contains, in addition to iron, 15 per cent nickel, 9 per cent cobalt, 5 per cent molybdenum and .5 per cent titanium. When heat-treated as shown in the fourth panel in the top illustration on page 80, its tensile strength is more than 300,000 pounds per square inch. The alloy is heated to about 1,500 degrees F. and allowed to cool to room temperature in air. Drastic quenching is not required, nor is cold-working. The martensite that forms is soft and malleable, unlike that in quenched steels, and it can easily be fabricated into useful shapes prior to further heat treatment. The martensite is then aged at about 900 degrees F. for several hours. The aging step turns the soft martensite into a tough, hard material. Exactly why this happens no one knows.

Maraging steels have about twice the ductility of conventional martensitic and Ausform steels. Furthermore, their toughness is in a class by itself. Maraging steels have exceptional ability to resist brittle fracture when they are flawed by deep scratches or nonmetallic inclusions. Their advantages include simple heat treatment, excellent welding characteristics and good strength and ductility at temperatures well below zero Fahrenheit. Suggested applications include highly stressed rotating mechanical parts, aircraft landing gear, hulls for deep-diving submarines and containers for holding liquid hydrogen in rockets. At present Maraging steels are several times more costly than Ausform steels.

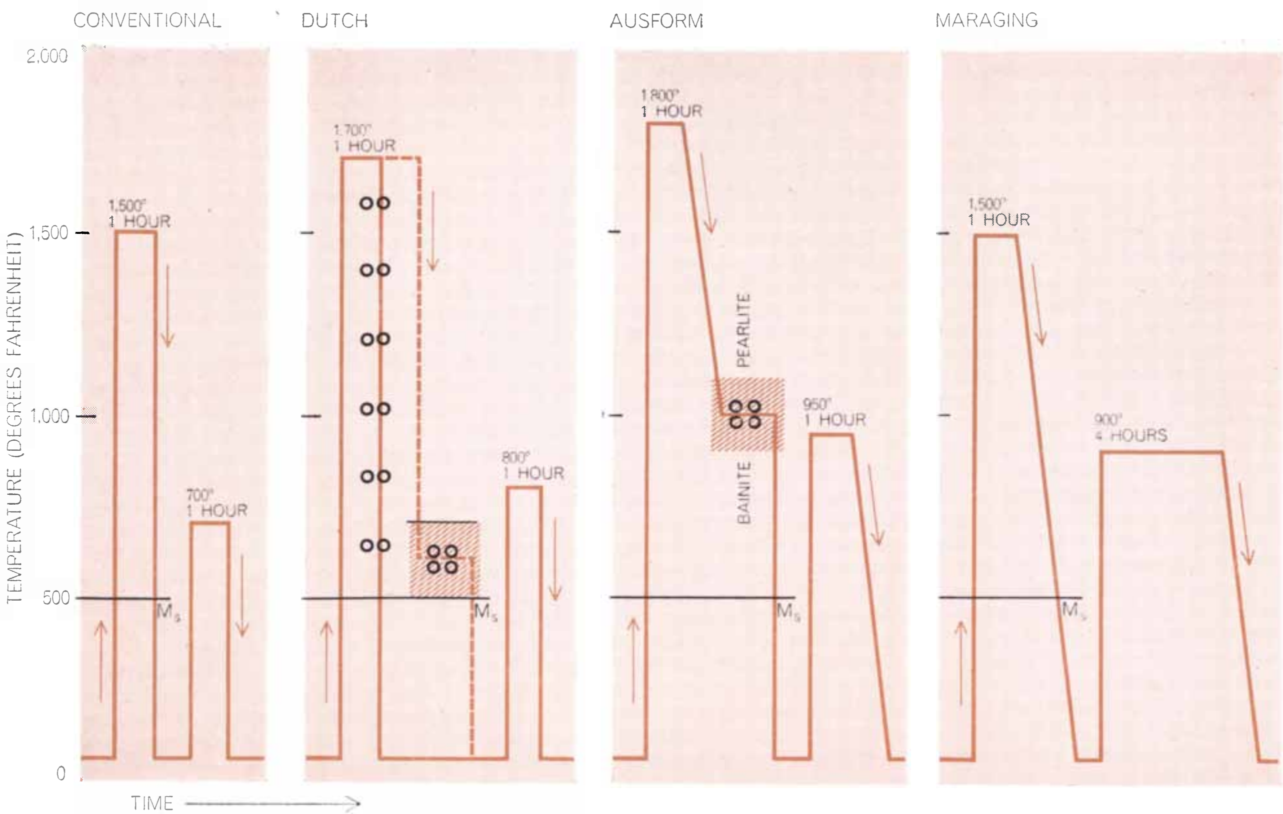
The structural features responsible for the excellent combination of strength and ductility in the Maraging alloys are being intensively sought. P. Swann of the United States Steel Corporation Laboratory has identified a precipitate, visible only in the electron microscope, that may be the first clue to the strength of these alloys. Evidently some component in the alloy is playing the role nor-



PHASE DIAGRAM OF IRON AND STEEL shows the effect of temperature and carbon content (*left*) and the further effect of time (*right*). Ordinary steel (*a*) decomposes quickly into pearlite and bainite, alloys that contain hard precipitates. The Ausform process requires alloys (*b*) in which the decomposition is postponed, allowing time for metastable austenite to be cold-worked.



MICROSTRUCTURE OF STEEL varies with time, temperature and deformation. In the conventional process austenite is directly quenched to martensite. In the Ausform process the austenite is quenched to an intermediate temperature and cold-worked. As a result of cold-working the strength of martensite is raised from about 300,000 to more than 400,000 pounds per square inch.

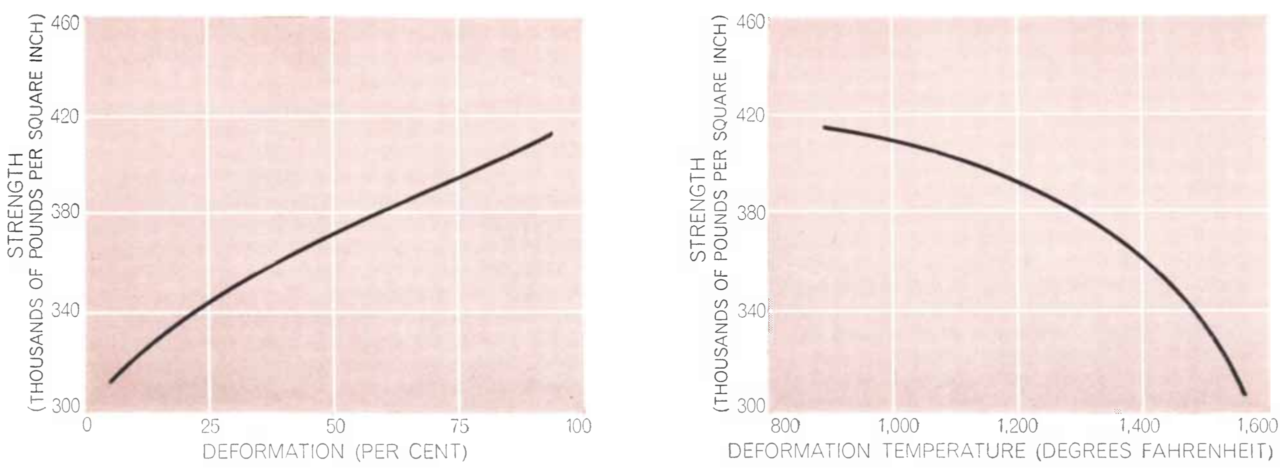


FOUR STEELMAKING PROCESSES, described in the text, all yield a strong product. The Dutch process was devised by E. M. H. Lips and H. van Zuilen and the Maraging process by International Nickel Company, Inc. Cold-working is symbolized by rollers. In the Dutch process the broken line indicates an alternative path. "M_s" signifies the temperature at which martensite starts to form.

mally played by carbon in conventional high-strength steels, and playing it more effectively.

Somewhat more has been learned about the factors contributing to the strength of martensite, but even here there is no general agreement among experts. Morris Cohen and P. G. Winchell of the Massachusetts Institute of Technology concluded from studies of iron-nickel-carbon alloys that carbon in solution and precipitation-hardening by carbides are the chief strengthening mechanisms in martensite.

P. Kelly and J. Nutting of the University of Leeds postulate a different mechanism. They find that the strength of martensite is proportional to the number of martensite plates incorporating fine internal twin crystals. The twins show up in electron micrographs as very



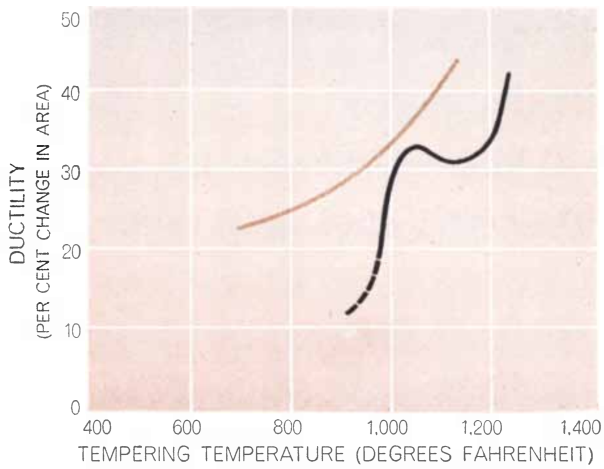
STRENGTH OF AUSFORM STEEL increases with the amount of deformation, or cold-working (*left*), and decreases as the deformation temperature increases (*right*). The per cent deformation is the per cent reduction in cross section when a billet is rolled.

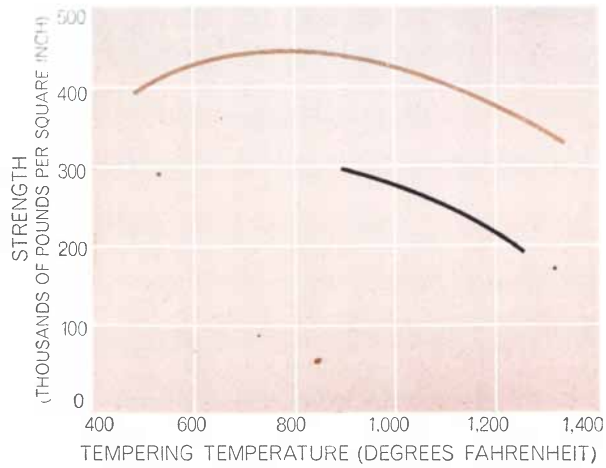
straight, thin, paired structures, and characteristically many twins are found lying side by side in a regular array [*see illustration at bottom left in the group of four on next page*]. There is no doubt that such structures must present an effective barrier to the movement of dislocations. Moreover, Kelly and Nutting have shown that the number of twinned plates is proportional to the amount of carbon in solution, thereby satisfying the empirical observation that the strength of martensite is proportional to carbon content. Although twinning undoubtedly contributes to the strength of conventionally quenched and tempered steels, other mechanisms are probably also important.

At the Ford laboratory D. J. Schmatz, F. W. Schaller and I have concluded that Ausform martensitic steels are primarily strengthened bv precipitation-hardening or by solid-solution-hardening. Although we also see more twins in Ausform steels than in conventional martensitic steels, we hesitate to credit them as a major source of strength. The argument in favor of precipitation-hardening or solid-solution-hardening runs as follows. As noted above, the strength of Ausform steel is relatively insensitive to tempering temperature. This implies that most of the strength in the steel is developed during either cold-working or quenching. In either case the time available for the formation of a precipitate is limited and, if a precipitate forms, it will have to be uniformly dispersed and consist of particles less than 100 angstrom units in diameter. (An angstrom unit is a hundred-millionth of a centimeter.) The alternative explanation is that the carbon is not in the form of a precipitate but is actually held in solid solution. Dislocation theory predicts that either a fine precipitate or a solution of carbon atoms could account for the high strength of Ausform steels.

By a suitable technique it is possible to see in the electron microscope whether or not a sample of steel contains hard carbide precipitates that are larger than 50 angstroms in diameter. When this technique is used to compare Ausform and conventional heat-treated steel, it is found that the density of coarse carbides is much less in the Ausform steel [*see illustration at bottom right in the group of four on next page*]. It is evident that the large amount of carbon in the Ausform steel is either in solid solution or in the form of a precipitate smaller than 50 angstroms in diameter.

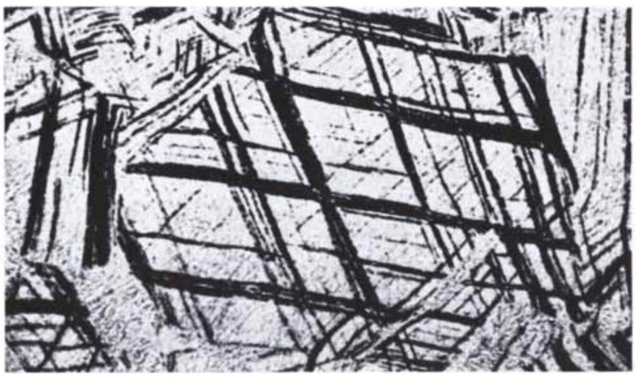
Looking toward the future, one can make a few fairly safe predictions. Ductile steels with a tensile strength of





STRENGTH AND DUCTILITY are generally traded when conventional martensitic steel is tempered (*black curves*). Ausform steels (*color*) match conventional steels in ductility (*left*) without significant loss of strength at high tempering temperatures (*right*).

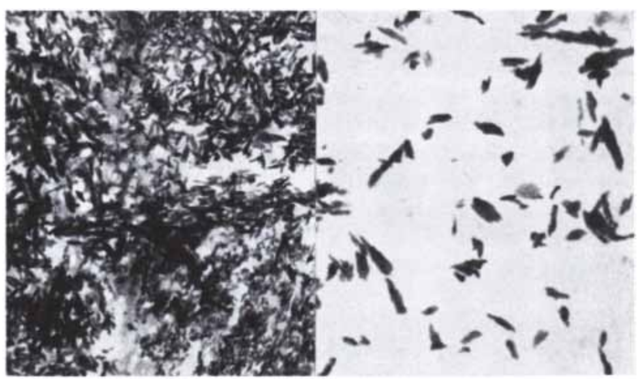
500,000 pounds per square inch will be an engineering reality before the end of the decade. To an increasing degree noncarbon alloys will replace carbon-containing steels for difficult jobs. Later, perhaps not in this decade, noncarbon alloys will begin to replace the more common structural steels. This development, however, will await a detailed understanding of how the Maraging alloys are strengthened without carbon. Wherever the paths of research may lead, they will probably support the canny observations of the 17th-century natural philosopher Joseph Glanvill, who wrote: "Iron seemeth a simple metal . . . but in its nature are many mysteries . . . and men who bend to them their minds shall, in arriving days, gather therefrom greater profit, not to themselves alone but to all mankind."



DEFORMATION MARKINGS, or slip bands, can be made visible if Ausform steel is allowed to cool slowly after deformation. Hard carbides precipitate along the slip bands, "decorating" them.

MARTENSITE PLATES, dark jagged shapes, grow to large size (*lower left*) in nondeformed region of martensite. In deformed region (*upper right*) plates are deflected when they meet slip bands.

TWINNED MARTENSITE PLATES appear as fine parallel lines in this electron micrograph of Ausform steel by P. M. Kelly, University of Leeds. Such crystal twins block movement of dislocations.



CARBIDE PARTICLES larger than 50 angstrom units in size are shown in ordinary martensitic steel (*left*) and in Ausform steel (*right*). Most Ausform carbon is in solution or in fine particles.

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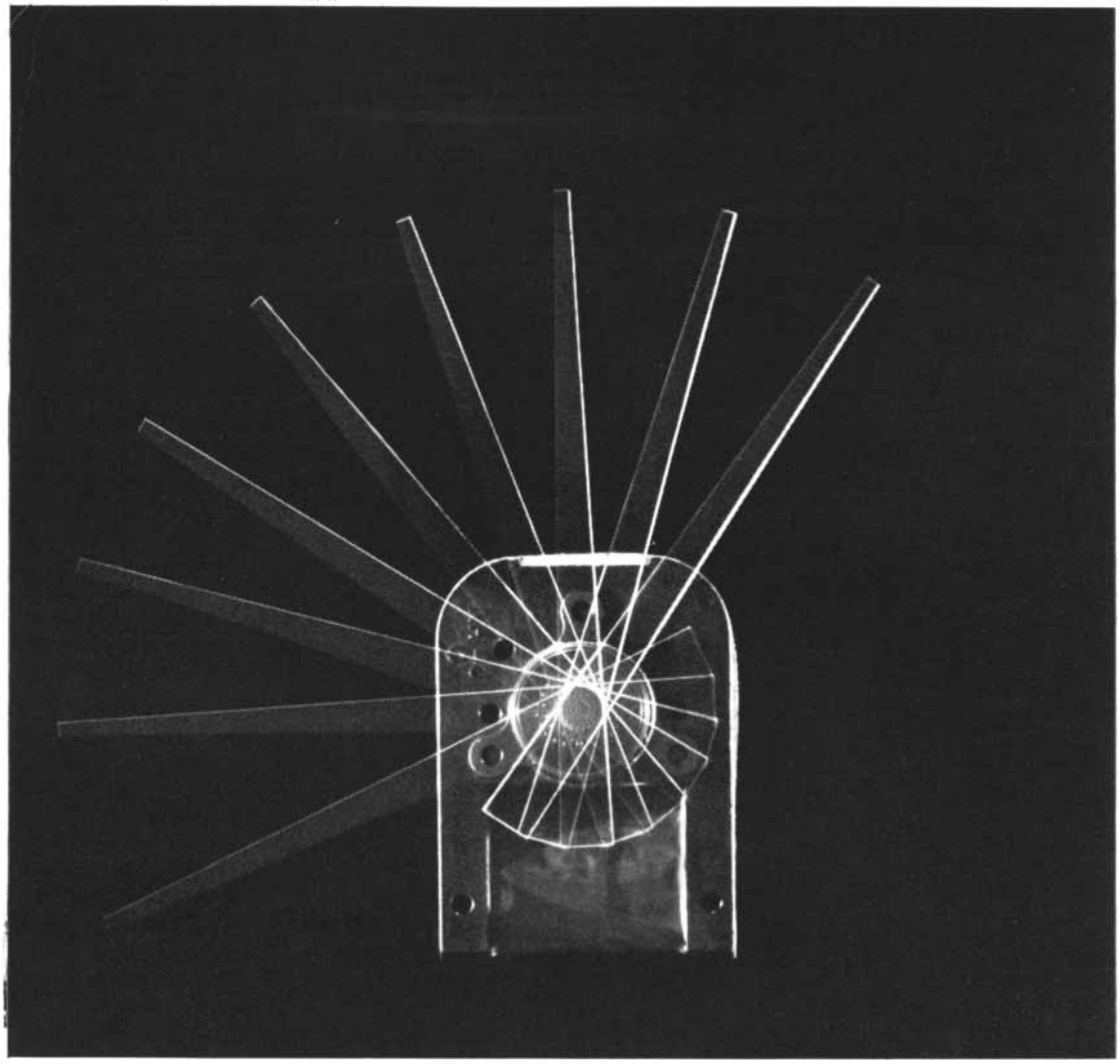

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HOW SLIME MOLDS COMMUNICATE

Slime-mold amoebae are free-living microorganisms that periodically gather together to form macroscopic fruiting bodies. It now seems that secreted gases play several important roles in this development

by John Tyler Bonner

Living things generally grow "up" because the earth's gravity pulls them "down." A stand of pines thus points to the zenith from a hillside as well as from a flood plain. The tiny fruiting body of the cellular slime mold is also lofted upward into the air—by as much as two whole millimeters—above the surface from which its spindly supporting stalk happens to spring. Now, a great many questions remain to be answered about this peculiar organism. In the first place, it is formed by the intricate and transitory collaboration of a number of single-celled animals. The system of intercellular communications that brings these social amoebae together and causes them to differentiate in form and function and find their proper places in the rigorously ordered structure of their fruiting body holds clues to the developmental processes of multicelled plants and animals that arise in the usual way from a single cell. The fact is, however, that gravity does not supply any significant cue to the orientation of the growth of the microscopic slime mold. Presumably the weights involved here are too insignificant.

Not long ago in our laboratory at Princeton University we came on another principle of action at a distance that may explain the orientation of the upward reaching of the social amoebae. We were not at the time worrying about what the cells say to one another in the process of marshaling a unified multicellular organism. We had become interested in what might be termed the conversations between the cell masses and their neighbors. We had raised the level of discourse, in other words, from that of cells to that of organisms composed of numbers of cells. It now appears that the same principle of communication is engaged at both levels. Slime-mold amoebae have turned out to be even more social than anyone had suspected.

Of the dozen or so known species of cellular slime mold, *Dictyostelium discoideum* has played the leading role in the laboratory ever since it was discovered and described by Kenneth B. Raper of the University of Wisconsin in 1935. In the free-living, single-celled state this amoeba has the size and appearance of one of our white blood cells. It feeds on bacteria in the moist humus where it dwells and, under favorable conditions, undergoes repeated division every three or four hours. By the time the local food supply is depleted there is a considerable accumulation of amoebae wandering about in different directions. Suddenly they shift their attention and begin streaming into central collection points. Much work has been done on this aggregation stage; it is known that an evanescent substance called acrasin is given off by the amoebae, and that the amoebae tend to move up the gradient of concentration of this substance, forming a clump of cells often visible to the naked eye [see "Differentiation in Social Amoebae," by John Tyler Bonner; SCIENTIFIC AMERICAN, December, 1959]. If the aggregation is sufficiently large, it will form a sausage-shaped slug that crawls about and orients toward sources of light and warmth with remarkable precision and sensitivity. Eventually the mass rights itself and the leading (now upper) third of the cells begin to differentiate into stalk cells. These cells form a central cylindrical stalk, stiffened by cellulose fibers that the cells secrete. The rest of the cells stream upward to the top of the stalk, where they form a little sphere, each cell encapsulated into a spore ready to start a new generation.

All sorts of intercellular communication play their parts in this curious life history. E. W. Samuel of Antioch College has shown that, before aggregation begins under the influence of acrasin, the amoebae tend to repel one another. Like sheep, they separate to graze; once the food is gone they come together. After aggregation the intercellular communication system regulates the differentiation and sorting out of the cells to form the stalk and fruiting body. Only a few features of this system have been demonstrated by experiment.

The first clear indication of communication between cell masses was uncovered by two college seniors working in our laboratory, J. Rorke and G. Rosenthal. They were investigating a phenomenon we first noticed in 1941. If a migrating slug is cut into three pieces, each piece will regroup and before long culminate, that is, rise into the air to form a small but otherwise normal sorocarp, or fruiting body. If the three pieces remain close to one another, they will tend to bend away from one another as they rise, instead of growing straight up. The readiest explanation appeared to be that the forward third of the slug grew faster and so pointed forward, whereas the slower growing hind third grew slower and pointed rearward. In one experiment, however, Rorke and Rosenthal noted that the forward fragment had wandered around and settled in position between the middle and hind fragments before the three fragments began to culminate. When they rose into the air, the two end cell masses still leaned away, whereas the new middle piece went straight up.

In other words, the orientation of the rising sorocarp has nothing to do with what part of the slug the cells come from. The only significant point is their relation to one another as they rise. If they are close to one another, they will repel one another. We confirmed this deduction by trying all the different permutations of forward, middle and hind fragments, as in the shell game, and even got the same result when we pushed two complete and unrelated cell masses close to each other. In every case they leaned away from each other as they rose.

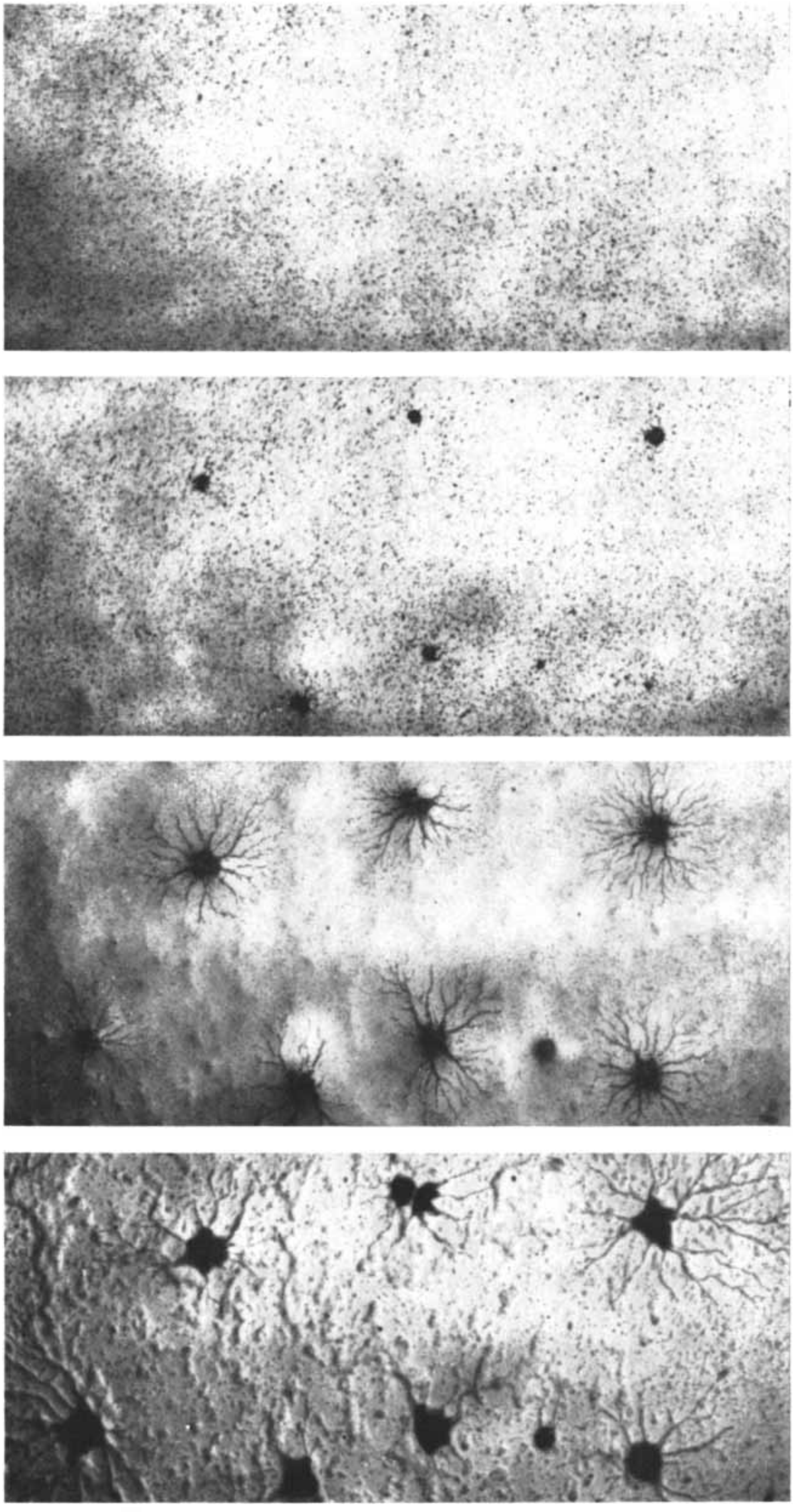
The most obvious conclusion—one that has been supported by all the experiments—was that the fruiting bodies give off a gas and that they orient in a gradient of the gas, leaning away from regions of high concentration. Our proof, however, still remains somewhat indirect, because the fruiting bodies are so minute and because it is not practicable to sample and assay a gas gradient of such tiny dimensions.

We did get a measure of the sensitivity of the mechanism. When the cell masses are placed more than .8 millimeter apart, they grow straight up in the air; at less than this distance they repel one another. The shorter the distance between them, the greater the mutual repulsion. With the cell masses side by side and touching, the two stalks rise at an angle of 45 degrees to the surface and make a perfect 90-degree angle to each other.

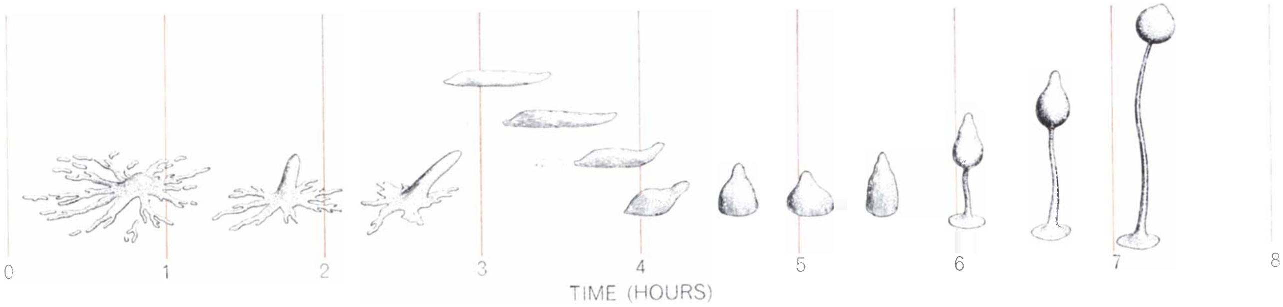
Similarly, we found that the stalks will lean away from the surfaces of inert objects, such as agar blocks, when they are placed close enough to allow a significant concentration of gas to develop in the space between stalk and surface. A growing stalk will even lean away from a glass rod planted next to it in the agar culture medium. With thin glass cover slips we were able to demonstrate geometrical precision in the response: the stalks always grow or lean equidistantly from the confining walls.

If a gas is given off, it should be possible to blow it away. With the help of D. C. Hazen of the Princeton aeronautical engineering department we constructed the world's smallest wind tunnel, with an aquarium pump for the source of its wind. Exposed to a breeze of 30 to 200 centimeters per second, solitary cell masses invariably gave rise to fruiting bodies that leaned into the wind. This was strong support for the gas hypothesis. Because the wind blew the gas to the leeward of the slime mold, the fruiting body would tend to grow "upwind" and away from the gas.

