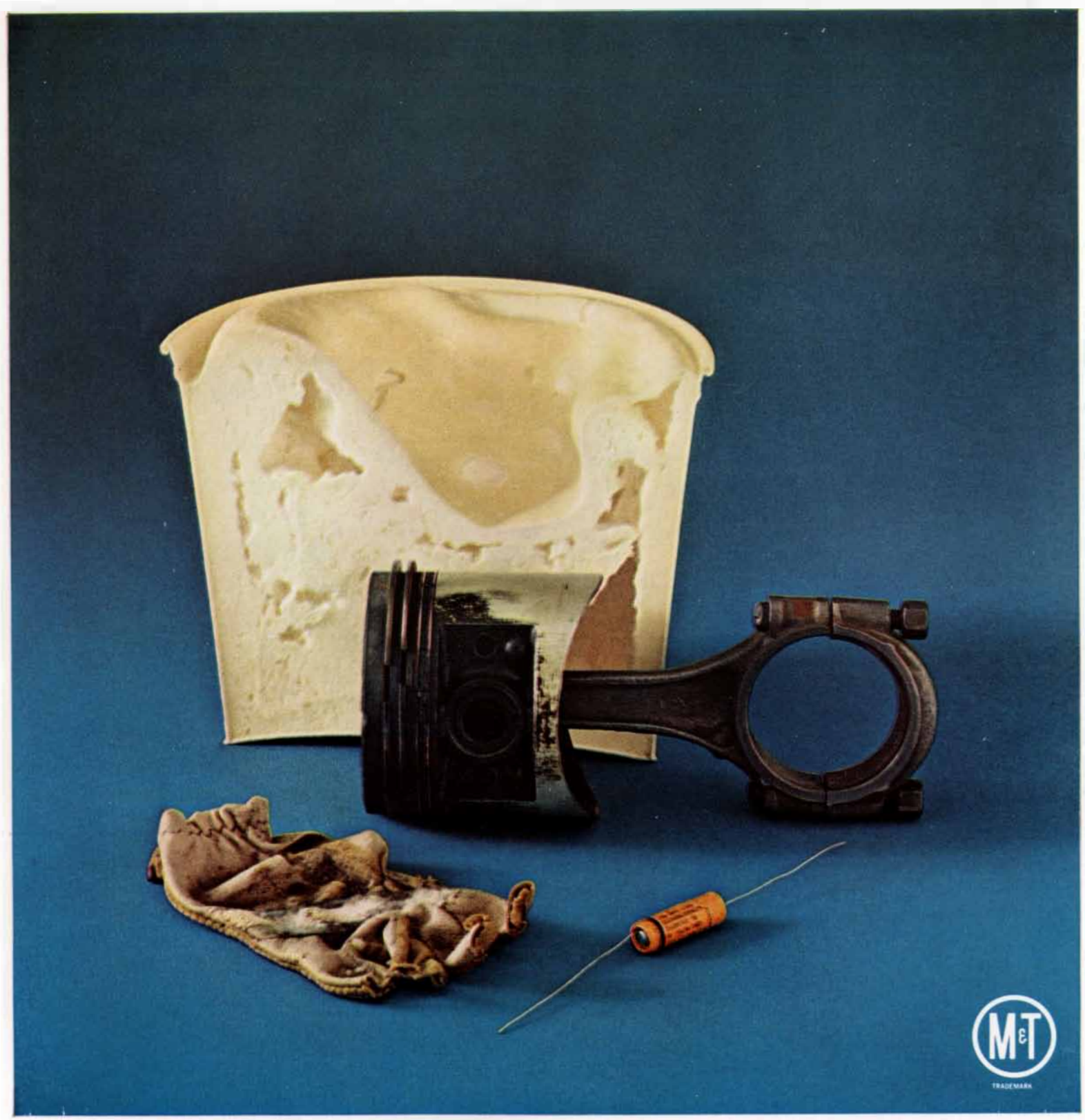
SCIENTIFIC AMERICAN

MACEDONIAN MOSAIC

SIXTY CENTS

December 1966



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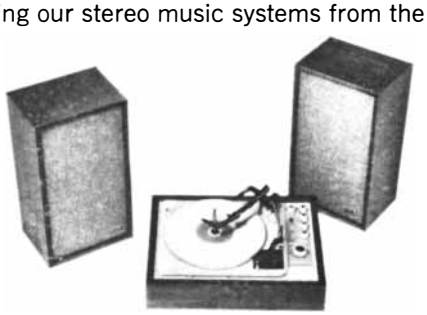
For those with an active interest in music and its reproduction in the home, one of the most persistent questions about sound is whether it can be measured accurately with present techniques. One reason for the question's persistence is the often audible difference between two pieces of equipment with apparently similar tested performance. Another is the lack of uniformity in test procedures and in the statements of specifications in advertising and manufacturers' literature for home music equipment.

At KLH, we believe that the subjective impact of sound can be measured, and that the measurements which are meaningful in determining the quality of equipment are carefully directed, basically simple ones that fall within generally accepted concepts of good design. Accepting the idea that sound reproduction can come no closer to reality than photography, we are not concerned with some of the esoteric techniques often suggested for transporting the concert hall into a home. But, again with photography as a reference, we are very much concerned both with techniques for making sound reproduction convincing on its own terms and with basic improvements in the convenience and usefulness of equipment.

In accepting and measuring reproduced sound on its own terms, we are especially concerned with gauging the final performance of equipment in a living room. It is here, we think, that some accepted techniques of measurement fall short—and their inadequacy accounts for the definite differences between apparently similar products.

We make one departure from usual test procedure in our design of loudspeakers. We begin here by designing a speaker that we know, from our direct experience in manufacturing every critical part of our own speakers, will meet certain basic requirements for good performance. (In designing a high-frequency speaker, for instance, we begin with a diaphragm of properly small size and proper cone materials for the dispersion of high-frequency energy over a wide listening area.) And after checking with conventional techniques to make sure that the point-to-point frequency response of the speaker itself is within correct limits, we go on to test the way in which the speaker's basic performance is integrated with customary acoustic conditions in a living room. Our technique is simply to use filtered segments of random noise, roughly half a musical octave wide in frequency range, to gauge and adjust the octave-to-octave musical balance of the speaker as heard over the usual listening area in a room. This balance, we feel, most accurately predicts what a speaker will sound like in a home. And the filtered random-noise technique is both simple and highly effective for checking this balance at various points in a room.

We also do things somewhat differently from most home-entertainment manufacturers by designing and testing our stereo music systems from the outset as integrated systems rather than as the sum of their parts. This basic practice, taken for granted in the design of an automobile or a communications system, is still rare in our own industry, and is as vital as it is simple in offering the buyer the performance and value he has a right to expect.



The new Model Twenty-Four. Suggested Price $300.

KLH*

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In the final manufacture of a product, we are concerned with setting up test procedures of the simplest kind and widest application to prevent drift away from basic design parameters. We also concentrate on assembly techniques that are both repeatable and reasonable for people to perform—to prevent the kind of fatigue and boredom that might produce an ultimate collection of hard-to-locate flaws. Using these techniques to manufacture a wider range of our own parts and assemblies than any other manufacturer, we have been able to achieve a high degree of uniformity in our products. We are able to guarantee, for instance, that any two loudspeakers of the same model will match within 1-½ db over the frequency range.

In advertising our products, we publish only specifications that we feel have straightforward and meaningful references, such as amplifier power. We do not provide specifications, such as the frequency response of a loudspeaker, that we feel will make the buyer confident of a reference that does not exist. When independent test reports are made of our products under stated conditions, we reprint and distribute them with our product literature, but we do not try to over-describe with adjectives or figures.

If you would like more information on our products and standards of quality, please write to KLH, 30 Cross Street, Cambridge, Mass. 02139.

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THE COVER

The photograph on the cover shows the head of a lion rendered in a mosaic of pebbles. This work of art decorated the floor of a house in Pella, the capital of Macedonia during the years when it rose to be the leading power of the Greek world (see "Pella: Capital of Ancient Macedonia," page 98). The mosaic, which was probably made shortly after 300 B.C., is composed of pebbles of contrasting colors; black, gray and white ones predominate. Where the artist needed fine detail, as in the lion's mane, strips of lead were inserted among the pebbles. The mosaic from which this detail is taken is reproduced on page 98. It commemorates an occasion in the life of Alexander the Great when he nearly lost his life during a lion hunt.

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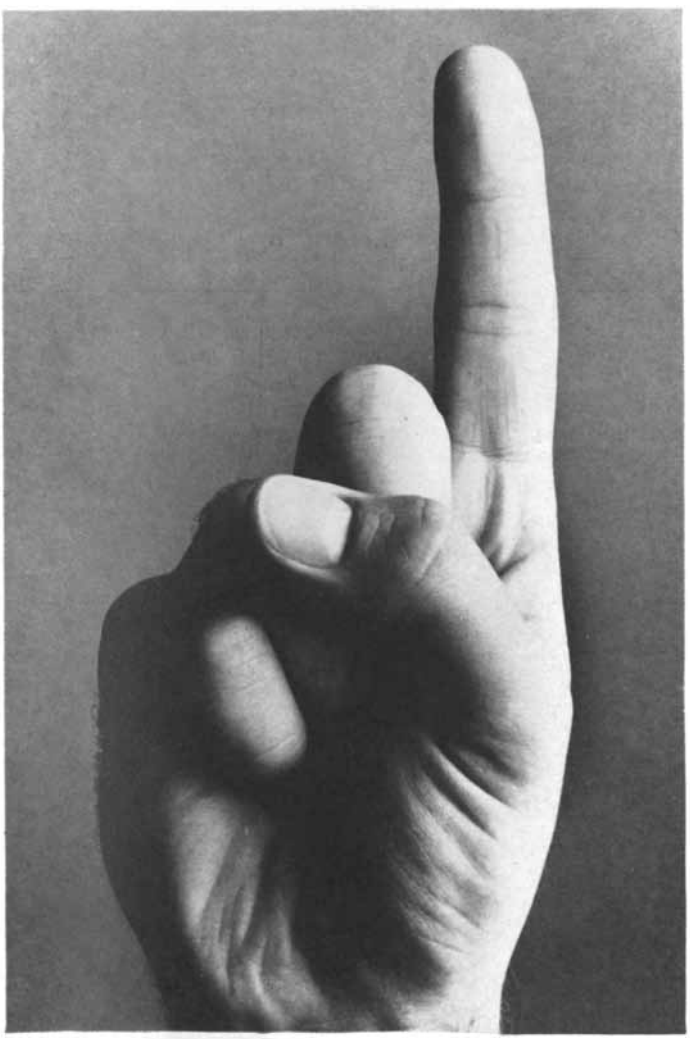

Hertz

LETTERS

Sirs:

Dr. Spain is to be congratulated for having written, and you for having published, his article on atherosclerosis ["Atherosclerosis," by David M. Spain; SCIENTIFIC AMERICAN, August]. In writing several hundred words on the possible causes of this disease he has managed to avoid all mention of the hypothesis that a high consumption of sugar may well be involved. This in an article published in August, 1966, is as distinguished as an article on gravitation that excludes the theory of relativity.

The evidence linking sugar consumption with the disease not only fulfills the criteria mentioned by Dr. Spain at the end of his article. It is also supported by the finding that *individuals* who suffer heart attacks eat more sugar than those who do not, whereas it has been shown that there is no difference in their fat consumption. Moreover, there are *no* exceptions to the association of the prevalence of the disease with sugar consumption in populations, whereas there are exceptions to the association with fat consumption....

JOHN YUDKIN

Queen Elizabeth College
University of London
London

Sirs:

Professor Yudkin's objection to my failure to mention the high-sugar-consumption hypothesis as an important factor in the causation of atherosclerosis is somewhat puzzling. The primary purpose of this article was to present an overall view of the pathogenesis and meaning of atherosclerosis. The inclusion of a dietary factor, in particular high saturated fats and cholesterol, was determined solely by the fact that at this moment there is a large-scale study under way in this country to test the validity of this hypothesis. Many other dietary hypotheses, in addition to the high-sugar-consumption one, could also have been included, but space limitations and the purpose of the report would not have been met.

Since Professor Yudkin raises the question, however, certain comments are in order. He categorically states that the high-sugar-consumption hypothesis meets the four criteria set forth in the article. Personally I would not accept the fact that the high-sugar-consumption hypothesis fulfills any of the criteria, but what is most significant is that I am totally unaware of any valid, careful, controlled prospective study that relates manipulation of sugar consumption in the diet to a decreased incidence of clinical evidence of coronary atherosclerosis. If Professor Yudkin has such evidence, it behooves him to inform the world at large and the medical community in particular so that a practical means of primary prevention of this disease can be instituted without delay. It is true that there are various types of hyperlipemia and, according to the work of Lena A. Lewis, Irvine H. Page and Helen B. Brown at the Cleveland Clinic, not all of these will respond by simple alterations of dietary fat. Some of these individuals with hyperglyceridemia may conceivably require carbohydrate alteration, but these do not constitute a major group. There is other indirect evidence against high sugar consumption's being an important causative factor in the development of atherosclerosis. This consists of the fact that obesity per se (generally due to overconsumption of carbohydrates) is only indirectly related to the risk of developing coronary atherosclerosis, as determined by the Framingham, Chicago and Albany studies and our own studies. Obesity increases the risk of developing coronary atherosclerosis only indirectly through its influence on hypertension and diabetes....

DAVID M. SPAIN, M.D.

Brookdale Hospital Center
Brooklyn, N.Y.

Sirs:

As a person with a background both in the management use and the teaching of information systems, I found your September issue on information extremely interesting. I especially noted that several authors made reference to the same timely information topic: invasion of privacy.

Today there are plans being discussed before a House subcommittee in Washington for the creation of a computerized information center. The proposed National Data Center would pool personal statistics on millions of Americans and would be sponsored by 20 departments and agencies of the Government. This proposed "cradle to the grave" pool of vital statistics is the greatest actual threat to individual privacy yet conceived by the bureaucratic minds in Washington.

Any centralized information center created must have adequate controls associated with the system to assure that no information would be available to any person—including the President—without the written authorization of the person whom the information concerns. Also, any authorization given must be very specific regarding the exact information accessible to the inquirer.

It is certainly not too early to recommend a "bill of rights" regarding accessibility into centralized files of information created on individual citizens. Let us hope that it is not too late to support the passage of appropriate legislation to assure private citizens against invasion of privacy by bureaucratic personnel in private or governmental organizations.

Tomorrow may well be 1984. Therefore we must take appropriate action today to establish safeguards sufficient to assure against the increasing opportunities for the invasion of privacy resulting from advances in computer technology!

GROVER L. PORTER

Professor
Department of Accounting
Louisiana State University
in New Orleans
New Orleans, La.

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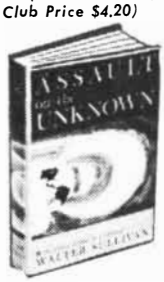

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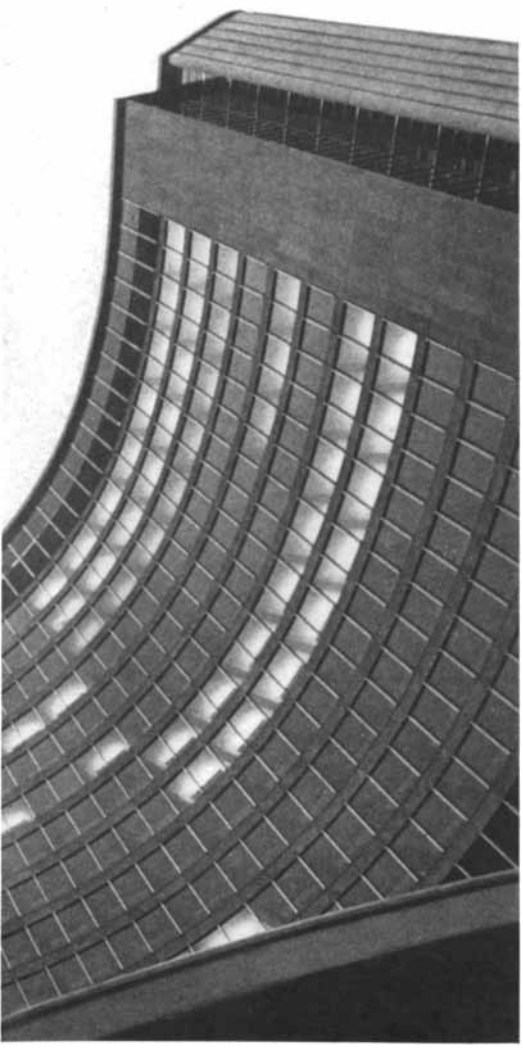
Suddenly concrete soars.



More concrete is used than all other construction materials combined. Possibly because of its relative cheapness, architects in the past regarded it as a work-horse material. Now, suddenly, it's become a wonder material and architects vie with one another in using it to create imaginative new kinds of space and form.

You can't beat concrete for structures like foundations, dams, bridges and highways.

It's relatively cheap, easy-to-use, strong.

Concrete is a combination of cement, water and aggregates (crushed rock, gravel, sand). Cement and water react chemically to bind the aggregates, which give concrete its structural strength. Often, additives are used to control closely the quality of the concrete. Martin Marietta produces cement, aggregates and concrete additives.

Although concrete was used in the building of ancient Rome, it continued over the centuries to lead a quiet, sedate life as an architectural material (doing the heavy, unglamorous jobs) until after World War II.

With the rebuilding of Europe, and a construction boom going on in America, concrete was "discovered" by a group of restless architects yearning to do new things. Le Corbusier, Nervi, Ponti, Saarinen, among others.

But concrete didn't become a Cinderella material overnight. Architects complained it was heavy and difficult to use for high-rise construction.

The manufacturers of cement, working with trade associations, took the hint.

Within a few years, great strides were made in finding new ways to reinforce concrete, precast it, prestress it, pipe it, pour it, tamp it. Additives were formulated to control "set."

The imaginative use of concrete could well be the esthetic salvation of cities. It frees the architect from the tyranny of the straight line and the right angle, while giving him an infinite variety of tone and texture.

It allows him to create buildings of monumental strength and grandeur, as in the twin towers of the Toronto City Hall, pictured here, certainly one of the important buildings in North America.

Or it allows him to create "light" structures that seem to float on air, as in Saarinen's terminal for TWA at Kennedy airport in New York.

It even allows him to create huge numbers of low-cost houses, using modular assembly of precast slabs, as in Puerto Rico.

In short, concrete allows the architect's imagination to soar, yet costs remain comfortably earthbound.

The several divisions of Martin Marietta produce a broadly diversified range of products, including missile systems, space launchers, nuclear power systems, spacecraft, electronic systems, chemicals and construction materials. Martin Marietta Corporation, 277 Park Avenue, New York, N.Y.

MARTIN MARIETTA

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1916: "X-ray investigation of crystals is young, but there is a dearth of workers and the war has cruelly put an end to the life of some investigators and has interrupted the work of others. Mr. H. G. J. Moseley has been killed at the Dardanelles, Mr. S. E. Pierce in France, and there may be other victims. M. de Broglie, who has tried both the Laue method and the Bragg method and has modified them, attended one of Prof. W. H. Bragg's recent lectures in the uniform of a French medical officer. Mr. W. L. Bragg has gone to the front. It was moving to hear Prof. Bragg mention this in a lecture before the Institute of Metals, lest credit be given to himself that was due to his son. Prof. Bragg has already lost one son in the war."

"For the present, and until the completion of the 100-inch reflector now being built for the Mount Wilson observatory, the telescope recently installed in the Dominion Observatory at Little Saanich Mountain, Vancouver Island, has the fleeting honor of being the largest in the world. Like all the largest telescopes of recent years, this one is of the reflector type. The enormous mirror, which in the reflecting telescope takes the place of the lens in concentrating the rays of light, weighs 2½ tons, measures 73 inches from edge to edge, is 12 inches thick at its outer rim and is pierced by a hole 10½ inches in diameter. The silvered upper surface acts as a parabolic mirror to bring the reflected light to a focus 30 feet above the mirror. Made in Belgium, it was shipped just two days before the declaration of war."

"From a reliable source it is learned that a fleet of 50 super-Zeppelins is now in course of construction in Germany for the express purpose of destroying London in a daring air raid. Evidently, if this report is authentic, the Germans have not yet come to realize that such a plan is doomed to failure at its inception. The fateful reception of the Zeppelins in recent raids over England has failed to convince the Teutons that an aerial raid on London is daily becoming more difficult and the chances of success more remote. It is obviously their belief that failure has hitherto been attributable to lack of numbers and that a fleet of sufficient magnitude can accomplish this one big aim of Count Zeppelin and the German people during the present war."