Given the tiny dimensions of the fruiting body and therefore of the gas gradi-



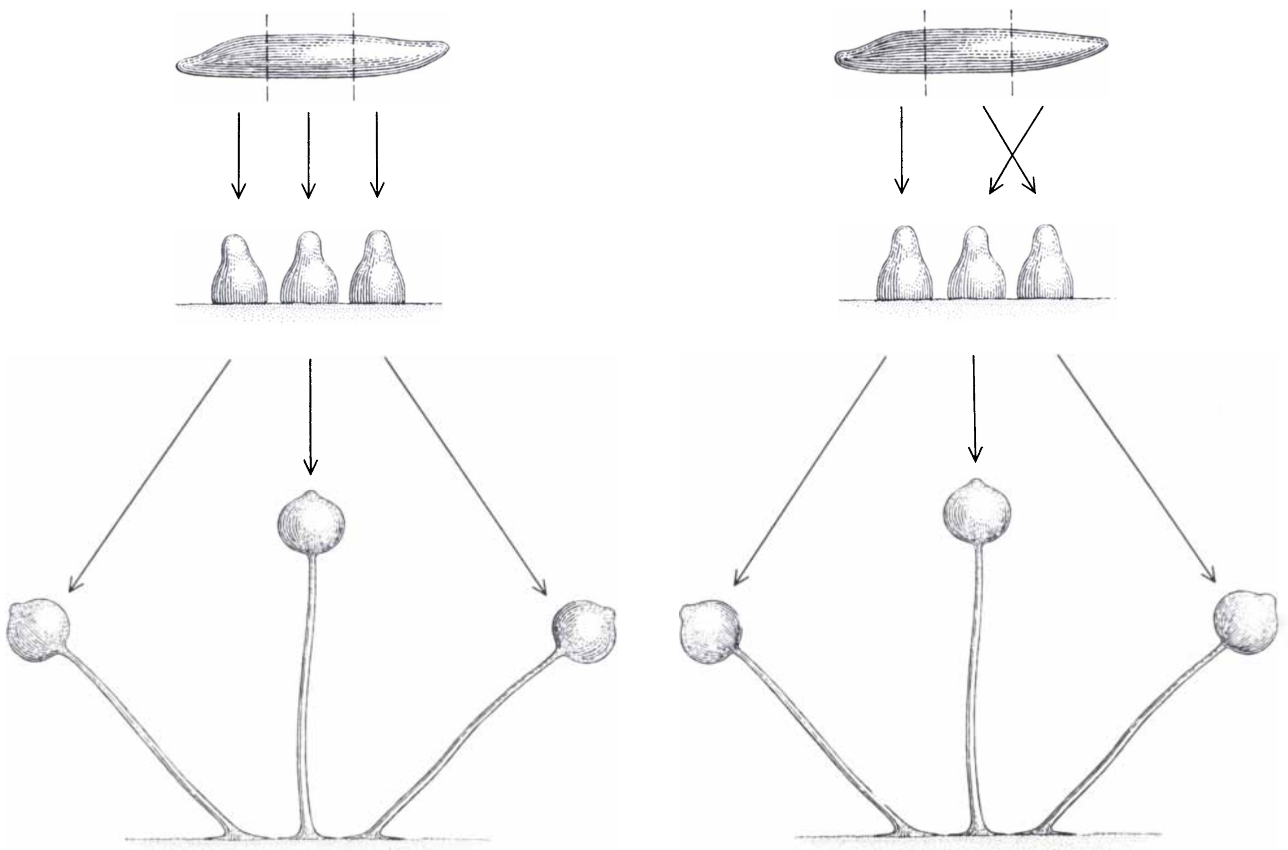
AGGREGATION of social amoebae is the first stage in the formation of slime-mold fruiting bodies. In the photograph at the top thousands of amoebae are spread evenly over an agar surface; an unknown substance repels them from one another as they forage for bacteria. In the second picture the food has been depleted and the amoebae begin to stream toward central collection points, attracted by a substance called acrasin, which is secreted by a few "founder cells." In the third and fourth pictures most of the amoebae in the area have become concentrated into central cell masses. The even spacing of the aggregates is accomplished by means of an aggregation-inhibiting gas, also given off by the founder cells.



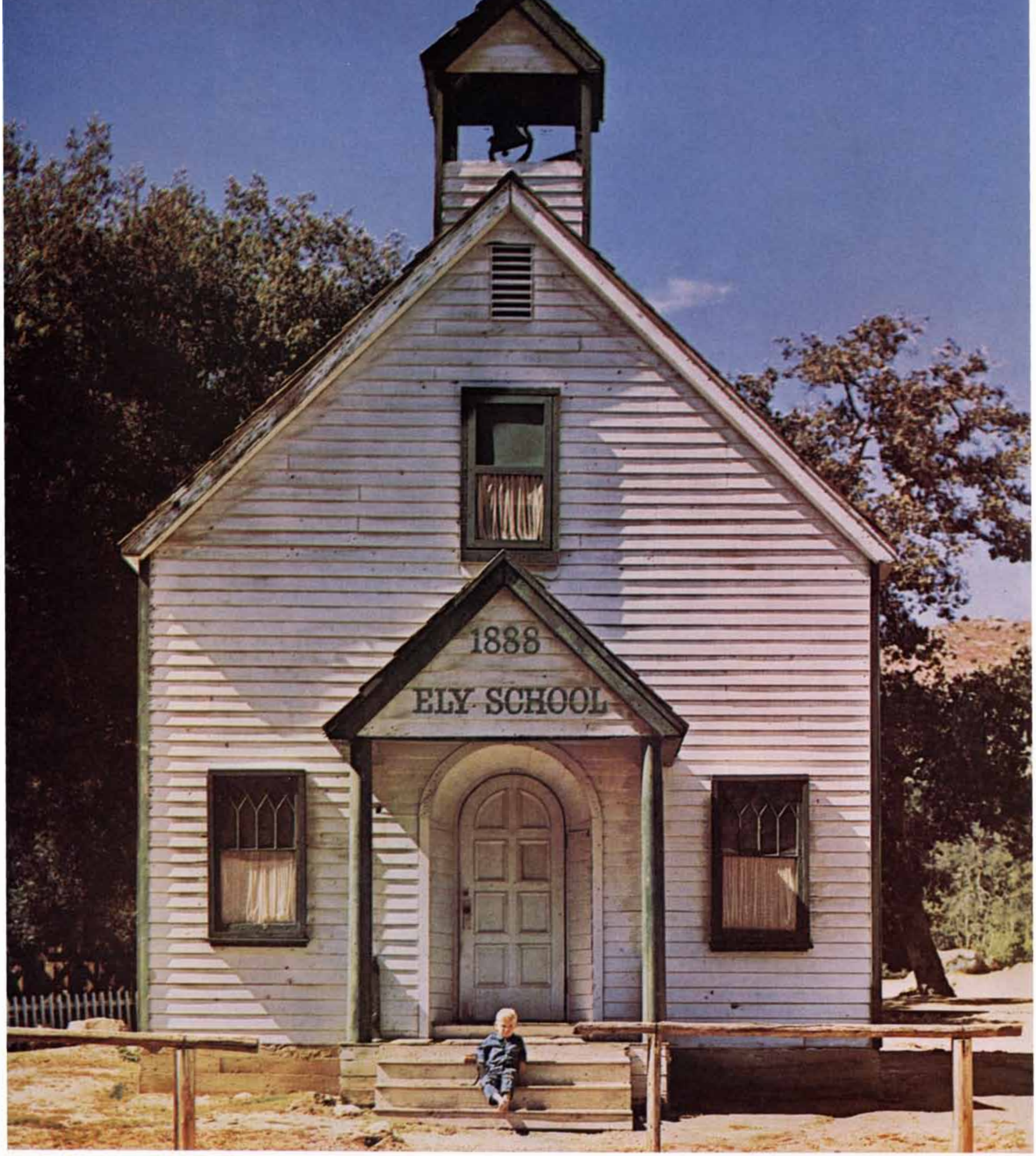
LIFE CYCLE OF A SLIME MOLD, typified in this series of drawings by the species *Dictyostelium discoideum*, covers the period from aggregation (*far left*) to the development of a mature fruiting body (*far right*). Between these two stages the cell mass migrates about for a time in the form of a slimy, sausage-shaped slug before settling into its final fruiting position. Times are only approximate.

ent, one could predict that in a very small chamber the total concentration of the gas would rise to such a level that the gradient would effectively disappear. A small piece of glass tubing, three millimeters in diameter, was heat-sealed at one end and the other was plugged with agar containing one or two cell masses. Culmination took place even though the volume of the chamber was only about 20 cubic millimeters. But the fruiting bodies showed a total lack of orientation; the stalks grew neither straight nor upward, nor did they avoid each other or the glass or the agar surface. With mineral oil, a strong absorber of gases, we found that we could produce the same effect but for exactly opposite physical reasons. Submerged in the oil, the cell masses threw up fruiting bodies, but in a completely disoriented fashion. In this case the gas phase was totally eliminated by the oil.

The best evidence for the gas hypothesis came from an experiment in which we placed a cube of charcoal alongside the cell mass. Instead of being repelled by this mass of material, the fruiting body culminated right into the charcoal. Presumably the charcoal absorbs the gas



CRUCIAL EXPERIMENT that indicated the operation of a gas mechanism in the orientation of slime mold fruiting bodies was performed by two senior students at Princeton University, J. Rorke and G. Rosenthal. The drawing at top left shows a migrating slug cut into three pieces; when these fragments culminate (*bottom left*), they tend to lean away from each other. If two of the fragments are exchanged (*top right*), the identical effect ensues (*bottom right*). This experiment showed that orientation has nothing to do with what part of the slug the cells come from: the only significant factor is their relation to each other as they rise.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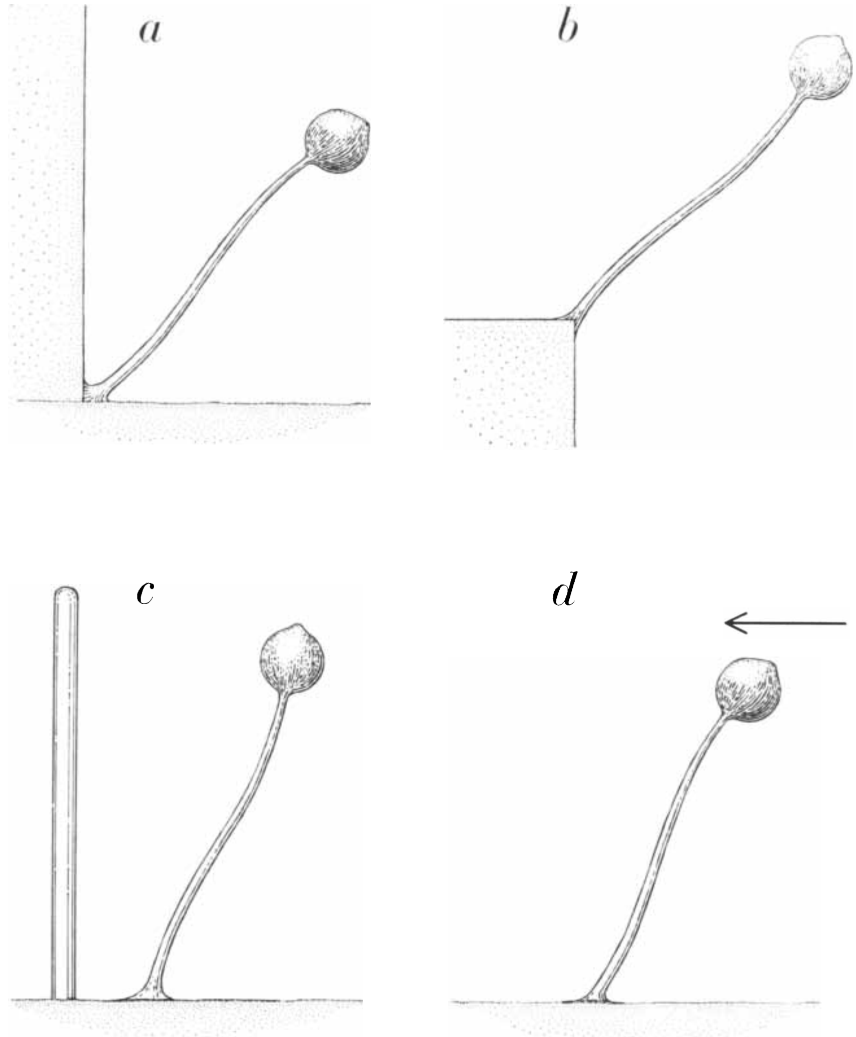


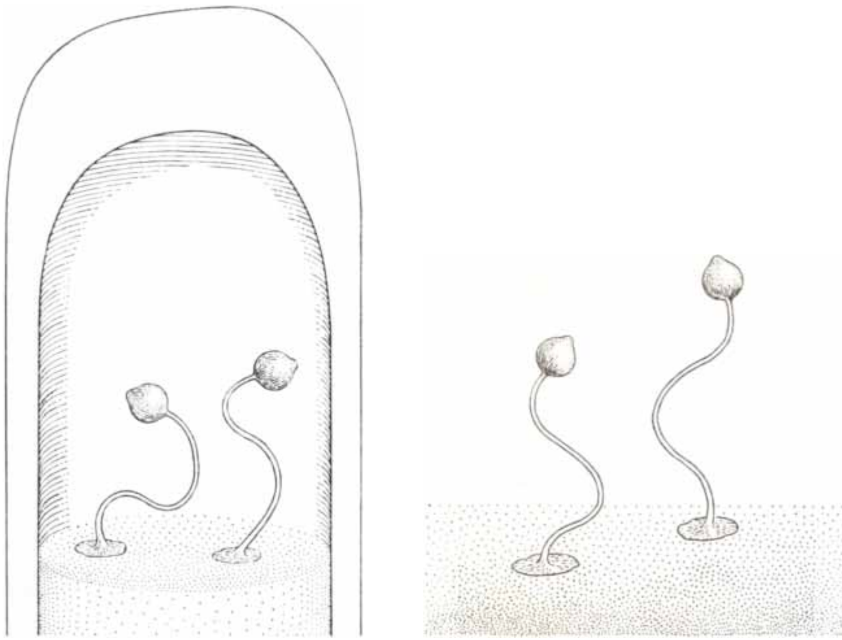
FOUR DEMONSTRATIONS of the sensitivity of a cellular slime mold's gas-orientation mechanism are depicted. A cell mass placed at the base of an agar cliff (*a*) tends to bisect the angle of intersection of the two surfaces. A cell mass placed at the crest of the cliff (*b*) culminates at an angle of about 135 degrees from each surface. When a small glass rod is planted in the agar near a rising fruiting body (*c*), the stalk leans away slightly from the rod. In a wind tunnel (*d*) the orienting gas is blown to the leeward of the fruiting body, causing the stalk to lean away from the gas and into the wind. In all four of these cases the fruiting body tries to maintain an equal concentration of gas on all sides.

and as a result there is less gas on the charcoal side. Subsequently B. M. Shaffer of the University of Cambridge showed that a drop of mineral oil would produce the same effect and would also cause migrating slugs to change course and approach the drop.

As for the chemical identity of the gas, we know at least that it is not specific to species; the gas given off by any species of slime mold will repel any other species. This suggests a common product of metabolism, such as carbon dioxide or ammonia. As will be seen, however, the question remains unsettled.

Whatever the nature of the gas, it is apparent that a vertical concentration gradient of the gas, under natural and normal circumstances, causes the fruiting body of the slime mold to grow straight up at right angles to the surface. The next question is: What good does this do the slime mold? There is no certain answer because we do not even know the evolutionary significance of the aggregation of the amoebae into cell masses in the first place.

For the moment let us grant that rearing the fruiting body into the air is advantageous and further assume that it serves the protection and dispersal of the spores. In nature, fruiting occurs in the small caverns and chambers that riddle the humus and upper crust of the



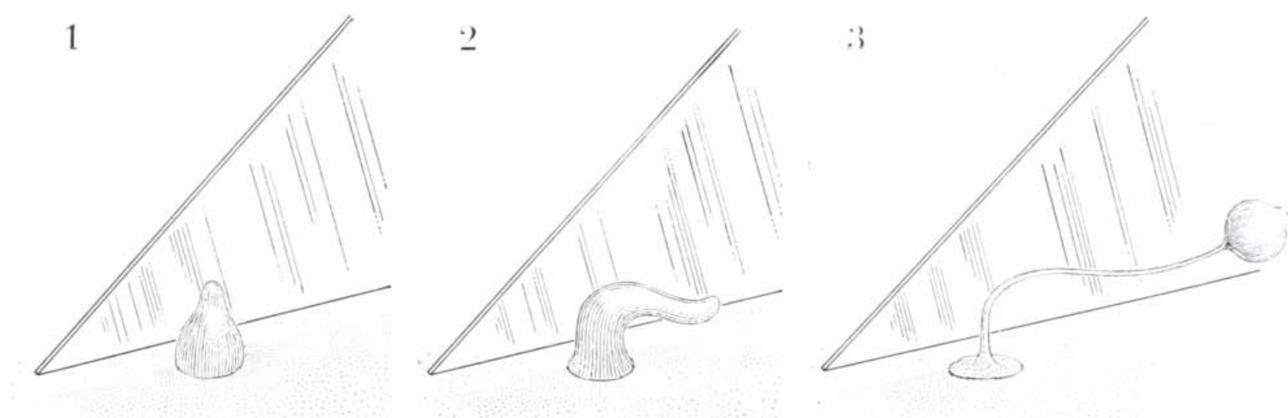
LACK OF ORIENTATION of slime mold fruiting bodies was achieved in two different ways. A thin piece of glass tubing was heat-sealed at one end to form a tiny chamber (*left*) in which the concentration of gas rose so high that the fruiting bodies inside were unable to establish an effective orientation gradient. When mineral oil was poured over some cell masses (*right*), they also culminated successfully, but in an entirely disoriented fashion.

soil. If it is advantageous to store the spores free from any surface, obviously the gas orientation will be extremely useful: it will keep the spore mass in the center of any cavity. It may be that dispersal is primarily effected by worms and grubs slithering by and touching the ball of spores. As soon as an object touches the spores, they come off and stick to the foreign object by surface tension. Finally, if a number of fruiting bodies should grow close together in a large pocket in the soil, the gas-orientation mechanism will space the rising spore masses so that they spread over the whole area in an optimal way, filling all the available space. The mechanism works with such precision that it is perhaps not unreasonable to expect that the growth of many other primitive plants—for example, simple fungi—is also oriented by gas gradients.

Meanwhile we had been working on what we thought was an entirely separate problem. In 1937 the German biologist A. Arndt observed that the number of fruiting bodies that formed in a culture dish appeared to be independent of the total population of amoebae in the culture. We confirmed this observation in experiments with five different species. To put the story the other way around, it appeared that the size of the territory in which an aggregation of amoebae forms is constant (under given experimental conditions). Roughly speaking, if there are 10 amoebae in the territory, they will aggregate to produce one fruiting body of 10 cells, and if there are 10,000 amoebae, the 10,000 will join in a single, much larger aggregation.

All of this was of interest as a lead to the mechanism that initiates aggregation. Such evidence was inconsistent with the "initiator cell" hypothesis of Maurice Sussman of Brandeis University. He had proposed that one cell in every 300 or 2,000 (depending on the species) was somehow capable of starting aggregation. The finding that aggregation is a function of space rather than cell density fitted in more readily with an observation by Shaffer; he demonstrated that a single cell, which he calls the founder cell, is the focal point of aggregation and that this cell inhibits other founders from forming in its immediate vicinity.

In the fall of 1962 we performed a simple experiment that immediately suggested the nature of the inhibitory influence exerted by the founder cell. We placed amoebae of the species *Dictyostelium mucoroides* in tightly stoppered culture tubes. No aggregation took place; this was not surprising because it had been shown by James H. Gregg of the University of Florida that the cells require oxygen for aggregation and the later stages of development. In one of these tightly stoppered tubes, however, I added a spatulaful of activated charcoal. Within an hour aggregation was fully under way in this tube. More careful repetitions of this experiment showed that it



ELEGANT CURVE in the stalk of a rising fruiting body can be produced by placing a microscope cover glass over the cell mass during culmination. The slime mold's gas-orientation mechanism tends to keep it equidistant from both the cover glass and the agar.

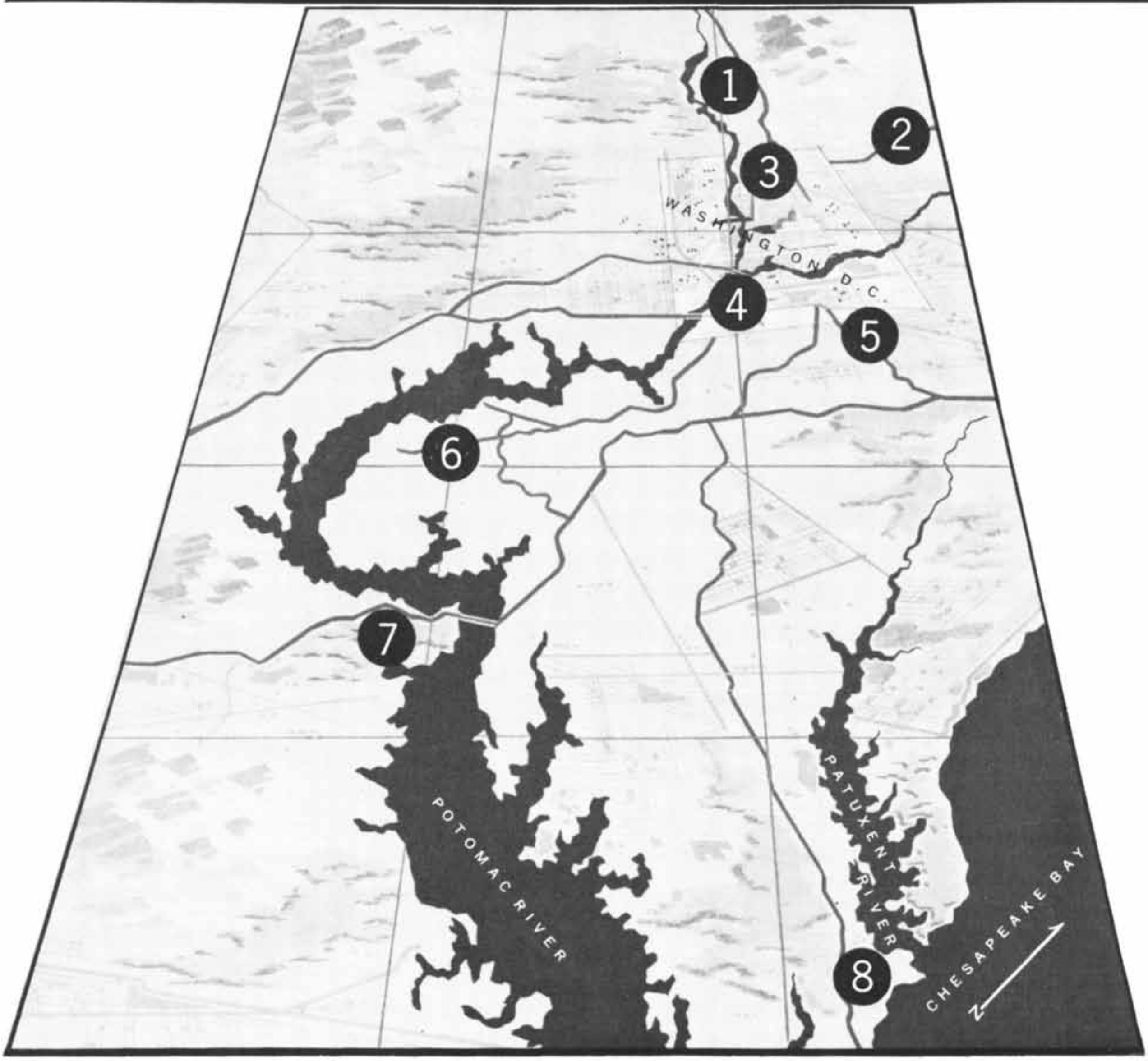
was not the absence of oxygen but the accumulation of some inhibiting gas that prevented aggregation in the closed tubes. We found also that aggregation would occur if we reduced the number of amoebae per culture tube below a certain threshold. From this it could be calculated that the presence of more than approximately 250 cells per cubic millimeter of air space would inhibit aggregation. Apparently if the cells were fewer, the gas did not accumulate in sufficient concentration to prevent aggregation. At threshold concentrations the amoebae formed abnormal aggregations or disoriented fruiting bodies. All these peculiarities disappeared when we added a small heap of charcoal to the culture.

From the known size of the chamber and the concentration of the amoebae it was possible to compare territory size or, conversely, to compute the number of fruiting bodies per square centimeter in the presence or absence of charcoal. It turned out that the fruiting bodies were approximately four times denser or more crowded together in the presence of charcoal. In other words, removal of the inhibiting gas reduced the size of the aggregation territory. This conclusion was dramatically fortified when we submerged the cultures in mineral oil—the territory size then became minute. In this case, however, it is not certain that the effect is exclusively due to the removal of the inhibitor. Raper showed some years ago, for instance, that drying markedly reduces territory size; oil might somehow promote this effect.

On the precedent of our wind-tunnel experiments in the orientation of the growth of fruiting bodies, we compared the sizes of territories formed in still and in circulating air. In circulating air the density of the fruiting bodies was four to nine times greater than in still air. Therefore by disturbing the normal diffusion pattern of the gas and blowing it away as well one can effectively reduce the territory size.

Other experiments showed that the gaseous "spacing substance" is not species-specific: each one of four different species cultured in the same confined chamber with *Dictyostelium mucoroides* produced a gas that inhibited the formation of centers of aggregation and correspondingly increased the territory size of the *Dictyostelium mucoroides* fruiting bodies.

Turning to the task of identifying the spacing substance chemically, we found that carbon dioxide is the one



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gas that will produce the same effect. On the one hand, the addition of approximately 5 per cent carbon dioxide to the atmosphere of the culture tube totally inhibits aggregation in *Dictyostelium mucoroides*. On the other hand, substances that absorb CO_2 selectively will lift the inhibition, although not so effectively as charcoal. The gas chromatograph showed no additional spikes other than the ones common to room air in samples of gas taken from tubes in which cultures were inhibited. CO_2 is, of course, one of the gases common to room air.

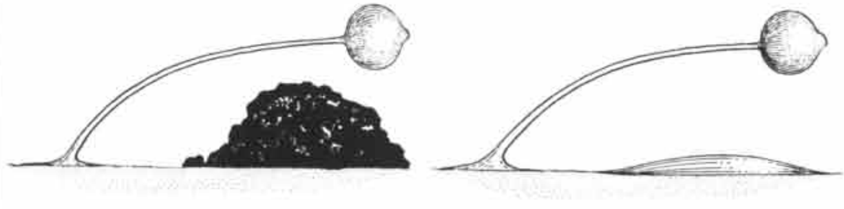
Can we conclude that the spacing substance is CO_2? It would be most unwise to do so at this time. The gas may merely imitate the natural spacing substances, one of which may be CO_2. I have a particularly strong reason for caution. We made all these tests with five species and found only two of the five sensitive to the gas, although they all produced it. Two species are totally insensitive at all times to either naturally produced spacing substance or added CO_2. Most mystifying of all, the fifth species sometimes exhibits sensitivity to the gas and at other times appears to be totally insensitive. It seems to be able to switch its sensitivity on and off. Much more work must be done before we can say we have identified the spacing substance.

In the case of *Dictyostelium mucoroides*, one of the species sensitive to the gas, we were able to demonstrate that it produces the gas not only at the initiation of the process of aggregation but also throughout the entire process and during migration and culmination as well. Thus when the fruiting body of a large cell mass rises above a culture swarming with amoebae in the preaggregation phase, the evolving gas totally inhibits aggregation in the rest of the culture until fruiting is completed. This suggests that in nature aggregation may occur in waves, each one starting only after all the fruiting of the previous wave is complete. We found also that, if conditions allowed a high accumulation of the spacing substance, migration is curtailed. Barbara Wescott, working in Raper's laboratory, had shown previously that a concentration of 5 to 10 per cent CO_2 in the atmosphere of the culture inhibits migration.

The fact that the gaseous spacing substance is produced during migration and culmination strongly indicates that this gas and the gas that orients the growth of the fruiting body are one and the same. Neither gas shows species-specificity and both are adsorbed by charcoal and mineral oil. What is more, from the point of view of their function they both do the same thing. At aggregation the substance controls the spacing of the aggregates; as the cell masses rise from the surface, they are again "spaced" by the mechanism of gas orientation. In the first case the spacing is in two dimensions; in the process of orientation the spacing effect is three-dimensional. Certainly we are justified in calling both gases spacing substances.

It is now permissible also to speculate about how the spacing substance produces its effects. One hypothesis that simultaneously accounts for the inhibition of aggregation and for orientation of the fruiting body suggests itself: the spacing substance tends to speed up the movement of the cells. Centers of aggregation are formed by a localized slowing of cells; if the cells are speeded up, they are inhibited from forming centers. Similarly, if two fruiting bodies are close together, the gas concentration will be highest between them; the cells on this inward side will then move more rapidly, and the growing stalks will bend away from each other. This hypothesis is attractive, but it remains to be tested.

What is established is that the multicellular cell masses of the slime mold can converse with one another by means of a gas. We have always known that the social existence of many higher animals is influenced by odors. Now we have to learn more about the gas communications of slime molds and of other microorganisms as well.



ADSORBING THE ORIENTATION GAS by a piece of charcoal (*left*) or a drop of mineral oil (*right*) lowers the concentration of gas on the side of the adsorbent, causing the stalk to lean in that direction. Migrating slugs can also be attracted toward these adsorbents.