"The business of producing alloy metals, though a virgin field, has sprung into especial prominence because of the necessity of husbanding the supply of iron. The steady advance in the price of ore gives the strongest evidence of the increasing scarcity of this metal; and the greatest economy in prospect is the use of the rare mineral alloys which produce such a radical increase in strength coupled with reduction in weight of material consumed. The use of tungsten and vanadium in this connection is more or less of an old story; and the producers of molybdenum now claim for it a future far out-reaching that of either of its competitors."

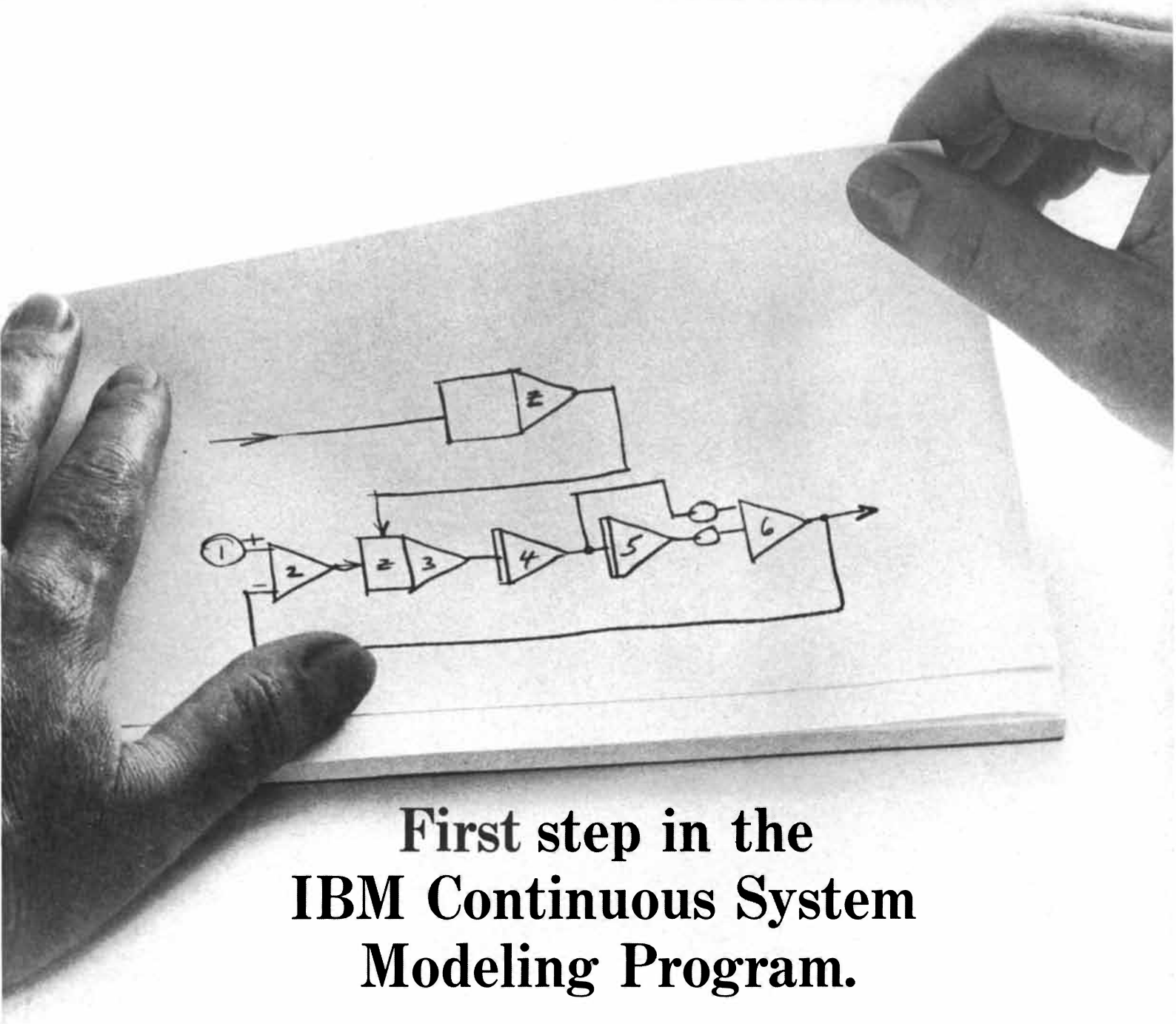
"It has taken this war to bring home to Englishmen the realization of the need for a tunnel under the English Channel —something which the French have long understood. It was announced in Paris last August that France had taken all the necessary steps to enter into negotiations with England for the joint construction of this tunnel, and Premier Asquith, in receiving a deputation favoring the tunnel, has said that the matter would be given full consideration either by the War Committee or by the Committee on Interior Defense. The tunnel will be about 22 miles in length and will cost $80,000,000 to build."

DECEMBER, 1866: "This journal enters upon its 22nd year on the first of January next, at which time the publishers have determined to considerably enlarge and otherwise improve it. SCIENTIFIC AMERICAN is the oldest and, by general consent, the most popular journal of science ever published; in point of circulation it is safe to say that it exceeds the aggregate issues of all similar papers in this country and Great Britain combined. The first number of SCIENTIFIC AMERICAN, a folio of four pages, appeared in the summer of 1845. Soon after its appearance the form was changed to a quarto of eight pages. In 1859, encouraged by the great success which met their efforts, the publishers determined to double its size to 16 pages. But this enlargement has finally proved inadequate to the demands upon its columns, and in spite of the greatly enhanced cost of paper and all other materials, the publishers have decided that their journal must be enlarged, without any increase in the terms of subscription, confident that their generous patrons will appreciate the benefits of the proposed change and lend their influence to increase its subscription list. It has been the constant aim of the editors of this journal, who are aided by some of the best known scientific writers in the country, to discuss all subjects relating to the progress of art, science, invention and discovery in a plain, practical and attractive manner."

"The Agricultural Committee of Sologne, France, has awarded the gold medal offered some time since to the inventor of a process which should enable French wines to be conveyed by land and sea, and preserved in any climate, without alteration in flavor. M. Pasteur, who receives the award, has succeeded in establishing the fact that the heating of ordinary wine to the extent of 50 degrees centigrade is sufficient to kill all microscopic vegetation, or the ferments by which it is produced, without affecting color or flavor, and to insure the preservation of the wine in closed vessels for an indefinite period. The various morbid changes in wines are found to be due to various stages or phases of microscopic vegetation, which M. Pasteur has accurately described."

"An English statistician calculates that the annual earnings of the working classes in Great Britain and Ireland amount to £418,000,000, of which the laborers of England receive nearly three-fourths, those of Scotland one-tenth and those of Ireland two-thirteenths. Taking the average weekly wages, and assuming that there are two earners in each laborer's family, the average family income may be estimated in our money at $8 per week in England, $7.25 in Scotland and $7.75 in Ireland."

"Surveys are going forward in the bed of the English channel for the projected tunnel from Dover to Calais. The engineers have a steam tug especially fitted out with scientific apparatus and employed in this survey."



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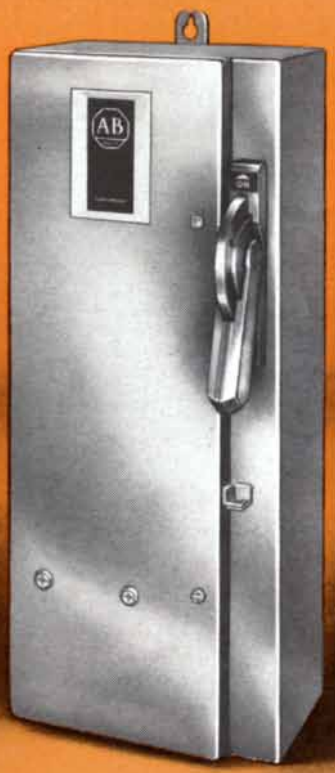
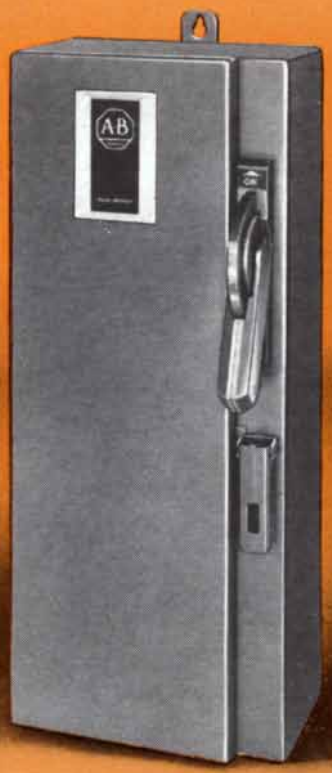
IBM

YOU can't afford not to know about these NEW A-B Combination Starters!

Bulletin 712 Form 2F with fused disconnect switch in NEMA Type 1 general purpose enclosure



Same starter, in NEMA Type 4 watertight and weatherproof stainless steel enclosure



Same starter, in NEMA Type 12 dust-tight and industrial use enclosure; also suitable for NEMA Type 5 requirements

■ This new design of the Allen-Bradley Bulletin 712 combination starters consists of a three pole single break disconnect switch, with or without line fuse clips, and one of the famous Bulletin 709 trouble free across-the-line starters, assembled in an attractive enclosure which harmonizes with modern machine designs. The Bulletin 713 combination starter is equipped with a circuit breaker, as the disconnect.

The basic starter provides the same rugged and trouble free construction for which the Bulletin 709 starters have justly earned their world-wide reputation. In the new disconnect switch, Allen-Bradley design engineers have matched the quality of the starter—it also is of a very rugged construction. All ratings easily handle the higher current interrupting requirements of the automotive industry.

The Bulletin 712 and Bulletin 713 disconnect handle is at all times solidly connected to the line switch—whether the enclosure door is open or closed. It can be locked in the "OFF" position with up to three padlocks, and where necessary to prevent shutdown of a continuous process, the handle can also be padlocked in the "ON" position. Likewise, the cabinet door can be padlocked.

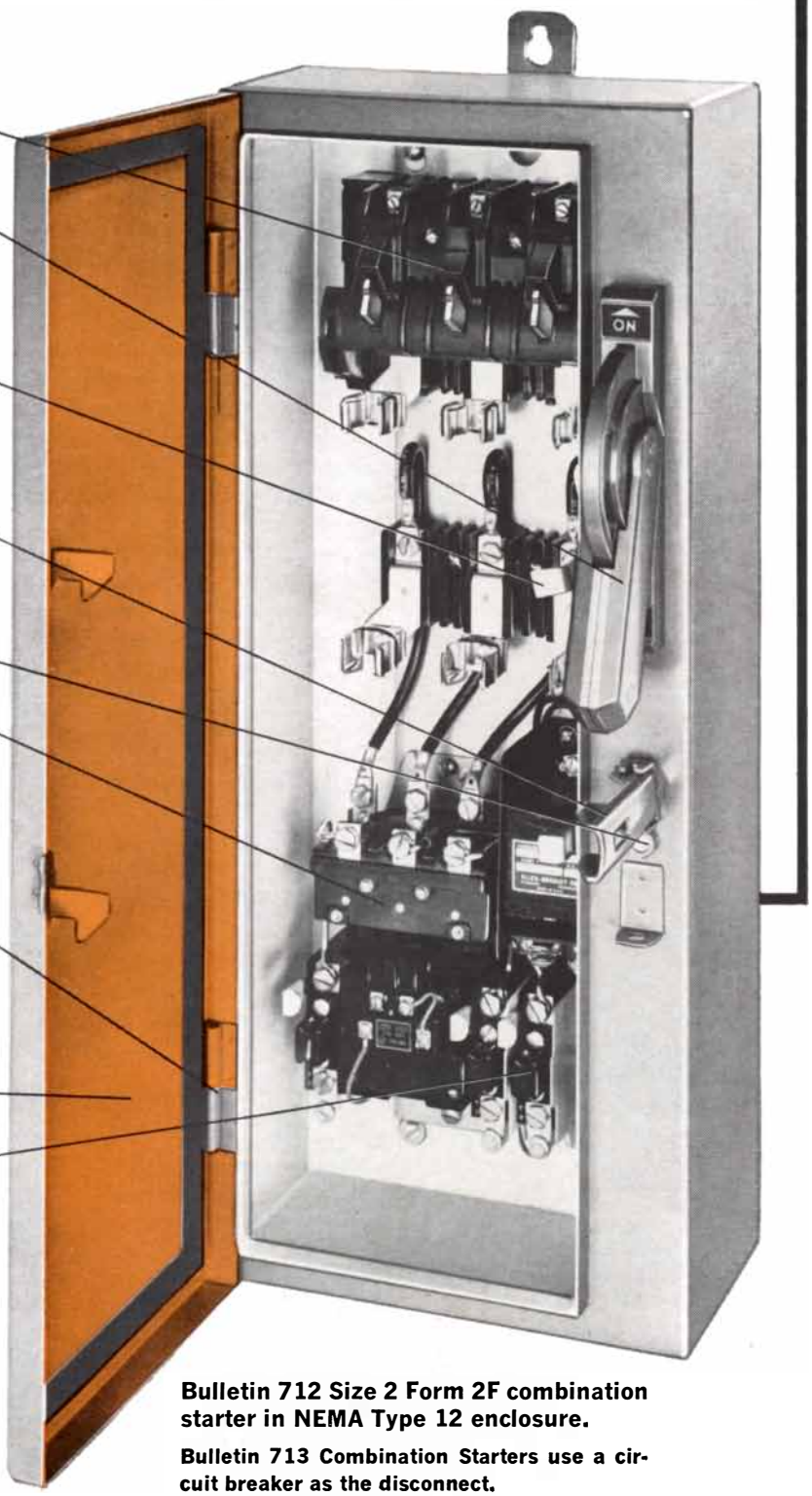
In this modernized Bulletin 712 design, only the disconnect switch, with its handle, is really new. It has been built to Allen-Bradley's traditional high standards of quality. The design is simple and rugged, with the switch blades clearly visible in the "OFF" position. The switch operation is positive, having a quick-make and quick-break snap action. Direct mechanical pressure forces the blades open—making them clearly visible. These blades must be in the "OFF" position before the cover interlock is released to permit the cabinet door to be opened. Bulletin 713 starters use a circuit breaker as the disconnect. These disconnects cannot be operated to the "ON" position while the cabinet door is open—except in the event that the "defeater" is purposely operated. Incidentally, the inside of the cover is finished in orange—a bright color which will attract attention to the open enclosure.

Since a more complete assembly of features—important to trouble free operation of the starter—cannot be found, have your local Allen-Bradley appointed distributor acquaint you with our new line of Bulletin 712 and Bulletin 713 combination starters. He has these starters in stock and can give you prompt service.

Allen-Bradley Co., 1204 S. Third Street, Milwaukee, Wisconsin 53204. Export Office: 630 Third Avenue, New York, N. Y., U.S.A. 10017.

Allen-Bradley Bulletin 712 and 713 starters in NEMA Type 12 enclosures satisfy all of the automotive industry's safety and switching requirements

- **Heavy duty disconnect switch or circuit breaker** will easily handle automotive I^2T switching requirements.
- **Operating handle** is at all times tied to the disconnect device. Can be locked in "OFF" position with up to three padlocks; also includes provision for locking in "ON" position, when required.
- **When the door is open,** the disconnect interlock mechanism must be released by means of a hidden "defeater" before the operating handle can be thrown to the "ON" position.
- **Door safety latch** must be actuated to open the door—even when operating lever is in the "OFF" position—where it can be padlocked, as a "safety" measure.
- **Defeater** requires a screwdriver for release—a coin will not do.
- **Bulletin 709 starter** features one moving part solenoid design, with lifetime guaranteed coil. Its simple ruggedness assures trouble free service. Contacts are of weld-resistant cadmium oxide silver. Overload relays are both trip-free and tamperproof.
- **"Lift-off" cabinet door** is an installation convenience. It also permits substitution of cover with "START-STOP" push buttons, or a selector switch, and with or without pilot light.
- **Cabinet door interior** finished in orange as a "flag" to warn that the door is open.
- **Two trip-free and tamperproof overload relays** are standard; three can be furnished.
- **Allen-Bradley Bulletin 712 and 713 line of Combination Starters** are available for maximum motor ratings of 100 hp, 240 v; 200 hp, 480-600 v.
- Very candidly, in your own interest, you ought to know more about this new line of Allen-Bradley combination starters, which is modern right up to this minute! Please write for Publication 6114.



Bulletin 712 Size 2 Form 2F combination starter in NEMA Type 12 enclosure.

Bulletin 713 Combination Starters use a circuit breaker as the disconnect.

A-B QUALITY

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556-2D

THE AUTHORS

T. K. FOWLER and RICHARD F. POST ("Progress toward Fusion Power") work on different aspects of the problem of controlling thermonuclear reactions at laboratories in California. Fowler is in charge of theoretical work on plasma turbulence at the General Atomics Division of the General Dynamics Corporation in San Diego. He studied electrical engineering at Vanderbilt University and obtained a Ph.D. in physics from the University of Wisconsin in 1957. He worked at the Oak Ridge National Laboratory from 1957 until 1965, when he joined General Atomic. Post is group leader of the Magnetic Mirror Program in the controlled thermonuclear project at the Lawrence Radiation Laboratory of the University of California at Livermore. He is also professor-in-residence at the Davis-Livermore campus of the University of California. A graduate of Pomona College, he received a Ph.D. in physics from Stanford University in 1950.

EDOUARD KELLENBERGER ("The Genetic Control of the Shape of a Virus") is a professor at the University of Geneva, where he directs both the Biophysical Laboratory of the Institute for Experimental Physics and the Center for Electron Microscopy. A native of Berne, Kellenberger interrupted his studies at polytechnical school in Zurich in 1939 to serve in the Swiss army during World War II. After the war he became a student at the University of Geneva, where he did research on electron optics and was instrumental in the formation of the Biophysics Laboratory and the Institute for Molecular Biology. He received his Ph.D. in biophysics from Geneva in 1953. Kellenberger is currently on leave and is serving as Invited Distinguished Regents' Professor at Kansas State University.

FRED HOYLE and GEOFFREY BURBIDGE ("The Problem of the Quasi-stellar Objects") have worked together on various problems in astrophysics. Hoyle is Plumian Professor of Astronomy and Experimental Philosophy at St. John's College in the University of Cambridge. He is also a member of the staff of the Mount Wilson and Palomar Observatories. He is known not only as an expositor of science but also as a novelist and playwright. Burbidge is professor of physics at the University of California at San Diego. He has also worked at the Harvard College Observatory, the Cavendish Laboratory at Cambridge, the Mount Wilson and Palomar Observatories and the University of Chicago. Both Hoyle and Burbidge are frequent contributors to SCIENTIFIC AMERICAN. They were coauthors of the article entitled "Anti-Matter," which appeared in the April 1958 issue.

LEO L. BERANEK ("Noise") is president of Bolt, Beranek and Newman, Inc., a research and consulting firm in Cambridge, Mass., and lecturer at the Massachusetts Institute of Technology. He did his undergraduate work at Cornell College in Iowa and received a D.Sc. from Harvard University in 1940. During World War II he was director of the Electro-Acoustics and Systems Research Laboratories at Harvard. He was associate professor of communications engineering at M.I.T. from 1947 to 1958. Beranek has lectured on acoustics at the Physical Society of London, the Zurich Federal Institute of Technology, the Swiss Society of Architects and Engineers, the technical University of Prague, the Polish Academy of Sciences, the Acoustical Society of Moscow, the University of Moscow and the Engineering Society of Finland. He was visiting professor at the University of Buenos Aires in 1949. In 1958 he presented the 45th Thomas Hawksley Lecture at the Institute of Mechanical Engineers in London and repeated this lecture at Oxford and Bristol universities. Beranek is the author of four books: *Acoustics, Acoustic Measurements, Noise Reduction* and *Music, Acoustics and Architecture.*

T. G. R. BOWER ("The Visual World of Infants") does research on problems of ontogenetic and phylogenetic development, perception and animal behavior in the department of psychology at Harvard University. Bower was born in Scotland in 1941 and was graduated from the University of Edinburgh with an M.A., summa cum laude, in 1963. He received a Ph.D. from Cornell University in 1965. His training at Edinburgh, he writes, "strongly inclined me towards the empiricism of the philosopher David Hume. The experiments reported in this article were undertaken in the belief that they would prove empiricism and disprove nativism—but the results were the reverse."

CH. J. MAKARONAS ("Pella: Capital of Ancient Macedonia") has directed the excavations at Pella since 1957. Born in Athens in 1905, he studied classical philology and archaeology at the University of Athens and at the University of Thessalonike. He has held a number of government posts, including that of curator at the National Museum and at the Acropolis in Athens, director of the archaeological museum of Thessalonike, ephor of antiquities of central Macedonia and chief of the department of archaeology. His present title is Honorary Ephor of Antiquities.

ROBERT R. SOKAL ("Numerical Taxonomy") is professor of statistical biology at the University of Kansas. Sokal was born in Vienna in 1926 but moved with his family to China at the beginning of World War II and received his high school and undergraduate education in Shanghai, where he obtained a B.S. in biology from St. John's University. He came to the U.S. in 1947 and acquired a Ph.D. in zoology at the University of Chicago in 1952. He has been a member of the Kansas faculty since 1951. Sokal is a National Institutes of Health career investigator. During 1959–1960 he was a National Science Foundation Senior Postdoctoral Fellow at University College London, and during 1963–1964 he was a Fulbright visiting professor at Hebrew University and Tel Aviv University in Israel. He is coauthor, with Peter H. A. Sneath, of *The Principles of Numerical Taxonomy.* Sokal wishes to acknowledge the assistance and constructive criticisms of Sneath, Joseph H. Camin, Charles D. Michener and F. James Rohlf in the preparation of this article.

L. K. RUNNELS ("Ice") is associate professor of chemistry at Louisiana State University. A graduate of Rice University, Runnels received an M.S. and a Ph.D. in chemistry from Yale University in 1961 and 1963 respectively. He is currently an Alfred P. Sloan Research Fellow and chairman of the physical chemistry division of the chemistry department at Louisiana State. In addition to ice, his research interests include the theory of nuclear magnetic resonance and relaxation, the general theory of liquids and gases, and the application of computers and information theory to a description of molecular systems. This last interest, he writes, "has been heightened by my wife's current research in the area of physiological psychology, more particularly dealing with the problem of memory." His wife is a graduate student in the psychology department at Louisiana State.

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Nerve System of an Airplane: A report from General Dynamics

Next time you take a trip in your car, try to drive there without steering wheel, accelerator or brakes.

Impossible, of course. They are vital to the job. Without them, the car won't do what it must, even though the chassis, body, motor, power train, tires, fuel, driver—and passengers—are all there.

The function of any vehicle is to deliver something from one place to another. The family car is a passenger-delivering system. A military aircraft is a weapons-delivering system. Avionics are vital to that job.

Extending human will:

In a modern military aircraft, the human crew is the intellect and the will. Avionics—or what used to be called aviation-electronics—are its nervous system, extending the human will through machines for tasks that require accurate control, sustained precise effort, or ultra-fast computation.

Here are some of the things current avionics do:

- Provide exact and unjammable navigation.
- Help the crew fly smoothly and safely, so low that detection and tracking capability of enemy radar will be sharply reduced, or so high and fast that it can circumvent other forms of attack.
- Assist the easy transition from one flight regime to another.
- Detect potential sources of attack from air or ground.
- Help fire any combination of weaponry with precision.

The F-111 fighter-bomber being built by General Dynamics is a case in point.

The F-111's variable-sweep wing, which makes it possible to redesign the aircraft *in flight,* is one of the great aerodynamic advances.

This airplane can fly fast or slow; 12 miles high or skimming the treetops; drift through the air for hours, or attack at two and a half times the speed of sound; ferry itself across an ocean without refueling, and land or take off from rough tactical fields in short distances.

All in all, it is the most versatile aircraft ever designed.

But first and foremost it is a weapons-delivery system. Its avionics, much more sophisticated than those of earlier airplanes, are a good indication of what is required nowadays.

A generation ago, aviation-electronics consisted mainly of radio. Today's avionics include a large assortment of separate systems which are segments of a larger fully integrated electronic system. This, in turn, is integrated with the airframe, the engines and weaponry. To see how it ties together, look at a few of the F-111's avionics parts.

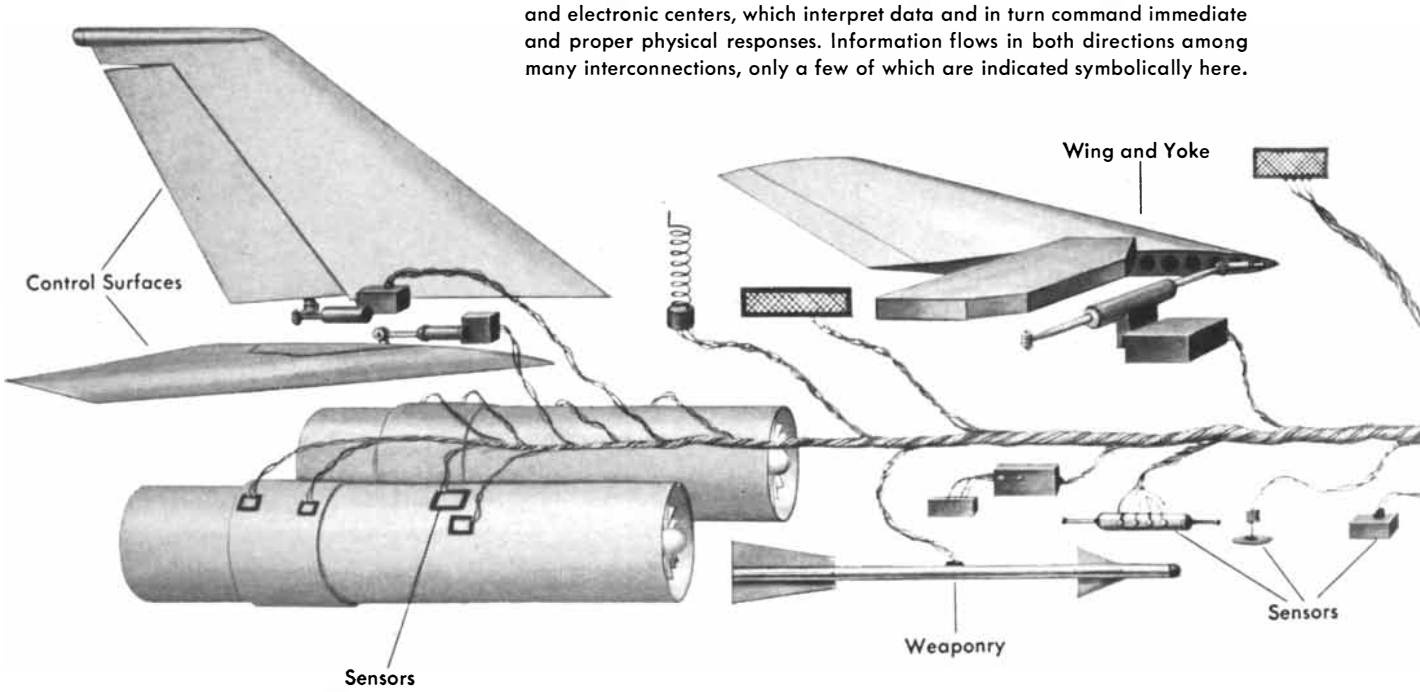
The triply redundant, self-adaptive flight-control system relates directly to the unique ability of the F-111 to vary the way it flies.

A complex of electronic sensors and computers measures motions of the aircraft and commands, through hydraulic and mechanical components, any necessary compensation to control surfaces.

In case of sudden change in atmospheric conditions (i.e., clear air turbulence or strong gusts), or rapid shift in altitude or direction, the self-adaptive flight-control system will automatically make any necessary adjustments for pitch, roll or yaw—often before pilots even know they are needed.

When wings change position, changes in other control surfaces take place simultaneously. The plane never loses its desirable flying qualities at any speed,

Seeing, hearing and feeling devices receive and transmit impressions to crew and electronic centers, which interpret data and in turn command immediate and proper physical responses. Information flows in both directions among many interconnections, only a few of which are indicated symbolically here.



or change in speed, from takeoff through Mach 2.5.

An inertial navigation system eliminates the uncertainties inherent in earlier magnetic-compass, radio or radar navigation techniques.

The inertial system measures every inch of passage, fluctuation in direction or change in speed. At any given moment, the pilot knows precisely where he is in relation to his takeoff point, his target and his return base.

"Hideability":

Terrain-following radar (TFR) improves mission efficiency.

A fast low-flying airplane which can be "seen" only fleetingly is troublesome for ground search radar. For maximum "hideability," the aircraft's terrain-following radar can be set at an optimum clearance close to the ground. The plane can now dip into the valleys and skim the peaks at supersonic speed in any weather, day or night. It can keep on a direct path, yet make the enemy's problem of detection far more difficult.

The TFR constantly looks both down and ahead, and relays its information to the self-adaptive control system. The complex adjusts the entire aircraft far faster than could unassisted human reflexes. Even over particularly jagged territory, the ride is relatively smooth.

The pilot can fly through zero visibility, protected against physical obstructions ahead. Should any of the TFR's circuits fail, the overall avionic system is programmed to put the aircraft automatically into a very sharp climb to higher altitude.

The ultimate function of the F-111, however, is the delivery of weapons—a mix of many types, long and short-range, for defense and attack, with different methods of firing. This calls for three closely related systems.

Finding a target:

A bomb/navigation system, connected to every weapon, constantly measures the plane's speed, altitude, attitude and position. These are computed against information, already stored, on the particular drop or firing pattern of each weapon and the location of the target.

A "head-up" system projects flight and other data, in color bar form, to a transparent reflective plate at pilot's eye level. Through it, he can see all the information necessary to fire guns and missiles without moving his eyes from the target itself.

To extend his sight in bad weather or at night, *high resolution ground mapping radar* provides a clear picture of the terrain or of airborne targets, simultaneously reporting the changing range between plane and target.

With these reinforcing the pilot's judgment, the specific weapon needed can be released, manually or automatically, at the split second when it is most likely to hit its target exactly.

Each of the "separate" systems has a distinct job, yet all are, to some degree, interdependent. For maximum reliability, self-test devices check, before and all during flight, for any malfunction. Should one occur, the "work" can be shifted quickly to back-up equipment—and assure that the mission will not be impaired.

Even though the current avionic systems are advanced over anything that has gone before, newer and improved versions are already being jointly developed by General Dynamics and its many subcontractors who produce the individual systems that make up the whole.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communications systems; machinery; building supplies; coal, gases.

Reprints of this series are available.

GENERAL DYNAMICS

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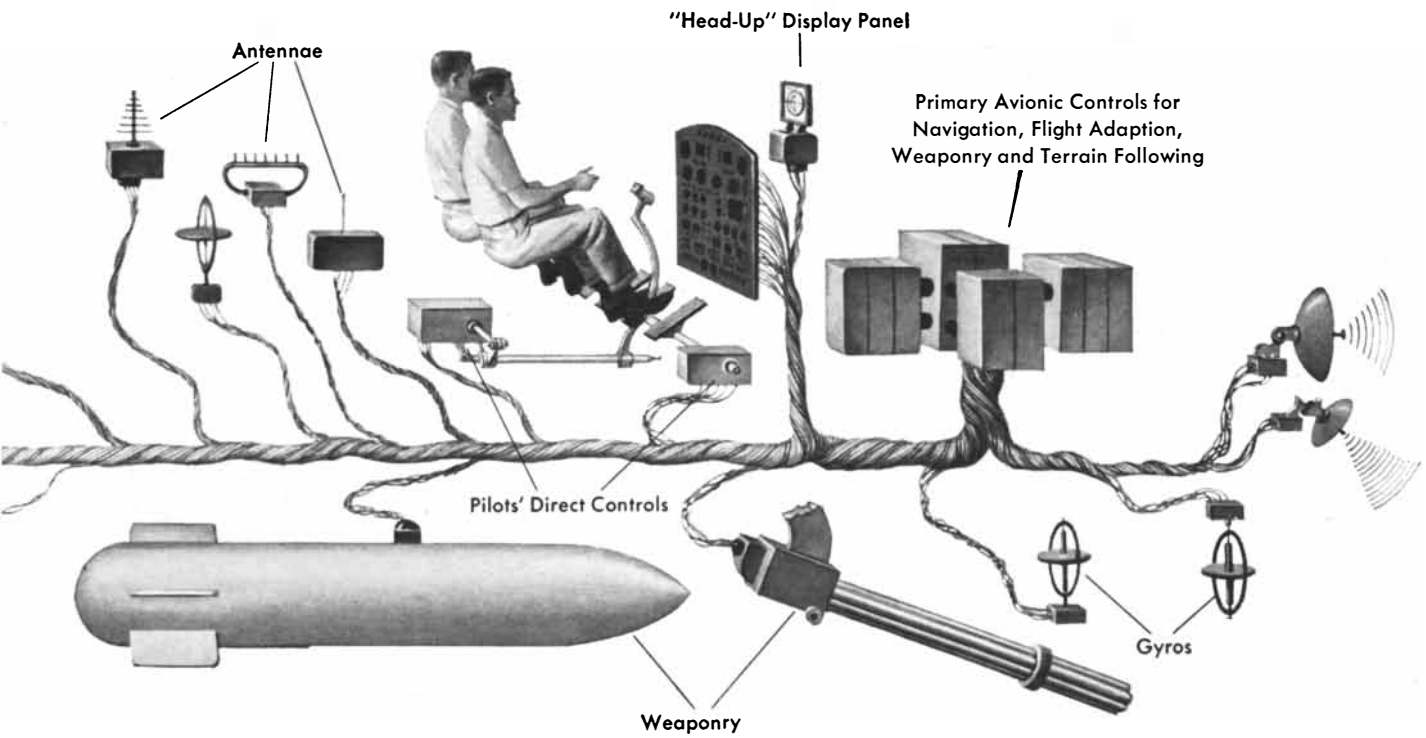

Sylvania ECG finds the way to "dig a hole" for destructive electrical surges.

Numerous protective devices have been developed for momentarily "grounding" electrical lines subjected to extreme voltage surges. The problem has been to devise a method that would shunt repeated high energy surges to ground instantaneously without damage to the protective device itself.

The Sylvania Electronic Components Group solved the problem through the development of an electronic surge arrestor capable of dissipating natural and man-made electro-magnetic impulses with energies as high as 110 coulombs—greater than the surge of an average lightning bolt!

Basic to the device is Sylvania's new Type SG-1360 spark gap composed of three metal alloy electrodes hermetically sealed in a ceramic and metal package back-filled with an inert gas. Under normal conditions, it presents a virtual open circuit between both sides of a communication line. In the presence of a voltage surge, it fires instantly, and bypasses the surge to ground, then restores itself to the open circuit condition.

When used as a primary protective device in communications and control equipment for industrial and military use, the Sylvania electronic surge arrestor is capable of reducing high transient energy from whatever source to a safe level for secondary protectors in applications such as solid-state power supplies and computers. And does so repeatedly without suffering damage or deterioration.

"Digging a hole" for destructive electrical surges is another example of advanced component design resulting from Sylvania ECG *unified* research and engineering. And a way to find the answers to your problems in system design.

Sylvania Electronic Components Group, Sylvania Electric Products Inc., Seneca Falls, New York 13148.

SYLVANIA

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Established 1845 SCIENTIFIC AMERICAN December 1966 Volume 215 Number 6

Progress toward Fusion Power

The controlled release of thermonuclear energy requires solving the problem of confining a hot plasma of electrons and positive ions. The problem is slowly yielding to analysis and experiment

by T. K. Fowler and Richard F. Post

This article is a progress report on the effort to obtain controlled power from thermonuclear fusion. For more than a decade fusion research has sustained a high level of enthusiasm in a sizable group of physicists and engineers in many countries. This enthusiasm flows from two exciting prospects. The first is that fusion power would provide a lasting solution to man's steadily increasing need for energy on a planet that has a limited supply of coal and oil, and a limited tolerance for the atmospheric pollution resulting from the combustion of such fuels. Compared with power from nuclear fission, which is already a reality, fusion power would be safer, would be free of radioactive waste and would have an abundant and cheap supply of fuel easily accessible in the oceans in the form of deuterium, or heavy hydrogen [see "Fusion Power," by Richard F. Post; SCIENTIFIC AMERICAN, December, 1957].

The second prospect is the progress of a new scientific discipline: the physics of hot plasmas. The fusion reactions themselves, studied in the laboratory and known as the source of energy in the sun and other stars, are well understood [*see illustration on page 24*]. It is rather the behavior of plasmas on which fusion research has converged. The crucial problem of such research today has to do with the stability of plasmas (or the lack of it).

The intimate relation between fusion research and plasma physics stems from the nature of the fusion process. Fusion is a fire that can be kindled only at the extremely high temperatures characteristic of the center of a star. To produce controlled fusion power on earth we must first heat the deuterium fuel to a kindling temperature above 100 million degrees centigrade. At such temperatures the fuel becomes a plasma—a fully ionized gas composed of free electrons and bare atomic nuclei, or positively charged ions.

The problem is how to confine a hot plasma long enough for a sizable number of fusion reactions to take place. The confinement time required is less if the plasma is dense, but energy would be released at a violent rate. To achieve a controlled release of energy rather than an explosion it is necessary to deal with rather rarefied plasmas confined for a comparatively long time. The plasma density would be no more than a thousandth or perhaps as little as a hundred-thousandth that of air at sea level. To produce power at such densities the plasma might need to be confined as long as tenths of a second—millions of times longer than it takes for an ion to traverse the entire plasma. Thus the ions must be repeatedly turned back at the surface of the plasma, which is to say that the plasma must be confined by something. A material vessel would not do; contact with the walls, or even with the air, would immediately cool the plasma below the kindling point.

Barring unforeseen developments, the practical solution to the confinement problem seems to be the "magnetic bottle." In this arrangement the plasma is located within a chamber that has been evacuated to keep the plasma out of contact with the air. In addition a strong magnetic field is applied to the plasma to confine it and keep its particles away from the walls of the chamber. The field can do this because magnetic fields exert forces on electrically charged particles such as the free electrons and ions of the plasma. One can establish an equilibrium in which the outward pressure due to the repeated attempts of particles to escape is exactly balanced by the magnetic forces. The question is whether this delicate balance of forces can be maintained. The situation is something like trying to keep a ball dancing atop a thin jet of air; any fluctuation of the jet or errant movement of the ball will allow the ball to escape.

When the magnetic confinement of plasmas was first considered some 15 years ago, it was clear that the stability of a plasma under such conditions would mean success in obtaining fusion power, and that pronounced instability would mean failure. At that time almost nothing was known, either theoretically or experimentally, about the behavior of hot plasmas in a magnetic field. Indeed,

there were no means of heating plasmas to fusion temperatures for laboratory investigation. Then, when the first fusion experiments were attempted, they failed because of plasma instability, dashing any hope for a simple solution to the problem. Nonetheless, it was found that under some circumstances magnetic confinement could be at least partially effective.

Encouraged by even such slender prospects, ambitious research programs were launched in many laboratories around the world. The effort has been a closely cooperative one since the declassification of fusion research by all countries in 1958. Progress has been impressive. We now have a vigorous new technology and new basic knowledge that is already influential not only in fusion research but also in astrophysics, space research and many other areas. Fusion research itself is now guided by a broad understanding of the causes of plasma instability. More important, with the new understanding has come suggested ways, some already successful, whereby certain classes of instabilities can be controlled.

It has now been demonstrated conclusively that some of the worst forms of plasma instability can be suppressed by several methods. The first method we shall discuss involves a principle of such general applicability that its future importance seems assured. This principle, called the magnetic well, concerns the shape of the magnetic-field lines confining the plasma and the influence of that shape on stability. It applies specifically to the control of the grossly unstable motions of the plasma as a whole. That the control of gross instability by magnetic wells is thoroughly effective and well understood was shown in many experiments reported at the most recent international gathering of fusion workers at the International Conference on Controlled Fusion Research held in England in September, 1965, under sponsorship of the International Atomic Energy Agency.