The Sea that Spills into a Desert

The Caspian empties into a shallow gulf, the high salinity of which gives rise to odd geological and ecological phenomena

by Maurice A. Garbell

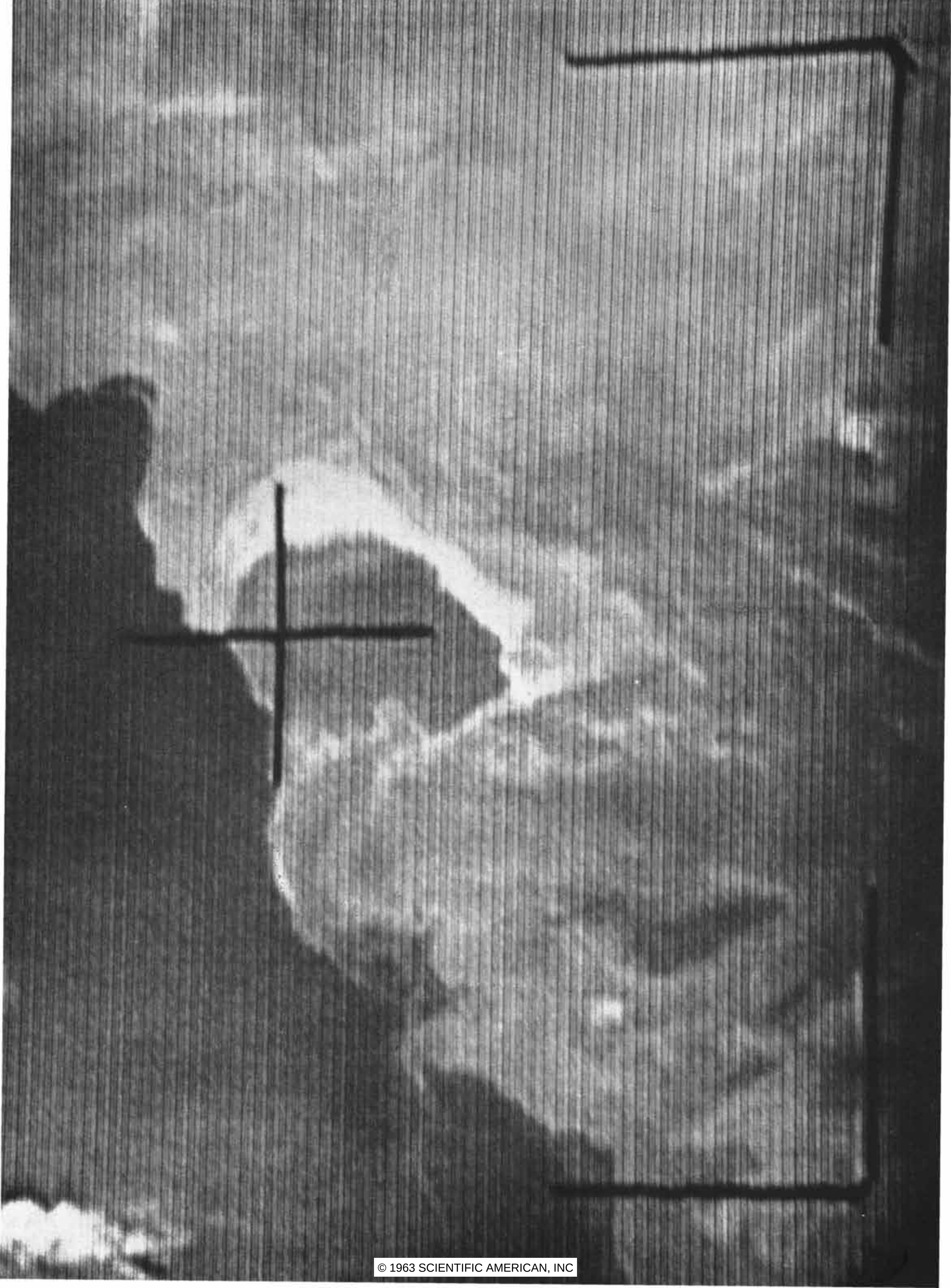
In the normal course of events the water and snow that fall on the land are drained by streams that ultimately empty into the world ocean, from which, of course, there is no exit. Then the water evaporates from the oceanic surface and completes the cycle by precipitating on the continents again. A most unusual variation on this grand-scale theme is represented by the Caspian Sea of the southern U.S.S.R. and northern Iran. Each year more than two cubic miles of the Caspian's water spills through a narrow strait into a shallow, thirsty depression in the desert to the east. This basin is the Zaliv (gulf) Kara-Bogaz-Gol, a gigantic natural evaporation pan that is parched by a blazing sun and a searing east wind. The rate of evaporation with respect to the volume of water is such that the gulf has become the saltiest large body of water in the world—even saltier than the Dead Sea, which is widely thought to be the saltiest.

The water in the gulf is a fully saturated brine, mostly of sodium sulfate (Na_2SO_4). Only 30 years ago the water stood at the level of the Caspian. In recent years a severe drop in the level of the Caspian has resulted in an even greater drop in the level of the gulf, creating a thundering miniature Niagara at the end of the once navigable strait. A strange, shifting marine delta has grown below the falls, sustaining an unusual animal and plant community based partly on Caspian fish and other organisms killed by the lethal waters of the gulf and cast ashore. The gulf itself has long supported a small community of people; they harvest the concentrated sodium sulfate for industrial purposes.

The Caspian, which lies in the borderland between Europe and Asia, is fed by the Volga, the Ural River and several minor rivers that descend from the Caucasus. Covering more than 150,000 square miles, an area comparable to that of California, it is the largest enclosed salt lake in the world. It is 750 miles long from the great delta of the Volga in the north to the Iranian shore in the south; 200 miles of water separates the Caucasus on the west from the Turkmenian shore and the Kara-Bogaz-Gol on the east. The surface of the Caspian now lies 92 feet below sea level. The main body of the sea attains a depth of some 1,500 feet in its northern basin and 3,240 feet in its southern basin. The two basins are separated by a sill, an underwater extension of the Caucasus.

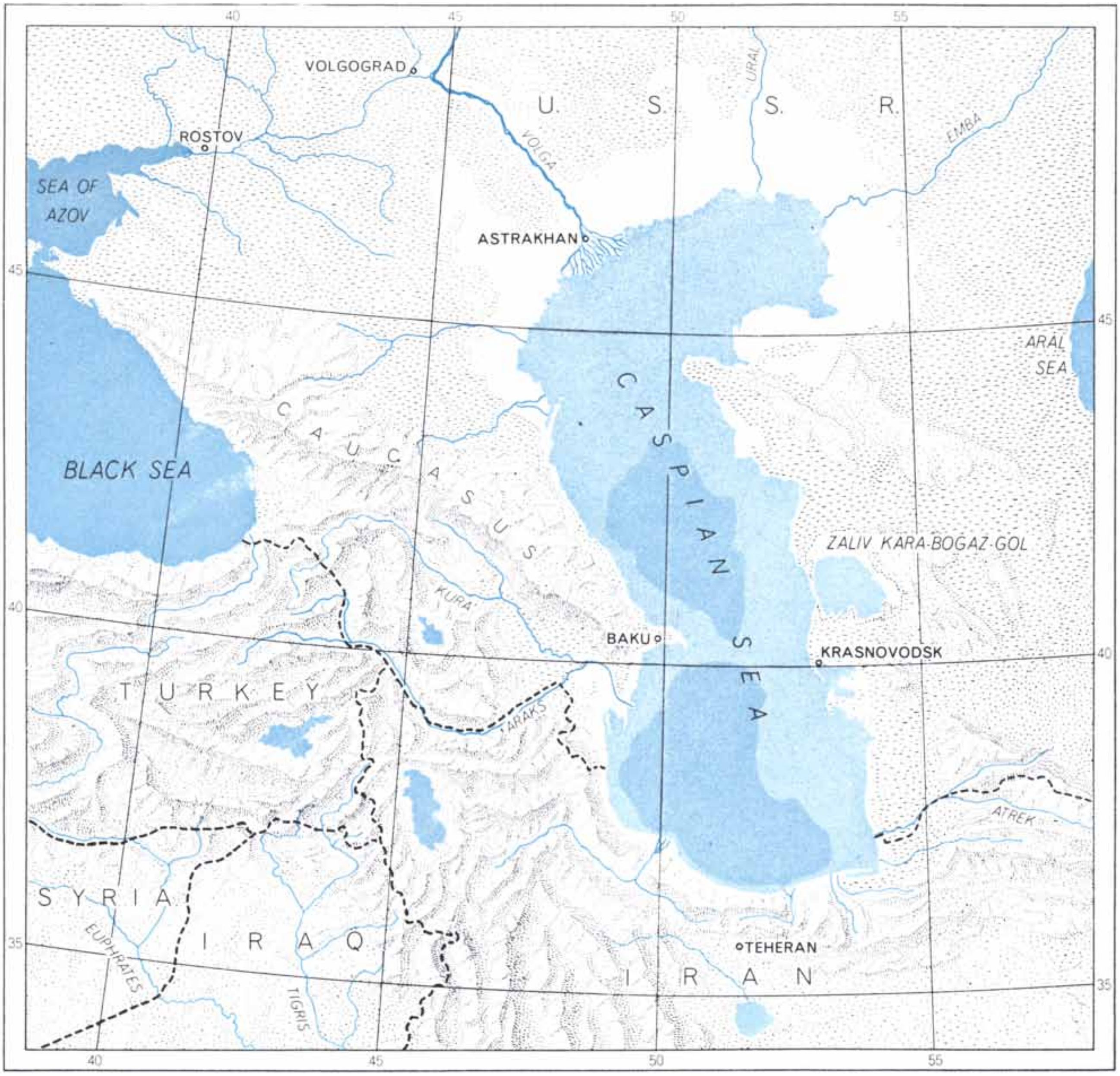
The Kara-Bogaz-Gol once covered 7,000 square miles, but now it has an area of only 4,000 square miles. Today its greatest depth is about 10 feet, compared with more than 40 feet three decades ago. Over the ages the Caspian has risen and fallen many times as a result of changes in the precarious balance between inflow from the rivers and "outflow" in the form of evaporation and seepage. Each modest rise inundated broad areas of the adjacent northern and eastern flatlands; each retreat laid bare the same expanses. On one occasion the

KARA-BOGAZ-GOL, the gulf where the Caspian spills into the Turkmenian desert, is marked by the cross in this television picture made by the U.S. Weather Bureau research satellite *Tiros V* on June 22, 1962. White shore-line areas of gulf are salt flats.



Caspian rose higher than usual and breached the natural dike that separated it from the shallow depression in the Turkmenian desert to the east. The outrushing water filled the depression and created the Kara-Bogaz-Gol; the break in the dike remained as a permanent passage, the Proliv (strait) Karabogazskiy. The most recent rise of the Caspian occurred in the latter half of the 19th century, slowing gradually to a standstill around 1889. Now for more than 70 years the level of the sea has been falling with only seasonal remissions. Over the past 25 years the recession has accelerated, bringing the dramatic changes in the level of the gulf and in the condition of the strait.

Since the turn of the century the Kara-Bogaz-Gol has been exploited as an important source of sodium sulfate, in the form of Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) deposited by the waves on the shallow shores. Sodium sulfate is used in the production of brown wrapping paper and paperboard boxes and of glass and detergents. (The U.S. consumes more than a million tons annually, about 60 per cent of it from natural sources in California and elsewhere and about 40 per cent from the by-product of certain industrial chemical processes. Presumably the U.S.S.R. also uses hundreds of thousands of tons of the salt.) In the early part of this century three production facilities grew up on the Kara-Bogaz-Gol: Sartas on the northwestern shore, Chagala on the northeastern shore and Kizil-Kup in the far south. Each had jetties where the sulfate was loaded onto small seagoing vessels that sailed into the Caspian through the strait to deliver their cargo at Krasnovodsk and other major Caspian ports.

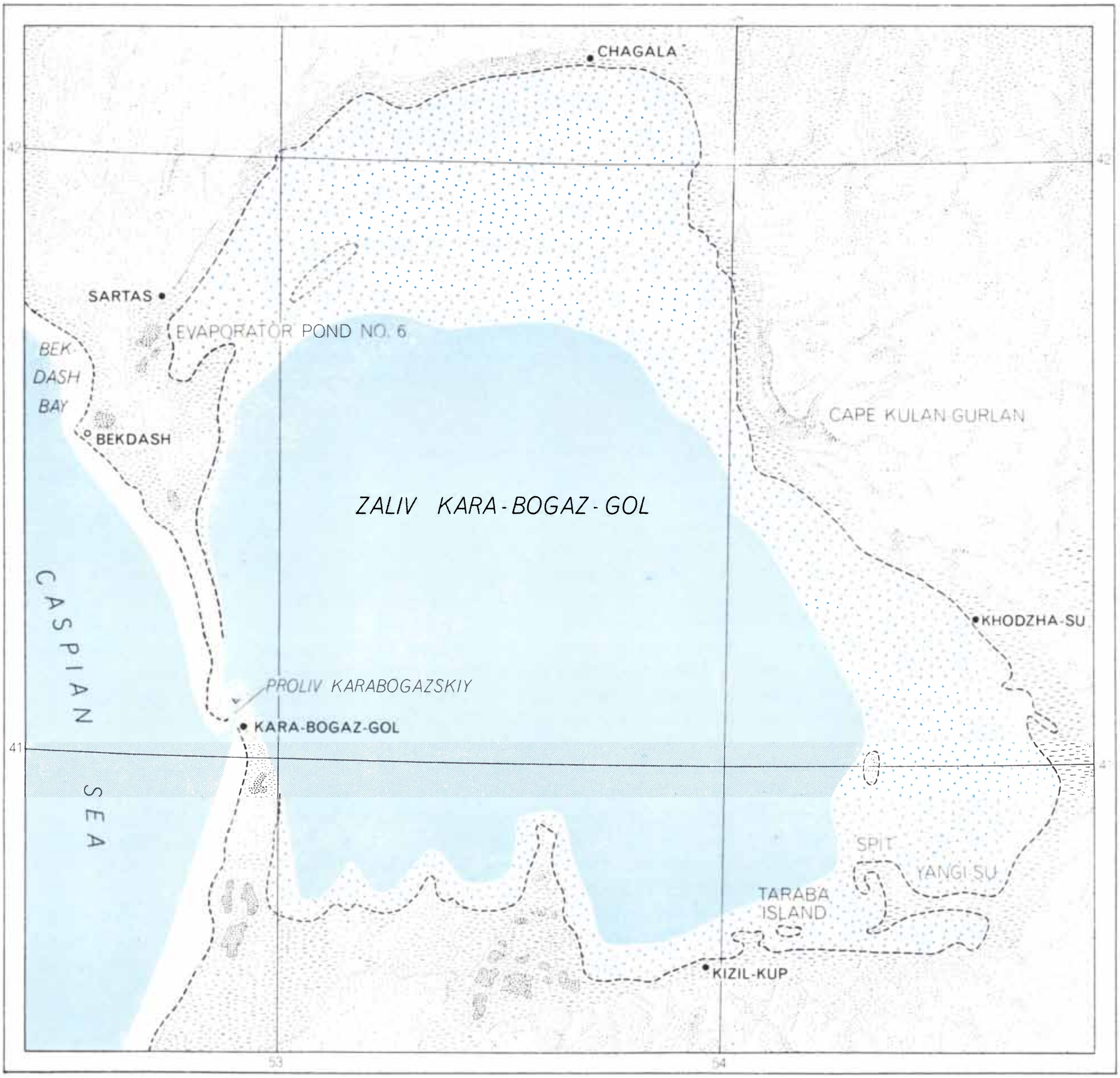


CASPIAN SEA, the largest enclosed salt lake in the world, covers more than 150,000 square miles. Its surface is 92 feet below sea level; white land areas on map are also below sea level. A sill extending from the Caucasus Mountains across the middle of the Caspian divides the sea into two basins. Darker color is deeper water. Caspian receives the inflow of the Volga and other rivers.

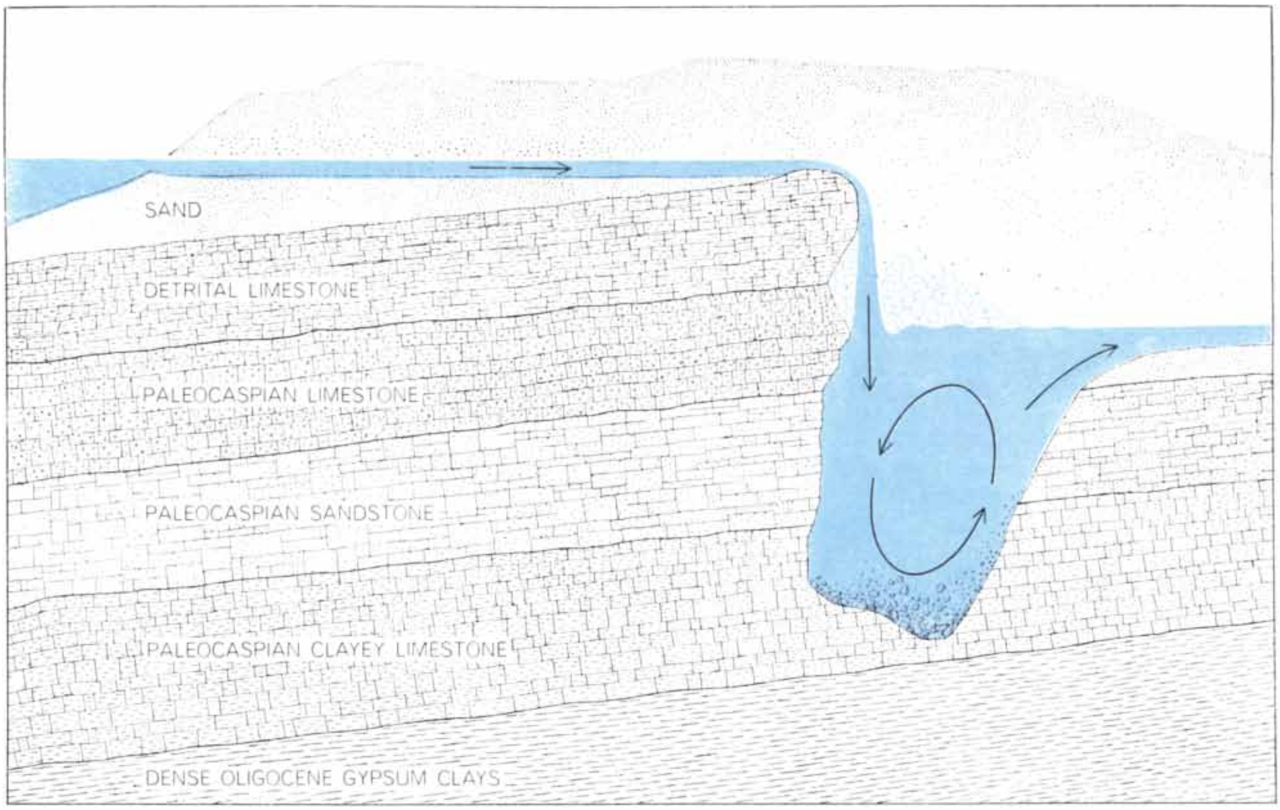
The symptoms of a falling sea level in the Caspian were first detected, although their true nature was not recognized, in the region of the Volga delta, where the waters were retreating rapidly. At some points the rate of retreat exceeded one mile per decade. In 1920 a surveyor named G. Migalkin retraced surveys of the sea made from 1855 to 1858 and soundings taken between 1854 and 1874. He reported that the shore line had "undergone such changes that it is hardly possible to use maps . . . published in 1876–1878." In one locality the sea had retreated nearly five miles in 40 years. Migalkin attributed the change primarily to the heavy loads of sand and silt deposited by the Volga and did not seem to be aware that the level of the Caspian was falling.

By 1930 the Karabugazsul'fat Trust, which operated the salt workings of the gulf, found itself in urgent need of accurate maps and information on navigable channels and approaches to existing and projected shipping centers. The only cartography of the gulf, which had become hopelessly obsolete, dated back to an 1845 naval map, some explorations of 1864 and a few astronomical determinations made in 1897. Continuous hydrometeorological records had been made at only two stations beginning in 1921. At the request of the trust the Soviet Administration of Navigational Safety dispatched a special hydrographic expedition aboard the research vessel *Maxim Gor'kiy* to take soundings in the gulf and survey its shore lines. The report of this expedition, published in the *Hydrographic Notes* of the Soviet Main Hydrographic Administration, presents a vivid picture of this forlorn corner of the world as it appeared some 30 years ago.

After a brief exploration of the Cas-



SHALLOW DESERT BASIN, the Zaliv (gulf) Kara-Bogaz-Gol, absorbs more than two cubic miles of Caspian water annually. Broken line marks its 1889 shore line; colored dots indicate salt flats left by retreat of water as level of Caspian Sea has fallen. Area of gulf has shrunk from 7,000 to 4,000 square miles. Older salt workings, such as Sartas and town of Kara-Bogaz-Gol, are abandoned.



STRAIT AND WATERFALLS where Caspian water spills into gulf are shown in schematic cross section. Vertical scale is greatly exaggerated. Broken-off stones agitated by falling water have carved a pocket 26 feet deep under falls. Surface of gulf (*right*) is now 15 feet below surface of Caspian (*left*) and is probably still dropping. Thundering waterfall is a development of the past decade or two.

pian shore off the northern Kara-Bogaz-Gol peninsula (the northern half of the breached dike), the vessel, which drew 10 feet, entered the strait but went aground on an eight-foot shoal; finally it got off and made its way to the jetty at the headquarters of the trust on the eastern shore of the strait. About 200 persons, mostly Turkmenians living in nomad tents, made up the highly unstable population of the town of Kara-Bogaz-Gol. These people would receive assignments to various salt workings on short notice and would at once dismantle their tents and leave for the sites. Although some fresh and brackish water was available in the town, most of the drinking water and all the food came by ship from Baku across the Caspian Sea.

In order to make their surveys, the scientists and technicians of the expedition switched to a broad-bellied Turkmenian sailing bark drawing only four feet and equipped with an auxiliary engine. The vessel could reach the various salt workings through all but the shallowest coastal waters. The first stop was Sartas, some 45 statute miles north of the strait. The population of about 300 were found living in nomad huts and tents, but in the town there were also warehouses, a newly established hydrometeorological station, a chemical laboratory, a bakery, a co-operative store, a communal dining hall and the embarkation jetty. Salt gathered there was carried by camels westward across the peninsula to be loaded aboard ships on the Caspian at the beach of Bekdash Bay.

About nine miles south of Sartas lay Kuŕguzul, another working. Surveyors had found a large natural saltpond a short distance inland, and the trust was planning to anchor a ship offshore to pump the highly saline water of the gulf into a sluice leading to the pond, which bore the designation "Evaporator Pond Number 6." The trust had calculated that the quick evaporation there would yield salt in 25,000-ton batches. It had dispatched dredges to carve a shipping channel to the beach and to dig the sluice.

From Kuŕguzul the expedition crossed the gulf eastward toward Cape Kulan-Gurlan (or Kulan-Kirlygan, "the cemetery of horses") and noted that the greatest depth sounded was 25 feet. The landscape around the cape was described as a playa, resembling the bottom of a dried-out bay or flat, surrounded by hills 450 to 600 feet high. Vegetation consisted of a few clumps of saksaul, a hardy, salt-resistant Asiatic shrub. The clay and gypsum soil had been washed down from the hills. Tracks of rabbits and foxes, horns shed by dzerens (Persian, or goitered, gazelles) and remains of sheep and camels bore silent witness to occasional visits of animals to this otherwise lifeless desert. The coastal heights continued inland as a fairly level plateau, and among the sparse vegetation north of the cape the scouts of the expedition encountered a few birds—snipe, martlets and marlins. The desolate beach was scattered with cockleshells, dead fish and driftwood cast up by the surf.

The expedition proceeded to the southernmost workings at Kizil-Kup, where a rocky, sandless shore rose directly from the limestone bottom of the gulf. Several long spits extended from the low coastal plateau into the water. Farther inland the plateau rose gently, forming hills about 1,000 feet high. During the heavy storms of winter the rocky coast became a natural repository of pure Glauber's salt, free of sand. Workers simply gathered it and loaded it aboard shallow vessels for transfer to the strait.

East of Kizil-Kup and opposite the offshore island of Taraba (named for a prayer recited during the Mohammedan fast of Ramadan) the expedition visited a coastal gorge two and a half miles long cut into the 500-foot-high plateau. Erosion caves pockmarked the sheer walls of the gorge, which were of gray, yellowish and red sedimentary rock. At the mouth of the gorge lay large piles of sulfate awaiting shipment. Wells of brackish water some 500 feet inland formed the hubs of settlements of Turkmenian nomad huts.

Following a narrow road up the gorge, the explorers encountered a few birds, including a screech owl, a kite and some rooks and martlets. The plateau itself was a desert, with sparse salt-marsh grasses and brush the only forms of vegetation. A desolate Turkmenian cemetery provided the sole evidence of human occupancy of the bleak flats.

The expedition touched briefly at Taraba Island, an elongated triangular rocky bulge covered with fine salty sand. On a bar off its eastern shore the men found large accumulations of dead locusts, dried, salted pike and perch of various sizes, and butterflies and beetles. Entering the shallowest part of the gulf, the expedition approached the Yangi-Su peninsula, which jutted westward into the water. The boat went aground repeatedly at distances between a mile and half a mile from the shore. Eventually it rounded the spit with ample leeway, crossed the southeastern bulge of the gulf, went along below a striking jagged formation on the eastern shore known as the White Hills and visited the post of the Khodzha-Su Gostorg (State Export and Import Office). This remote trading station consisted of a small stone building and a few nomad huts; its principal item of commerce with the Turkmenian and Kirgiz nomads was wool. The wells along the shore yielded salty water only, hence the name Khodzha-Su (bitter water).

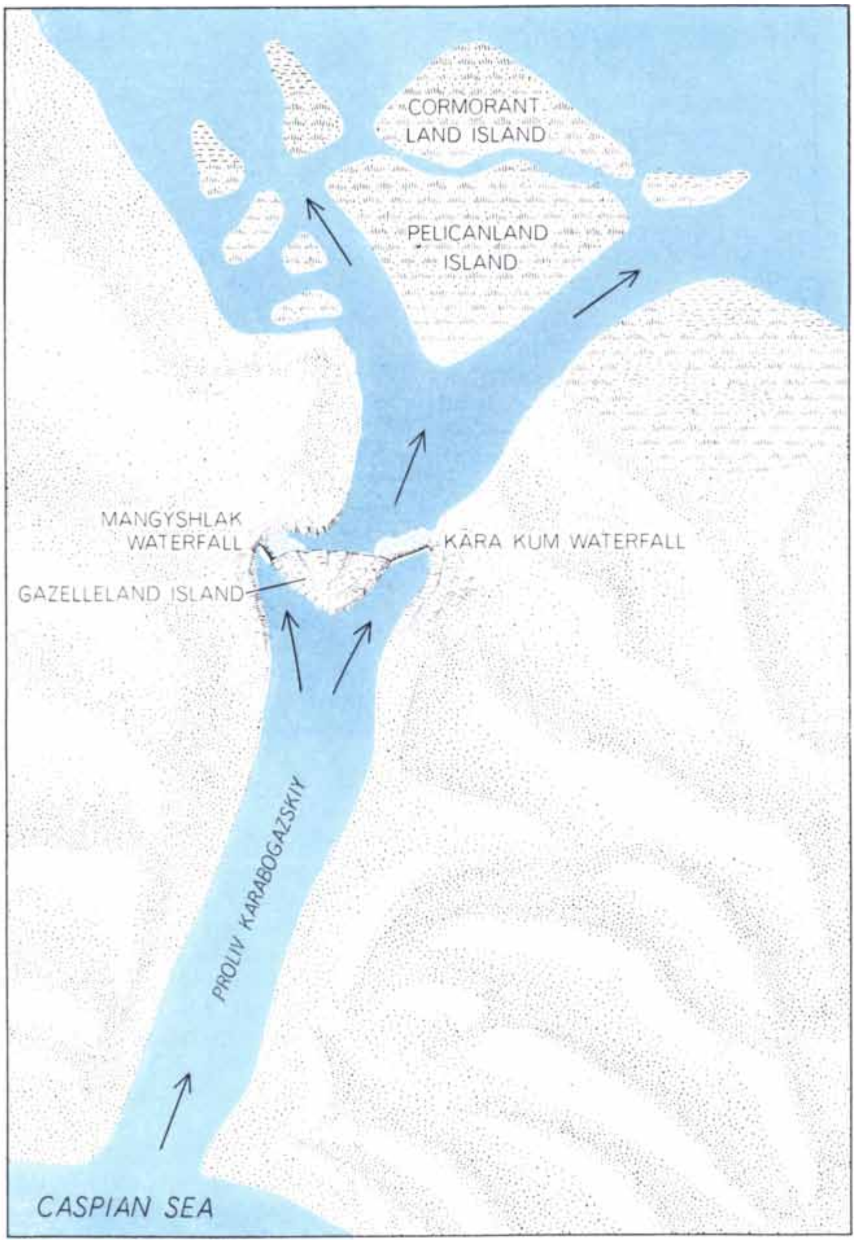
The call there completed the tour of the gulf. In addition to general ecological explorations, the expedition made a number of astronomical observations and placed many survey marks along the coast. The explorers proceeded by boat to the strait, boarded the *Maxim Gor'kiy* and sailed home to Baku.

During the early 1930's the town of Kara-Bogaz-Gol became a fair-sized community. New facilities included a plant for processing the sodium sulfate (heating drives the water out of Glauber's salt), a laboratory, an expanded hydrometeorological station, a hostelry and a recreational club. In 1932 the trust set up a workers' village at Evaporator Pond Number 6 and built a seaport on the Caspian at Bekdash.

Between 1935 and 1960 conditions changed radically as the level of the Caspian Sea dropped more than eight feet. This reduced the annual flow of Caspian water into the gulf from the six cubic miles of 1930 to two and a half cubic miles in 1960. The area covered by the gulf shrank from 7,000 to 4,000 square miles and the greatest depth decreased from 42 to 10 feet.

When the strait became too shallow for navigation, all the production facilities of the town of Kara-Bogaz-Gol were moved 70 miles north and a new town of Bekdash arose adjacent to the old Caspian port facility. Sartas has also been abandoned. All that remains of the old towns are the outlines of streets and wind-blown barkhans, or dunes, piled in waves to the second floor of stone houses and reaching the bridge of stranded boats.

Although the Caspian has continued



FLOW OF WATER through the Proliv (strait) Karabogazskiy and over divided waterfall is depicted in diagram based on 1956 Soviet survey. Vegetation, fish and other organic matter at the "delta" islands, which tend to change shape, support many birds and other animals.

to drop, the strait has not disappeared. A stream five-eighths of a mile wide flows out of the Caspian eastward into the desert. In a swift run of nearly seven miles the clear bluish-green water rushes at an increasingly rapid pace over the sandy bottom of the strait, then splits into two branches and leaps over a limestone and flagstone sill. It thunders into a water pocket 26 feet deep, wells up again and finally comes to a foaming, whirling halt three miles farther on in the gulf itself. A huge curtain of foam and spray rises thunderously from this place where the rushing waters meet the dunes. The east wind carries the roar and even the spray back to the shores of the Caspian, almost 10 miles to the west.

The decrease in size and depth of the gulf has enabled the hot easterly desert winds to evaporate the water at an increasing rate. The Caspian water that enters the gulf with a total dissolved-salt content of approximately 13 parts of salt per 1,000 parts of water soon "boils down" to a saturated brine that carries more than 300 parts of salt per 1,000 parts of water. This makes the Kara-Bogaz-Gol the saltiest body of water on earth. The world ocean has about 35 parts of salt per 1,000 of water, the Great Salt Lake of Utah 200 or so and the Dead Sea up to 250 parts of salt. Most of the salts in the gulf precipitate on the bottom and along the shores; only the most soluble—those containing the rare-earth elements—remain completely in solution.

For ages the nomads have watched the unceasing inflow of Caspian water. They speak with awe of a bottomless "black sink" under the gulf that, they believe, drains away all this water. In a sense the legend is true, but the "sink" is not a hole at the bottom of the gulf; it is the dry, thirsty air above.

The flow of Caspian water over the flagstone and limestone sill at the top of the waterfall is split by a bulky island, the Ostrov Dzheyraniy (Gazelleland Island). The southern branch of the cascade, known as the Kara Kum waterfall, is 400 feet wide, whereas the northern branch, named the Mangyshlak waterfall, is 250 feet wide. Below the falls the bluish-green water is blanketed with a lacework and even a "head" of saline foam that is swept into the desert by the gusty winds. Whitish foam covers the dark gray sandstone of the shores. Moving away from the falls, the flow broadens, loses speed and begins to drop its heavy load of silt, forming bars and islands that make an unstable delta. Two major flat islands emerge at the center of the flow and divide it again. One is Ostrov Pelenkaniy (Pelicanland Island); the other is Ostrov Baklaniy (Cormorantland Island). A relatively rich vegetation carpets their emergent flat surfaces, fed and fertilized by the steady stream of dead organisms and organic matter supplied by the water.

Beneath the waterfalls, on rocks that pierce the whitish mass of foam, lone desert eagles perch motionless as statues, their sharp eyes seeking the hapless Caspian pike, mullet, sturgeon and sevriuga that are thrust by the current into the whirlpool. Ultimately most of these fish are ejected into the lethal salt brine beyond the delta. The easterly winds and waves cast the dead fish ashore, still fresh and with comparatively low salt content, a welcome booty for seagulls, corsac foxes and wolves. Once they become permeated with the salt brine, however, they cannot be eaten by the other animals and often remain untouched on the beach for months, until an itinerant desert sheepherder picks them up, dried, salted and thoroughly preserved.

The waterfalls attract still another group of animals from the desert that surrounds the Kara-Bogaz-Gol: the sheeplike sayga antelope, the gazelle and the desert hare. All are chronically thirsty, and to their salt-adapted systems the slightly saline Caspian water probably tastes sweet. These denizens of the parched wastes are said to race 100 to 125 miles overnight to "fill up" with Caspian water at the falls, rest and return to their usual haunts in the desert by daybreak. Desert foxes too converge at the delta to feed on freshly cast-out fish and on the plentiful seafowl. The presence of all the other animals lures the predatory gray desert wolf to the water hole.

The seafowl are also attracted by the limitless supply of Caspian fish and mollusks weakened or overcome by the excessive salinity of the water. Great flocks of seagulls, snipe, pelicans, gray geese and swans occupy the delta islands. In the shallower reaches of the delta channels pink flamingos patrol the waters. The bird traffic becomes particularly heavy in spring and fall, when seasonal migrations bring many transients.

Altogether the strait, its marine waterfall and the Zaliv Kara-Bogaz-Gol make up one of the strangest geographical and ecological provinces on earth. The world's largest deposit of Glauber's salt and the wildlife bent on survival in a narrow zone of chemical death owe their existence to the sea that spills into a desert.

BE THE FIRST IN YOUR NEIGHBORHOOD TO LIVE 100 YEARS

Think ahead. Far ahead—to your one hundredth birthday. And think big—about what you'd really like for this very special birthday present. A two-week Martian cruise with a quick side-trip to the Moon for some free-port bargains? A round-the-world-in-80-minutes rocket tour? Or a quiet family dinner to celebrate, after the doctor has said you're good for another twenty years?

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Scientists everywhere—in universities, in laboratories, in corporations like American Cyanamid Company—started asking questions, questions about disease, about why the human body aged so quickly, about the effects of heredity, nutrition and environment on our life span. They found answers, and applied them in practical ways. As a result, you just may be the first in your neighborhood to live 100 years.

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Cyanamid has played its part in these advances. Anything that can make you live better or longer is, for us, a matter of major concern. Drugs, for instance. And specifically, AUREOMYCIN® chlortetracycline, the first broad-spectrum antibiotic, which was developed by Cyanamid's Lederle Laboratories. You've heard about that one, of course. But you may not know about DIAMOX® acetazolamide, a newer drug used in the treatment of congestive heart failure and glaucoma. It's just one in a long list of drugs developed by Lederle scientists for the treatment of many of the dread degenerative diseases.

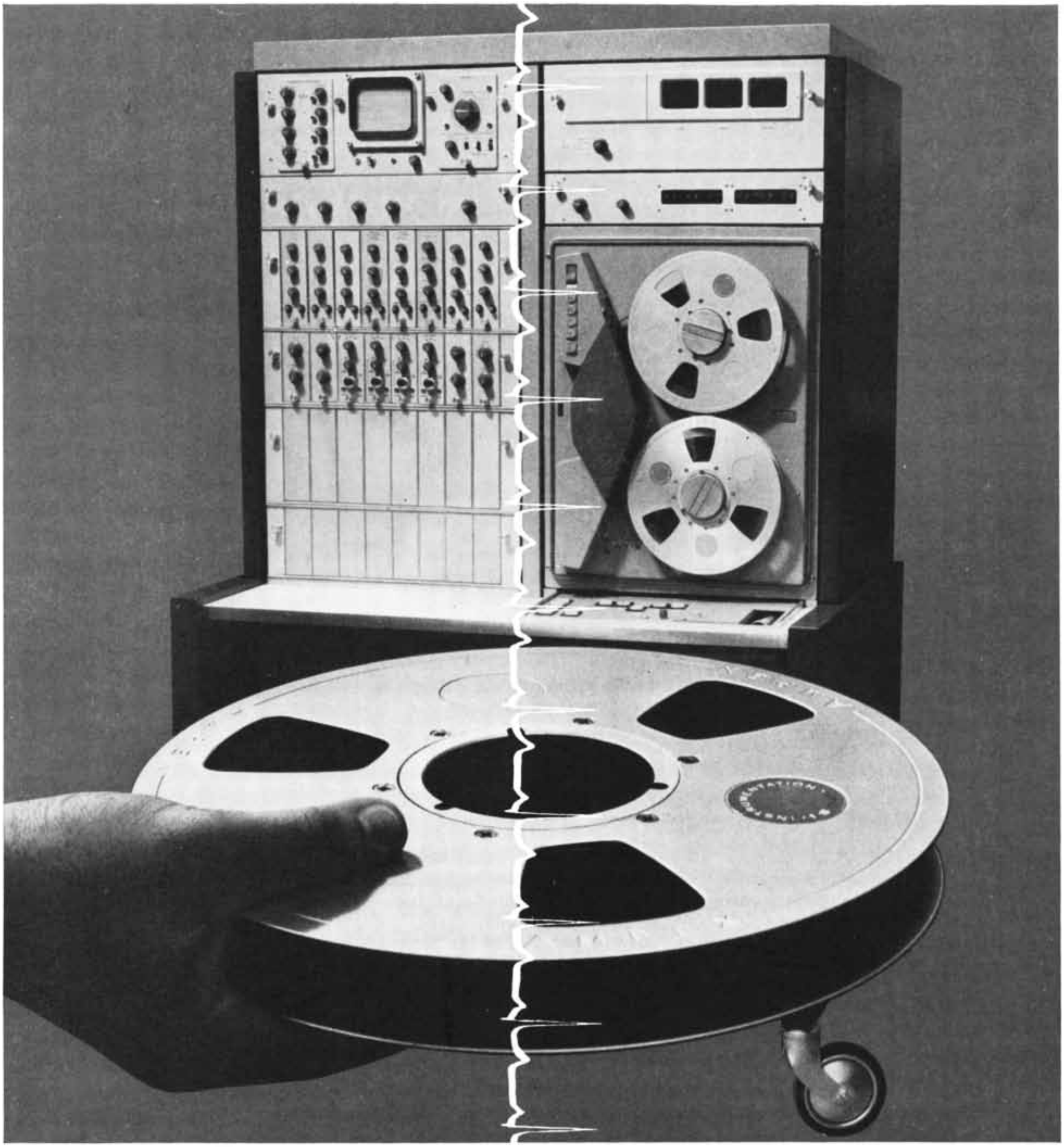
Some Cyanamid scientists take a different approach toward helping you live longer and more comfortably. They try to check and control conditions that might make you sick or uncomfortable. They're working to perfect a catalyst that removes smog-forming impurities from automobile exhaust. Others are trying to find safe and more effective ways to control noxious weeds, insects, fungi and animal pests.

Still others at Cyanamid work down on the farm—on one of the largest privately maintained agricultural research centers in the world, at Princeton, New Jersey. Here, products to help protect our sources of proteins and carbohydrates are explored, experimented with, improved. The goal: to let you eat better—and spend less.

Well nourished, well cared for as it may be, the human machine occasionally breaks down. When surgery is needed to repair the damage, chances are that one or more products from Cyanamid's Davis & Geck Division are right on hand in the operating room. They help today's highly skilled surgeons perform real miracles in preserving and extending human life.

Cyanamid, of course, is a profit-making business. But for the 29,860 people who work in its plants, offices and laboratories across the country and around the world, it is also a personally satisfying business. The job being done is meaningful. It's important.

You may or may not be the first in your neighborhood to live 100 years. The important thing is to enjoy that life, in comfort and good health. And that's one of the things we work for at Cyanamid.



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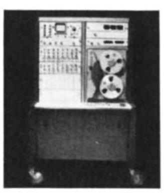

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data rapidly and automatically to a resolution of one millisecond, feeds analog data to a graphic recorder and permits visual monitoring during and after the experiment. The system includes a 7- or 14-track FR-1300 recorder/reproducer, preamplifiers and their associated input couplers, a time code generator, an oscilloscope monitor, a level indicator and a master control panel for ease of operation. For more data about the new DAS-100 write Ampex Corporation, Redwood City, Calif. Worldwide sales, service.

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AUTOBIOGRAPHIES OF CELLS

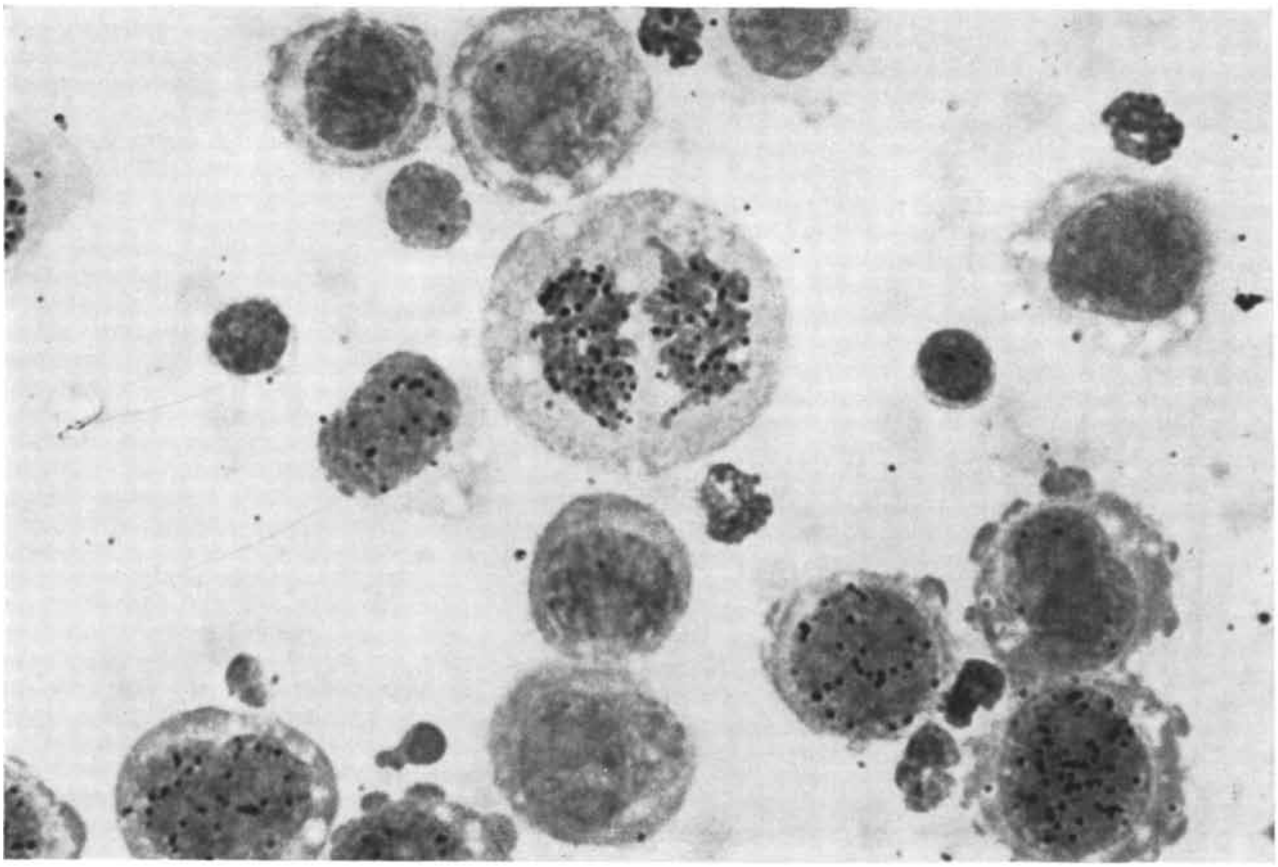
Advances in radioautography, in which molecules labeled with radioactive atoms reveal themselves in photographic emulsion, now make it possible to trace the life cycle of cells in detail

by Renato Baserga and Walter E. Kisieleski

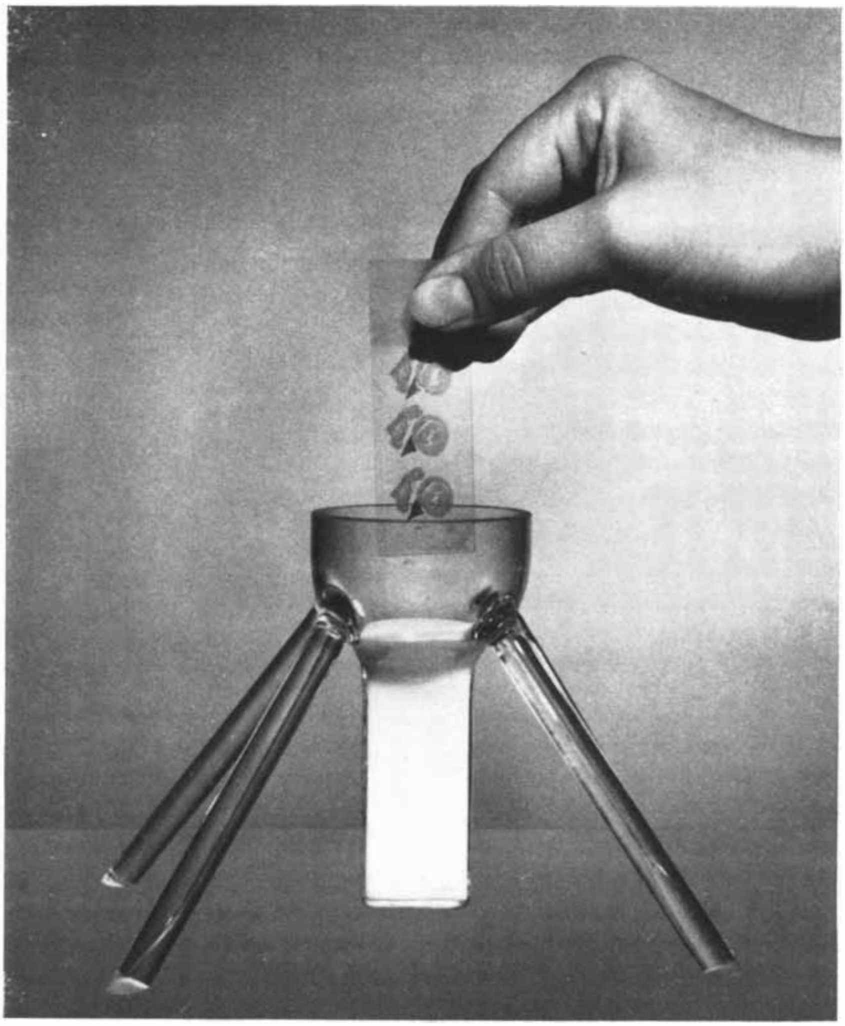
If one could study the lives of cells as one can study the life of a man, it would not be difficult to discover the fundamental laws of biological organisms. On the macroscopic scale one knows how a human being is born, grows and reproduces, how long he lives, how and where he travels, behaves and interacts with others. All of this is accessible to observation and even to measurement. In the microscopic realm of the cell, on the other hand, one must largely grope in the dark, and such information can be won only with great labor.

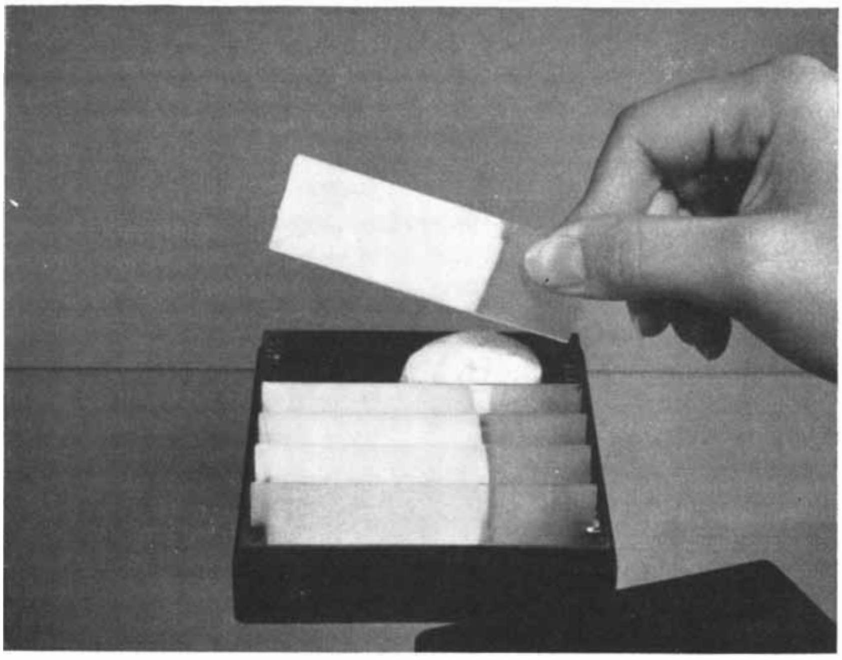
The tools employed by the student of cells, however, are becoming sharper, and in the past two decades devices for exploring the lives of cells have entered a new range of resolving power. This article is an account of a particularly promising technique: the radioautography of cells. A refinement of the use of radioactive tracers, it has already yielded much new information about cell behavior.

Radioautography is a form of photography. Just as light forms an image in a photographic emulsion, so do the various kinds of ionizing radiation: X rays, gamma rays, alpha rays, beta rays and



RADIOAUTOGRAPH OF CELLS from an Ehrlich ascites tumor of a mouse is stippled with black dots, each made by the decay of an atom of tritium (the radioactive isotope hydrogen 3). Eight hours earlier these cells had been given a dose of tritiated thymidine, a substance used in the synthesis of DNA. Those cells that were synthesizing DNA incorporated the radioactive atoms, which later revealed how the DNA is localized within the cell nuclei. In the dividing cell at top center the DNA is localized in the chromosomes.





RADIOAUTOGRAPH IS MADE by dipping a glass slide covered with a sample of cells into a special flask filled with a liquid photographic emulsion (*top*). The slide is then removed, placed in a light-tight box (*bottom*) and stored in a refrigerator to preserve the cells. After the emulsion has been exposed to the radioactive atoms for the prescribed time, the slide is removed and developed. All these operations are of course performed in the dark.

so on. When struck by any of these radiations, the crystals of silver bromide embedded in the gelatin of the emulsion are ionized, with the result that the chemical action of a developer can then reduce the bromide to silver atoms. After the film is developed and fixed, each little aggregate of reduced silver atoms becomes a black dot visible under a microscope, and the black dots make up a picture of the radiation to which the film was exposed.

The honor of having made the first radioautograph belongs without question to the French physicist Antoine Henri Becquerel. The story has often been told of how he laid a crystal of uranium salt on a photographic plate, wrapped the plate in black paper and put it away in a drawer and later found that radiations from the uranium had darkened the plate—thereby revealing the phenomenon of radioactivity. The deliberate use of this method to make pictures of radioactive specimens did not begin, however, until the 1920's, when the Hungarian chemist Georg von Hevesy performed tracer experiments with radioactive lead in plants and the French biologist A. Lacassagne did the same with radioactive polonium in animal organs. After World War II, when radioactive isotopes became available in appreciable quantities, radioautography came into its own.

The development that currently lends the greatest promise to radioautography is the use of tritium (radioactive hydrogen), introduced in the 1950's by Patrick J. Fitzgerald and his co-workers of the State University of New York. This isotope provides sufficient resolution to locate radioactively labeled substances not only in individual cells but also in the chromosomes and other structures within the cell.

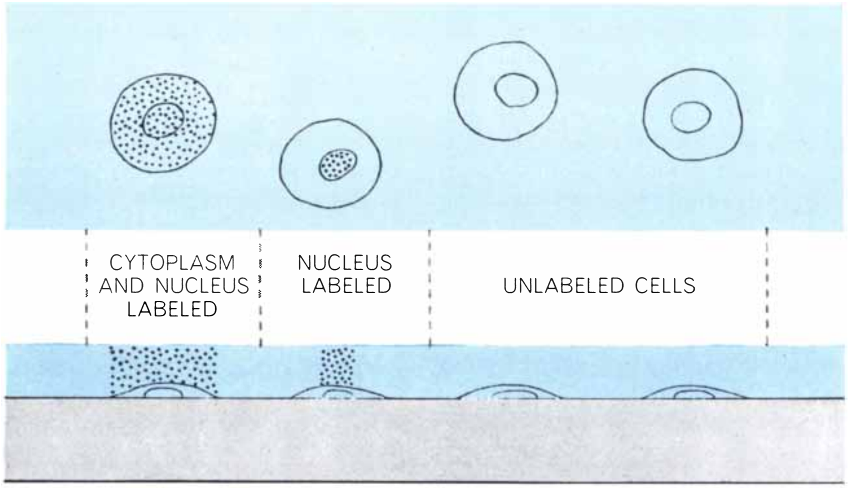
To achieve this kind of resolution two conditions must be met: (1) the cells must be in close contact with the photographic emulsion and (2) the radiation from the radioactive element in the cells must be of very short range, otherwise it would fan out too widely in the emulsion and fail to pinpoint the source. When these conditions are fulfilled, the telltale black dots will appear in the film just above the cell or the part of the cell from which the radiation came.

The second condition—shortness of range—is satisfied by tritium: its radiation (beta particles) travels only about one micron, a much shorter distance than is traversed by the beta particles from the radioactive isotope carbon 14, for instance. The close contact between cells and emulsion is achieved simply by dipping the slide with cells on it into a melted emulsion, a film of which then clings to the slide. First a suspension of the cells is spread, like a blood smear, on a glass slide. The slide is then dipped in a special, slot-shaped flask containing the melted emulsion [*see illustration on opposite page*]. Finally the slide is dried, put in a light-tight box and kept in a refrigerator for the desired period of exposure of the emulsion to the radioactivity from the cells. This exposure takes days or weeks, in contrast to the brief exposures in ordinary photography. After completion of the exposure the slide is developed and fixed like a photographic plate, and a stain is applied that penetrates the emulsion to show the outlines of the cells and their structures.

Now examine the slide under a microscope. If a cell has incorporated the radioactive tracer in both the nucleus and the surrounding cytoplasm, there will be black dots in the emulsion above the entire area of the cell; if only the nucleus has taken up the tracer, the dots will appear over that part of the cell; and above a cell with no radioactive material in it the emulsion will display, of course, no dots except possibly a few produced accidentally by light or mechanical artifacts [*see illustration at top right*].

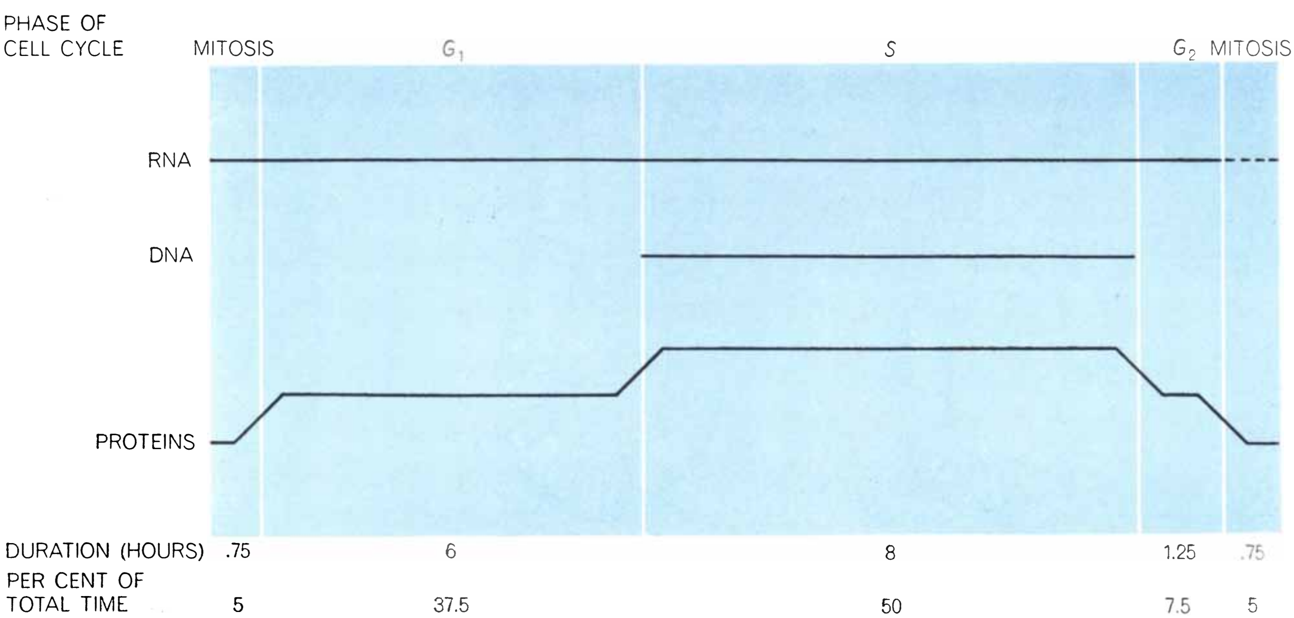
All of this is clearly illustrated by the radioautograph on page 103, which shows a group of cells that were fed a labeled material. The cells are those of a transplantable tumor known as Ehrlich ascites, which grows vigorously in the peritoneal cavity of mice and usually kills a mouse in 10 to 15 days. This tumor tissue had been exposed to a tritiated, or tritium-labeled, substance that is used by cells in the synthesis of DNA. Since DNA is manufactured in the nucleus, one would expect the labeled material to show up in the nuclei of those cells that were synthesizing DNA at the time the substance was injected into the tumor. The radioautograph shows this beautifully: the label is definitely located in the nuclei, and one of the cells actually pinpoints its location more precisely within the chromosomes.

Note that such a picture enables one to tell which cells were synthesizing DNA at the time the radioactive label was administered and which were not. That information turns out to be of great importance in following the life of a cell.



EMULSION IS EXPOSED only above those parts of the cell that have incorporated radioactive atoms into their molecules. Each beta particle from a decaying tritium atom ionizes a single crystal of silver halide, which, upon development, shows up as a black dot. In this diagram, which exaggerates the range of the beta particles, the dots make it appear that the particles move vertically; in actuality they radiate in all directions from the source.