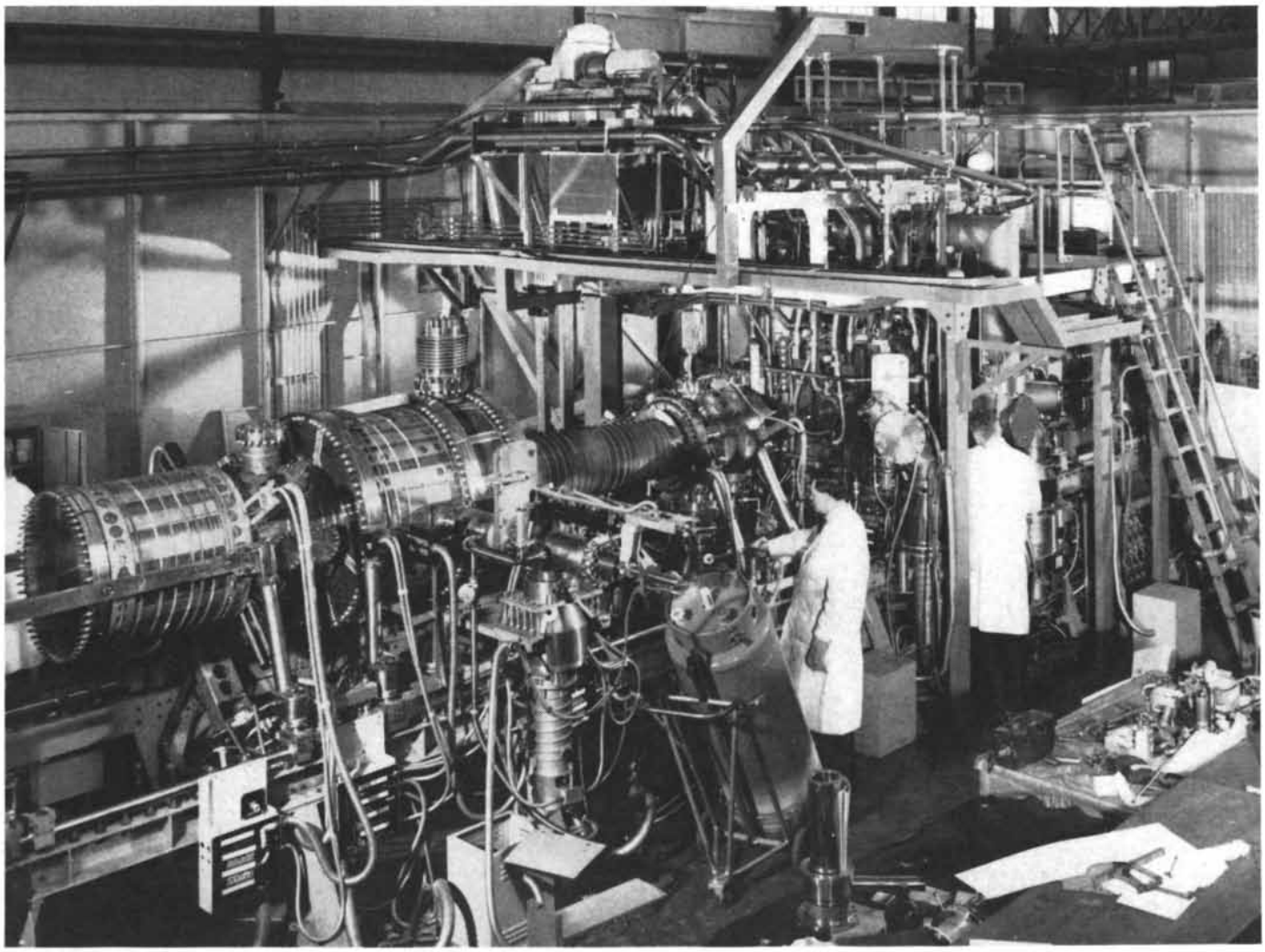
UNSTABLE PLASMA is made visible in this photograph produced by passing a laser beam through the plasma. The dark and light fringes resulting from interference of the light waves are displaced by inhomogeneities in the plasma. The photograph shows a common type of interchange instability called a "flute" instability. The phenomenon occurred in a "theta pinch" experiment conducted by Fred L. Ribe at the Los Alamos Scientific Laboratory.

To explain the magnetic-well principle we must review some basic facts about the behavior of plasma particles in a magnetic field. Early fusion experiments attempted to confine the plasma by the "pinch" effect, in which the magnetic field is generated by current flowing through the plasma itself. This type of system proved to be so unstable that investigation soon turned to confinement by magnetic fields generated externally. A simple form of such a magnetic bottle employs concentrations of field strength at the ends (or poles) to act as mirrors reflecting the plasma particles back into the bottle [*see middle illustration on page 25*]. The field is strengthened at each pole by a coil that squeezes the field lines there close together. As a particle moves toward this region the increasing strength of the field stops the particle and drives it back; thus the particles are bounced back and forth between the end "mirrors."

The sides of the bottle, however, where the magnetic-field lines bulge outward and the strength of the field weakens with distance from the axis of the field, allow the particles a means of escape. The particles spiral around the magnetic-field lines as they shuttle back and forth between the poles. In spiraling around these lines a particle is subjected to a weaker magnetic force during its swing around the outer side than it is on the inner one, where the field is stronger; consequently its orbit is less sharply curved in the outer part of its circuit than in the inner part. Thus in addition to their spiraling motion the plasma particles tend to drift in larger circles around the magnetic axis.

Now, if the plasma or a part of it is momentarily displaced off-center, the drift of the particles, which is still centered on the magnetic axis, causes particles to pile up at the edges of the displaced region. Because the positive ions and electrons are drifting in opposite directions (clockwise and counterclockwise, as oppositely charged particles do when they are bent by a magnetic field), ions are deposited at one edge and electrons at the other [*see bottom illustration on page 25*]. The electric field produced by the separation of charges promptly propels the plasma out of the magnetic field. This catastrophic sequence of events is called an interchange instability.

In the mirror system described above the plasma is in an unstable situation analogous to that of a ball perched on the top of a hill. A slight displacement



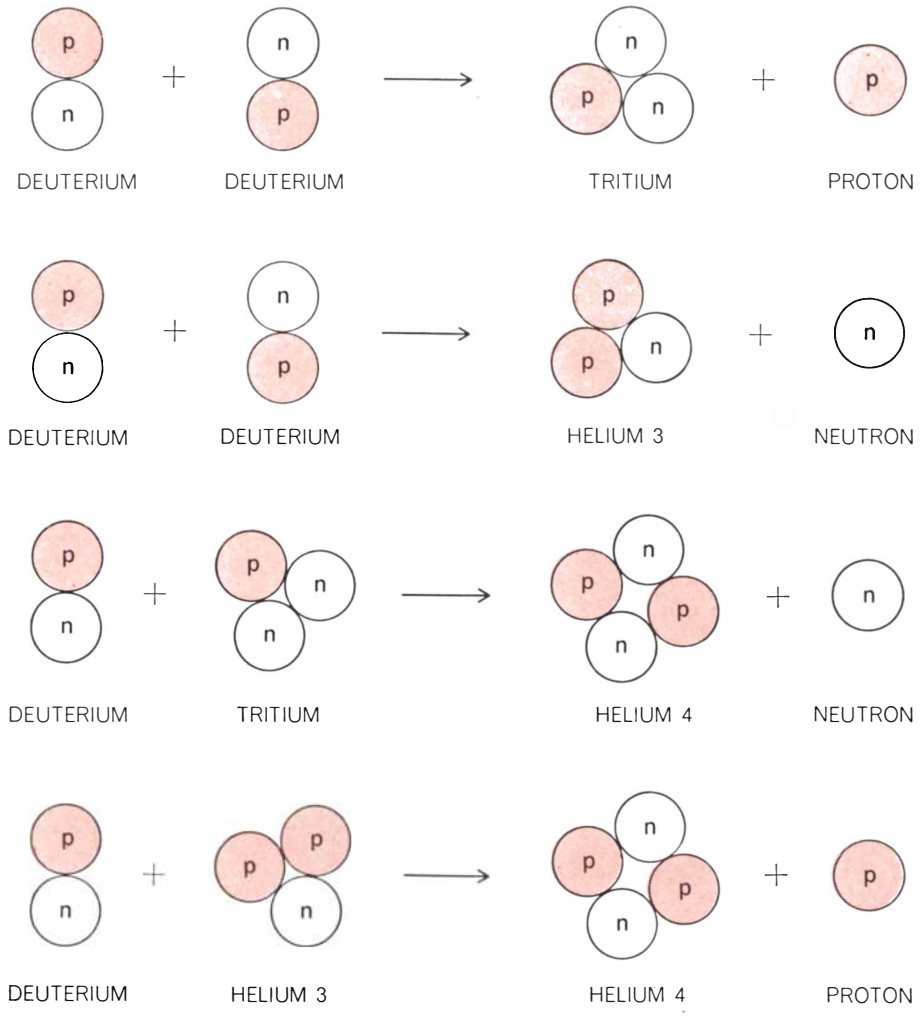
PLASMA-MAINTENANCE APPARATUS called *Phoenix II* is operated at the Culham Laboratory near Oxford by the United Kingdom Atomic Energy Authority. *Phoenix II* uses a high-energy injection system, in which a continuous stream of energetic neutral atoms is injected into the heart of a confining field. The goal is to produce and maintain a plasma at thermonuclear temperatures.

will allow the ball to roll down the hill; similarly, if some slight disturbance displaces the plasma sideways in the magnetic field, the plasma will fall off the magnetic hill, that is, will move in the direction of declining field strength toward the sides. If the ball were not at the top of a hill but at the bottom of a well, it would be in a stable position. This presents the question: How might one create a magnetic field that would confine a plasma by blocking its escape in every direction?

The answer lies in the fact that the gross motion of a plasma in a direction of increasing magnetic strength is resisted. We have already encountered this fact in regard to motion along magnetic lines; it gives rise to the mirror effect. It also applies to motion across magnetic-field lines if some force, such as the electric field that develops during interchange instability, tries to push the plasma across the field lines. In principle, therefore, the plasma should be confined stably if it were placed in a magnetic field that increased in strength in every direction away from the plasma, that is, if it were placed in a "magnetic well." Such magnetic configurations were devised quite early, but the first experimental proof of the idea came in 1961 when a group of workers in the U.S.S.R. led by M. S. Ioffe demonstrated magnetic-well stabilization of the interchange instability.

A comparatively simple version of the magnetic well has coils at each end, which compress the magnetic-field lines so that their ends will act as mirrors, and also four current-carrying rods arrayed around the sides of the field [*see illustration at top left on page 26*]. The current in adjacent rods flows in opposite directions; as a result the rods generate opposed magnetic fields that cancel each other at the "bottom" (the central axis) of the well and hence do not add to the field created there by the end coils. There is no cancellation, however, near the rods in the outer areas of the well, where the fields created by the rods and the coils add up. Accordingly the magnetic field is weakest at the center of the well and is progressively stronger toward the walls. The magnetic-field lines bulge inward instead of outward; this has the effect of reversing the drift of the plasma particles. Therefore any separation of electrons and ions caused by drift generates a reversed electric field, and this field drives escaping particles back toward the center.

By running tests with and without the current in the rods turned on one can give a striking demonstration of the effect of the magnetic well. If only the mirror coils at the ends are turned on, interchange instability occurs; the plasma particles are driven to the walls of the chamber and the plasma escapes within a few millionths of a second. With the current in the rods turned on, the escape of plasma particles to the walls is reduced by a factor of hundreds of thou-



FUSION REACTIONS result when the nuclei of certain hydrogen and helium isotopes are provided with enough energy to overcome the electrostatic repulsion between them. When this energy is provided, one obtains a plasma: a fully ionized gas consisting of ions (positively charged particles) and electrons. To achieve a self-sustaining thermonuclear reaction a plasma composed of heavy isotopes must be raised to a temperature of about 100 million degrees centigrade. This corresponds to ion energies of about 10,000 electron volts (10 Mev).

sands [*see illustration at top right on page 26*].

The magnetic-well idea is a milestone in fusion research. Success in controlling the troublesome interchange instability has created the hope that the same principle can be used to control other gross instabilities. In particular, the principle may be applicable to certain instabilities in "closed" systems. Such systems overcome a disadvantage of the open-end type of system we have been discussing.

In systems with mirrors at the ends the magnetic-field lines extend beyond the necks of the magnetic bottle. The strong field at each end drives back particles that are circling around the field lines, but any particle that happens to move nearly parallel to the lines (as may happen if its movement is deflected by collision with another particle) can escape through the open end. Thus there is a slow leak of plasma particles from the system. End leakage is eliminated in closed systems with the shape of a torus, or doughnut; in such systems the magnetic-field lines are endless [see "The Stellarator," by Lyman Spitzer, Jr.; SCIENTIFIC AMERICAN, October, 1958].

In a torus, however, it is generally found that the plasma rapidly escapes sideways across the magnetic-field lines. Although other factors may also be involved, there is evidence of gross instability that could cause this loss. If so, again invoking the magnetic-well idea, we would expect that the escape of plasma could be blocked by placing the entire length of the doughnut within a sufficiently deep magnetic well, that is, by surrounding all parts of it with a field that gains strength in the outward direction. Unfortunately this cannot be done with coils and rods. As we have seen, the well is created by making the magnetic lines bulge inward. In order to go around inside a doughnut the lines must sometimes curve the other way; in some places the lines must bulge outward as seen from inside the doughnut.

Two ways out of this dilemma are being pursued. In one approach, called the Astron concept, the plasma is embedded in an "*E* layer": a configuration shaped like a napkin ring in which electrons circulate together at nearly the speed of light [*see upper illustration on page 29*]. These circulating electrons, themselves guided by an externally produced magnetic field, conduct a current that generates a toroidal (torus-shaped) magnetic well to confine the plasma. Although it is impossible to create a toroidal magnetic well using ordinary metallic conductors, there is a deep well inside a conductor, where the field is weak. The same kind of well exists in the "conductor" represented by the circulating electrons of the *E* layer. If the well generated by the electrons is to be effective, it must be stronger than the external guide field, and this requires a large electron current in the *E* layer. A crucial question is whether an adequate *E* layer would itself be stable. A substantial and apparently stable electron layer has been produced in the laboratory, although the field generated in it is not yet as strong as the guide field.

The second way to apply the magnetic-well principle to closed systems employs ordinary metallic conductors and relies on a compromise. Although here a true toroidal magnetic well is impossible, a toroidal chain of "good" magnetic-well regions connected by "bad" regions where the field lines tend to follow the toroidal curvature is not ruled out. If the distance between good and bad regions is short enough, the rapidly moving plasma particles traverse the bad regions in less time than is required for a gross instability to develop. Insofar as gross instability is concerned the particles are effectively controlled by the average of forces they experience in their travels along the magnetic-field lines. If they spend more time in good regions than in bad, the good regions predominate and manage to stabilize the plasma, much as a ship buffeted by variable winds manages to keep on its course because favorable spells outweigh unfavorable ones.

The first tests of this "average well" concept have been most encouraging. One experimental apparatus is a torus in which the field is generated by four rods. The rods are arranged like the

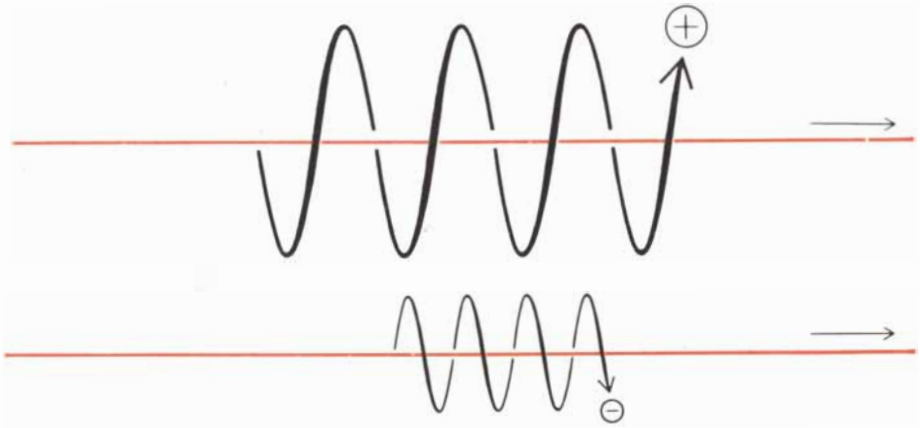
stabilizing rods used in the open-end magnetic well, but the rods are bent in the circular shape of the torus [*see illustration on page 27*]. Here the magnetic-field lines encircle the rods in a closed loop. The plasma particles following the field lines encounter weak field regions on the outside of the rods, but in their total circulating journey the stabilizing forces predominate. Experimental results so far indicate that the system overcomes gross instabilities.

In addition to the magnetic well there is a second important method of controlling gross instabilities. It is the "short circuit" principle, whereby any separation of charges in the plasma is relieved by short-circuiting the charges. A plasma in a magnetic field has good electrical conductivity parallel to the magnetic-field lines, since the particles travel freely along the lines. In directions across the field lines, on the other hand, the conductivity is rather poor. This is the reason why, when positive ions and electrons drift apart in a direction perpendicular to the field lines, as they do in the development of interchange instability, they remain separated for an appreciable time; they are, so to speak, sequestered in separate longitudinal channels. Suppose, however, we insert a conductor in the system to connect the channels. This will provide a path by which current can flow across the field, and groups of positive ions and electrons that have been separated will promptly return to the previous mix.

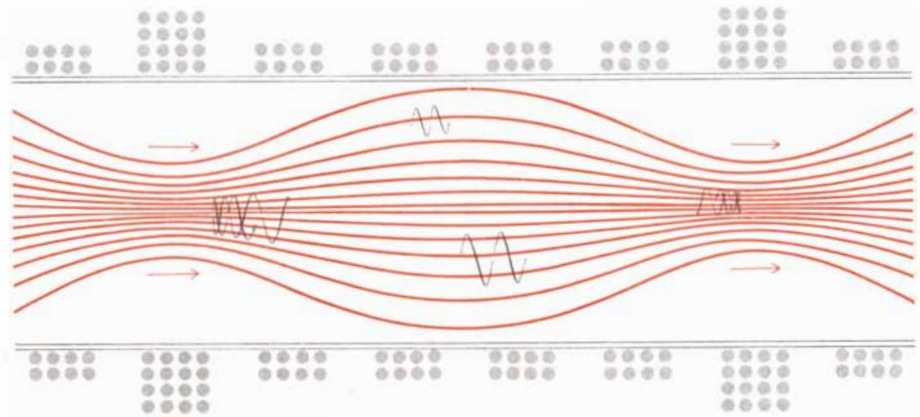
The principle has been found to work as predicted in experiments with the end-mirror system. As an alternative to magnetic-well stabilization, placing a highly conducting metal plate at the end of the system also prevents interchange instability. We are mainly interested, however, in applying the short-circuit principle to closed, toroidal systems. In such a system we cannot use metal end plates, because the system has no ends. An entirely different scheme for short-circuiting has been studied for some time.

Consider a magnetic field so shaped that the magnetic-field lines twist around the central axis like the threads of a screw or like stripes on a barber pole [*see top illustration on page 28*]. The field is given a property called "shear" if the amount of twist of the lines is made to vary with distance from the axis: the farther from the axis, the steeper the pitch of the lines, or vice versa. In such a field the lines are not all parallel; they intermesh. This has the important consequence that neighboring plasma regions where positive and negative charges might accumulate as instability develops tend to be connected by some lines passing through both regions. If the connecting distance is not too great (the distance is shorter the stronger the shear), the connecting lines should act as a short-circuit and the charge should be quickly neutralized by a current flowing along them.

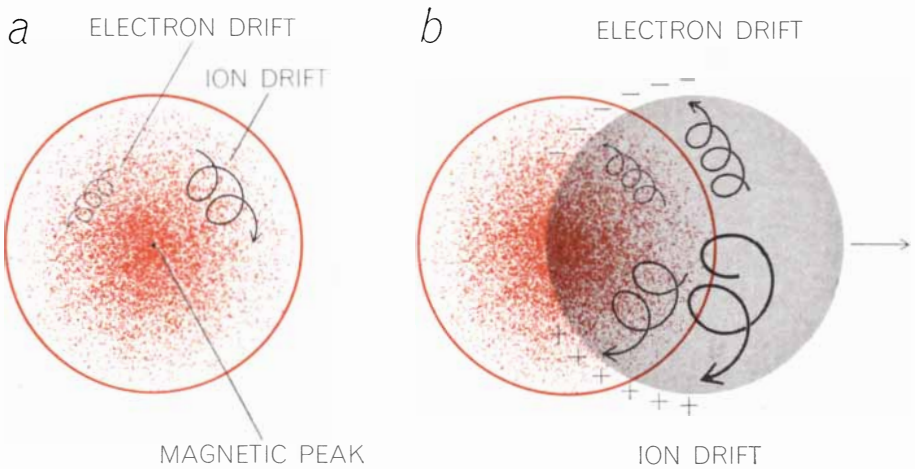
Although magnetic-shear stabilization is not a new idea, it remains largely untested at high plasma temperatures.



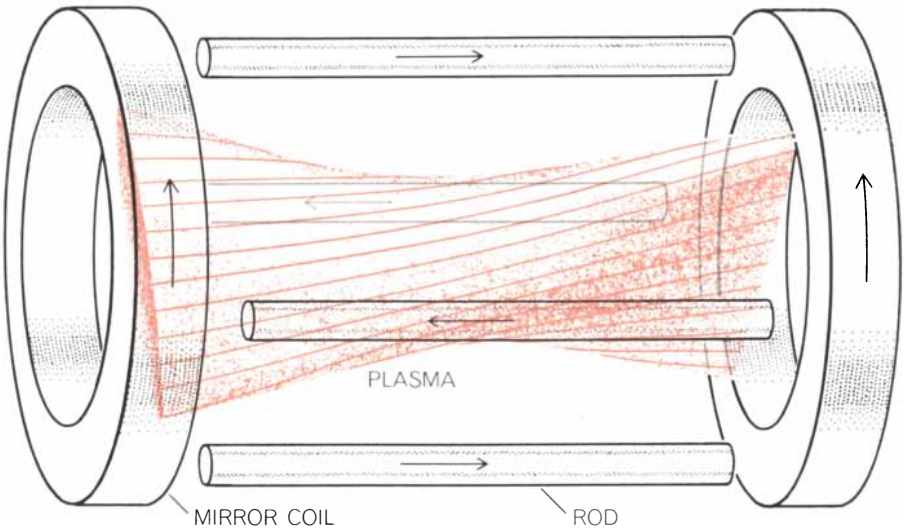
PLASMA PARTICLES IN MAGNETIC FIELD tend to travel in helixes around lines of magnetic force (*color*). Electrons (−) and positive ions (+) rotate in opposite directions.