Every dividing cell goes through a certain production cycle. In a typical case (epithelial cells of the small intestine of the mouse) the process of mitosis, or cell division, takes about 45 minutes. After the division the daughter cell enters a phase called G_1, during which it synthesizes RNA and proteins but no DNA [*see illustration below*]. Then, six hours later, it starts another



LIFE CYCLE OF A TYPICAL CELL is divided into three phases between one mitosis, or cell division, and the next. The horizontal lines indicate the level at which RNA, DNA and proteins are synthesized during each of the phases and also during mitosis.

phase, called S, in which it synthesizes DNA, RNA and, at a stepped-up rate, proteins. That phase lasts for eight hours, and at the end of this time the cell stops making DNA, reduces its production of proteins and goes into a 75-minute phase called G_2, which prepares it for a new mitosis. During mitosis it produces no DNA, very little protein and sometimes no RNA.

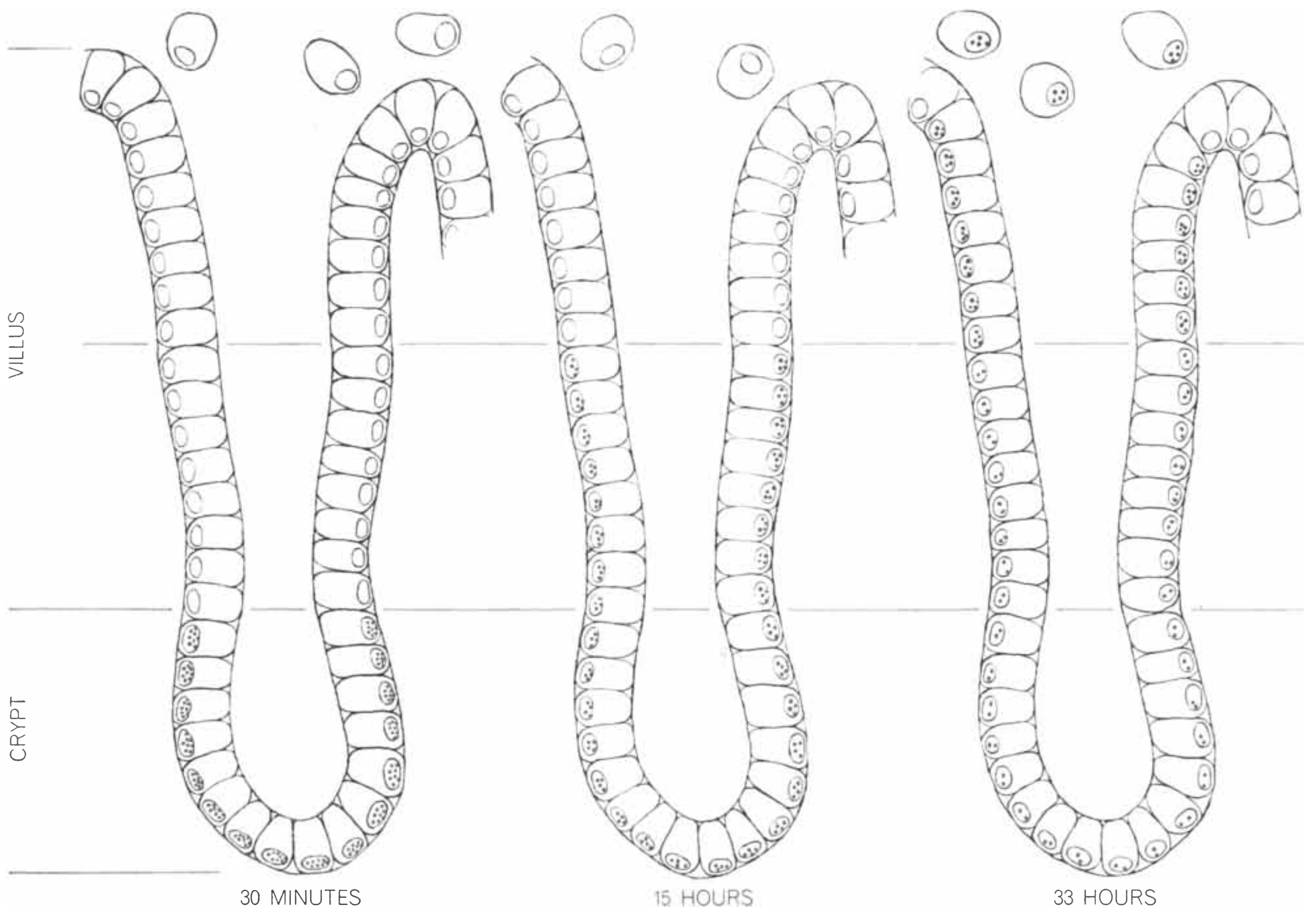
The timetable of the cycle varies from one type of cell to another and from species to species, but the interesting and helpful feature from the standpoint of experimental studies by radioautography is that, in general, dividing cells spend a sizable part of their time synthesizing DNA. This fact helps to give us a measure of the multiplication rate of the cells in a given cell population.

In the 1950's J. Herbert Taylor and a group of other workers at the Brookhaven National Laboratory, including Walter L. Hughes, Victor P. Bond, Eugene P. Cronkite and the late Henry Quastler, opened up this field of investigation by labeling DNA with tritiated thymidine, the precursor of thymidylic acid, which is one of the four building blocks of DNA. Because thymidine is used by cells solely for the synthesis of DNA, the presence of this marker unmistakably identifies the nucleic acid. Therefore an experimenter who takes a sample of cells from an animal shortly after thymidine has been injected into its tissues can be sure that the marker represents DNA and that the cells containing it were synthesizing DNA at the time the thymidine was injected. The percentage of cells bearing the label tells what proportion of the cells are synthesizing DNA at a given time; hence this index, called the thymidine index, is a measure of the rate of cell division, or of how fast the cell population under investigation is proliferating.

One of the things one can learn by this technique is the percentage of cells in the body that are capable of dividing, that is, the percentage of cells that are embryonic rather than differentiated. This in turn indicates the daily rate of turnover, or the death rate of cells that have to be replaced. Experiments with labeled thymidine confirm that most of the cells in an adult animal body do not divide at all. In the human body only about 3 per cent of all the cells are capable of dividing for purposes of tissue repair.

What happens now if one injects tritiated thymidine into a mouse? When a cell that takes up the label divides, each daughter cell gets about half the radioactive atoms that were incorporated in the parent cell. By measuring the rate of dilution of the label with time, one can determine the time interval between one mitosis and the next, or the duration of the cell cycle. By similar procedures one can also measure the length of each phase of the cycle.

One of the most interesting facts that have come to light in this study of individual cells is the discovery that the two daughters of a cell division usually



INTESTINAL MUCOSA of a mouse, like that of other animals, is replenished by cell division, a process that can be followed by labeling the cells. The diagram at left shows a fold of the mucosa. The bottom of the fold is called the crypt; the top, the villus. Above the villus is the lumen, or open channel, of the intestine. Thirty minutes after the mouse has been given a dose of tritiated thymidine, the cells at the bottom of the crypt are labeled (*colored dots*). After 15 hours (*second from left*) labeled cells are found farther up the crypt. After 33 hours (*third from left*) labeled cells have arrived at the top of the crypt and are shed into the lumen.

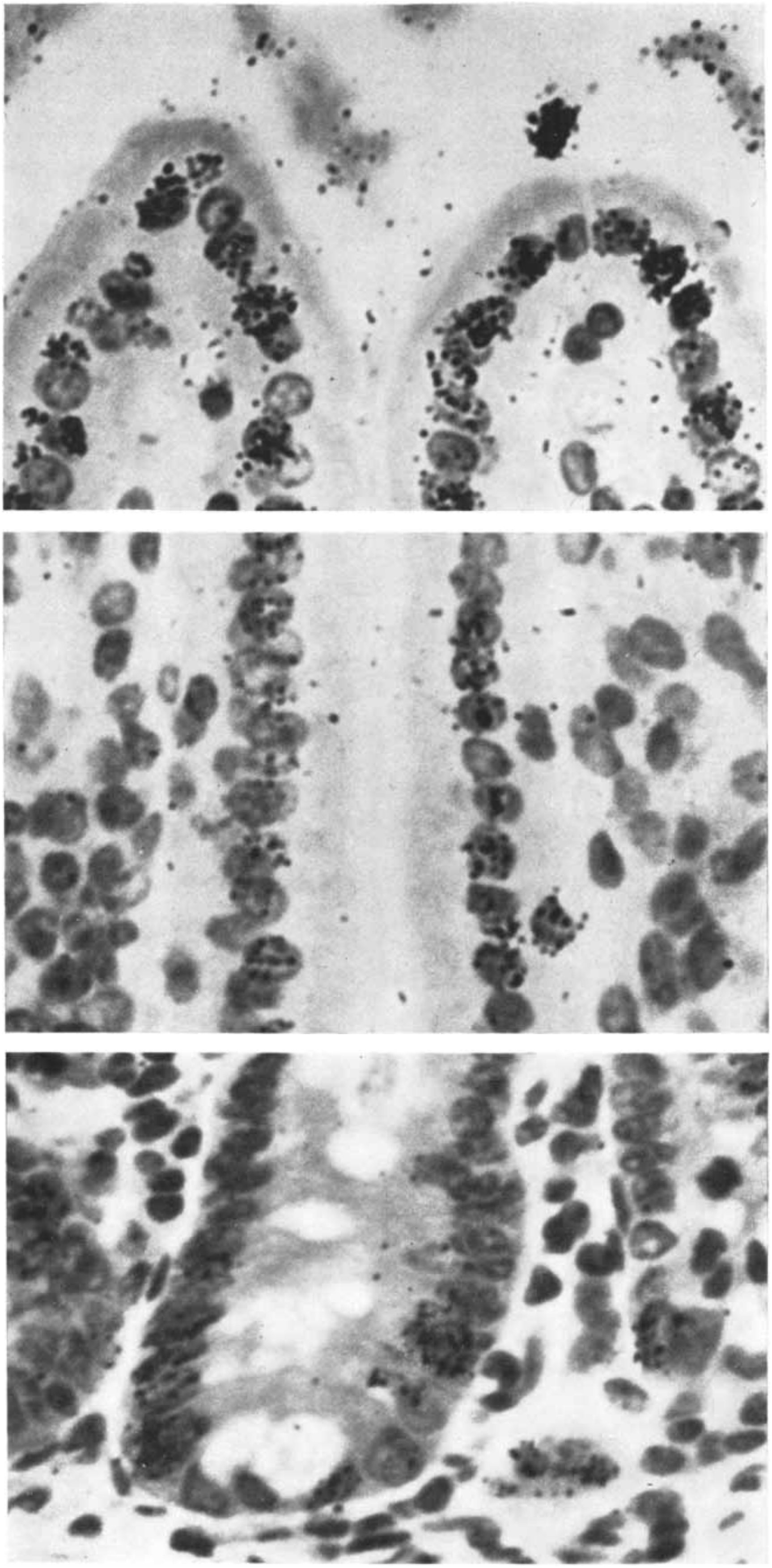
have different destinies. As a spectacular example, let us take the epithelial cells that form the lining of the small intestine of the mouse.

The lining is a washboard affair of folded tissue, resembling the nap of a rug. At the base of each fold is a small loop called the crypt, and the part of the mucous membrane extending from the crypt to the lumen, or cavity, of the intestinal tube is called the villus. It is in the crypt that the membrane is continually replenished and renewed. There each cell divides and produces two daughters. One daughter stays in the crypt and divides like its parent. The other daughter cell is fated to die. It migrates to the villus and once there becomes incapable of synthesizing DNA. Gradually it moves up along the villus, pushing the other cells ahead of it. When it reaches the tip of the villus, it is in turn shoved off into the lumen, where it perishes and is carried away in the stream of matter passing through the intestine. In the picturesque description of C. P. Leblond of McGill University: "The intestinal epithelium glides lumenward toward its death."

The entire process has been followed and timed by labeling the cells with radioactive DNA by means of tritiated thymidine. A few minutes after the thymidine is administered to the mouse about half the cells in the crypts become labeled, because they have synthesized DNA. Some 24 hours later many of the labeled cells have traveled into the villus. Finally, several hours later, some of these cells begin to fall into the lumen [*see illustrations on these two pages*]. The period from the birth of a cell in the crypt to its death plunge from the tip of the villus (called the "transit time" by Michael Fry and his co-workers at the Argonne National Laboratory) has been found to be about 33 hours.

This is perhaps the best example so far of how fruitful radioautography can be in investigating the demography of cells: the fertility of the population, the identification of the fertile members, the length of the gestation period, the life span and so on. These cells also provide important information about the difference in rates of proliferation between normal cells and malignant cells, as we shall see.

Studies of the same kind have been conducted on various other tissues and types of cells, including cultures of protozoa and bacteria. One of the most thoroughly investigated subjects is the life history of the red and white blood cells. With tritiated thymidine as the labeling material, investigators are learning the



RADIOAUTOGRAPHS DEPICT THE THREE STAGES outlined in the diagrams on the opposite page. The radioautograph at bottom shows labeled cells at the bottom of the crypt. The autograph in the middle shows labeled cells farther up the wall of the crypt. The autograph at top shows labeled cells at the top of the crypt and being shed into the lumen.

rates of production of these cells, their rates of migration into the bloodstream and their life spans.

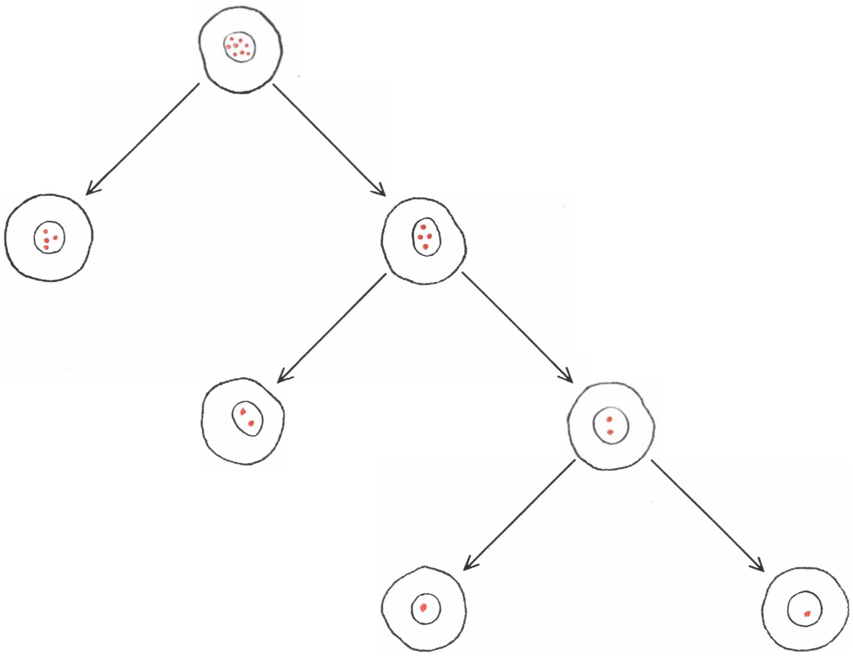
Where the radioautographic technique shows its greatest power, however, is in the study of cancer cells. Why does a cancer grow so wildly if the growth of normal cells maintains a controlled equilibrium? Is it because the tumor cells divide faster than normal cells? With tritiated thymidine and radioautography we can answer this question.

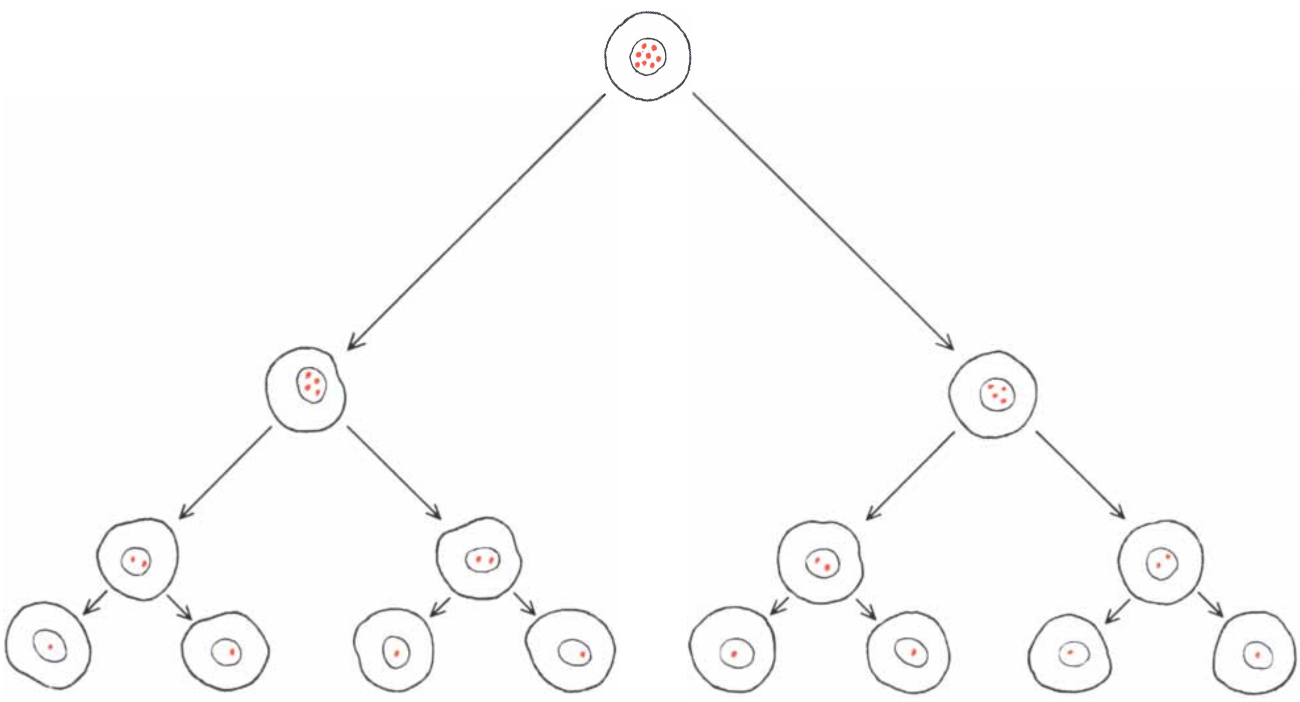
Let us take one of the fastest growing tumors we know: the Ehrlich ascites tumor that grows in the peritoneal cavity of mice. If we plant these cells in a mouse and follow their growth with labeled thymidine, we find that the length of their cycle—their gestation period between divisions—is 18 to 20 hours. In other words, the cells double every 18 to 20 hours. This is the rate during the first week of the tumor's growth; after that it slows down.

It turns out that the division rate of these cells is actually slower than that of many normal cells. The crypt cells in the mouse's small intestine, for instance, divide every 10 to 15 hours. Epithelial cells in its duodenum divide in less than 12 hours. And the myeloblasts, or marrow cells, of a dog have a still shorter cycle: only nine hours.

So it is not the speed of cell division, or shortness of gestation time, that accounts for the malignant growth of a tumor. The answer lies rather in the unusual fertility of these cells.

In the tumor every single cell is capable of dividing. During the first week each cell in an Ehrlich tumor of a mouse gives rise to two daughters, each of the two daughters in turn gives birth to two others, and so on. After the first week some of the progeny fail to divide, but the multiplication curve of the cell population is still increasing. In short, what we have is a population explosion, re-





NORMAL AND ABNORMAL CELL DIVISION can be traced by radioautography. In normal division (*top*) only one of the two daughter cells is capable of dividing, and the radioactivity is distributed accordingly. In the division of cancer cells (*bottom*) both daughter cells can divide. The autograph experiments indicate, however, that cancer cells divide more slowly than normal ones.

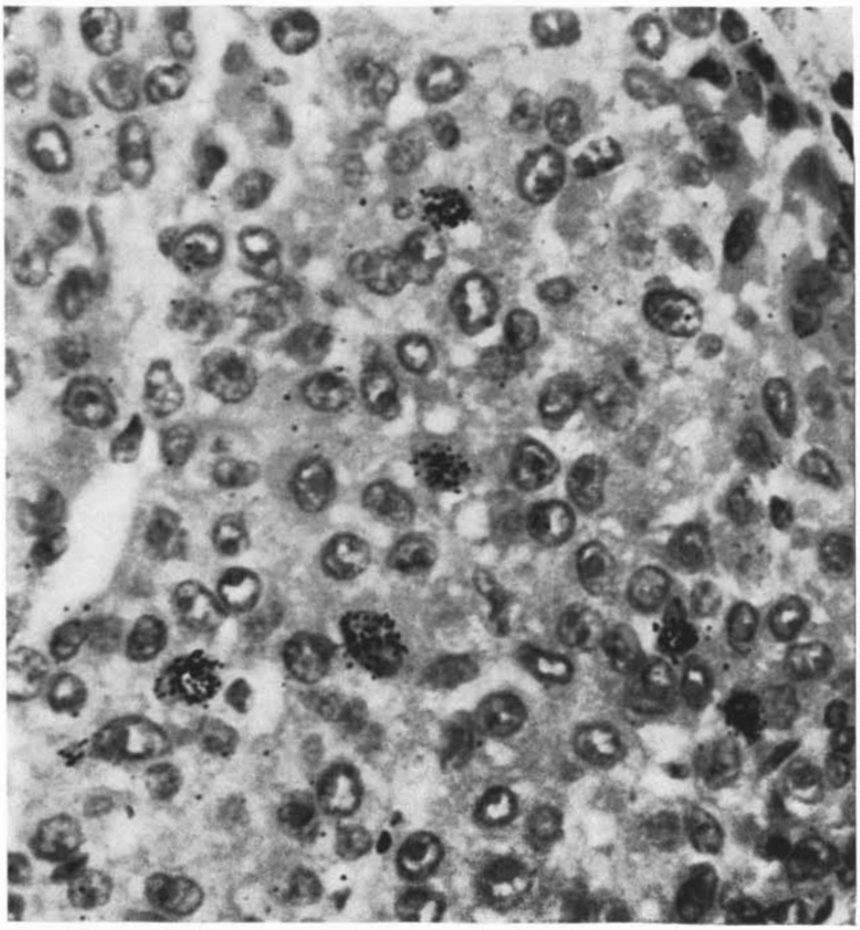
sulting from a very rapid rise in births that far outstrips the death rate.

A normal dividing cell, on the other hand, does not produce two fertile daughters. As we saw in the case of the mouse's crypt cells, only one of each pair of daughters divides again; the other moves away, produces no DNA and dies in about 33 hours. That is to say, the death rate of normal cells is about equal to the rate of new births.

This general picture, traced in the mouse, applies also to man. Radioautographic studies of human cells have been made in cancer patients at Northwestern University and Brookhaven. These show that normal human cells divide faster than cancer cells. At Brookhaven, Martin Lipkin and his co-workers found that the interval between divisions of epithelial cells in the human gastrointestinal tract is about 25 hours. On the other hand, in the fastest growing human tumor we have studied (a colon cancer) the cell-division interval was 27 hours, and other tumors had considerably longer cell cycles: 75 hours in another colon cancer, 10 days in a liver tumor and months in an ovarian cancer. What makes the tumors malignant is not the speed of cell division but the fact that each division doubles the number that can divide again.

Tracer studies with tritiated thymidine have also told us something about another aspect of cancer—the fatal process of metastasis. Today most cancer deaths are caused by secondary growths that have spread through the body rather than by primary tumors. A primary tumor can often be extirpated by surgery, but surgery and radiation therapy are helpless after a tumor has sent out malignant colonies to many other sites in the body.

Fragments of tissue detach themselves from the primary tumor and are transported throughout the body by the lymph and the blood. A bit of the tissue—usually only a single cell or a tiny cluster of 10 to 20 cells—lodges in some distant organ and begins to grow. This minuscule germ of malignancy of course cannot be detected; in fact, a tumor nodule usually is not detectable until it is at least one centimeter in diameter, which corresponds roughly to 500 million cells.



HUMAN CANCER OF THE LIVER is revealed by this radioautograph. Some cancer cells are labeled by black dots. The study indicated that the cells divided only once every 10 days.

Let us follow the process in a mouse. We inject a suspension of Ehrlich tumor cells into the mouse's bloodstream. After a short time many of these cells will turn up in the lungs, where they lodge in the capillaries. The body's defense mechanisms will kill most of them within 48 hours. But a few of the migrants—less than 1 per cent—will survive, synthesize DNA and give birth to colonies. These groups, clustered around the blood vessels, will grow into nodules; the nodules will combine to form metastases visible to the eye; and in two to three weeks they will kill the mouse.

From the information gained in tracer experiments we can picture the course of a metastasis in man. Imagine that a single migrant tumor cell has lodged in the liver. Its reproduction cycle there is 10 days; thus after 10 days the cell divides in two, 10 days later the two become four, and so on. With a doubling time of 10 days it will take 10 months for the original cell to grow into the one-centimeter nodule of 500 million cells that can be detected. In the case of a tumor with a doubling time of one month, the metastasis will remain undetectable by ordinary means for two years. This explains why, after a surgeon has apparently cut out all of a primary tumor, metastases may crop up months or years later. Cells may already have migrated from the tumor to distant parts of the body at the time of the surgery, but the metastases were then too small to be detected.

Tumor cells grow much like bacteria or protozoa in a culture, or like a fertilized egg cell in its early stages. That is, they do not differentiate but keep on dividing and producing identical offspring in a primitive fashion. Thus the cells of cancer behave like elementary forms of life and seem to represent a throwback to its early history.

The story of investigation of the life of the cell with high-resolution radioautography has, of course, just begun. Tritium labeling (not only of DNA but also of RNA and components of proteins) offers a wide range of possibilities for detailed study of the careers and activities of the various kinds of cells. This powerful technique adds an entirely new perspective to cell biology. We can think of it as a hybrid offspring of two fields of 20th-century research that have transformed the study of biology—biochemistry and the microscopic investigation of the anatomy of the cell. If the rule of hybrid vigor holds, radioautography should become a very lively child indeed.

MATHEMATICAL GAMES

Permutations and paradoxes in combinatorial mathematics

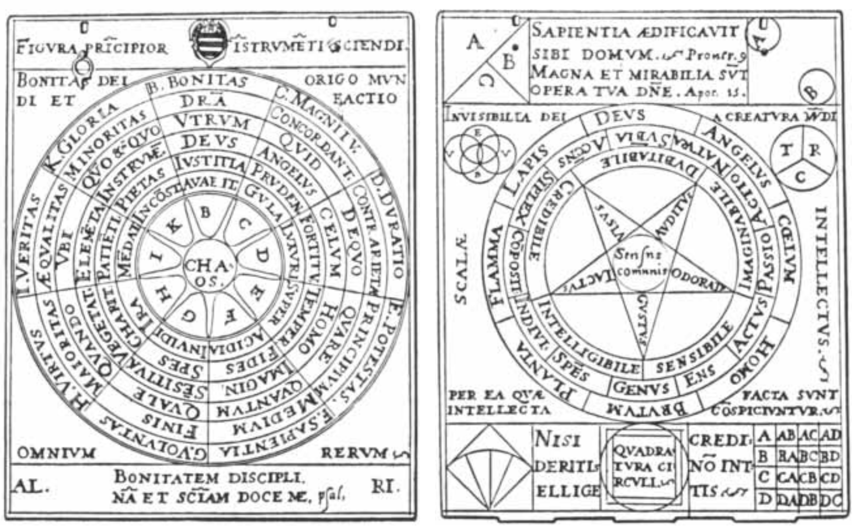
by Martin Gardner

"Amid the action and reaction of so dense a swarm of humanity," Sherlock Holmes once remarked in reference to London, "every possible combination of events may be expected to take place, and many a little problem will be presented which may be striking and bizarre...." Substitute "mathematical elements" for "humanity" and the great detective's remark is not a bad description of combinatorial mathematics.

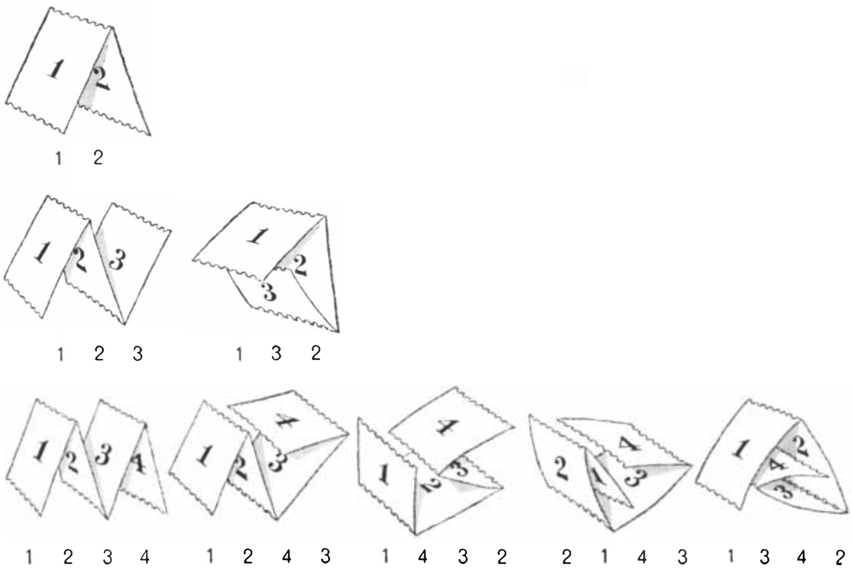
In the language of set theory, combinatorial analysis is concerned with the arrangement of elements (discrete things) into sets, subject to specified conditions. A person playing chess is faced with a combinatorial problem: how best to bring about an arrangement of elements (chess pieces) on an eight-by-eight lattice, subject to chess rules, so that a certain element (his opponent's king) will be unable to avoid capture. A composer of music faces a combinatorial problem: how to arrange his elements (tones) in such a way as to arouse aesthetic pleasure. In the broadest sense, combinatorial tasks abound in daily life: seating guests around a table, solving crossword puzzles, playing card games, making out schedules, opening a safe, dialing a telephone number. When you put a key in a cylinder lock, you are using a mechanical device (the key) to solve the combinatorial problem of raising five little pins to the one permutation of heights that allows the cylinder to rotate.

Combinatorial number problems are as old as numbers. In China 1,000 years before Christ mathematicians were exploring number combinations and permutations. The *Lo Shu*, an ancient Chinese magic square, is an exercise in elementary combinations. How can the nine digits be placed in a square array to form eight intersecting sets of three digits (rows, columns and main diagonals), each summing to the same number? Not counting rotations and reflections, the *Lo Shu* [*see bottom illustration on page 116*] is the only answer.

In the 13th century Ramón Lull, an eccentric Spanish theologian, built a flourishing cult around combinatorial thinking. It was Lull's fervid conviction



Two of Ramón Lull's combinatorial wheels



Ways of folding two, three and four stamps

that every branch of knowledge could be reduced to a few basic principles and that by exploring all possible combinations of these principles one could discover new truths. To aid the mind in such endeavors Lull used concentric disks mounted on a central pin. Around the rim of each disk he placed letters symbolizing the basic ideas of the field under investigation; by turning the wheels one could run through all combinations of ideas. Even today there are survivals of Lullism in techniques developed for "creative thinking."

Until the 19th century most combinatorial problems were, like magic squares, studied as either mystical lore or mathematical recreations. To this day they provide a large share of puzzle problems, some of which are trivial brain teasers: A drawer contains two red socks, two green socks and two blue socks. What is the smallest number of socks you can take from the drawer, with your eyes closed, and be sure you have a pair that matches?

There are moderately difficult questions such as: In how many different ways can a dollar be changed with an unlimited supply of halves, quarters, dimes, nickels and pennies?

And there are problems so difficult they have not yet been solved. Find a formula for the number of different ways a strip of n postage stamps can be folded. Think of the stamps as being blank on both sides. Two ways are not "different" if one folded packet can be turned in space so that its structure is the same as the other. Two stamps can be folded in only one way, three stamps in two ways, four in five ways [*see illustration above*]. Can the reader give the number of different ways a strip of five stamps can be folded?

It was not until about 1900 that combinatorial analysis began to be recognized as an independent branch of mathematics, and not until the past decade that it suddenly grew into a vigorous new discipline. There are many reasons for this upsurge of interest. Modern mathematics is much concerned with logical foundations, and a large part of formal logic is combinatorial. Modern science is much concerned with probability, and most probability problems demand prior combinatorial analysis. Almost everywhere science looks today it discovers not continuity but discreteness: molecules, atoms, particles, the quantum numbers for charge, spin, parity and so on. Wolfgang Pauli's "exclusion principle," which finally explained the structure of the periodic table of elements, was the outcome of combinatorial thinking.

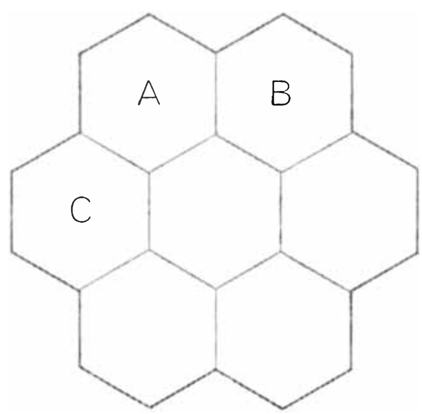
The great revolution that is now under way in biology springs from the sensational discovery that genetic information is carried by a nucleic acid code of four letters taken three at a time in a way that recreational mathematicians have been exploring for more than a century. Information theory with its bits and code words, computers with their yes and no circuits raise a myriad of combinatorial questions. At the same time the computer has made possible the solution of combinatorial problems that had previously been too complex to solve. This too has surely been a factor in stimulating interest in combinatorial mathematics.

The two main types of combinatorial problem are "existence" problems and "enumeration" problems. An existence problem is simply the question of whether or not a certain pattern of elements exists. It is answered with an example or a proof of possibility or impossibility. If the pattern exists, enumeration problems follow. How many varieties of the pattern are there? What is the best way to classify them? What patterns meet various maxima and minima conditions? And so on.

We can illustrate both types of problem by considering the following simple question: Is it possible to arrange a set of positive integers from 1 to n in a hexagonal array of n cells so that all rows have a constant sum? In short: Is a magic hexagon possible?

The simplest such array of cells is shown below. Can the digits from 1 to 7 be placed in those seven cells in such a way that each of the nine rows has the same sum? The sum, called the magic constant, is easily determined. We have only to add the digits from 1 to 7 and then divide by 3—the number of rows that are parallel in a given direction. The sum is 28, but it is not evenly divisible by 3. Since the magic constant must be an integer, we have proved that an "order 2" magic hexagon (the order is the number of cells on a side) is impossible. For an even simpler impossibility proof consider corner-cell A. It belongs to two rows that contain only two cells. If both rows have the same sum, cells B and C will have to contain the same digit, but this violates a condition of the problem that was given.

Turning attention to the next largest array, an order-3 hexagon with 19 cells, we find that the numbers sum to 190—which *is* divisible by 5, the number of



"Order 2" magic hexagon impossibility proof

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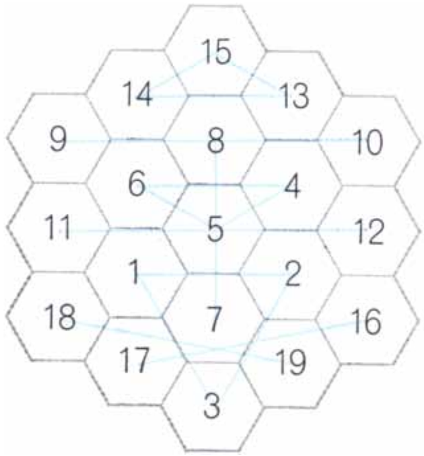


The only possible magic hexagon

parallel rows in one direction. The magic constant is 38. The previous impossibility proof has failed, but of course this does not guarantee that an order-3 magic hexagon exists.

In 1910 Clifford W. Adams, now living in Philadelphia as a retired clerk for the Reading Railroad, began searching for a magic hexagon of order 3. He had a set of hexagonal ceramic tiles made, bearing the numbers 1 to 19, so that he could push them around and explore patterns easily. For 47 years he worked at the task in odd moments. In 1957, convalescing from an operation, he found a solution [*see illustration above*]. He jotted it down on a sheet of paper but mislaid the sheet, and for the next five years he tried in vain to reconstruct his solution. Last December he found the paper, and early this year he sent me the pattern. Each of the 15 rows sums to 38. The colored lines connect consecutively numbered cells in sets of twos and threes to bring out the pattern's curious bilateral symmetry.

When I received this hexagon from Adams, I was only mildly impressed. I assumed that there was probably an extensive literature on magic hexagons and that Adams had simply discovered one of hundreds of order-3 patterns. To my surprise a search of the literature disclosed not a single magic hexagon. I knew that there were 880 different varieties of magic squares of order 4, and that order-5 magic squares have not yet been enumerated because their number runs into the millions. It seemed strange that nothing on magic hexagons had been published.

I sent the Adams hexagon to Charles W. Trigg, a mathematician at Los Angeles City College who is an expert on combinatorial problems of this sort. A post-card reply confirmed the hexagon's unfamiliarity. A month later I was staggered to receive from Trigg a formal proof that no other magic hexagon of *any* size is possible. Among the infinite number of ways to place integers from 1 to n in hexagonal arrays, only *one* pattern is magic!

Trigg's proof of impossibility for orders above 3 calls on Diophantine analysis, the obtaining of integral solutions for equations. Trigg first worked out the formula for the magic constant in terms of order n:

$$\frac{9(n^4 - 2n^3 + 2n^2 - n) + 2}{2(2n - 1)}$$

Applying Diophantine techniques that cannot be explained here, he was able to show that this formula has integral values only when n is 1 or 3. A magic hexagon of one cell is of course trivial. Adams had found one pattern for order 3. Are there other arrangements of the 19 integers (not counting rotations and reflections) that are magic? Trigg's negative answer was obtained by combining brute force (he used a ream and a half of sheets on which the cell pattern had been reproduced six times) with clever short cuts. Perhaps a reader with access to a computer can verify his surprising result.

As an elementary exercise the reader is invited to see if he can rearrange the 19 digits in Adams' hexagon so that the pattern is magic in the following way: each 3-cell row adds to 22, each 4-cell row to 42, each 5-cell row to 62. Magic hexagons of *this* type have been explored before and there are large numbers of them. (The problem is solved easily with the right insight. Hint: The new pattern can be obtained by applying the same simple transformation to each number.)

A pattern of integers arranged in a unique, elegant manner usually has many bizarre properties. Even the ancient *Lo Shu* still harbors surprises. A few years ago Leo Moser of the University of Alberta discovered an amusing paradox that arises when the *Lo Shu* is regarded as a chart of the relative strengths of nine chess players [*see illustration at bottom left*]. Let row *A* be a team of three chess experts with the playing strengths of 4, 9 and 2 respectively. Rows *B* and *C* are two other teams, with playing strengths as indicated. If teams *A* and *B* play a round-robin tournament, in which every player of one team plays once against every player of the other team, team *B* will win five games and team *A* will win four. Clearly team *B* is stronger than *A*. When team *B* plays team *C*, *C* wins five games and loses four, so that *C* is obviously stronger than *B*. What happens when *C*, the strongest team, plays *A*, the weakest? Work it out for yourself. Team *A* is the winner by five to four! Which, then, is the strongest team? The paradox brings out the weakness of round-robin play in deciding the relative strengths of teams. Moser has analyzed many paradoxes of this sort, of which this is one of the simplest. The paradox also holds if teams *A*, *B* and *C* are the columns of the *Lo Shu* instead of the rows.

A	4	9	2
B	3	5	7
C	8	1	6

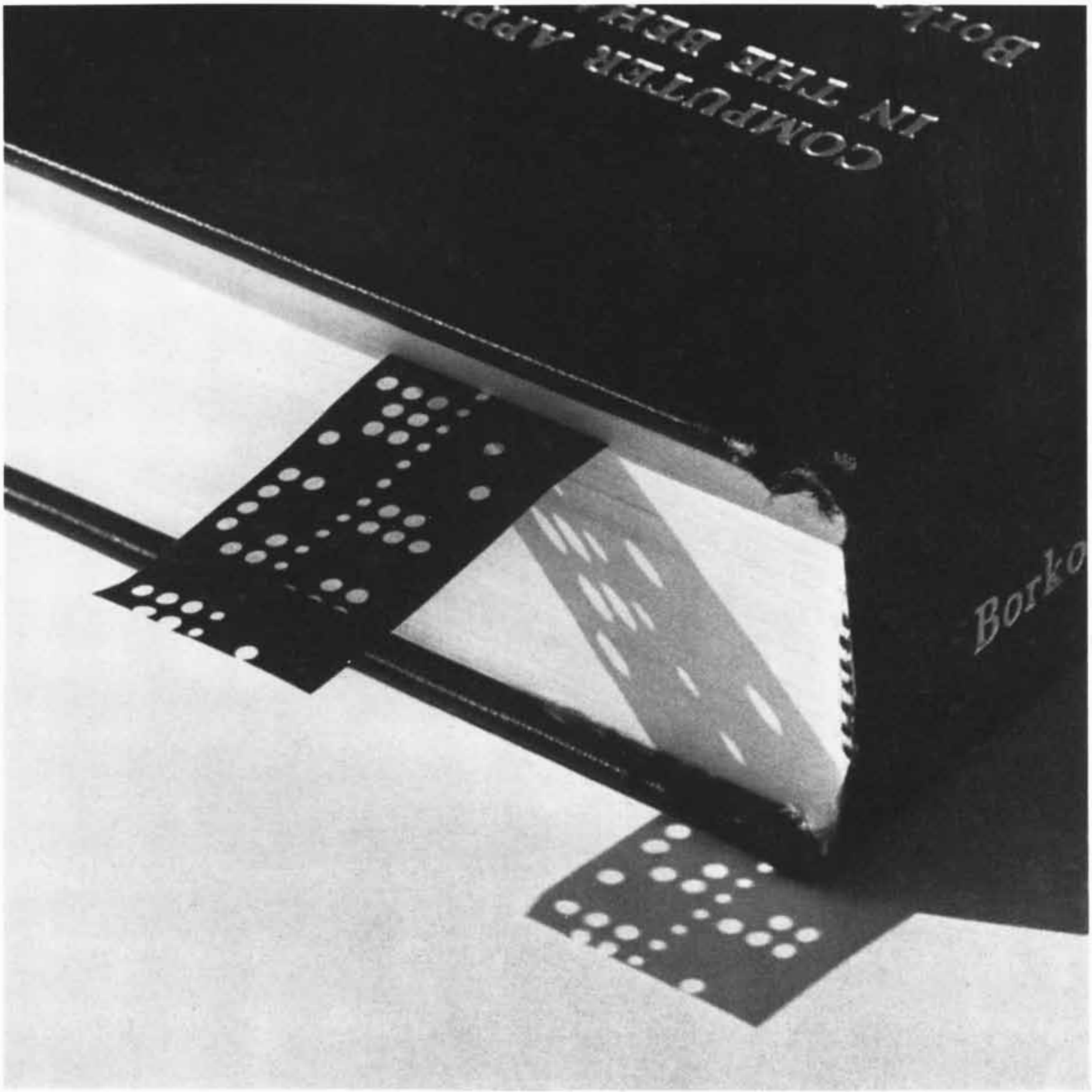
The* Lo Shu, *ancient Chinese magic square

Similar paradoxes, Moser points out, arise in voting. For example, assume that one person's preference for three candidates is in the order *A*, *B*, *C*. A second person prefers *B*, *C*, *A* and a third prefers *C*, *A*, *B*. It is easy to see that a majority of the three voters prefers *A* to *B*, a majority prefers *B* to *C* and (confusingly) a majority also prefers *C* to *A!*

The arrangement of elements in square and rectangular matrices provides a large portion of modern combinatorial problems, many of which have found useful applications in the field of experimental design. In Latin squares (discussed in this department for November, 1959) the elements are so arranged that an element of one type appears no more than once in each row and column. Here is a pretty combinatorial problem along such lines that is not difficult but conceals a tricky twist that may escape many readers:

Suppose you have on hand an unlimited supply of postage stamps with values of one, two, three, four and five cents (that is, an unlimited supply of each value). You wish to arrange 16 stamps in a square formation so that no two stamps of the same value will be in the same row, column or any diagonal (not just the two main diagonals). In other words, if you place a chess queen on any stamp in the four-by-four square and make a single move in any direction, the queen's path will not touch two stamps of like

Continuum I: today and tomorrow in information-systems technology



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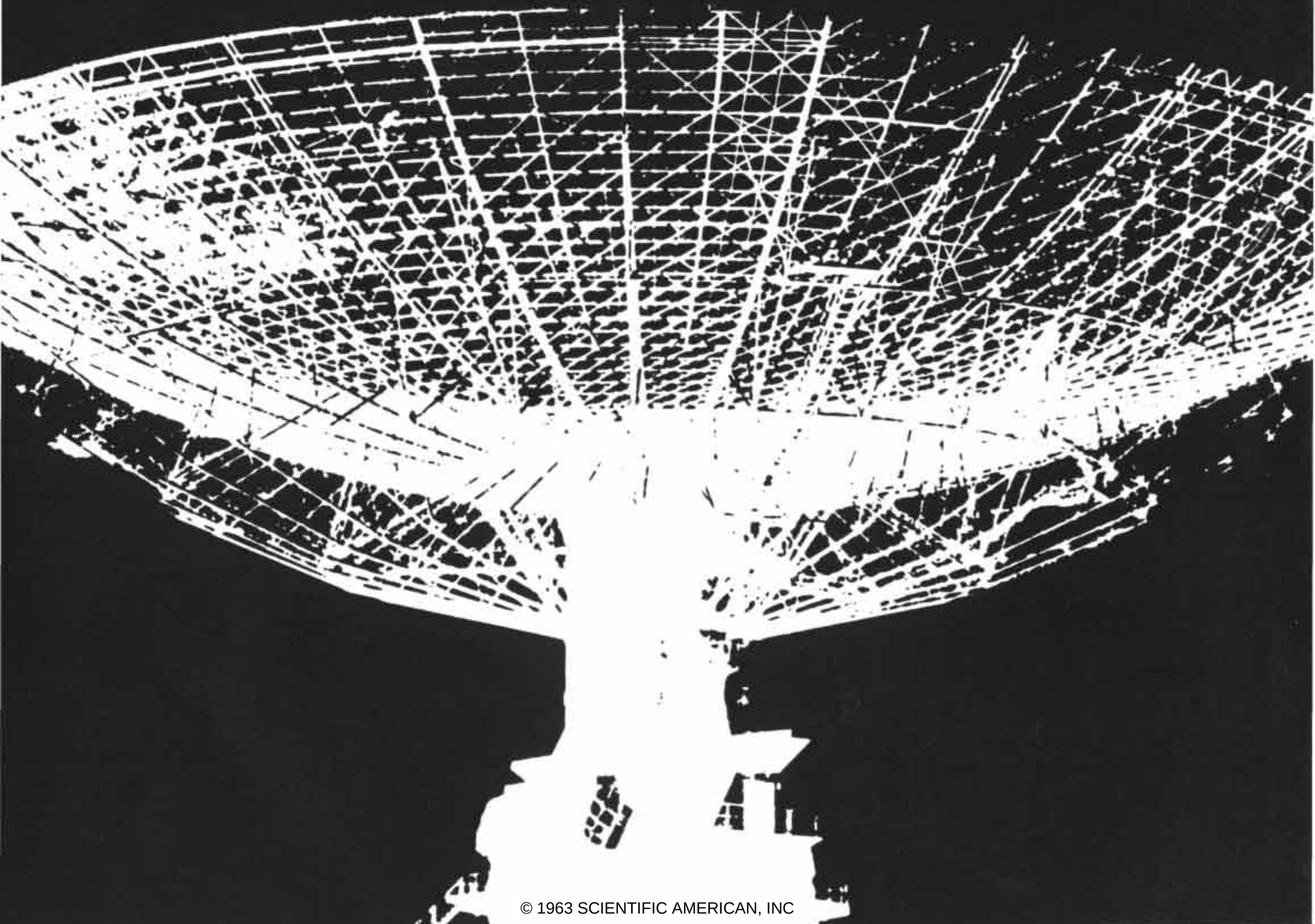
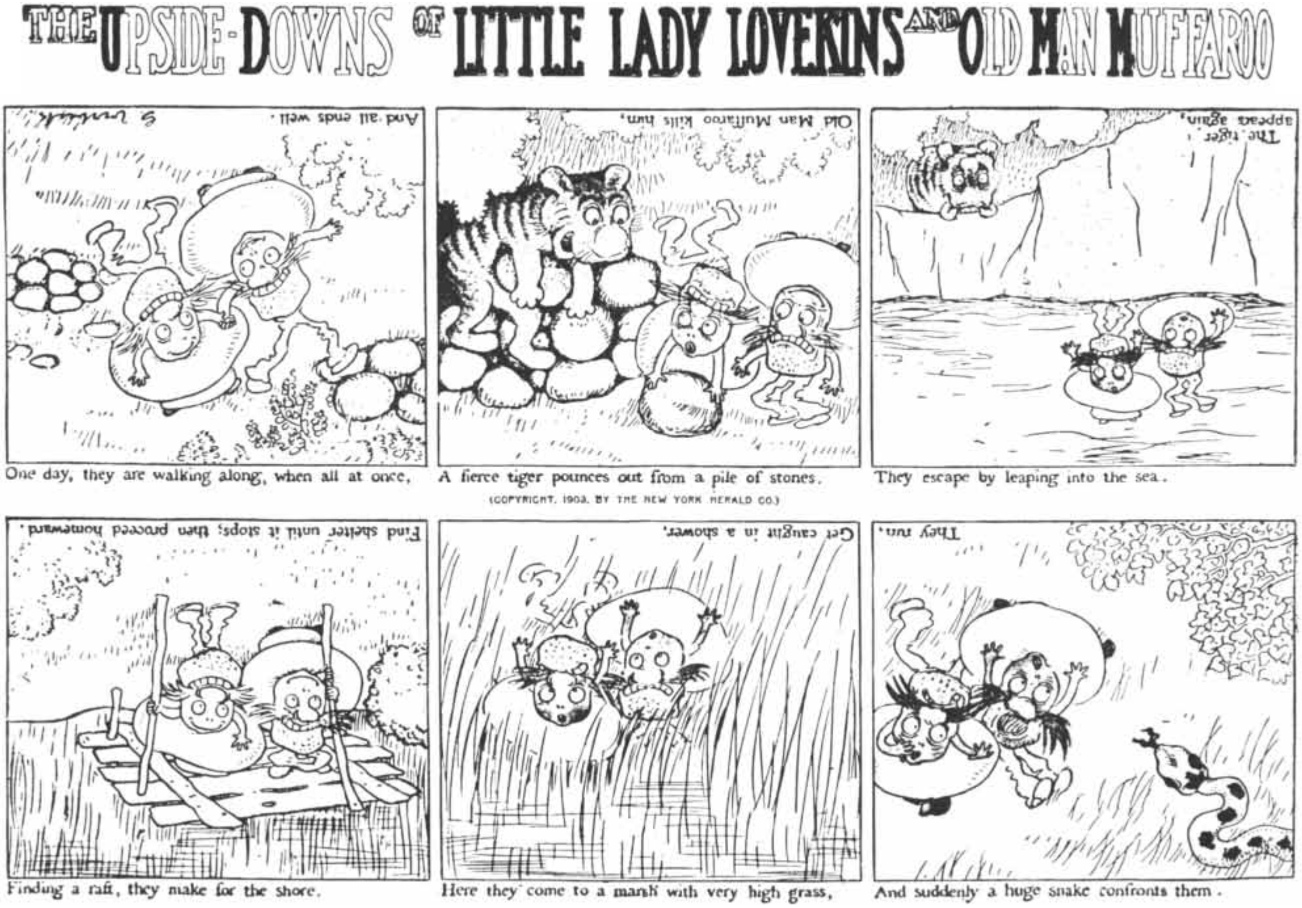




A typical upside-down cartoon by Gustave Verbeek

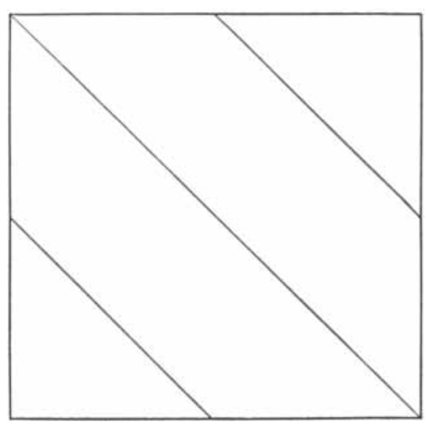
value. There is one further proviso: the total value of the 16 stamps in the square must be as large as possible. What is the maximum? The answer to this and the preceding questions will be given next month.

Readers may recall that in this department for May, 1962, in a discussion of rotational symmetry, mention was made of a remarkable series of comic strips by Gustave Verbeek that ran in a New York newspaper in 1903 and 1904. Each strip has six panels, which are read in order; then the page is inverted and the same six panels, taken in reverse order, complete the story [*see illustration above*]. George Naimark of Summit, N.J., has reproduced 20 of these fantastic strips in large format and bound them in a booklet called *The Incredible Upside-Downs of Gustave Verbeek.* Interested readers can obtain copies, postpaid in the U.S., by sending $2 to the Rajah Press, Box 23, Summit, N.J.

The first of last month's two topological problems was to make two loop cuts in the torus model that would produce two interlocked bands. This is solved by first ruling three parallel lines on the unfolded square [*see illustration at bottom right*]. When the square is folded into a torus as explained last month, the lines make two closed loops. Cutting these loops produces two interlocked bands, each two-sided with two half-twists.

The second problem was to find a loop cut on the Klein bottle that would change the surface to a single Möbius strip. On both left and right sides of the narrow rectangular model described last month you will note that the paper is creased along a fold that forms a figure-eight loop. Cutting only the left loop transforms the model into a Möbius band; cutting only the right loop produces an identical band of opposite handedness.

What happens if both loops are cut? The result is a two-sided, two-edged band with four half-twists. Because of the slot the band is cut apart at one point, so that you must imagine the slot is not there. This self-intersecting band is mirror-symmetrical, neither right- nor left-handed. You can free the band of self-intersection by sliding it carefully out of the slot and taping the slot together. The handedness of the resulting band (that is, the direction of the helices formed by its edges) depends on whether you slide it out to the right or the left. This and the previous cutting problems are based on paper models that were invented by Stephen Barr and are described in his forthcoming book on topological recreations.



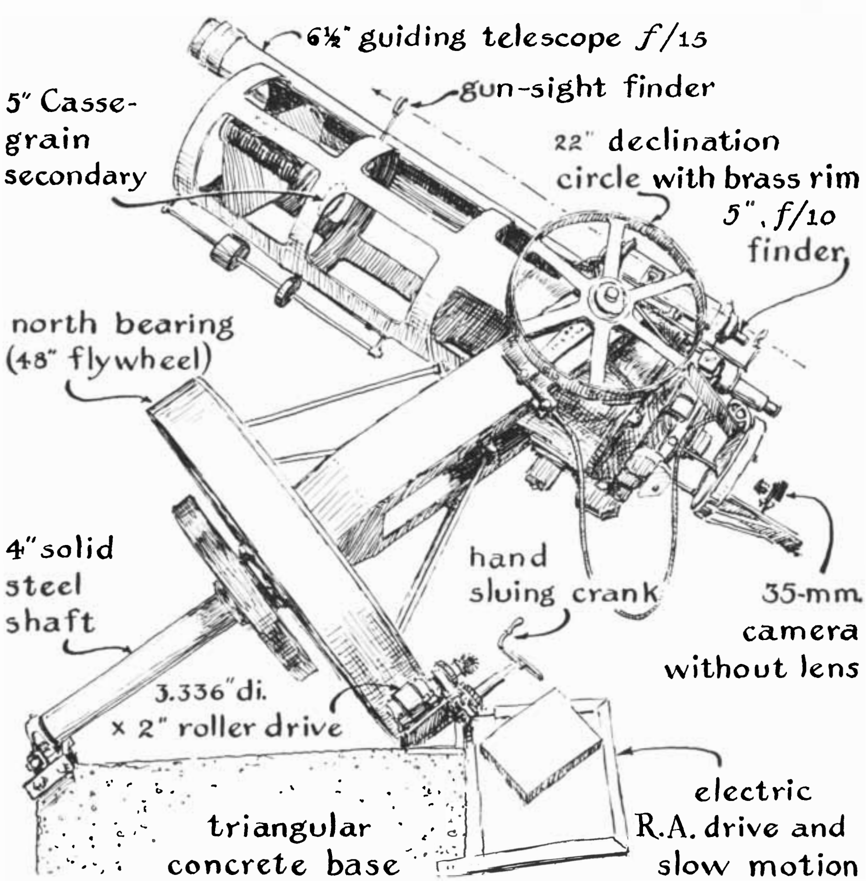
Solution to torus-cutting problem

THE AMATEUR SCIENTIST

A large telescope for a home observatory and a light meter for use in the darkroom

Conducted by C. L. Stong

Shortly after World War II one of the U.S. Government's surplus-property agencies put up for sale 100 disks of Pyrex glass 16 inches in diameter. They had been planed on one side to a thickness of three inches for use in industry as reference flats, and they appeared to be ideal for conversion into telescope mirrors. Amateur telescope makers, sensing a once-in-a-lifetime opportunity to own a telescope of professional caliber at a fraction of the usual cost, eagerly snapped up the entire lot at $12.50 each. What happened to most of these Pyrex blanks I do not know, but I have been able to trace four of them. One was last heard of in Omaha, Neb. Another, scratched and chipped beyond reclaim, is part of an ornamental stone fence in Connecticut, a perpetual reminder to its purchaser that the difficulty of constructing a reflecting telescope increases exponentially with the diameter of the objective mirror. The third, much thinner for having been abraded by some 2,500 pounds of carborundum grit, still awaits completion as a telescope mirror in Virginia. The fourth disk has fulfilled its owner's dream: it now reposes, as an aluminized paraboloid, in a precision mounting beneath the dome of a trim observatory in Putnam County, N.Y., the proud possession of Frank Aime, a retired engineer and amateur astronomer.



A 16-inch reflecting telescope built by a New York amateur

"This project," writes Aime, "would never have reached the drawing board 15 years ago had I then realized its full proportions. Like all stargazers, I had long wanted a good telescope; in the 1920's I had acquired a few acres of inexpensive mountainside in Putnam County, 50 miles from the lights of New York, with the hazy notion that the plot would make a good site for an observatory. Until the end of World War II, however, I did most of my 'observing' in the city, at the Hayden Planetarium of the American Museum of Natural History. Then I learned of the availability of the 16-inch Pyrex blanks. My close friend the late Albert G. Ingalls, who at that time conducted in *Scientific American* a department largely devoted to amateur telescope making, warned me that a 16-inch instrument was no undertaking for a beginner. 'If you are determined to make a big telescope,' he said, 'first construct at least two small ones. You can make a six-inch, a 10-inch and a 16-inch in much less time than you will waste if you first tackle the 16-inch.' I ignored his sound advice. As a result I have spent more than 6,000 hours during the past 11 years at the drill press and lathe alone, a figure that omits the machining time required by parts that were too large for the shop of the Hayden Planetarium, where I did much of the work.