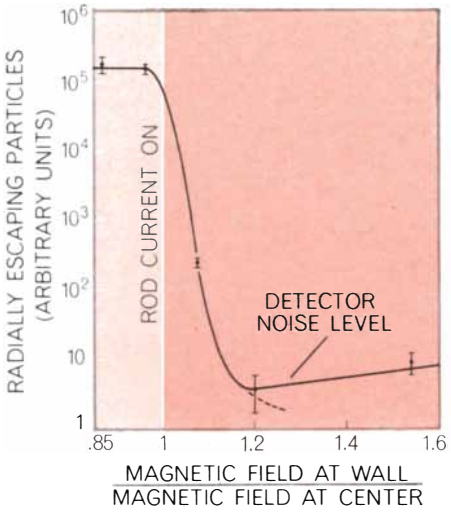
MAGNETIC-MIRROR EFFECT is produced by a "magnetic bottle" in which the magnetic field increases at each end. The stronger field bends the path of an approaching particle into even tighter circles and exerts a force that reflects it away from the ends of the bottle.



INTERCHANGE INSTABILITY arises because particle orbits vary in curvature with variations in magnetic-field strength, causing electrons and ions to drift apart. In equilibrium (*left*) charges drift parallel to the surface and neutralize each other. If the plasma is displaced (*right*), the drifts intersect the surface and cause a separation of charge. When the magnetic field is as shown, the resulting electric field displaces the plasma still farther.



"MAGNETIC WELL" can be created by surrounding a mirror-type magnetic field by four rods carrying current. The result is a twisted field (*color*) whose strength increases in all directions away from the center and thus tends to reflect particles inward no matter where they seek to escape. The arrows show the direction of current flow in the rods and in the two end coils. The magnetic well marks a major advance in plasma containment.



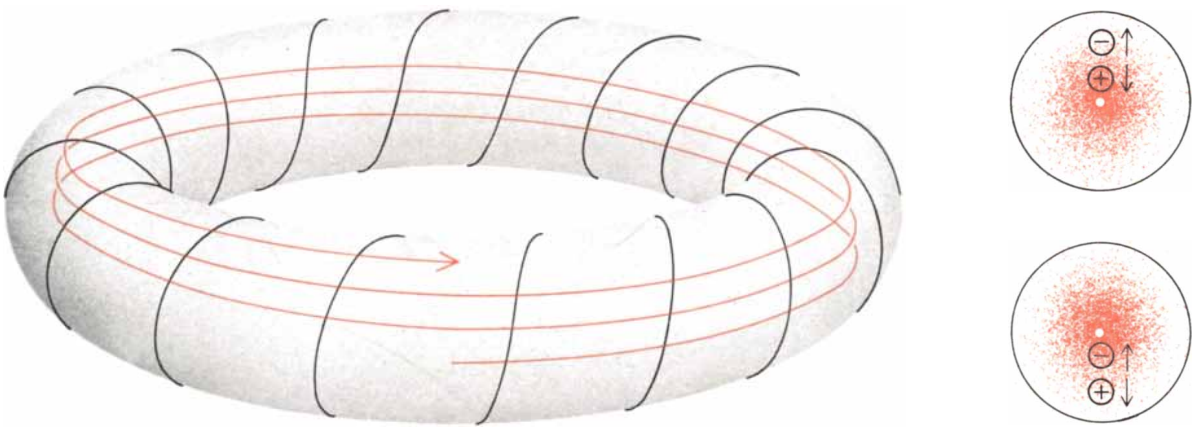
WELL EXPERIMENT by Walton A. Perkins III and William L. Barr of Lawrence Radiation Laboratory shows the number of particles escaping from a plasma in a mirror field before and after a well has been created.

At lower temperatures the short-circuit effect is nullified by the poor conductivity due to frequent collisions among particles. Indeed, low-temperature plasmas are unstable even when they are subjected to strong shear. At higher temperatures, where collisions are less frequent, shear should be more effective. Studies are also under way to determine if it would be profitable to combine shear with an average well in toroidal systems.

The progress so far in dealing with the gross instabilities of hot plasmas encourages us to believe that these instabilities will eventually be mastered. Let us consider the problem of the weaker instabilities—those that arise from streaming motions and diffusion processes among the plasma particles. These instabilities involve small-scale effects rather than gross motions, and they are less susceptible to stabilization by the magnetic-well principle and other principles we have described. In searching for ways to catalogue and understand the weak instabilities plasma physicists have been taking a new look at an old concept: the second law of thermodynamics.

The second law deals with the inevitable tendency toward randomness and disorder in nature. As the second law is applied to a gas it implies that the gas will unavoidably approach an equilibrium in which (1) its temperature is the same as that of its surroundings, (2) the particles of the gas are distributed uniformly throughout the container, (3) their motions are in random directions and (4) their distribution in velocity can be described by the well-known probability curve (here called the Maxwellian distribution) in which most of the particles move at or near an average speed and only a small number move either substantially slower or faster.

A hot plasma under confinement is clearly not at such an equilibrium. Its temperature must be much higher than that of its material container. Its particles cannot be uniformly distributed throughout the container, because they must be prevented from leaving the region of magnetic confinement, and by



TOROIDAL MAGNETIC FIELD is a feature of the "Stellarator" principle developed at Princeton University. The magnetic field is generated by passing electric current through a helical coil wrapped into the shape of a doughnut. A simple helix would produce a nonuniform field in which charges would separate as shown in the illustration at the bottom of the preceding page and the plasma would soon break from confinement. To prevent this, additional coils are introduced that twist the magnetic lines in such a way as to counteract the tendency of charges to separate. The diagram at left shows a part of one line of force (*color*), which generates a ring-shaped surface. Each magnetic-field line is above the axis of the torus in some sections (*top right*) and below it in others (*bottom right*), with the result that electrons and ions tend to drift away from the center line at some points and toward it at others.

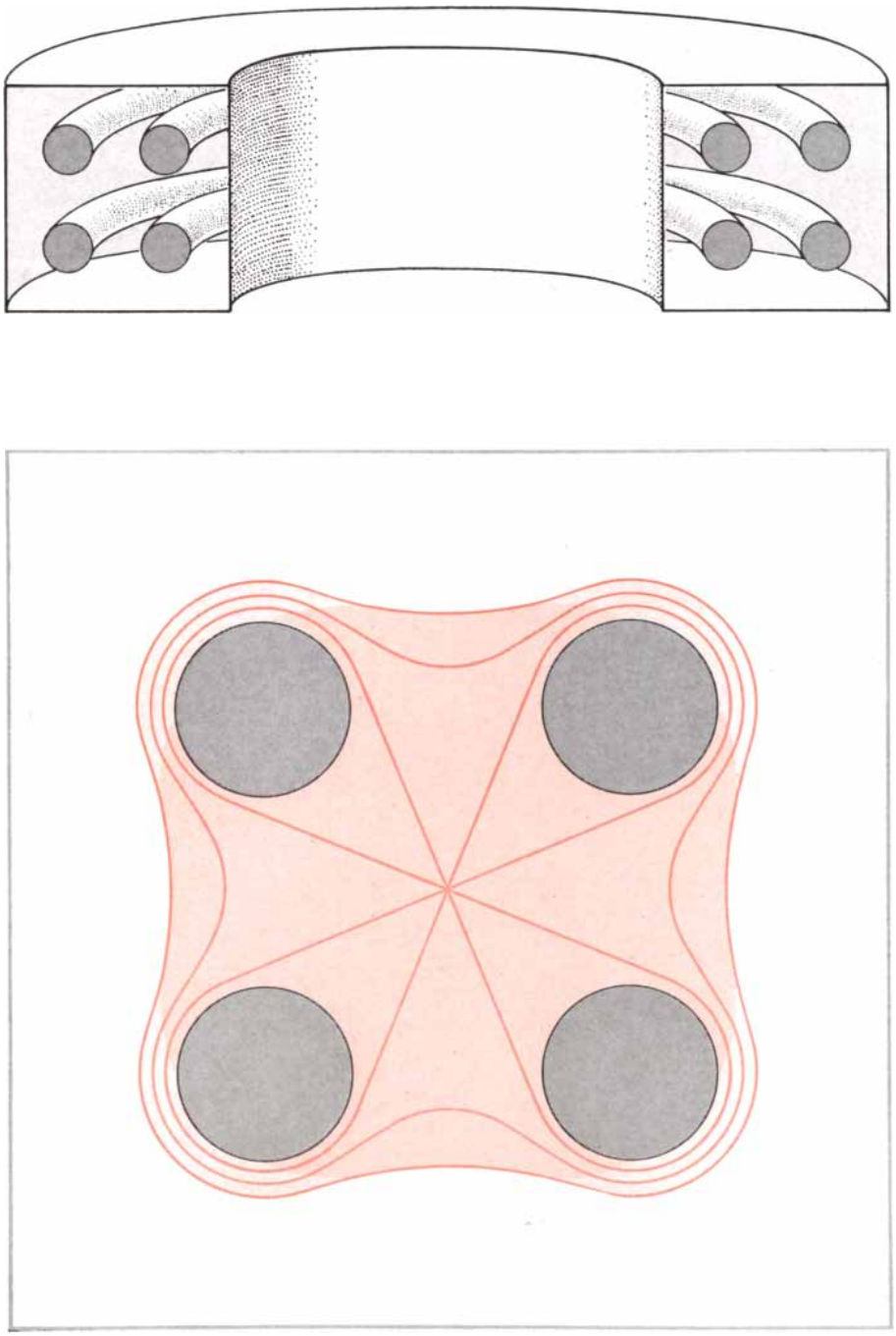
the same token they cannot be allowed to travel in completely random directions. Moreover, the distribution of their velocities may deviate markedly from the Maxwellian distribution.

Where fusion is concerned everything hinges on how long the inevitable approach to equilibrium can be delayed. In an ordinary gas the mechanism that drives the system toward equilibrium is collisions among the particles. If this were the only mechanism operating in a magnetically confined plasma, the plasma could be held together more than long enough to kindle fusion. When the plasma is unstable, however, the approach to equilibrium can be much faster; the collective action of the plasma's charged particles generates sizable electric and magnetic fields that can destroy confinement. The large-scale fields produced by gross instabilities expel the plasma bodily. The small-scale fluctuating fields associated with the weaker instabilities, on the other hand, dissipate the plasma by causing its particles to diffuse out of the confining field, much as a puff of smoke is dissipated by diffusion into the surrounding air.

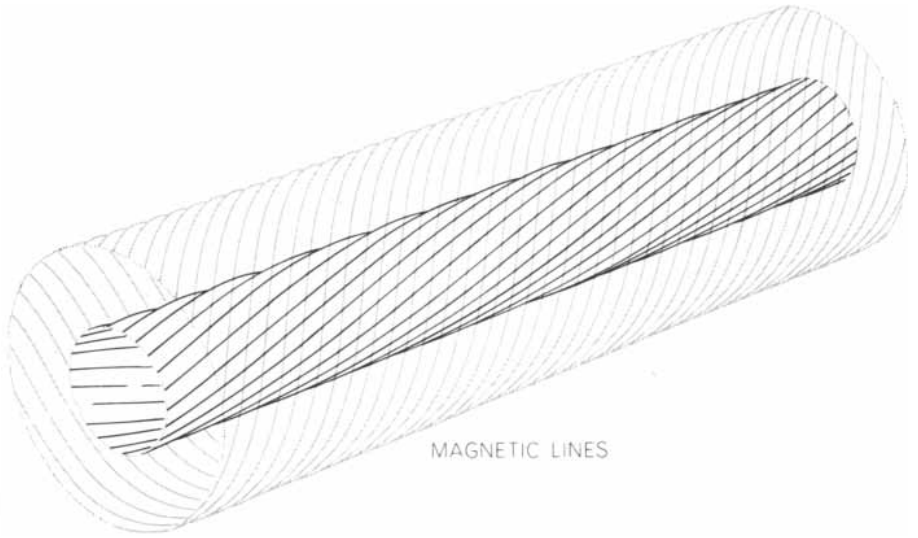
Thermodynamic concepts suggest a means of minimizing the effects of the weaker plasma instabilities. The energy carried by the plasma's collective electric and magnetic fields is obtained from its "free" energy: that part of its energy which represents its departure from equilibrium. (To be sure, a gas in equilibrium contains energy in its moving particles, but this energy is not "going anywhere.") Accordingly if we reduce the plasma's departure from equilibrium as much as possible, we will correspondingly reduce the available free energy and decrease the forces creating instabilities.

Since a magnetically confined hot plasma cannot be in equilibrium with its surroundings, sources of free energy can never be completely eliminated. Nonetheless, there are circumstances in which the plasma can be prevented from tapping some of these sources. An example is the action of a magnetic well in preventing gross instabilities. Here the free energy in question is analogous to the energy released when steam expands in a steam engine. Plasma held in a magnetic well cannot undergo this kind of gross expansion, and hence cannot tap this reservior.

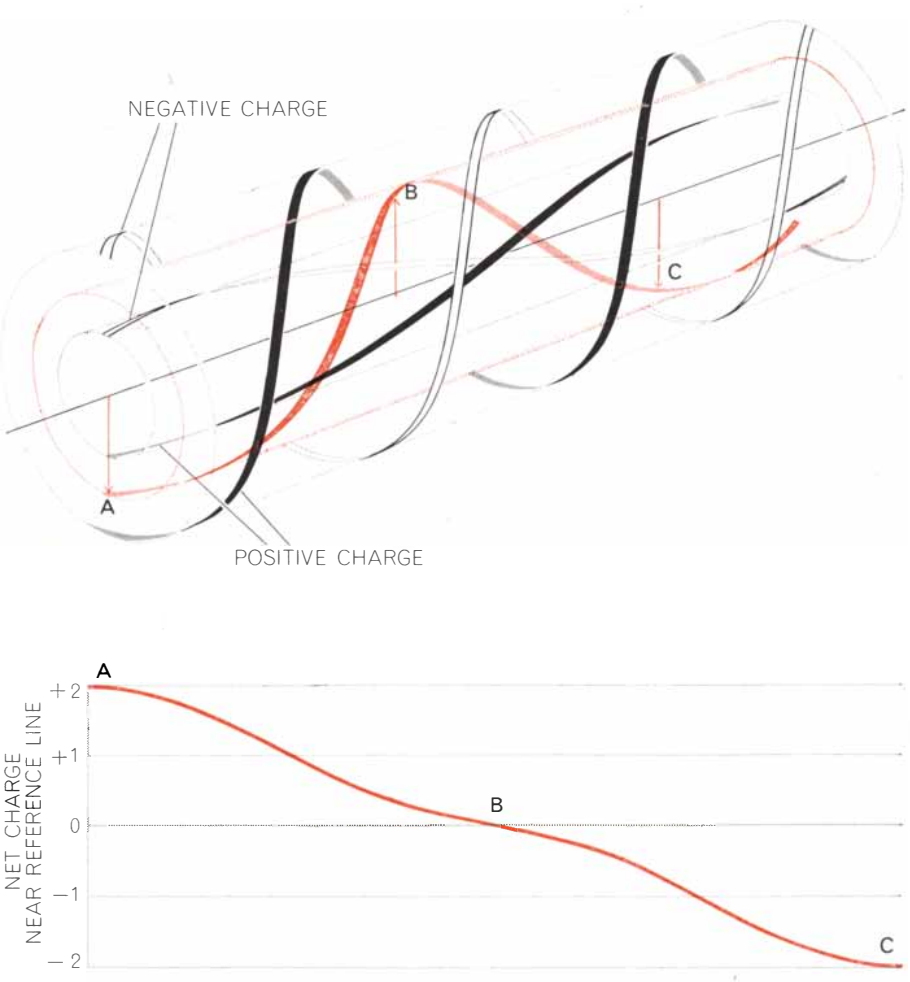
The remaining reservoirs can be greatly reduced by arranging for a nearly uniform and Maxwellian distribution of the plasma particles. At this point thermodynamics steps in with an optimistic prediction: Once the available sources of free energy have been identified, a calculation can be made of the maximum level to which the fluctuating electric and magnetic fields associated with the weak instabilities can rise. From this information it is possible to calculate the maximum rate of plasma loss these instabilities can cause. The prediction is that if gross instabilities can be prevented, as now seems possible, and if the free-energy reservoirs responsible for the weak instabilities can be reduced to the extent that theory now predicts, then it should be possible to build a system that would yield net thermonuclear power and would not be impracticably large. The predictions of thermodynamics do not, however, spell out in detail which path will lead to success. The problem of finding the best magnetic geometry for plasma confine-



TOROIDAL-MAGNETIC-WELL GEOMETRY (*top*) incorporates the rod concept illustrated at the top of the opposite page. The bottom diagram indicates how "good" regions (*dark color*) and "bad" regions (*light color*) average out to produce a field with a net stabilizing effect on the plasma. This has recently been shown by experiments at the General Atomic Division of the General Dynamics Corporation and at the University of Wisconsin.



MAGNETIC FIELD POSSESSING SHEAR offers a way to produce an electrical short circuit in a plasma, thereby suppressing the separation of charges that leads to interchange instability. To obtain shear in a magnetic field, the field lines are made to twist helically around the central axis of the plasma in such a way that the amount of twist changes with increasing distance from the center. The diagram shows the twist at two different radii.



SHORT CIRCUIT is created in a sheared field because some lines at intermediate radii (*color*) connect regions where charges tend to separate. The positive regions are represented by black ribbons: magnetic lines on which positive charges are held. The negative regions are represented by white ribbons: lines on which negative charges are held. At the far left and far right two white ribbons are on one side of the axis and two black ribbons are on the other, creating electric fields that could provoke instability. A flow of charge across the axis, which would neutralize the field, cannot occur because the charged particles travel mainly along magnetic lines. The field can be short-circuited, however, by charges flowing along the colored line. The graph at the bottom shows the net electric charge near this line.

ment also calls for finding the conditions for the onset of all possible instabilities, including the weaker ones.

The weaker instabilities could more precisely be called "wave-particle" instabilities. Arising from interactions of particles and waves in the plasma, they remind one of storms. A hot plasma is a restless thing. The random motions of its particles continually produce minute density fluctuations and electric currents; these in turn generate weak electromagnetic waves. The waves span a wide range of frequencies, mainly in the radio and microwave regions of the spectrum. Each tiny wave would soon die away unless it were amplified, and the plasma particles can provide one source of amplification when the frequency of a wave corresponds to some natural period of the particle motion (for example the periodic motion of ions circling around the magnetic lines at the "cyclotron" frequency). Such resonances enable the particles to surrender part of their energy to the wave. If this reservoir of free energy is substantial, the wave can grow to large amplitude and disrupt the plasma.

Another energy reservoir feeding wave-particle instabilities arises from streaming particle motions—"winds"—within the plasma. Instabilities set up by streaming, well known in electronic devices such as the traveling-wave tube, resemble traffic jams on a crowded freeway. The flow of traffic may remain smooth as long as nothing goes wrong, but if an accident takes place traffic is impeded and cars pile up near the scene of the accident. An analogous situation occurs in the plasma. A momentary increase in ion density at some point along the stream will create a slight excess of positive charge at that point; the ions following are repelled by the like charge and slow down. Soon there is a pileup. (The same is true of the electrons following one another in a stream.) This particular kind of wave-particle instability is called a stream instability.