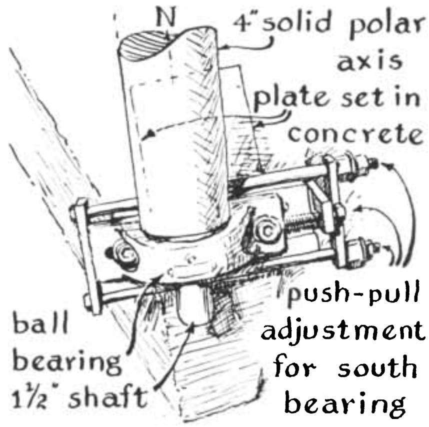
"Other thousands of hours have gone into such related tasks as procuring materials and erecting the telescope. One of the largest parts, the hour circle, once functioned as the 1,500-pound flywheel of a rock-crusher. It was given to me for the taking by the owner of a gravel bank —but taking it involved the use of a 50-ton hydraulic jack and a husky friend. We managed to remove the wheel from its shaft and load it onto a truck in less than two hours. The smaller parts include odds and ends picked up from scrap piles all over the northern half of the hemisphere. A special electrical fitting, for example, was recovered from the gutter of the Avenida Juárez in Mexico City. Luck at the scrap piles, in fact, played no little part in the final choice of materials.

"In its present form the telescope is of the Cassegrainian type: a perforated paraboloidal mirror of $f/4$ aperture directs converging rays of starlight to a convex mirror on the optical axis that in turn reflects the rays back through the perforation to a focal plane behind the objective mirror. The image can be examined through an eyepiece or photographed. The arrangement enables the designer to fit a relatively long optical path into a short mechanical structure and still achieve the high magnification made possible by extended focal length without sacrificing the convenience of a short instrument. The focal length of the objective mirror is 64 inches. Starlight, after reflection by the secondary convex mirror, comes to focus at the optical equivalent of 256 inches. Objects examined through an eyepiece of one-inch focal length are magnified 256 diameters; objects viewed through an eyepiece with a focal length of six millimeters are magnified 1,085 diameters. At this maximum magnification the moon is seen at an apparent distance of about 230 miles and can be picked apart crater by crater.

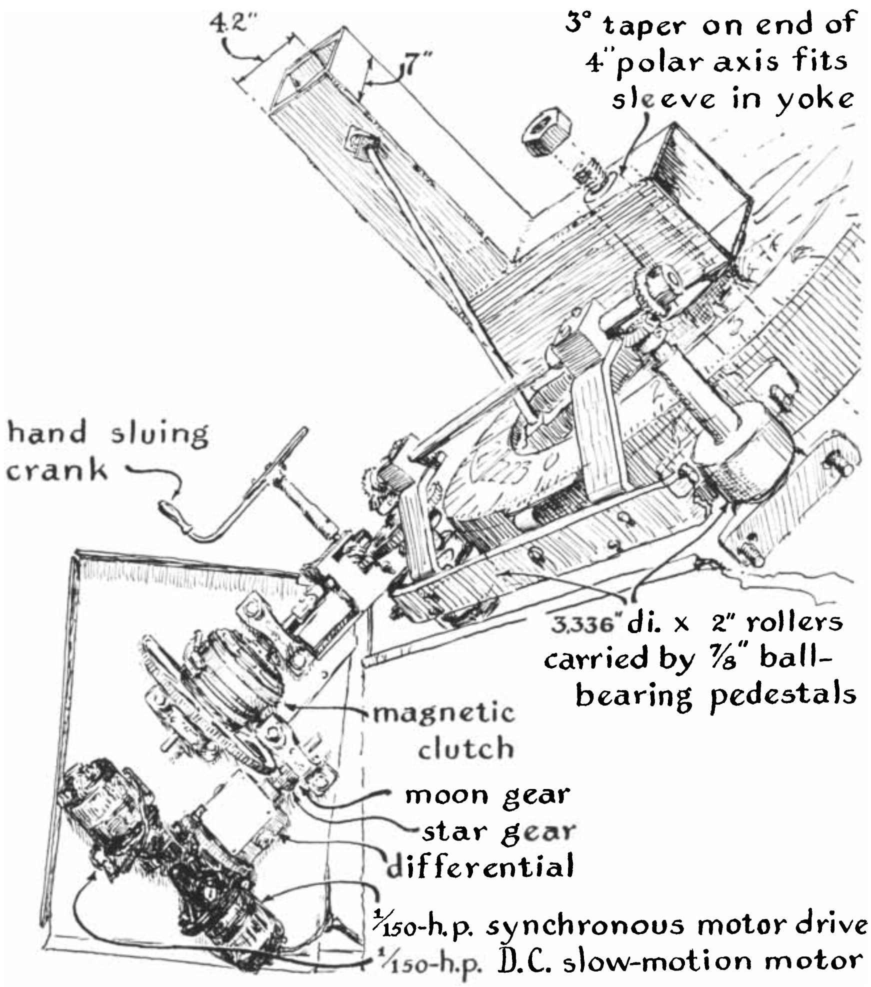
"The mechanical structure, or mounting, that supports the optical parts in physical alignment and keeps them trained on a desired star or other celestial object resembles the design proposed by the late Russell W. Porter, who with Ingalls founded amateur telescope making as a hobby in the U.S. Essentially the structure consists of a skeleton tube suspended by bearings between the tines of a stiff fork that rotates about an axis parallel to that of the earth, as shown in the accompanying drawing [*opposite page*]. The tube, in addition to supporting the mirrors and eyepiece, serves as the mounting for a 6½-inch achromatic telescope of 96-inch focal length that is used for guiding the instrument when photographing stars. It is an excellent instrument in its own right; it resolves to Dawes's limit and presents a flat field substantially free of color. The tube also mounts two smaller achromatic telescopes of four and 4-3/16 inches respectively that serve as finders.

"The supporting fork is made of welded boiler plate and channel sections rigidly attached to one end of a solid steel shaft four inches in diameter that functions as the polar axis. The south end of the shaft rests in a thrust bearing that can be adjusted both laterally and vertically to point the shaft precisely toward the north celestial pole. The north end of the shaft makes a close fit with the center hole of the 1,500-pound flywheel, the rim of which rides on a pair of solid steel cylinders that are rotated by a clock mechanism. The cylinders and the thrust bearing thus form a three-point suspension, with the front points—the two cylinders—spread 15 degrees to the east and west of center. The entire instrument rests on a triangular pier of concrete that extends down to the solid rock of the mountain. The image is correspondingly rock-solid, even when the instrument is used at magnifications 36 per cent above the normally accepted limit of 50 diameters per inch of aperture.

"Although the tube and the movable parts of the mounting weigh more than 1½ tons, the assembly can be rotated easily by hand in both right ascension and declination. For convenience and particularly for photographic observing, the tube is driven in both axes by electric motors. Sidereal drive is supplied by a 1/150-horsepower synchronous motor that operates from the 60-cycle power line. It carries the load easily without heating. The tube is advanced or retarded in right ascension by a second 1/150-horsepower motor geared to the drive mechanism through a differential. The drive mechanism also includes a gearshift for tracking either stars or the moon, and an electric clutch that allows the tube to be slued by hand. A universal motor drives the tube in declination through a train of gears at a rate that enables the observer to cut the moon's



Adjustable south bearing of polar axis



Drive mechanism for right-ascension axis disk easily into eight parts. All three motors are controlled through a cable that terminates in a portable switch box at the eyepiece.

"The tube carries a platform just behind the cell of the objective mirror for supporting cameras, spectrographs, photometers and related accessories at the Cassegrainian focal plane. All instruments seat against stops in the platform so that they can be removed and then returned precisely to their former positions. I use either of two cameras as plateholders: a Leica M2 with or without its lens and a Medalist II. The Leica is focused by means of a microscope attachment and the Medalist is focused through a ground glass. When fitted with these plateholders, the optical assembly acts as a camera of substantial light-gathering power.

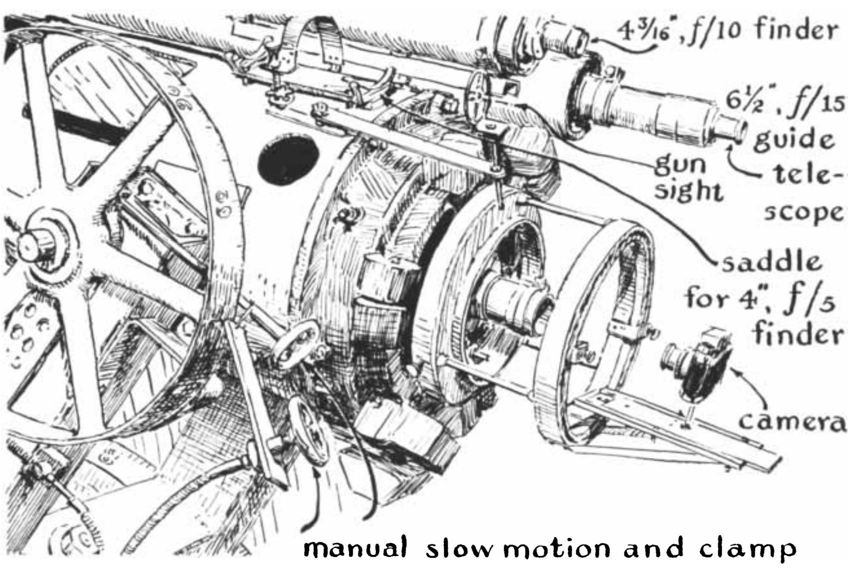
"The circular observatory is constructed of concrete blocks topped by an aluminum dome slightly more than 16 feet in diameter. The dome rolls on eight pulley wheels that ride a circular track of 3/4-inch pipe and is rotated by an electric winch controlled from the eyepiece position. Access to the sky is provided by a pair of quadrant shutters that roll laterally on similar tracks and are moved by a hand winch. The clear area measures four feet in width and extends from the horizon to the zenith.

"In general the telescope is pleasant to use and capable of doing good work. On the other hand, several disadvantages should be mentioned. The optical elements are not easy to collimate, or align, and the field of view is quite narrow—only a tenth of the moon's diameter. This means that the optical axis of the finder telescope must be aligned within 1½ minutes of arc with respect to the primary objective, and this was not an easy task. Until the finder was adjusted to the proper position I had difficulty in locating objects even as brilliant as Jupiter in the main scope, to say nothing of specific stars. The problem of pointing the polar axis directly toward the north celestial pole was even more difficult, in spite of jackscrews for shifting the south bearing laterally in small increments.

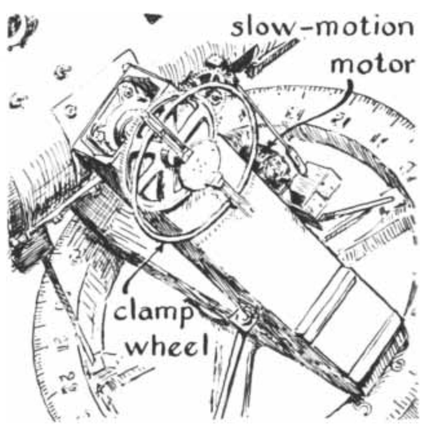
"Although the construction started as a one-man project, many friends were drafted for specific jobs. The figuring of the objective mirror, for example, was done by Stanley Brower, a former amateur turned professional. Friends also helped me to erect the observatory wall, weld the fork, lay the floor and pour the concrete pier. The heaviest machine work was done in a commercial shop.

"No amateur can expect to avoid errors in a project of this size, and I was no exception. I should not, for example, have geared the instrument directly to the motors for rotation in right ascension. I did not know much about observing when I designed the drive or I would have applied the power to the hour circle and linked the hour circle to the polar shaft by a clutch arrangement. The hour circle could then be set as a clock at the beginning of an observing session and the instrument thereafter clamped at any desired right ascension without the need for computing sidereal time when shifting from one celestial object to another. I am now reconstructing the drive to include this feature.

"Several scraps of knowledge emerged from the project that may prove useful to others who undertake the construction of an instrument with an aperture of



Platform for supporting instruments at telescope eyepiece



Drive mechanism for declination axis

more than six inches. First, decide what kind of objects you want to observe and what kind of observing you want to do before you attempt the design. Are you interested in visual observing or do you intend to go in for photography? Will the instrument be used primarily for observing the moon, planets and star clusters or individual stars or nebulae? No single instrument can perform equally well on objects of all classes.

"Second, complete the mechanical design before you cut or grind a single part, including the optics, the drive mechanism and the observatory. Nothing is more exasperating than to discover an omission that must somehow be squeezed into an otherwise completed assembly. Procure materials well in advance and make no component until all its essential parts are at hand. Devote enough time and care to the job so that each piece reflects credit on your craftsmanship and is worthy of the instrument. Remember, you will be looking at the parts for years and they will be staring right back at you. Prepare a sketch of each part before you attempt to make it. Parts that seem ideal in the mind's eye have a way of becoming much simpler on the drawing board. Finally, if you do not know how to design a component, don't guess. Ask someone who knows."

According to Aime, the observance of these simple rules spared him many headaches, cut his construction time substantially and resulted in a better telescope. Now that Aime's dream has been fulfilled, what does he intend to do with the instrument? I put the question to him a few weeks ago during a short session at the observatory.

"That's easy," he replied. "I have had a lot of fun playing with it already. Lunar detail interests me in particular and I am looking forward to having a ringside seat when the next spacecraft reaches the moon. I tried to observe the

impact of the first Soviet moon probe but had no luck, perhaps because the instrument had not been properly collimated at that time. Not all my hobby hours are spent at the observatory, however. I enjoy working with my hands and for several years have taught mirror making to beginners at the Hayden Planetarium, where the Optical Division of the Amateur Astronomers Association of New York conducts evening courses for amateurs. The observatory is made available on a scheduled basis without charge to graduate students in astronomy and other qualified observers."

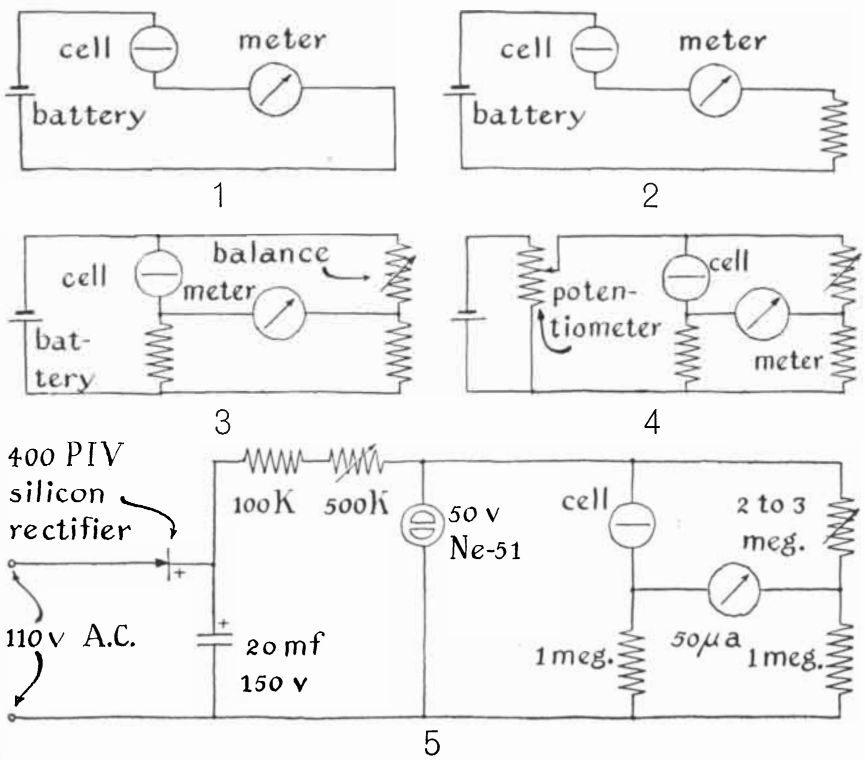
I asked Aime what he knew about the remaining 96 Pyrex disks. He shrugged. The question is of more than passing interest because several school groups have indicated a desire to make large telescopes. Readers having knowledge of any 16-inch blanks in good condition can get in touch with these institutions through this department.

Most amateur photographers use light meters for determining correct exposures but rely on guesswork in the darkroom when they select printing paper of the proper contrast and the correct lens opening of the enlarging projector. George Ginn, an electronics engineer and amateur photographer of Mountain View, Calif., writes that he used to print by guess, "and after practicing for 10 years I became so proficient I could sometimes make a good black-and-white print in 30 minutes without wasting more than a dozen sheets of projection paper. Now I use a simple light meter that enables me to make a good print every time on the first try.

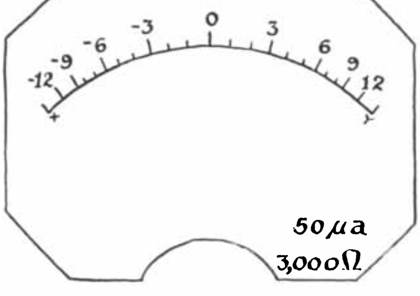
"There is nothing essentially new in the idea of controlling the process by measurement. Commercial laboratories long ago adopted densitometers for the purpose, but these devices cost substantially more than the average amateur can afford. My meter measure is not the density of the negative but the intensity of the light at the enlarger easel.

"I assembled my meter largely from parts found in the scrap box; it could be duplicated even with new parts for less than the cost of an ordinary exposure meter. It consists of a photocell connected by an extension cord to a few resistors, a regulated power supply and a microammeter. All parts except the photocell are housed in a small metal box.

"Proper exposure and paper contrast are fully determined by two measurements made by placing the photocell in the lightest and darkest parts of the negative image projected on the enlarging easel. The photocell does not generate current but acts as a resistance that varies inversely with the intensity of the impinging light. This property immediately suggests a circuit. The photocell,



Evolution of circuit design for light meter



Calibrated instrument scale for meter

battery and microammeter can be connected in series, as shown by the first drawing of the accompanying set of circuit diagrams [*opposite page*]. This simple arrangement would work, but examination of the circuit discloses two obvious disadvantages. First, accidental exposure of the photocell to bright light would minimize the photocell resistance and the resulting high current could damage the microammeter. This defect can be corrected by inserting a limiting resistor in the circuit to keep the current to a safe value when the photocell is short-circuited, as shown in the second schematic diagram. The other disadvantage stems from a common property of all photocells: their resistance rises to maximum but does not become infinite in the absence of light. The current of constant minimum amplitude transmitted by photocells even in total darkness would deflect the needle of the microammeter to some point on the scale above zero, thereby wasting a portion of the scale. Most experimenters prefer light meters that indicate zero in darkness and full-scale deflection when exposed to light of maximum intensity. This can be achieved by two more modifications of the basic circuit. The first modification balances out the 'dark current' and the second provides an adjustment for controlling full-scale deflection. To balance out the dark current a variable balancing resistor is connected across the cell and microammeter and a fixed resistor across the microammeter and current-limiting resistor, as shown in the third diagram. The circuit configuration now constitutes a bridge, with the photocell and balancing resistor forming the upper branches of the bridge and the fixed resistor and current-limiting resistor forming the lower branches. The microammeter connects across the center of the bridge between the upper and lower branches. If the resistance of the variable resistor is adjusted to equal that of the photocell in darkness and the resistance of the current-limiting resistor is selected to match that of the fixed resistor, the bridge will be balanced when the photocell is in darkness and each side will transmit equal current. No current will then appear in the microammeter. In effect, the dark current has been balanced out. The problem of adjusting the circuit for maximum meter deflection when maximum light falls on the photocell can be solved by installing a potentiometer across the battery for adjusting the voltage applied to the bridge circuit, as shown in the fourth diagram.

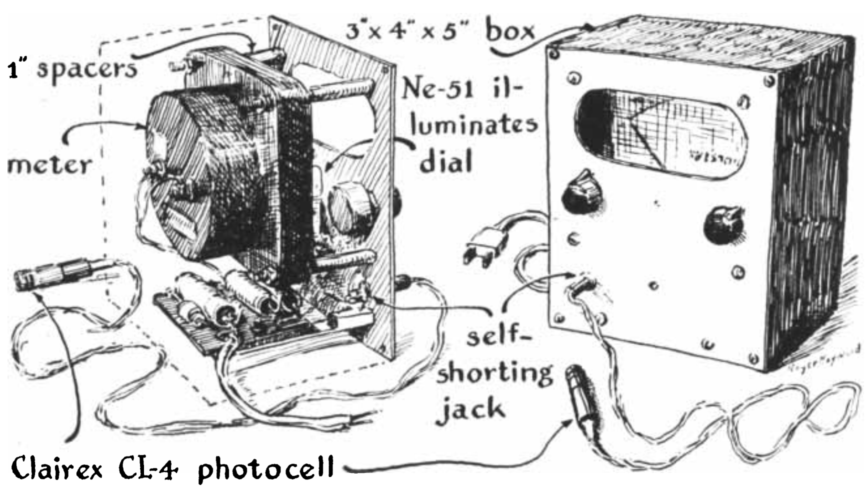
"A meter so constructed would work, but I wanted mine to operate from ordinary 110-volt, 60-cycle house current. So I added a rectifier and a small neon lamp that doubles as a light for the microammeter scale and as a regulator for maintaining the rectified voltage at constant amplitude. The final form of the instrument is shown in the fifth diagram.

"It turns out that the sensitivity of the meter is high at low values of light intensity and progressively less sensitive at higher intensities. This is an advantage because the measurement that determines exposure is made in the darkest area of the negative image, where maximum sensitivity is needed. A new scale was made for the meter and calibrated so that each scale division corresponds to one stop of the enlarger lens, or a factor of two in brightness. This conforms to the standard ASA scale used on exposure meters. Each of the divisions was then subdivided into three parts, which represent a change in density of .1, as shown in the accompanying drawing [*preceding page*].

"All components except the Clairex CL-4 photocell are assembled in a standard apparatus box five inches high, four inches wide and three inches deep. A window in the front cover provides access to the scale of the microammeter, which is mounted behind the front cover on tubular spacers and long bolts. The neon lamp is located behind the front cover and beneath the window to shield the cell from direct exposure to the lamp.

"To relate the light measurements to the characteristics of printing papers, I test each batch of paper as it is opened. For this purpose I made a test negative by masking a strip of process negative in increments and doubling the exposure of each increment to produce a 10-step gray scale. With this test strip in the enlarger, I determine for each paper the stop that causes a dark area of the negative to produce a barely discernible high-light gray in a print exposed for 15 seconds and a light area to produce a black just short of maximum. The next step is to take a meter reading, at the easel, of the light and dark areas of the negative image with the enlarger set at that stop. The difference between these two measurements is my contrast index for the paper in question. Depending on the individual meter, differences of 1, .8, .7, .6 and .5 may be found to characterize papers of contrast grades 0, 1, 2, 3 and 4 respectively.

"To print a negative, finally, insert it in the enlarger and open the lens until a meter reading in the darkest area of the negative image indicates that the high light will just register. Then take a reading in the lightest area. Subtract the lower reading from the higher one to find the difference between the two. Select a paper that matches this difference. A print made with this paper exposed at this lens opening for 15 minutes and developed as recommended by the manufacturer should come out right on the button."



Internal and external views of completed meter

BOOKS

Was modern science stimulated by the ethic of Puritanism or by the ethic of liberty?

by A. Rupert Hall

THE SCIENTIFIC INTELLECTUAL: THE PSYCHOLOGICAL & SOCIOLOGICAL ORIGINS OF MODERN SCIENCE, by Lewis S. Feuer. Basic Books, Inc. ($10).

Some 70 years ago Andrew D. White gave classical expression (in his *History of the Warfare of Science with Theology in Christendom*) to the conviction of a generation of scientists who remembered Bishop Wilberforce's attack on Huxley: that science was the professed enemy of superstition, dogma and unreason. Servetus, Bruno and Galileo were to them martyrs at the hands of theology for science's sake, and it was only in so far as religion had been forced to retreat that science had been enabled to advance. Lewis S. Feuer has undertaken the defense of views that, if they are considerably more sophisticated than White's, are nevertheless closer to his than to the popular ones of recent times. Feuer has little patience with neoreligious explanations of the sudden flowering of science in western Europe and America. He particularly rejects the opinion, which he believes to prevail among sociologists, that "makes the modern scientific spirit into an offspring of Protestant asceticism." Rather, Feuer believes, true, progressive science has always been the product of what he calls the "hedonist-libertarian ethic."

Most readers will applaud Feuer's belief; we cannot resent being told that what we prefer to do is the right thing to do. Like him, many of us have doubted that the harsh Calvinistic creed was as great a stimulus to the material and intellectual development of Europe as Max Weber and his followers supposed. Even if it is granted that the Puritan's lust for salvation was readily converted into a lust for gold, so that material success became the measure of spiritual purity, still it does not follow that the virtues of sobriety, industry and preaching led the Puritan to develop a love of knowledge outside of the Scriptures and the *Institutes.* Like ascetic Catholics, Puritans were often likely to condemn as vain all learning that was not divine and to rate theology Queen of the Sciences no less than the medieval universities had done. Neither Calvin's Geneva nor Knox's Scotland was remarkable as a center of science; it was rather the case that science and other intellectual activities began to flourish in communities where the Puritan spirit was already declining. As Feuer points out in acute analyses, from the end of the 17th century on, in both Scotland and New England, only the possibility of a dissident spirit's surviving in an atmosphere of weakened theological rigor made science possible. Often the very men now celebrated as scientists were then singled out for the freedom of their lives or their relative carelessness toward clerical sanctions.

This is conspicuously true of England when the Royal Society was founded. The founders were actually seeking to escape into intellectual discussion of natural phenomena from the boring recitation of religious platitudes. They became, some of them, habitués of the flippant and free-loving court of Charles II, or time-serving Puritans who welcomed the bishoprics and other rewards of the Anglican Church. Of the 94 out of 119 Original Fellows of the Royal Society (1663) for whom evidence is available, no fewer than 54 were pleasure-seekers by Feuer's reckoning, and only five were Puritans; 68 were Royalists and only 12 were would-be Republicans. Other investigators—notably the dean of U.S. sociologists, Robert K. Merton, in a magisterial monograph 25 years ago—have put forward sharply contrasting estimates. The discrepancy lies in the fact that most men conform to the powers and the churches that be, outwardly at least. Most of the founders of the Royal Society accepted the rule of the Independents before 1660, just as they accepted Anglicanism afterward. Like the Abbé Sieyès, they were capable of surviving many vicissitudes, and although they were by no means indifferent to the reality of Christianity (scientists were nothing if not devout), they were latitudinarian as regards its forms. Feuer seems to be largely correct in suggesting that religion has not often driven men to practice science, although it has sometimes hindered their doing so.

In the 20th century, which no longer experiences even the stuffiness of a Victorian Sunday, to say nothing of the harshness of Calvinistic intolerance, it has become relatively easy to praise the Puritan virtues of self-denial, industry and parsimony—our society no longer suffers the pangs that must accompany them. It is refreshing that Feuer should honestly avow the creed that is almost universally adopted in the rich countries today, and should not hesitate to add that in fact our riches are in part a consequence of that creed. His is a message of optimism:

"In this study I shall try to show that the scientific intellectual was born from the hedonist-libertarian spirit which, spreading through Europe in the sixteenth and seventeenth centuries, directly nurtured the liberation of human curiosity. Not asceticism, but satisfaction; not guilt, but joy in the human status; not self-abnegation, but self-affirmation; not original sin, but original merit and worth; not gloom, but merriment; not contempt for one's body and one's senses, but delight in one's physical being; not the exaltation of pain, but the hymn to pleasure—this was the emotional basis of the scientific movement of the seventeenth century."

If it were true that the turning point in the history of our Western civilization was the Reformation, and that its psychological foundations lay in the Puritan ethic, then the hedonism of the 20th century ought to make us despair, since we should by now have destroyed the springs of our society. Only collapse could lie ahead, as indeed the enemies of hedonism (and science) have so often predicted. The prophets of doom, almost as in the days when penny pamphlets confidently identified the Four Horsemen and the Beast of *The Revelation*, have increased the burden of guilt to the breaking point by proclaiming that the increasing violence of 20th-century warfare is itself the measure of this inevitable ruin: Western humanity (at least) must perish because it has sought power and pleasure.

Against this gloom—which may well be the cause of the catastrophe it laments—Feuer arms us with hope. He assures us that our civilization took not the wrong road but the right one. The 17th century particularly, with its first liberation of the human spirit from sectarian bonds and its decisive revolution in science, set the West on a track toward material progress and intellectual truth. This is a combination of empirical merits hard to beat. The claim that people are in some mysterious way "better off" at the starvation level than in our own more tense societies is simply perverse. The related claim that we have sacrificed an equally mysterious insight into Truth for the sake of scientific truths is simply nonsense. Accordingly we do not need to see science and technology as guilty companions in a rake's progress; instead, like our forefathers, we can ask with Feuer why it was that earlier civilizations failed to secure these essential advantages.

The answer here proposed is that earlier societies failed to develop the uninhibited release of energy that the progress of science requires. "All the classical schools of Chinese philosophy were affected by self-defeat and renunciation; all looked upon nature through the masochist mode of resignation. There were variations, to be sure, in the degree of this acknowledgement of self-defeat, but the general characterization holds, just as does the opposite for European-American thought from the seventeenth century on."

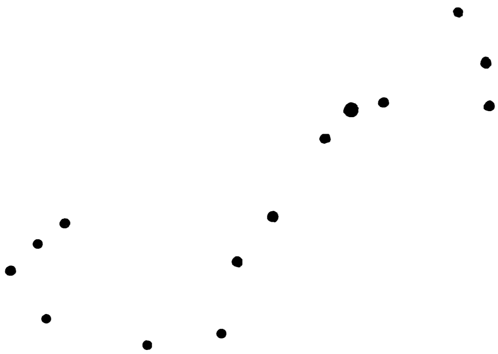
Men trained to endure pain rather than to covet joy do not seek knowledge of or power over the sources of pain and joy in nature; a Chinese psychological revolution necessarily took place before modern science could be naturalized in China. So in Japan the exaltation of "nothingness"—the epitome of the extinction of self—was the fatal enemy of science. Yet (in China at any rate) the prevalence of ethical or psychological values different from those of the West did not wholly prevent the development of technical skills or the study of mathematics and astronomy. The achievements of this alien civilization were perhaps more remarkable than Feuer allows, and the absence of an Epicurean philosophy less complete. In turning to Judaism, however, he considers the history of a people who cut themselves off from the intellectual life of the Europe they inhabited no less firmly than they were excluded from participating in it; the religious prejudice on both sides was equally strong. Hence until the mid-19th century Jewish learning was scholastic and medieval, and the brilliant Jewish achievement in science is a recent event. Yet this, after all, is a merely negative instance; it does not prove that the "hedonist-libertarian ethic" has the creative virtue Feuer attributes to it.

If asceticism, mysticism and self-immolation are by no means sufficient conditions for the development of science, neither are they invariably hostile to it. Many creative individuals have been personally frugal, ascetic and withdrawn. Some good scientists, like Boscovich, have been Jesuits; others, like Faraday, have clung throughout life to a puritanical form of religious observance. Categorizations of an "either-or" type such as puritan or hedonist are as difficult to determine as they are doubtful in value, except when they are applied to uninteresting polar examples. The antithesis between atheist-materialists and deist-formalists can be traced down the ages from Greek antiquity, and both have made crucial contributions to science—the vitalist, Catholic Pasteur, for example, as well as the determinist, agnostic Bernard. Consider the opposite pole to Feuer's: if the acme of hedonism and libertarianism were a lotus-eating Tahitian utopia, we should look in vain for Salomon's House. Presumably the author of "A Jug of Wine, a Loaf of Bread—and Thou/Beside me singing in the Wilderness," being a mathematician, could (like the blind Galileo) while away the long hours of siesta by solving problems in his head; but if his investigations had required the collection of some dozen pounds of aphids or the performance of a few thousand routine analyses, Omar Khayyám would have found a puritan discipline in perseverance not altogether beside the point.

It is not difficult to think of examples that run counter to Feuer's thesis. The hedonist ethic flourished more openly by far in 18th-century England than in the England of the 17th century, but the excellence of English science was inverse. The upper levels of Russian society from, say, 1800 to 1917 were not notably austere, ascetic or superstitious. Yet science did not flourish. The Ottoman Empire in its later stages was notorious for its sybaritic ease, whereas scientific eminence belongs to an earlier period of tougher virtues. The Romans knew both opulence and moral license; Greek philosophy and science were the fruits of a poorer, simpler and stricter society. And so on. Certainly the outlook praised by Feuer may be associated with the love of freedom, intellectual independence and advancement that he rightly praises; yet it may also be an aspect of a society that is decaying, corrupt and hopeless. Everyone knows the bad sense of the Epicurean philosophy (Eat, drink and be merry, for tomorrow we die); indeed, this is the interpretation that—perhaps unjustly—has been most often put on it.

The truth, as it appears from some further examples studied by Feuer, is that what he really finds most conducive to scientific and material progress is not free indulgence at bed and board (as his insistence on the "hedonist-libertarian ethic" might lead one to suppose) but a combination of human qualities hardly more esoteric than the puritan ones of perseverance and frugality. Against asceticism and other-worldliness he sets common sense, receptiveness, impatience of dogma, healthy skepticism, inquisitiveness and a normal enjoyment of what is natural to man, such as delight in one's work. He favors the open society and the open individual, and he argues (with complete justice, I believe) that when life has seemed to promise broad vistas of opportunity to men and when hope for a better life on earth has been strong, men have accomplished great things in science and, one might add, in other areas too. The enemies of science are narrowness and the foregone conclusion. Hence Feuer writes well of the freedom of Franklin's Philadelphia and the subsequent closing in of the gray fog of religious revival that shrouded the bright dawn of American genius. Men like Franklin, Bartram, Rittenhouse and (most famous and almost the last of all) Jefferson avoided religious bigotry and welcomed the delights of life; it is no accident that in their generation the craving for political freedom was joined to a striving for intellectual freedom.

With the end of Jefferson's democracy came the beginning of a transcendentalist revival; the free outlook of the 18th century was eclipsed even more completely in the U.S. than in post-Napoleonic Europe, and with it science was eclipsed. If a measure "of scientific work persisted in the American colleges during the two generations of antiscientific reaction...it was that minimum compatible with the clerical philosophy, and it lived off the residual hedonistic-libertarian energy of the eighteenth century." Science was not fostered by the great democracy; it was better cherished by



Prussian autocracy. A change in the U.S. (typified by the founding of Johns Hopkins University in 1876) came only when free inquiry replaced religious dogmatism. Similarly, in France it was the enormous liberation of the Revolution that made possible the brilliant efflorescence of science during the early 19th century.

Although these are indeed excellent examples to offer against the "Puritan ethic" history of science, together with the earlier renaissance of science in Italy that Feuer also discusses, they hardly enforce more than a sound, old-fashioned view of European history to the effect that increase of freedom has been a "good thing"—good for people, for science, medicine, painting and plumbing. It is very right and proper that this should be said, and said often. But the point should not be overdone; when Copernicus becomes the exponent of a hedonist-libertarian ethic and Platonism becomes the unrelenting foe of modern science, one begins to doubt. The scientists of Napoleonic France were not all atheists, still less were those of Renaissance Italy. Nor were they all deep drinkers and great lovers, nor all champions of political radicalism. The categorization begins to lack subtlety and the explanation variety.

There is, in the end, a ghost in Feuer's time machine: the ghost of Dr. Freud. It is not enough to show by historical examples that creativity is more often than not an attribute of normal, happy men, of *l'homme moyen sensuel;* Feuer feels his deductive generalization must be given a sound theoretical basis. This he finds in the Freudian account of personality. Now, a theoretical explanation is no more valid than the theory on which it depends; if one doubts that we have today a universally accepted and verifiable psychological theory, then one must also doubt our ability to provide psychological explanations of history. Arguments turning on the superego, the Oedipus complex and other concepts of psychoanalysis do not yet possess proved power to deal with the problems of intellectual history, in spite of all the progress that has been made in psychology by different schools at different levels.

In fact, the schematic, indirect and undemonstrable character of the psychological conceptualization to which Feuer turns on occasion is exactly parallel in structure to that of the religious conceptualization he would replace. He can write:

"In the sixteenth century, however, contempt for priests and monks, which Vesalius shared, had become widespread. The eunuchoid monk became a figure of ridicule with a touch of the hypocrite. The Renaissance men experienced a sense of liberation from some emotional thralldom. We might say that the unresolved Oedipus complex ceased to dominate their feelings and perceptions. They could dissect bodies, picture nude women, without feeling that they were engaged in the violation of their mothers; they could depict and dissect men without thinking they were engaged in bodily vengeance against their fathers."

This is exactly like saying (in fewer words) "They were without original sin" or "They were possessed by the devil." It is another appeal to the ghost in the machine as the arbiter over human history.

It would be unjust to insist heavily on this feature of Feuer's stimulating book, partly because Freudian ideas are separable from its structure and argument, and partly because the author's unquestioning Freudianism will no doubt seem perfectly natural to many readers. Nevertheless, the historian of science and perhaps the scientist too may have a sense of loss at the absence from Feuer's book of any concern for the intrinsic problems of science, and for the internal dialogue between successive generations of scientists that is always so fascinating and important. If one holds, as Feuer seems to hold, that anatomists such as Vesalius had undergone a form of spontaneous analysis or emotional release, so that they no longer had a neurotic regard for all corpses as those of their parents, then the story of Renaissance anatomy as we know it (the recovery of Galen, the reaction against Galen based on dissection and so forth) becomes almost meaningless. Similarly—although I imagine Feuer would resist the inference—Lavoisier's chemical researches become the less significant if we answer the question "Why did chemistry become for a time virtually a French science?" by appealing to the Revolution's release in France of intellectual energies that were elsewhere restrained. Surely no one doubts that psychology, religion, economics, the structure of society and so on have had a tremendous influence on the agelong development of scientific thought, with now this and now that external influence being the more effective. But there is a danger in insisting on the power of any of these influences if at the same time the truth that the problems of science are intellectual problems is neglected. Copernicus' emotional life is really irrelevant to his performance of one group of mental acts (the formulation of well-known difficulties within medieval astronomy in a particular way) and then of a second group (enabling him to remove these difficulties in a particular way). It would be fascinating indeed to have a Kinsey report or a couchside tape recording of Copernicus, but there is little reason to believe that even such massive evidence would help us much in understanding Copernicus' mental machinery.

Perhaps, therefore, it is worth noting that although Feuer's book is based on wide and diverse reading, he makes relatively few references to work in the history of science published in the last 10 years or so. Within this period historians of science have been profoundly concerned with the development of the internal structure of science and very little with scientific thought as the play ball of social forces. If it is true that sociologists commonly consider the "Protestant ethic" a determining influence in the rise of modern European science, this is not now a view shared by historians of science. Among them the "Protestant ethic" has not been much discussed for at least 20 years, although (like economic determinism) it was indeed an issue of the 1930's. Sociologists have studied science as the creation of peoples; historians have studied it as the creation of individual minds. There is no doubt which gets closer to the actual content of science, as one can see by comparing Feuer's book with, for example, C. C. Gillispie's *The Edge of Objectivity.* Of course Feuer makes no claim to be relating the history of science; but what is that history if the scientific intellectual is omitted from it? A mere chronicle, a list of discoveries and experiments. It is precisely the history of the scientific intellect that mid-20th-century historians of science are trying to construct.

They will welcome this book as an enticing study and a revealer of new horizons. There are perhaps grounds for saying that the historians have too much neglected the sociology of science. But Feuer's significance will be of a different order if his book contributes toward dispelling the prevailing doubt and despair. Are we returning to a second dark age, as Karl Popper has suggested? That might happen if belief in the steady advance of knowledge is lost and if scientific knowledge appears to humanity as a curse rather than a blessing. Scientific optimism and technological confidence have been driving features of modern Western society, qualified (and sometimes properly restrained) by those doubts and "unreal" notions that should

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Organized in the public interest and dedicated to providing objective leadership in the advancement and application of space science and technology for the United States Government not be too lightly dismissed as mere hindrances. Feuer is surely right in arguing that a twin hedonism—the love of discovery and the sweets of triumph—have urged men forward in science as in other fields. Can they do so any longer unless the former simplicity of the scientific attitude is restored? That is the problem contemplated in the last chapter of *The Scientific Intellectual* and, it must be confessed, it remains unsolved there. Feuer's heart is in the right place: he would like us to see science as the means to a better life, which indeed it can be. But he does not teach us how, in a practical world of administrators, politicians and soldiers, of international crises and ideological rivalries, the marriage of science and power play is to be dissolved.

Short Reviews

THE CONCEPT OF THE POSITRON, by Norwood Russell Hanson. Cambridge University Press ($5.95). This curious book purports to be an account of Carl D. Anderson's "discovery" of the positron. (As is so often the case in science, he was the discoverer not because he was the first to see the new thing but because he was the first to realize that it was a new thing.) In truth all but the last chapter is a stout, historically buttressed plea on behalf of the "Copenhagen interpretation" of quantum theory, whose champion was Niels Bohr, seconded by Werner Heisenberg. Another feature of the book leaves something to be desired on the side of candor: many of the chapters were previously published as journal articles, a fact that seems so completely to have slipped the author's mind that it is nowhere mentioned—neither in the preface nor in the text nor in the elaborate 42-page baggage train of footnotes.

Accepting this, the reader can settle down to an interesting—at times even better than interesting—excursion into the evolution and meaning of the modern theory of small events. At what point was Newton overthrown, or is he still with us? Does the dual wave-particle interpretation of nature—said to have been validated by the proof of Erwin Schrödinger and others of the equivalence of his wave mechanics and Heisenberg's particle-centered matrix mechanics—explain happenings without claiming to be able to predict them? If so, is this a serious flaw in a scientific theory? Must we abandon all hope of picturing the new world of physics or must it be our fervent hope that we can abandon our need for pictures? For those who can no more still this hunger than the tobacco addict can give up the weed, is there a chance that the researches of David Bohm and Jean Pierre Vigier will uncover a new promised land of determinism, or will the subtle "conspiracies" of particles and waves thwart this happy ending? Is the uncertainty principle man's fate, a built-in blemish of the world as it is, or are we simply in the toils of a self-administered kind of logical mescaline that both reveals and distorts?

These are among the questions Hanson weighs. It must be said that he lays about him mightily to prove that if the famous Dane did not give the last word on the subject, his positivist melancholy is nevertheless much to be preferred to the fatuous metaphysical optimism of others. Without swallowing all of Bohr's "philosophy of quantum mechanics," some of which is too much even for his most ardent disciples, Hanson is unmistakably a Copenhagen man. One suspects, from reading this argument, that he would be prepared to accept for physics a variant of Bertrand Russell's aphorism about mathematics, to the effect that physics is the science in which we do not know what we are talking about, nor if what we are saying is more than probable. In the more passionate periods of his advocacy Hanson is quite capable of misinterpreting or distorting the ideas of those who argue with the Copenhagen view. He can overestimate the force of "proofs" that there is no escaping certain Bohr and Heisenberg "fundamentals" (he misses, for example, telling points that Bohm and P. K. Feyerabend have made against John von Neumann's proof of the "impossibility of hidden variables"); and he can so lose the thread of his own positivist thesis that he enlists common-sense, pictorial, intuitive points in defense of the very theories that entirely repudiate the validity of such props and guides. After all, even a pointer reading is a picture, and without the beautiful photographs of particle tracks—which have to be run through our optic nerves and by heaven knows what cerebral processes "interpreted"—where would modern physics be? Biting the hand that feeds you is not only a bad thing; it is apt to be silly.

ANIMAL SPECIES AND EVOLUTION, by Ernst Mayr. Harvard University Press ($11.95). One of the most active areas of biological research is concerned with how evolution happens and what causes bring it about. Impinging as it does on a wide range of subjects, from philosophy and sociology to such intensely "practical" disciplines as medicine and agronomy, this branch of study is full of exciting possibilities. The "synthetic," or biological, theory of evolution was shaped in the late 1930's and the 1940's by the convergent efforts of zoological and botanical systematists, anatomists and ecologists, geneticists, cytologists and paleontologists. The pioneer formulations of this theory are contained in roughly half a dozen books, by as many authors, published at that time. One of these books, familiar to most if not all biologists interested in evolution, was Mayr's *Systematics and the Origin of Species* (Columbia University Press, 1942). In a way the book under review can be regarded as a second edition of the 1942 classic, but its new title is justified. The book has more than twice as many pages as the old, twice as many chapters and a bibliography of 107 instead of 16 pages, and the plan of presentation is entirely different. The new book has a style of superb craftsmanship, which can only be a product of years of thought and patient scrutiny of ideas and arguments. Yet it does not have an air of dogmatic finality; it could not, in view of the tremendous expansion of studies in the field of evolutionary biology in recent years. In Mayr's words, "the fact that the synthetic theory is now so universally accepted is not in itself proof of its correctness," and he explicitly recognizes that many problems are unsettled and controversial and that these are key problems, not fringe ones.

Mayr's general conception of evolution is, in broad outline, like that of other modern exponents of the biological theory. He recognizes that adaptation to the environment is the principal directive agency of evolutionary change and that this adaptation takes place through the action of various forms of natural selection on the genetic raw materials as they are modified by the processes of mutation and gene recombination. As the title indicates, the study of "microevolution"—the processes of race and species formation—receives most of the author's attention. The discussion is, however, set in the context of general biology: several chapters are devoted to evolutionary genetics, at least one chapter to microevolution ("transpecific evolution," as Mayr prefers to call it) and one chapter to human evolution. It may be useful to quote Mayr's definitions of those perennially controversial concepts, race (subspecies) and species: "A subspecies is an aggregate of local populations of a species, inhabiting a geographic subdivision of the range of the species and differing taxonomically from other populations of the species";

species are "groups of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups." "All the different kinds of living man on the face of the earth belong to a single species. They form a single set of intercommunicating gene pools." Finally, "Biologically, it is immaterial how many subspecies and races of man one wants to recognize. The essential point is to recognize the genetic and biological continuity of all these gene pools, localized in space and time, and to recognize the biological meaning of their adaptations and specializations."

Drugs in Psychoanalysis and Psychotherapy, by Mortimer Ostow, M.D. Basic Books, Inc. ($8.50). In recent years pharmacotherapy, the use of drugs in the treatment of mental illness, has replaced most of the physiological shock therapies. To date no adequate rationale has been offered for the value of the drugs, nor has any systematic attempt been made to study their role when they are used in combination with psychotherapy. The author of this book advocates a combined program of therapy and proposes a hypothesis to explain how and why the drugs work. Based on his experience with 13 patients in such a program, Ostow presents a theory founded on Freud's libido concept, long under attack by many behavioral scientists and psychoanalysts. He characterizes mental illnesses in broad terms as either "ego libido deficiency" or "ego libido plethora states" according to criteria and a scale he has devised. The drug is then chosen on the basis of this rating and the general attitudes and behavior of the patient. Unfortunately the lack of definition of the criteria makes the scale purely subjective and difficult to apply. Ostow's speculations on the role of psychic energy (libido) in mental illness yield the conclusion that tranquilizers tranquilize and energizers energize. The psychoanalytic arguments used to support this arresting thesis are windy and bewildering.

Two Cultures? The Significance of C. P. Snow, by F. R. Leavis, with an essay by Michael Yudkin. Pantheon Books ($1.65). The main part of this book consists of Leavis' notorious polemic against C. P. Snow, first given as the Richmond Lecture at Downing College, Cambridge. It can be argued that Snow's Rede Lecture on the two cultures was not particularly profound or original, and that the response to it in both Britain and the U.S. was quite out of proportion to its merits. But it was an intelligent essay, informed throughout with good will. It has had no good-will effect on F. R. Leavis. Instead it has provoked him to a disgracefully intemperate attack not only on the contents of Snow's lecture but on Snow personally. Leavis, a long-winded, turgid literary critic of the highest reputation in Great Britain, first denounces Snow's lecture as a "nullity" with "an utter lack of intellectual distinction and an embarrassing vulgarity of style" and then works himself into a froth denouncing the harm that this "nullity" has done. An envy-ridden, painful performance.

Bodily Changes in Pain, Hunger, Fear and Rage, by Walter B. Cannon. Harper Torchbooks ($2.45). The Wisdom of the Body, by Walter B. Cannon. W. W. Norton and Co., Inc. ($1.95). Soft-cover reprints of the best-known books by the late Walter B. Cannon, who is regarded as being one of the founders of psychosomatic medicine. The first of these volumes, considered a classic in the literature of physiology and medicine, sets forth a fascinating account of the connection between bodily changes and social stimuli in circumstances ranging from a dog's barking at a cat to the excitement of armed combat and religious hysteria. The second volume deals with the relation of the autonomic nervous system to the self-regulation of physiological processes, with much material on the condition of homeostasis, which Cannon was the first to describe and define.

The Evolution of the Human Brain, by Gerhardt von Bonin. The University of Chicago Press ($5). Von Bonin's book treats of the evolution of the human brain from the Australopithecines to modern man. One of its main points is that exaggerated claims have been made about what can be learned from casts of fossil skulls. Nothing, of course, is known about the mental life of earliest man, but theories about mental capacity have been put forward on the basis of data on the size and complexity of the frontal lobes of fossil man. Von Bonin carefully examines these data and concludes that they are too fragmentary to justify any dependable inferences. Moreover, as he points out, even if our information on this point were much fuller, we would scarcely be in a position to draw justifiable inferences about early mental capacity, since brain size is a poor indicator of intelligence. Anatole France's brain, for example, weighed 1,100 grams, Byron's and Samuel Johnson's 2,000 grams and sundry nitwits have had brains either heavier or lighter than these.

THE ORGANIZATION OF CELLULAR ACTIVITY, by Ch. M. A. Kuyper. American Elsevier Publishing Co., Inc. ($7). A monograph by a Dutch biochemist on the chemical and morphological constitution of the cell and specifically on the interrelation of composition and structure, of function and form. The main object of this book, to show that the brilliant successes of biochemistry have tended to obscure the need for morphological studies, has been stressed increasingly in the past few years by other investigators. Many good photographs and other illustrations.

ALIENS AND DISSENTERS, by William Preston, Jr. Harvard University Press ($6.75). An account of the Federal suppression of radicals and dissenters from 1903 to 1933. Preston, a historian at Denison University in Ohio, reminds us of our heritage of intolerance, still very actively felt today, and also—more encouragingly—of the many Americans who have resisted the dominant trend and have kept alive the freedoms proclaimed by the Constitution.

THE HARPER ENCYCLOPEDIA OF SCIENCE, edited by James R. Newman. Harper & Row, Publishers ($29.95). An encyclopedia of the physical sciences, mathematics, logic and the history and philosophy of science, and including some 1,500 biographies of scientists. The treatment is for the general reader and for the specialist reading in fields other than his own. Twenty-five hundred illustrations, more than 250 in color.

HISTORY OF HINDU MATHEMATICS, by Bibhutibhusan Datta and Avadhesh Narayan Singh. Asia Publishing House ($9). A source book, first published in 1935 and 1938 in two volumes, treating of the growth and development of mathematics in India from the earliest known times to the 17th century. Among the topics considered by means of translations of relevant Sanskrit texts and notes are the emergence of numeral notation, elementary arithmetic operations and the history of algebra.

THE MEASURE OF THE MOON, by Ralph Baldwin. The University of Chicago Press ($13.50). A detailed history of the moon from the time it reached its present size, about 4.5 billion years ago, until now. The author's theories and conclusions are based on a large mass of data accumulated by others as well as on his own research. Many illustrations.

ENVIRONMENTAL RADIOACTIVITY, by Merril Eisenbud. McGraw-Hill Book Co., Inc. ($12.50). This book consolidates information developed over the past 20 years. It considers the effects of radiation on man; the mechanisms by which radioactive substances are transported in air, water and the food chain from soil to man; sources of environmental radioactivity and methods of environmental surveillance.

THE MOSQUITOES OF THE SOUTH PACIFIC, by John N. Belkin. University of California Press ($20). The first volume of this impressive work describes all the species of mosquitoes of the South Pacific and brings together all the readily available information on bionomics, disease relations and distribution. The second volume consists of maps, tables and hundreds of drawings by Charles L. Hogue.

KIRK-OTHMER ENCYCLOPEDIA OF CHEMICAL TECHNOLOGY: VOLUME I, edited by Anthony Standen and others. Interscience Publishers. John Wiley & Sons, Inc. ($45). A revised and expanded second edition of a comprehensive summary of industrial knowledge of materials, methods, processes and equipment. Two volumes are to be issued each year; the complete work is to have 18 volumes.

Notes

ELECTRON SCATTERING AND NUCLEAR AND NUCLEON STRUCTURE, by Robert Hofstadter. W. A. Benjamin, Inc. ($10). For this volume the editor has selected some 80 papers on nuclear and nucleon structure, representing important investigations in this field beginning in 1928 (viz., Dirac's celebrated paper on the quantum theory of the electron), and including a number of his own summary articles.

RADIO WAVE PROPAGATION AND THE IONOSPHERE, by Ya. L. Al'pert. Consultants Bureau ($22.50). A translation from the Russian of a monograph dealing with the basic phenomenology of the propagation of radio waves of different wavelengths, based on the author's research and that of others.

APPLIED ASTRONAUTICS: AN INTRODUCTION TO SPACE FLIGHT, by Frederick I. Ordway III and others. Prentice-Hall, Inc. ($16). A survey of the techniques, equipment and operations involved in space flight, written primarily at the descriptive level. Illustrations.

DICTIONARY OF ARCHITECTURE, by Henry H. Saylor. Science Editions ($1.45). A paperback that, considering its brevity, assembles a remarkable amount of useful information. Ideal for anyone who needs a small lexicon in this field.

THE ROLE OF SCIENTIFIC SOCIETIES IN THE 17TH CENTURY, by Martha Ornstein. Archon Books, The Shoe String Press, Inc. ($8.50). A most welcome reissue of a respected study first privately printed as a doctoral dissertation in 1913, then copyrighted and published in 1928.

VOYAGES, by Richard Hakluyt. Everyman's Library (eight volumes, $1.95 each). A reissue of Hakluyt's famous *Principal Navigations, Voyages and Discoveries of the English Nation,* a chronicle of superb scholarship and broad interest that is still a basic work for students of geography and the history of exploration.

ANIMALS OF EAST AFRICA, by C. A. Spinage. Houghton Mifflin Co. ($7.50). A splendid collection of wildlife photographs taken in Kenya, Uganda and Tanganyika. The accompanying text is relaxed and chatty, filled with interesting observations and obscure facts.

PHILOSOPHY OF MATHEMATICS AND NATURAL SCIENCE, by Hermann Weyl. Atheneum Publishers ($1.65). A paperbacked reissue of a well-known book on the relation between science and philosophy by one of the most penetrating mathematicians of this century.

CLOUDS, RAIN AND RAINMAKING, by B. J. Mason. Cambridge University Press ($4.50). A clear and concise account of researches on the formation of clouds and on the genesis of rain, snow, hail and lightning. Good photographs.

THE NATURAL PHILOSOPHY OF TIME, by G. J. Whitrow. Harper Torchbooks ($1.95). A soft-cover reprint of a knowledgeable examination of scientific and philosophical speculations on time.

CRYSTAL DATA, edited by J. D. H. Donnay and others. American Crystallographic Association ($20). The second enlarged and revised edition of a standard work that presents determinative tables of the properties of crystals.

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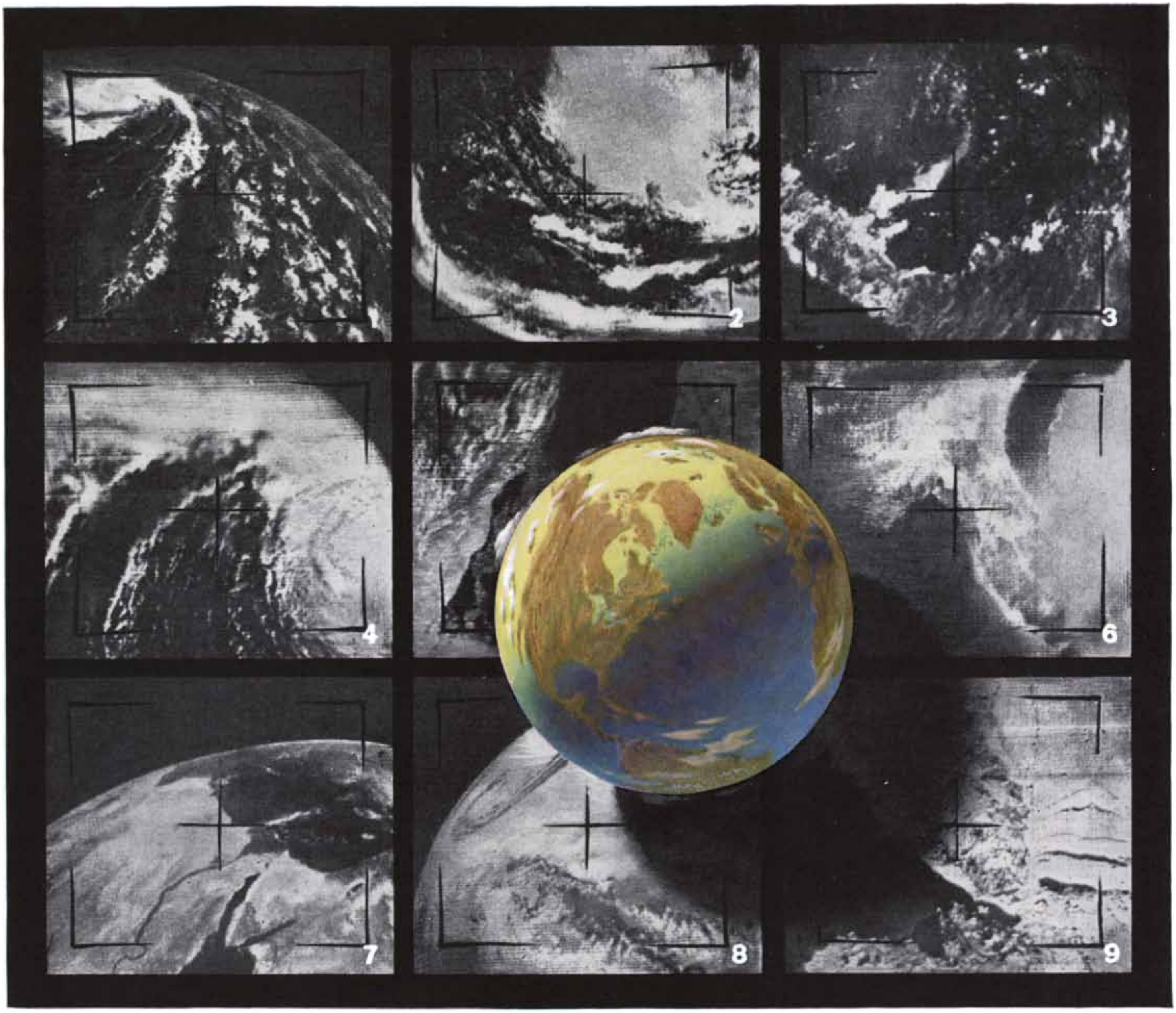

1. *Hurricane Anna over the Caribbean.*
2. *Weather in vicinity of Great Lakes.*
3. *Showers over Florida and Gulf of Mexico.*
4. *Typhoon in Pacific Ocean near New Zealand.*
5. *Ice in the St. Lawrence River.*
6. *Florida, Lake Okeechobee reflecting the sun.*
7. *Red Sea, Nile River and Dead Sea.*
8. *Large vortex near New Zealand.*
9. *Ice floes in the Gulf of St. Lawrence.*

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