There will always be some streaming in a magnetically confined plasma. For example, the interaction of the magnetic field with the plasma generates streaming currents at the plasma surface. Strong instabilities fed by these currents have been discovered and identified in several experiments. They can probably be controlled by attacking their source: the currents. The currents become weaker with increasing magnetic field or plasma diameter; hence

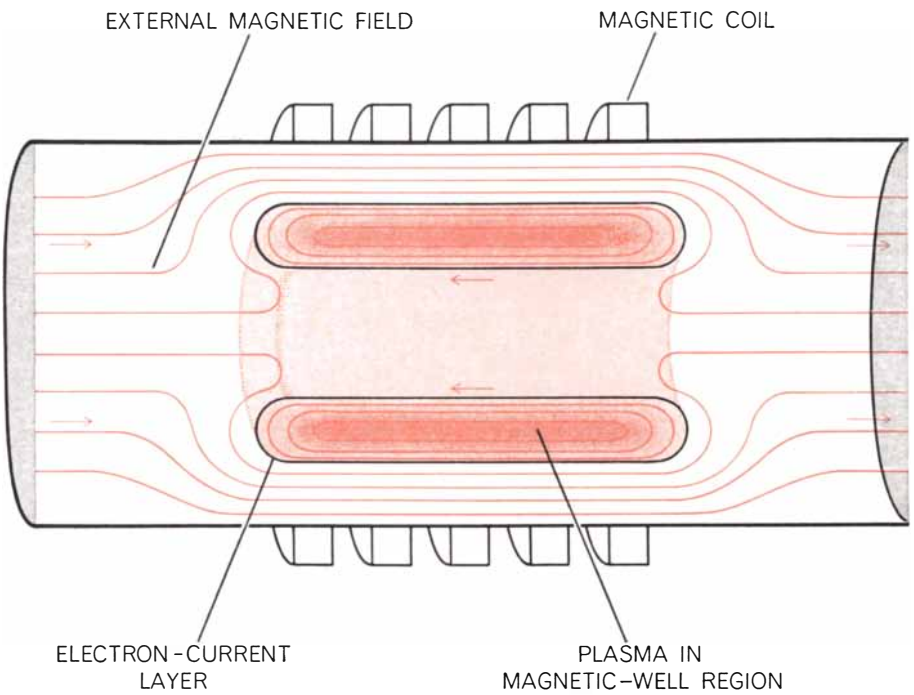
this source of instability can be reduced to a tolerable level by using intense magnetic fields and scaling up the plasma size. Predictions are that, if the motions of the plasma particles are otherwise random enough, a plasma diameter of a meter or so should suffice.

Another source of stream instability has been observed in plasmas confined in open-end mirror systems, even those of the magnetic-well type [*see illustration at bottom left on page 31*]. As we have seen, in mirror systems particle leakage through the ends leads to an excess of particles moving largely perpendicularly to the magnetic-field lines over those moving parallel to the field lines. This means that the particles move preferentially in a transverse direction and net streaming exists. In systems with weak mirrors or plasmas whose particle motions are not random enough this effect is marked and leads to the strong stimulation of instabilities.

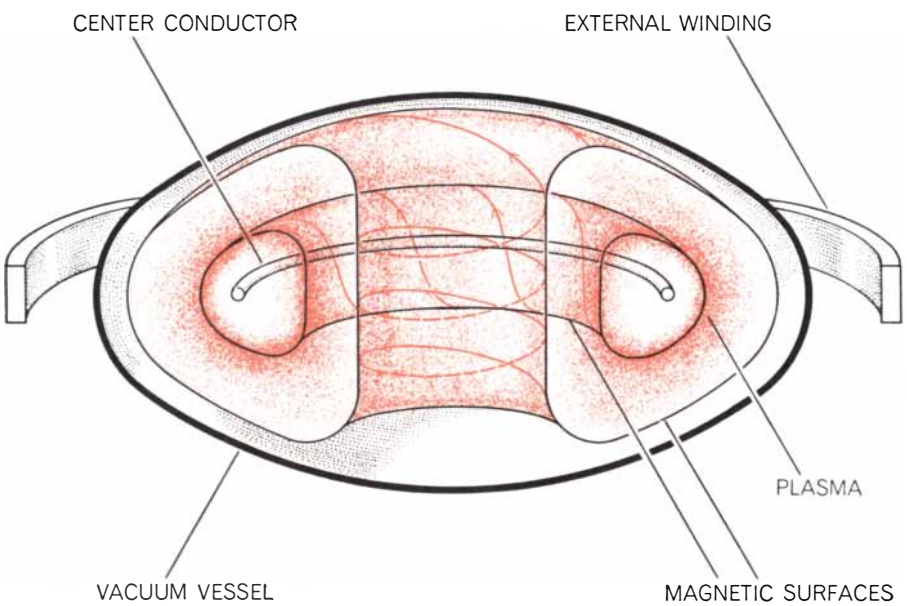
A process acting to inhibit wave-particle instabilities in mirror systems is the absorption of the waves at the ends of the plasma. One mechanism by which such absorption takes place in a plasma is the phenomenon of Landau damping. This effect, the opposite of the amplifying mechanism of the wave-particle instabilities, arises when a wave moves through the plasma at a speed slightly higher than the average particle speed. Particles caught in the trough of the wave will be speeded up, thus extracting energy from the wave and attenuating it. In one of the fundamental experiments of modern plasma physics the theory of Landau damping has recently been precisely verified. The experiment provided a critical test of the concept of the resonance of particles and waves, which underlies the entire theory of wave-particle instabilities [*see illustration at bottom right on page 31*].

Having outlined the theoretical problems of fusion research and described how these problems are being tackled, let us turn to some of the technical problems of such research—how one develops the hardware for testing or implementing the theories. Pacing fusion research today is a highly sophisticated and rapidly advancing technology. Only a few years ago some of today's most significant fusion experiments could not have been performed at all. No doubt these same experiments will seem primitive compared with those soon to come.

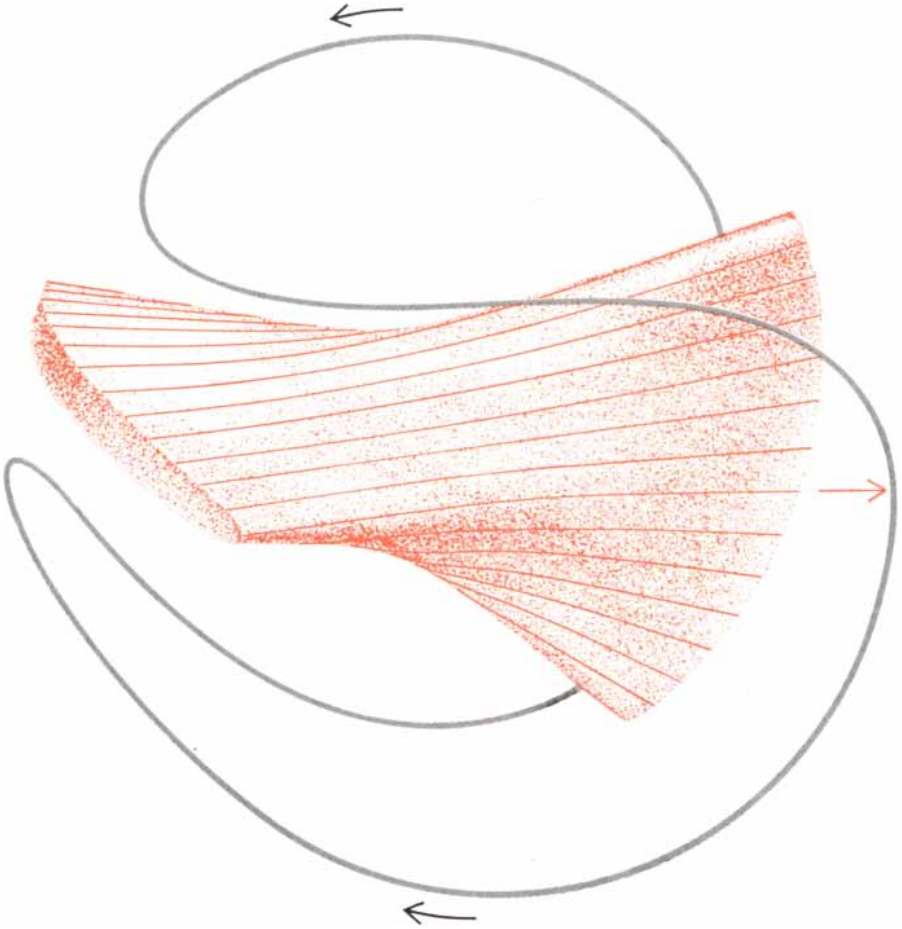
In order to experiment with high-temperature plasmas one must first make them. Three general methods have been used, and a highly intriguing fourth one is now under test. The effort to produce thermonuclear plasmas began with a comparatively simple method that creates the plasma *in situ*. The container is filled with a cold gas, the confining magnetic fields are turned on, and the process of ionizing and heating the gas is started by initiating an electric discharge in it. A heavy electric current is then passed through the plasma to



ASTRON CONCEPT, under development at the Livermore branch of the Lawrence Radiation Laboratory of the University of California, will employ a layer of high-speed electrons (called an *E* layer) in conjunction with magnetic coils to produce a magnetic well in which field lines close within the well region. Such a closed magnetic well can exist only inside a region in which current flows. The *E* layer forms such a region. It is expected that collisions between the energetic electrons and plasma will produce fusion temperatures.



TOROIDAL SHEARED-FIELD DEVICE called a "spherator" is being designed and built by the Plasma Physics Laboratory at Princeton University. It will create a closed magnetic surface in which plasma is contained. Shear is produced because the magnetic-field lines (*color*) follow different paths on different magnetic surfaces. An "average" magnetic well is created: that is, the average strength of the field is at a minimum where plasma is located.



"BASEBALL COIL" GEOMETRY is under test at the Lawrence Radiation Laboratory in Livermore. Its coil, shaped like a baseball seam, should produce a deep magnetic well.

further ionize it and raise its temperature. More recently, strong additional heating has been provided by exposing the plasma to powerful electromagnetic waves at a frequency that resonates with some natural frequency of the plasma particles' motion (for example their cyclotron frequency).

In the second method plasma accelerated from a "gun" at high velocity is injected into an empty magnetic field, usually weakened momentarily to allow the burst to penetrate it and be captured. Like the first method, this is a one-shot technique producing a single transiently confined blob of plasma. In both methods powerful additional heating can be provided by pulsing up the strength of the magnetic field, thus compressing the plasma.

The third method employs a steady stream of high-energy particles injected into the field, so that the system can be operated continuously [*see illustration on page 23*]. Since the field can be readily penetrated by particles that are electrically neutral, the simplest approach is to use a beam of energetic atoms. A beam of ions is first created and accelerated to an energy of many thousands of electron volts. The beam is then passed through a cell containing gas at low pressure, where it picks up electrons from the gas atoms (losing little energy in the process). The beam of reconstituted atoms then passes into the confining magnetic field, where some of the atoms are again broken down into ions and electrons by collision with the particles already trapped. In this way the new particles are themselves trapped, and under favorable circumstances the plasma density may "bootstrap" itself to higher values.

All these methods have been developed to the point where they can produce plasmas at thermonuclear temperatures. Creation *in situ* has been used in both open and closed systems. The injection methods are most often used in open-end systems but are being adapted for closed ones as well.

The method under test is an entirely novel one that uses lasers. A laser beam is focused on a point deep within an empty confinement chamber. With the magnetic field turned on, a pellet (for example a pellet of lithium hydride or frozen hydrogen) is dropped from the top of the chamber; at the precise moment it reaches the focal point the laser beam is pulsed on, vaporizing the pellet and forming an expanding cloud of highly energetic ions and electrons—in short, a dense hot plasma.

Another vexing problem in creating a viable hot plasma is the necessity of protecting the plasma from impurities that would quench its heat. Before the plasma can be created the chamber must be highly evacuated, in some experiments to less than a millionth of a millionth of atmospheric pressure. To achieve this antiseptic purity the inner walls of the chamber are coated with monomolecular layers of a refractory metal such as molybdenum or titanium and are kept at a cryogenic temperature to prevent any evaporation from them. These techniques, perfected originally for plasma research, have now been adopted in other fields, for example in the space program, where they are used in the construction of evacuated chambers to simulate the vacuum of interstellar space.

The workhorse of fusion research is the magnetic field, and it is in this area that some of the most spectacular technological developments have taken place. Confinement of a hot plasma calls for fields of very high intensity, sometimes approaching a million times the intensity of the earth's magnetic field. In some experiments the fields must be pulsed on in a few millionths of a second, to catch, compress and heat the plasma. Generating such fields requires heavily braced coils carrying millions of amperes, huge condenser banks and specially constructed transmission lines that can deliver the required current within microseconds. In experiments where a continuous field is required—for example those employing a beam of electrically neutral atoms—the coil power consumption may be enormous. An example is the "baseball coil" (named for its resemblance to the seam on a baseball), which is designed to produce a deep magnetic well [*see illustration on this page*]. If this coil were operated at ordinary temperatures, it would require some 50 million watts of power. To reduce the power required the coil is cooled to the temperature of liquid nitrogen (−195 degrees C.), which cuts the demand tenfold. Even so, the coil can be operated only intermittently because of its large consumption of liquid nitrogen.

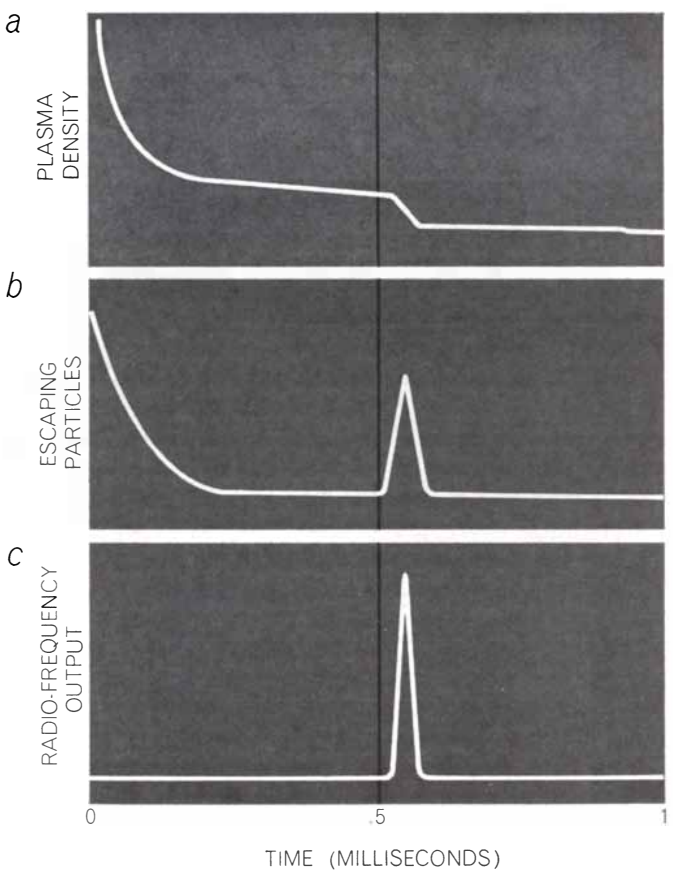
Since magnetic fields are essential to fusion research, and no doubt to the future of fusion power, fusion researchers

are intensely interested in the recent discovery of "hard" superconductors. These are alloys that not only lose all their electrical resistance when cooled to temperatures near that of liquid helium (4.2 degrees C. above absolute zero) but also resist the tendency to lose their superconducting state in a strong magnetic field. With such conductors magnetic coils that would require hundreds of millions of watts if wound with copper can now be energized with no expenditure of energy except the energy stored in the magnetic field. Once "charged up" such a magnet can be short-circuited on itself, and current will continue to flow through it indefinitely. Keeping such coils cooled to the temperature of liquid helium is not a serious problem, because in many experiments the walls of the chamber must be cooled to cryogenic temperatures in order to maintain high-vacuum conditions. A small baseball coil embodying such ideas has already been wound and tested. The cable in the coil carries 500 amperes, yet it is smaller in cross section than conductors used in ordinary household circuits.

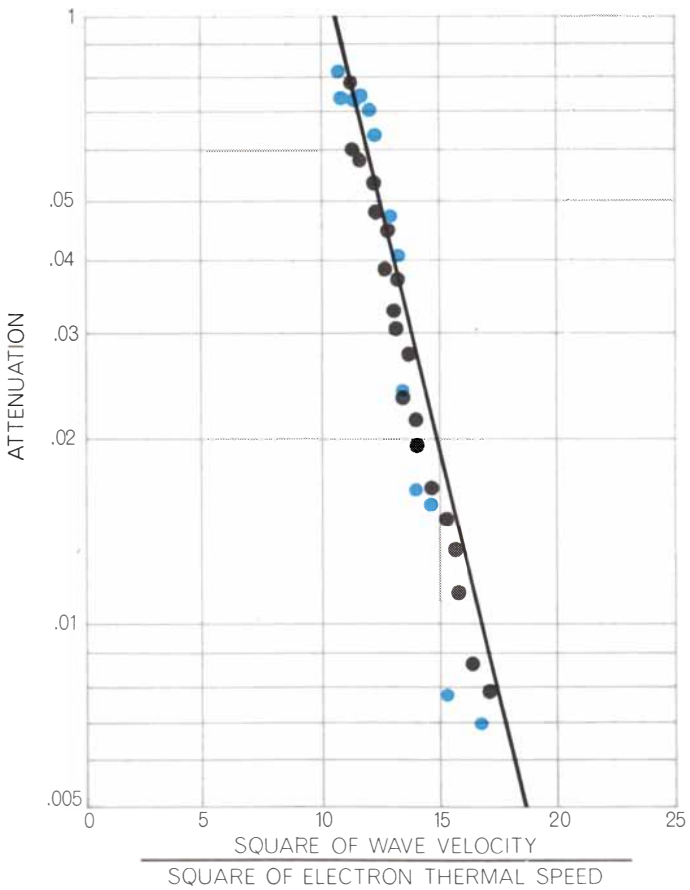
Some of the most interesting technological developments in high-temperature plasma research have come in solving problems of measurement. To observe the behavior of a very hot plasma requires special tricks. Direct measurements can rarely be made; any physical obstacle inside a hot plasma would either be instantly vaporized or would soon intercept a large fraction of the plasma particles. Ingenious methods of indirect measurement have therefore been devised for probing the plasma. Temperature and density can be measured by analyzing X rays emitted from the plasma or by studying particles escaping from it. It has even become possible to make a snapshot of the plasma by shooting a laser pulse (only millionths of a second in duration) down its length [*see illustration on page 22*].

We have undertaken here to describe progress toward the goal of fusion power. It is of course highly encouraging that such efforts have already begun to yield successful principles of plasma stabilization. Powerful concepts such as the magnetic-well principle and short circuit by magnetic shear, and guidelines from thermodynamics, give direction to the research. Important as these principles are, the accumulating understanding of plasma physics is of even greater significance. Plasma theory has developed from simple fluid models to detailed analysis of plasma waves and how they grow. We have also seen a progressive sophistication in the experiments that test and guide the theory.

The effort to obtain power from fusion is rather like the efforts of the blind men to describe the elephant by exploring its various parts. We are making steady progress in understanding our elephant, but we cannot yet claim to be able to draw a picture of it: a workable scheme for fusion power. Still, the outline is taking shape. We have little doubt that the beast exists, and that the dream of extracting unlimited energy from the seas will one day become a reality.



WAVE-PARTICLE INSTABILITIES in a magnetic well are shown in these curves from a typical experiment. The sudden drop in plasma density (*a*) coincides with a sharp peak in the number of escaping particles (*b*) and is accompanied by a burst of radio-frequency energy at the cyclotron frequency of the ions in the plasma (*c*). The results shown here were published by the Russian workers Yu. T. Baiborodov, Yu. V. Gott, M. S. Ioffe and E. E. Yushmanov.



"LANDAU DAMPING" EXPERIMENT confirms a prediction of how waves and particles interact in a heated plasma. Theory predicts (*black line*) that attenuation, or damping, should decrease sharply with increasing wave velocity. Black and colored dots show measurements made at two different electron temperatures near 100,000 degrees C. by John H. Malmberg and Charles Wharton of General Atomic Division of the General Dynamics Corporation.

The Genetic Control of the Shape of a Virus

The protein shell of a virus is an assembly of subunits. In simple viruses the subunits themselves may specify the shape of the shell. Complex viruses seem to be formed on an interior core, or scaffold

by Edouard Kellenberger

Living things are enormously diverse in form, but form is remarkably constant within any given line of descent: pigs remain pigs and oak trees remain oak trees generation after generation. The morphological character—the form—of a species is inherited, and this hereditary information must surely be contained in the genes; indeed, genes that determine morphological traits have been identified in many plants and animals. So far, however, little is known about how these genes carry out their morphopoietic, or form-making, function. For the general study of the morphopoietic function a particularly suitable group of organisms is the viruses: a virus has shape (a precisely defined shell of protein) and hereditary information (a core of nucleic acid) and not much else. Among viruses the bacteriophages, the viruses that infect bacteria, are especially convenient subjects of investigation because their genetics is accessible to manipulation and experimentation. In the past decade a number of investigations, in our laboratory at the University of Geneva and in many other laboratories, have been directed at trying to learn how viruses control the process by which they assemble themselves in characteristic shapes.

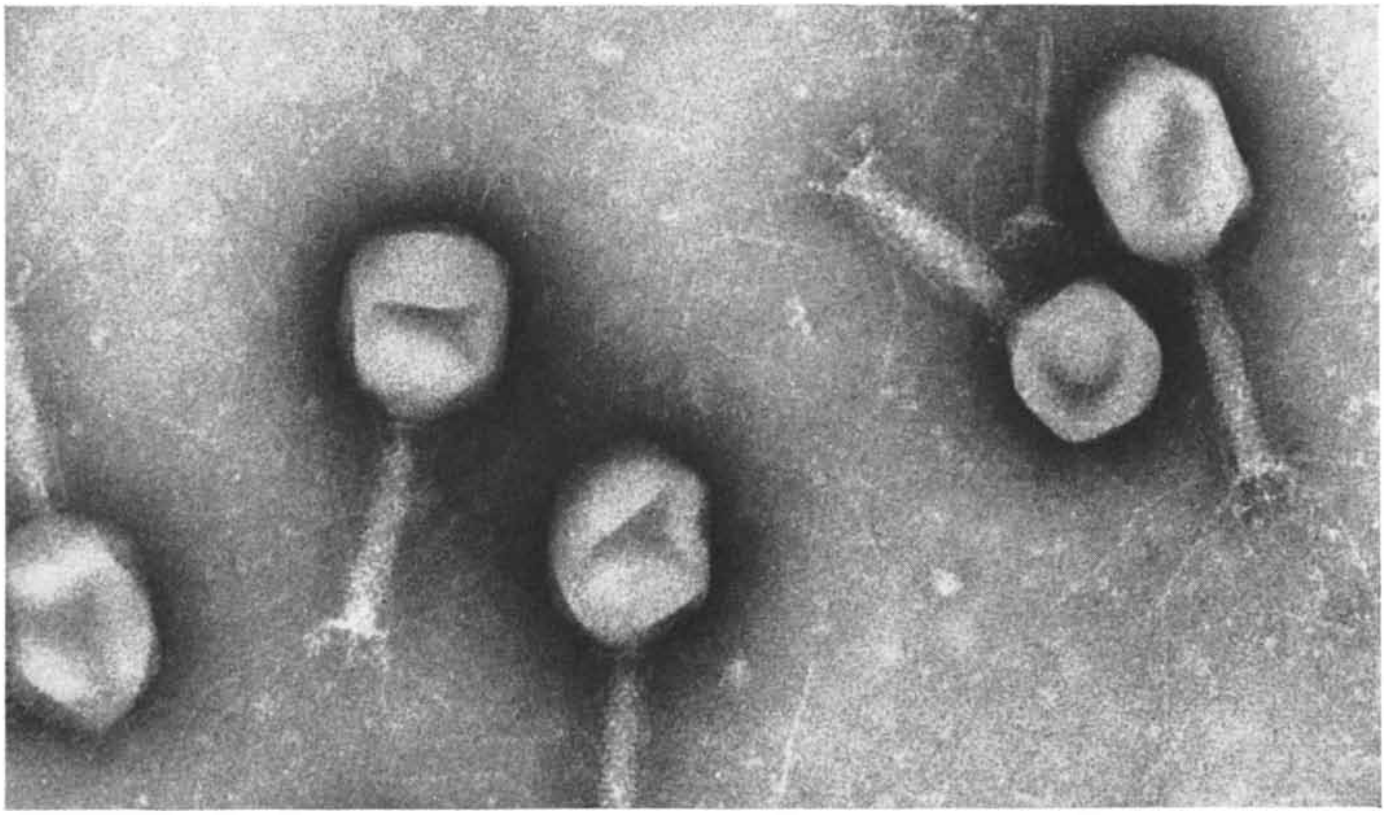
As viruses go, bacteriophages have a rather complicated structure, so I shall first describe some simpler viruses. One of the simplest is the virus that causes the mosaic disease of tobacco, and this virus is the only one that has been taken apart and then reassembled in the test tube [see "Rebuilding a Virus," by Heinz Fraenkel-Conrat; SCIENTIFIC AMERICAN, June, 1956]. The tobacco mosaic virus has the form of a rod: a cylindrical assembly of protein subunits with a long molecule of ribonucleic acid (RNA) inside the cylinder. Treatment with acetic acid separates the virus into an RNA molecule and some 2,000 protein subunits. When the protein fraction is spun in an ultracentrifuge or otherwise analyzed, it is found to be homogeneous, that is, all the protein subunits are alike. If this fraction is in solution under the appropriate ionic and temperature conditions, rods form that are nearly indistinguishable from the active virus particles. Apparently the protein subunits can assemble themselves into these geometrically defined rods without any outside help; the subunit contains all the information needed to build the rod.

Such self-assembly of identical subunits is not hard to understand. Imagine a two-dimensional array of identical subunits [*see top illustration on page 34*]. The shape of these imaginary subunits is such that they can assemble only into a ring of a certain size, even though each subunit is asymmetric and its shape is unrelated to that of the ring. Such subunits are said to have a stringent fit; they are fully shape-specifying and cannot join to form any shape other than the specified ring. Similarly, three-dimensional subunits can be imagined that will assemble into cylindrical or spherical shells [*see bottom illustration on pages 34 and 35*]. In each case the shape of the subunits is fully shape-specifying, so that each set can make only a single geometric structure of a fully determined shape and size. Note, however, that in the two cylinders illustrated the difference between the shapes of the subunits is very slight. This implies that a single subunit might be designed that could give rise to both cylinders. Such subunits would not be fully shape-specifying; some outside influence—even if it were only chance—would have to determine which kind of assembly was to prevail. This theoretical prediction has been verified for the tobacco mosaic virus: the reassembled rods can exist in either a helical or a "stacked disk" form.

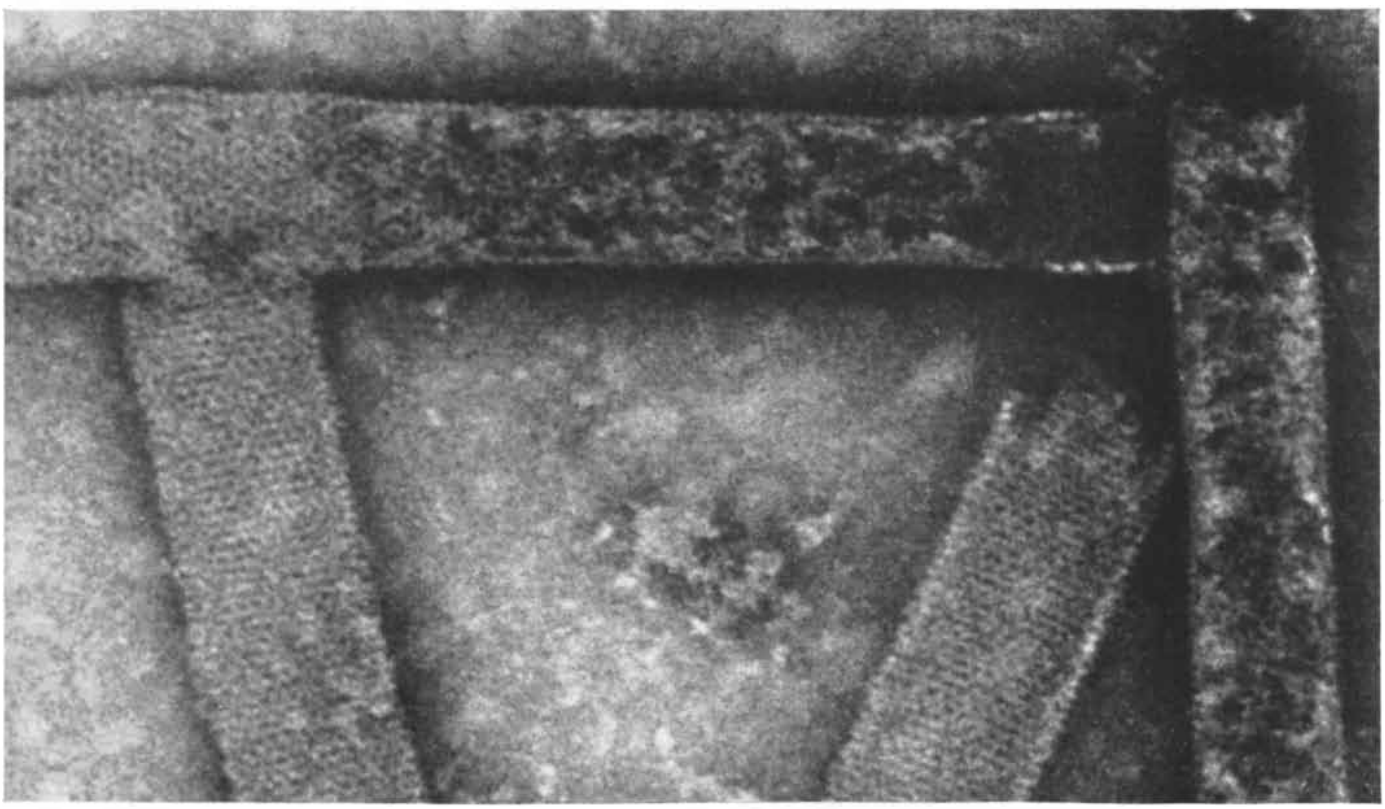
Here I should point out that any geometric model of subunit assembly is somewhat naïve. A protein molecule consists of amino acid units arranged in a linear sequence according to information in the genes. Each chain (the primary structure) is coiled into a complex three-dimensional shape, and often chains are combined (the secondary and tertiary structure). The resulting molecule is not a sharp-edged geometric object but an assembly of curved, sausage-like elements, and its fitting properties depend not only on shape but also on the location and specificity of chemical bonds. In other words, what is involved is a stereochemical fit, and this can be represented only figuratively as a purely geometric phenomenon.

One more statement can be made about the inheritance of shape in viruses. When all the shape-specifying information is contained in one protein and therefore in one gene, the assembly is called a morphopoiesis of the first order. When additional information is contributed by other genes, the morphopoiesis is said to be of a higher order, the order of morphopoiesis equaling the number of implicated, independent "bits" of information.

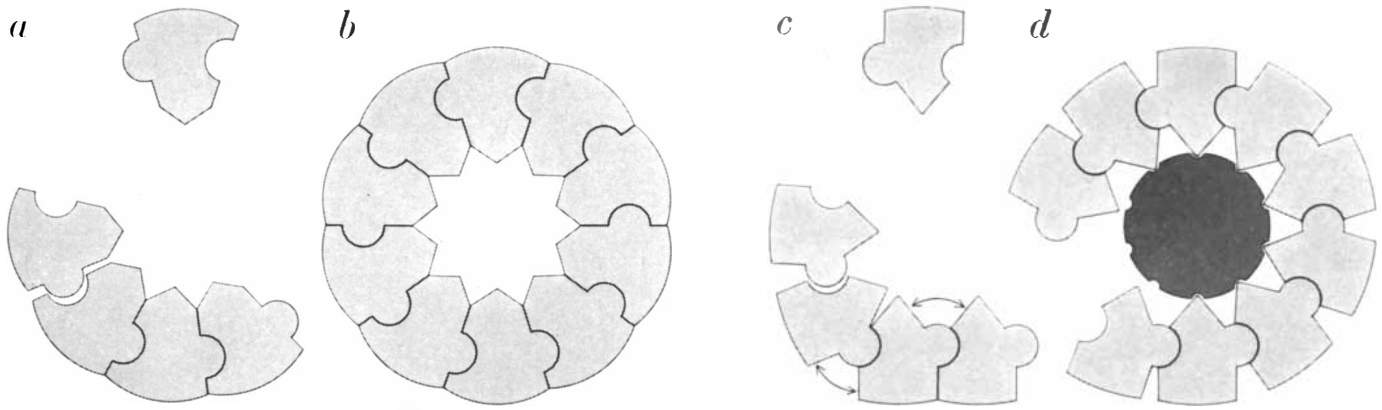
Most viruses that infect animals are



T4 BACTERIAL VIRUS, or bacteriophage, is complex in form: a polyhedral head with an elaborate tail assembly. The head capsid, or shell, is an assembly of protein subunits. It may be shaped by a morphopoietic, or form-making, core on which subunits are laid down. Such a scaffolding is presumably defined by morphopoietic genes. When the virus is mutant in one of these genes, No. 66, a short-headed variant is made (*second from right*). For this negative-contrast electron micrograph made by E. Boy de la Tour at Kansas State University the viruses were embedded in phosphotungstate, an electron-dense material. Viruses are enlarged 260,000 diameters.



"POLYHEADS," produced when virus is mutant in gene No. 20, are tubular assemblies of protein subunits. Unlike normal heads, they contain no deoxyribonucleic acid (DNA), but they are not always empty. This micrograph made by R. Favre and Boy de la Tour at the University of Geneva shows some full portions; they are not as flat as empty portions and are therefore surrounded by more dark phosphotungstate. The material inside them may be what is left of morphopoietic cores. Polyheads are enlarged 260,000 diameters.



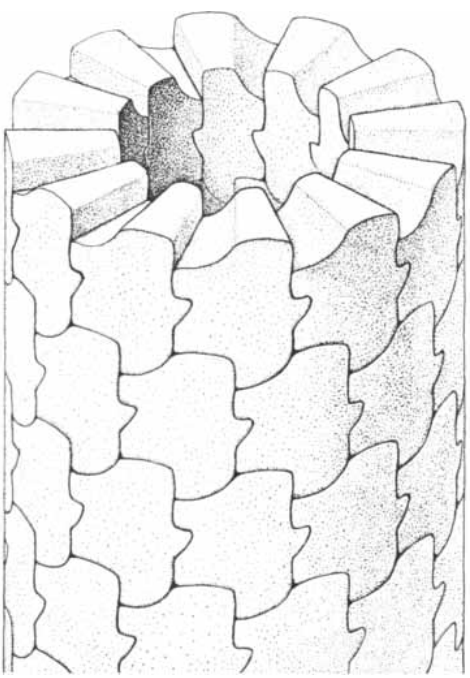
IDENTICAL SUBUNITS that have stringent fit (*a*) can assemble only into a specific ring (*b*); they are fully shape-specifying. Subunits with less stringent fit (*c*), however, assemble into a somewhat flexible chain that can assume many shapes unless there is a scaffold of some kind, such as a morphopoietic core (*d*). Once the ring has been shaped it should persist even if the core is removed.

not rod-shaped like the tobacco mosaic virus but nearly spherical. As long ago as 1956 F. H. C. Crick and James D. Watson suggested that small spherical viruses probably consisted of a number of identical protein subunits; they argued that this would represent the most efficient use of the genetic information in the small amount of nucleic acid inside the virus. Now, identical subunits bound together at specific sites must necessarily be arranged in a regular pattern that can be called a surface crystal. Analysis of spherical viruses by X-ray diffraction indicated that their surface crystal had a cubic symmetry—that is, a symmetry along three mutually perpendicular axes—and were therefore regular polyhedrons of a certain class. As the spherical viruses have been subjected to further X-ray analysis, to electron microscopy and to chemical study, it has become clear they are composed of subunits assembled into a capsid, or shell, that usually has the shape of an icosahedron: a polyhedron with 20 faces (each an equilateral triangle), 30 edges and 12 vertexes [see "The Structure of Viruses," by R. W. Horne; SCIENTIFIC AMERICAN, January, 1963]. D. L. D. Caspar of the Children's Cancer Research Foundation in Boston and Aaron Klug of the University of Cambridge have concluded after exhaustive investigation that there are compelling reasons, having to do not only with geometry but also with bonding properties and energy content, why icosahedral forms are the most likely.

How might an icosahedral surface crystal be formed from an array of asymmetric shape-specifying subunits? Consider a hexagonal lattice of arbitrary shapes in which groups of six shapes (hexamers) and three shapes (trimers) can be distinguished [*see top illustration on page 36*]. If a 60-degree sector of the pattern is removed, the edges can be rejoined, forming a cone. The lost segment is not missed; the shapes still fit one another exactly as before, but at the vertex of the cone a hexamer has been replaced by a group of five shapes (a pentamer). If 12 adjacent hexamers are taken as centers for the removal of 60-degree sectors, the result is the smallest icosahedron that can be built from this lattice [*see top illustration on page 37*]. It has 12 vertexes, each the center of a pentamer, and therefore has 60 identical subunits. The subunits of this minimal icosahedron are in perfect symmetry: each is in an "equivalent location," and when the shell is rotated any subunit can lie directly above another one. Clearly such a capsid could result from the assembly of 60 subunits that have stringent stereochemical fit. Thus an icosahedron can, at least in principle, be the result of first-order morphopoiesis: the subunits can be imagined to have complete shape-specificity.

This does not hold, however, for shells with more than 60 subunits. Caspar and Klug showed that larger shells are not perfectly symmetrical and that their subunits are only in "quasi-equivalent" locations. Quasi-equivalence makes possible the assembly of many more than 60 subunits into somewhat distorted shells that have icosahedral symmetry. In such cases there are variations of as much as 5 degrees in the angles of the bonds between subunits, the surface crystal has a variable curvature and the shell is somewhat flexible. This reduced stringency of fit represents a reduced content of information. Whether or not the information remains sufficient for first-order morphopoiesis is still not known. One has the feeling, however, that these large shells are not stable configurations until they have been completed. Caspar compares them to an arch, which requires some kind of scaffolding until the keystone has been fitted.

To proceed to more complex shapes, let us consider a capsid that does not have cubic symmetry—that is not, so to speak, the same shape in all directions. In our laboratory we have been studying the bacteriophage called T4, which infects the colon bacillus. One of the more complex viral structures, the T4 particle consists of a polyhedral head and a tail assembly with a number of different components [*see bottom illustration on pages 36 and 37*]. We have been concerned primarily with the morphopoiesis of the head. Recent investi-



STRINGENT SUBUNITS assemble to make cylindrical and spherical shells. A cylindrical rod (*left*) is built from a translational

gations by M. F. Moody of the California Institute of Technology and in our laboratory indicate that the design of the head capsid can be represented by a folded hexagonal lattice; it is therefore closely related to the surface lattices of icosahedral shells. Whereas the icosahedron has axes of fivefold, threefold and twofold symmetry, however, the T4 capsid has only fivefold and twofold symmetry.

The shape of the T4 head capsid might be called a prolate icosahedron. It consists of the two pyramids of an icosahedron (each having a vertex with five facets) separated by two "equatorial bands" cut from an icosahedron. If the assembly of such a shape begins with a pyramid and proceeds to the addition of one equatorial band, something must influence the subunits to form a second band or they will close the shell into the usual kind of icosahedron. Some morphopoietic factor must exist that chooses one vertex to become the top of a pyramid and then enforces the building of two equatorial bands instead of only one. It must be a "long range" factor that is somehow able to relate two geometrically defined sites that are rather far apart.

What kind of factor it is we do not know. Two hypotheses have been formulated. The first supposes that the factor is contained in the virus shell—that it is a chemically distinct minor component of the capsid. The second supposes that the factor acts on the growing capsid from the inside or the outside, somewhat like a scaffold.

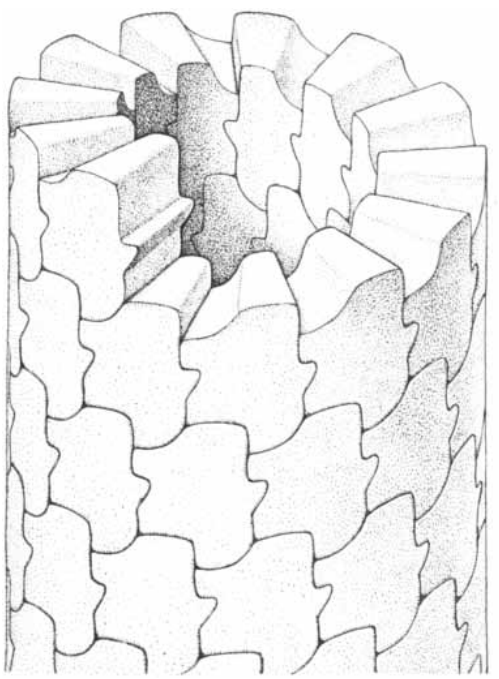
There are observations and experiments that tend to support both hypotheses. Several investigators have established that the capsid of viruses in the group called the adenoviruses contains more than one protein; they have shown that different subunits react differently to an antiserum. In other viruses, including the T4 virus, the presence of two or more types of subunit has been demonstrated by the fact that subunits move at different speeds in an electric field, so that either their volume or their electric charge (or both) must be different. In none of these cases, however, has a morphopoietic role been demonstrated for the minor components; it is possible that they have another function.

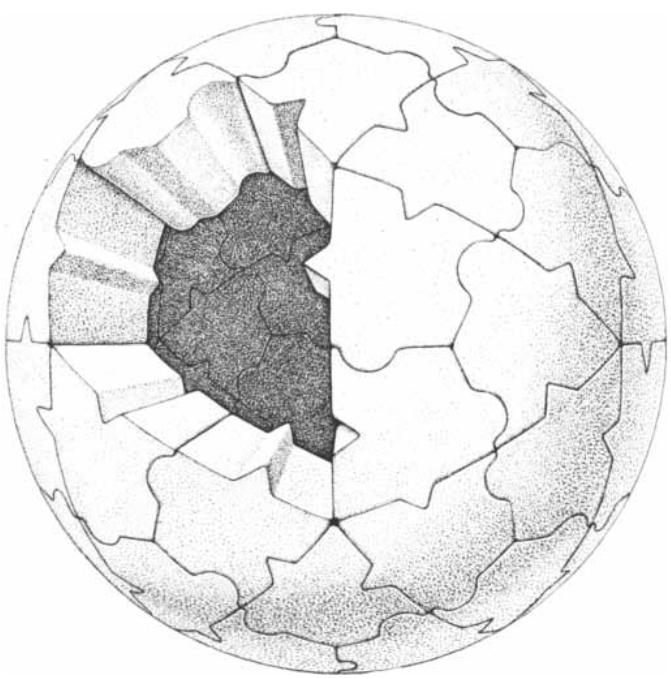
The favored version of the second hypothesis—the scaffold hypothesis—envisions a morphopoietic core: a geometric body consisting of a minimum number of subunits that is built first and on which the capsid subunits grope their way into position before being linked together. The proper shape is thus forced on the capsid by the core, which stays inside the capsid, intermixed with the nucleic acid. Some time ago it was found that proteins are present inside the T4 head; these may be core proteins.

The genetics of the T4 virus has been thoroughly investigated, and more than 70 different genes for various characteristics of the virus have been mapped [see "The Genetics of a Bacterial Virus," by R. S. Edgar and R. H. Epstein; SCIENTIFIC AMERICAN, February, 1965]. The products of at least seven of these genes have been found to be essential for the assembly of a complete, stable virus head. If a mutation occurs in one of the genes and its product is therefore imperfect or missing, no normal head capsids are produced [*see top illustration on page 38*].

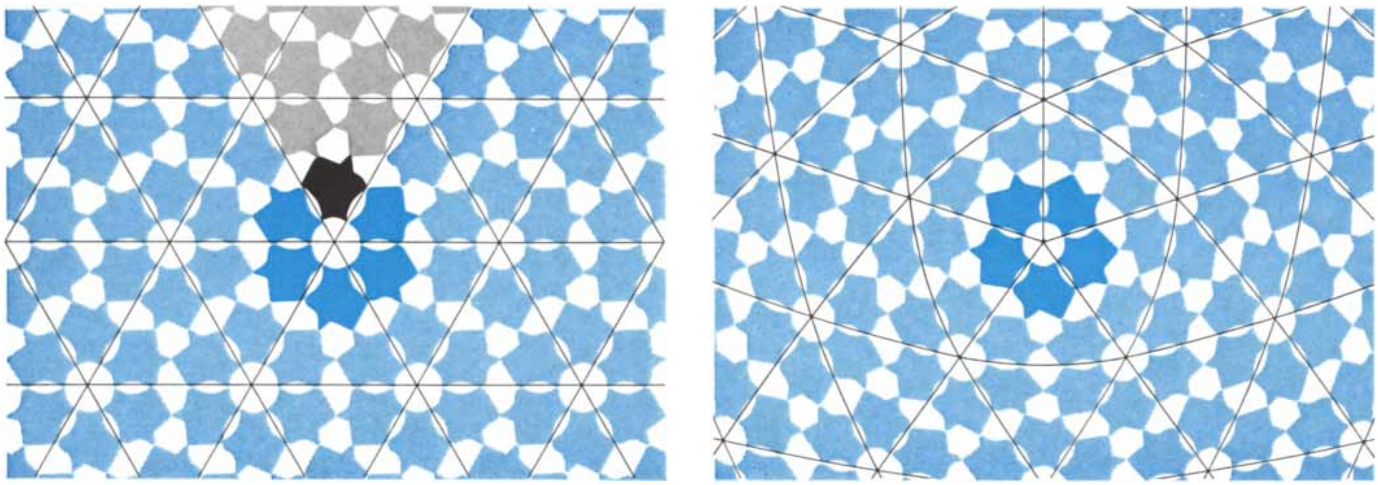
Gene No. 23 is responsible for the major subunit of the capsid, which accounts for about 80 percent of the protein of the complete virus particle. A morphopoietic function has been established for two other genes: No. 66 and No. 20. Gene No. 66 directs the synthesis of an "elongation factor," without which normal prolate virus heads are not produced. Instead abnormal short heads are made; these particles contain about 20 percent less deoxyribonucleic acid (DNA) than normal virus particles and are therefore not active. Gene No. 20 apparently produces a "rounding up factor" that closes off the icosahedral shape. When it is missing or ineffective, long tubular heads that we call polyheads are made, as if the elongating factor were running wild.

Four more genes are known to be essential for the formation of stable head capsids. Two of them, No. 22 and No. 24, have yet to be identified with any





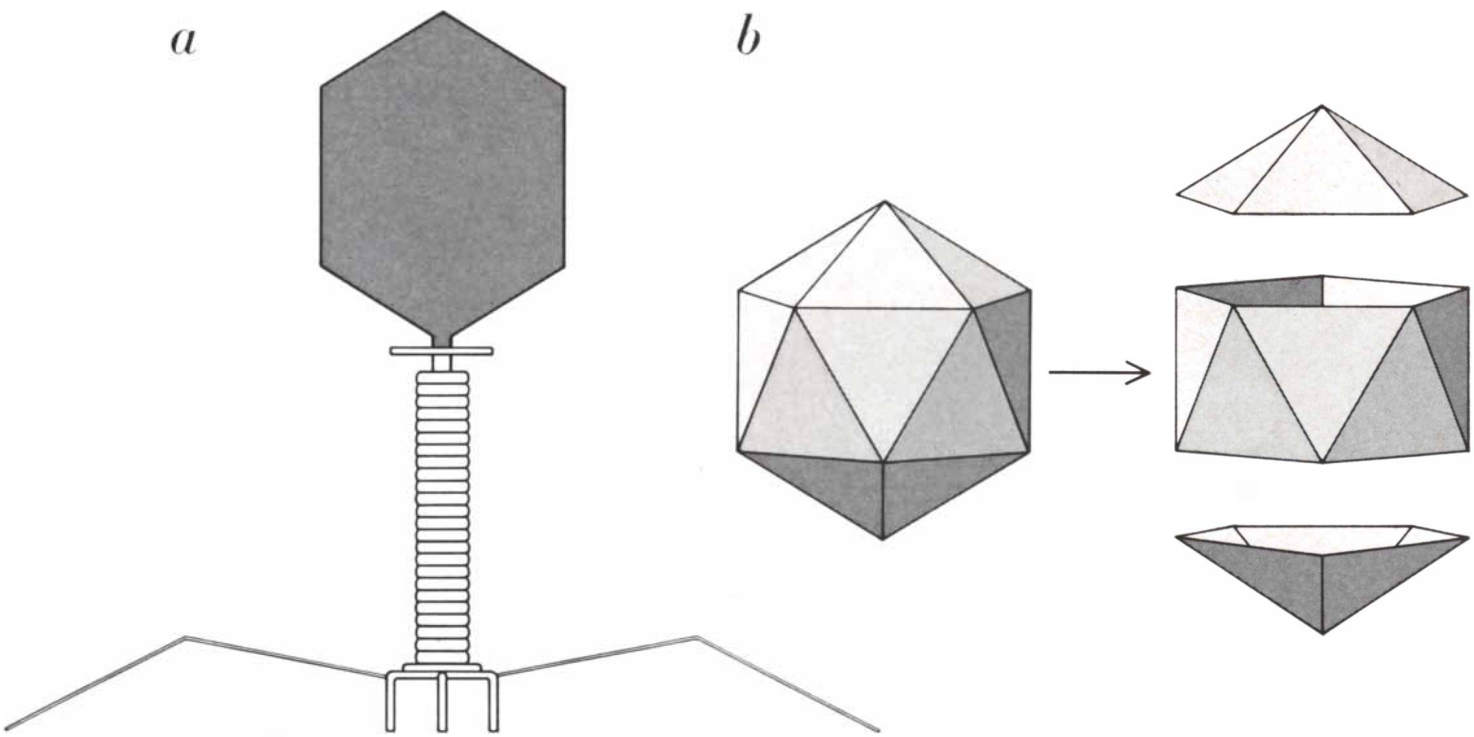
lattice, or a net of subunits arrayed side by side. Very slightly different subunits form a lattice that folds into a helical rod (*center*). A different kind of lattice, a hexagonal net with rotational symmetry, is the source of the sphere (*right*). It has 60 identical subunits arranged in pentamers, or groups of five. Five of these subunits have been removed in the drawing to show the structure.



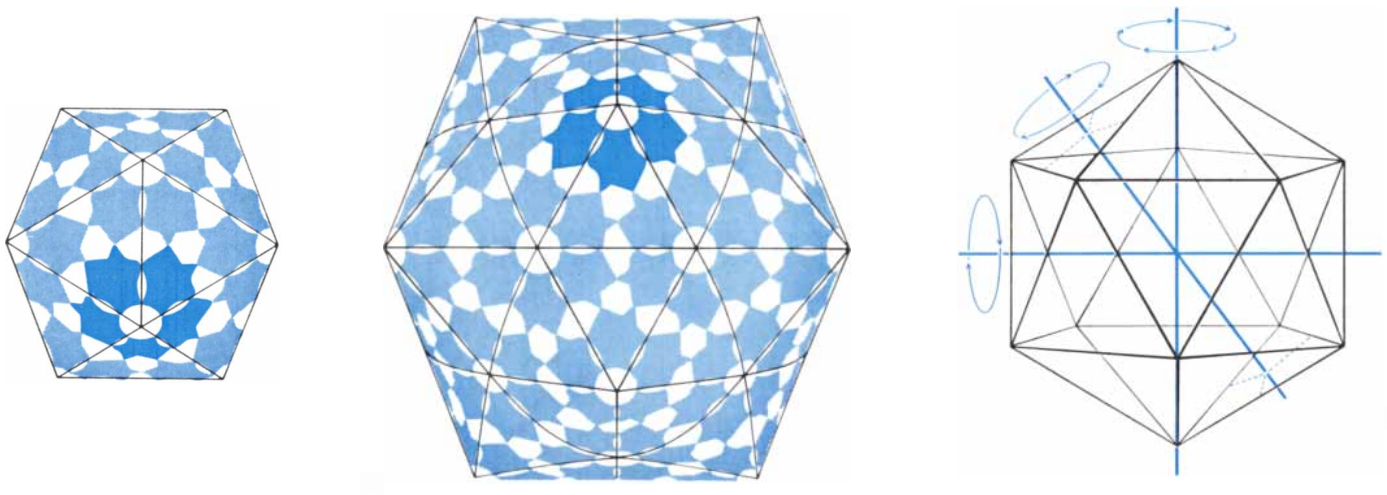
VIRUS SHELL can be visualized as being folded from a hexagonal lattice of asymmetric shapes (*left*) in which groups of six shapes (hexamers) can be distinguished (*dark shapes*). If a 60-degree sector is removed from such a lattice, the edges can be rejoined without disturbing the fit of the shapes; a cone is formed and a hexamer is replaced by a pentamer. This illustration is based on a pattern devised by D. L. D. Caspar of the Children's Cancer Research Foundation and Aaron Klug of the University of Cambridge.

specific function. The absence of gene No. 21 induces the formation of abnormal heads that apparently contain no DNA or only very small amounts of it. Gene No. 31 contributes a "solubility factor," without which the major protein derived from gene No. 23 aggregates into lumps instead of staying in solution and is therefore not available for the assembly of the capsid. Two of my students have demonstrated the action of gene No. 31 both in the test tube and in living cells of the bacterium infected by the T4 virus. If one applies the product of this gene to disrupted cells that contain lumps of the major virus protein, the lumps disappear. This test-tube result is confirmed with a particular mutant virus in which the product of gene No. 31 is inactive when it is formed at a high temperature but is activated as the temperature is lowered. When cells infected with this mutant are incubated at a high temperature, the lumps are produced; as soon as the temperature is lowered the lumps disappear and the redissolved product of gene No. 23 becomes available for virus assembly.

The fact that the same major subunit can be assembled into at least three morphologically distinct particles—the normal head, the short head and the polyhead—shows that the subunit derived from gene No. 23 is not fully shape-specifying. In an effort to understand how the head genes work we have concentrated on the polyhead, which appears to be a very simple variant. First we undertook to find out what order of



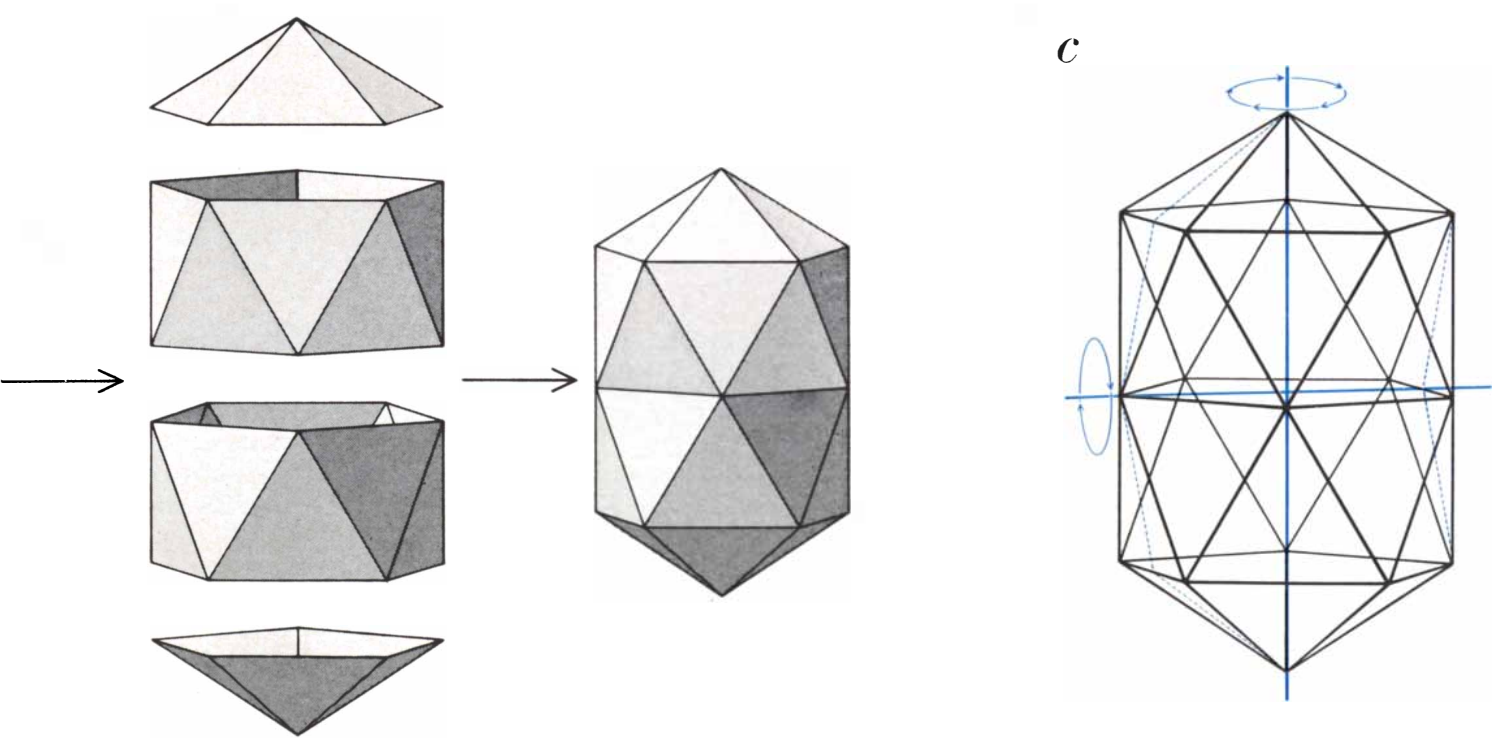
T4 BACTERIOPHAGE is shown schematically (*a*) as its form has been deduced from micrographs such as the one at the top of page 33. It now seems that the head capsid is a kind of prolate icosahedron. It is as if two pyramidal vertexes of an icosahedron



ICOSAHEDRON, a polyhedron with 20 faces and 12 vertexes, is built from the hexagonal lattice (*top of opposite page*). If each hexamer is converted into a pentamer, the result is the smallest virus shell for this lattice, a regular icosahedron with 60 subunits (*left*). The next larger shell for this lattice has 20 hexamers in addition to the pentamers, or 180 subunits (*center*). Like the shell at the left, it has icosahedral symmetry (*right*), that is, it has three kinds of axes of symmetry (*color*): fivefold, threefold and twofold.

morphopoiesis its assembly represents. To do so we made double mutants: viruses in which the functions of two head genes were blocked by mutations. In each case one mutation was in gene No. 20 (the polyhead gene) and the other in one of the other known head genes [*see bottom illustration on next page*]. The results indicate that polyheads are not formed without the active products of at least three genes: No. 23, No. 66 and No. 31. Since No. 31 produces a solubility factor, it is unlikely to contribute morphopoietic information. The other two, however, are certainly morphopoietic. We can say, then, that the morphopoiesis of polyheads is probably of the second order, with two independent functions carried out by the major protein of gene No. 23 and by the elongating factor of gene No. 66. This comparatively low order of morphopoiesis of the polyheads means that we can hope soon to know in detail just what the factors do; then it should be possible to isolate and purify them, learn their chemistry and eventually attempt to assemble polyheads in the test tube.

It is already clear that the shape-specifying information cannot be very stringent. This is indicated by the wide variability in the diameter of the polyheads and by the fact that various degrees of pitch can be imparted to the folded hexagonal lattice of subunits that forms a polyhead cylinder. The pitch can be measured because the polyheads in a sample prepared for electron microscopy are flattened and two layers of



were separated by two 10-faceted "equatorial bands" instead of by the usual one band (*four drawings at "b"*). Whereas the icosahedron has three classes of symmetry, however, the prolate bacteriophage capsid has only two classes: fivefold and twofold (*c*).

HEAD GENES							RESULT
20	21	22	23	66	24	31	
+	+	+	+	+	+	+	NORMAL HEADS
0	0	0	0	−	0	0	SHORT HEADS
−	−	−	+	+	−	+	POLYHEADS
0	−	0	0	0	0	0	"21 PARTICLES"
−	0	0	+	0	0	−	"LUMPS"
0	0	−	0	0	0	0	NO VISIBLE PROTEIN
0	0	0	−	0	0	0	NO VISIBLE PROTEIN
0	0	0	0	0	−	0	NO VISIBLE PROTEIN

FUNCTIONS of the seven head genes are illustrated. The table shows that for a given stage of synthesis to occur (*right*) certain genes must contribute their product effectively (+) and others must be nonproducing (−). In many cases the need for a gene product is not established (0). The table is based on investigations made by Sydney Brenner and his colleagues at the University of Cambridge and by the author's colleagues Boy de la Tour, Favre, F. Eiserling, R. S. Epstein, P. Geiduschek, G. Kellenberger and J. Sechaud.

hexagonal lattice are superposed. The moiré pattern this creates can be analyzed for information about the arrangement and orientation of the subunits.

The fact that the polyhead lattice is hexagonal tells us something else. A cylinder can practically build itself from a "translational" lattice in which the subunits are arrayed side by side. To fold a hexagonal net into a cylinder, however, is to subject it to a certain amount of stress and deformation. This is why it is unlikely that polyhead assembly would be a first-order morphopoiesis. Such reasoning provides theoretical support for the experimental results based on genetics.

As for the mode of action of the morphopoietic factors, our evidence is not yet conclusive. We do have some evidence against the idea that such factors are elements of the capsid itself. We isolated and purified normal and abnormal capsids and broke them down into subunits by treating the preparations with acetic acid or other agents. Then we analyzed the proteins by the technique of electrophoresis and established that the normal capsid contains two minor components in addition to the major component produced by gene No. 23. We were unable, however, to identify either of these minor proteins as the product of any known head gene. It therefore seems certain that the two known morphopoietic factors, the products of genes No. 66 and No. 20 that respectively govern elongation and rounding-up, are not present in the capsid.

The other possibility is that they are elements of a core that guides the assembly of subunits. We are far from proving this hypothesis, but the evidence for it is highly suggestive. Our electron micrographs indicate that all heads, normal and abnormal, do contain a core, whether or not they contain DNA. This is sometimes difficult to perceive, because cores that are not associated with DNA are severely affected by the process of fixation and staining for electron microscopy. For example, when polyheads are examined outside the bacterial cell (that is, after the cell in which they grew has burst and dissolved), most of them appear to be empty. When bacterial cells containing polyheads are fixed with great care and embedded in other material so that thin sections of them can be cut, the micrographs show that the polyheads have something inside them. The contents of the polyheads vary in appearance according to the method of fixation, but the polyheads in cells prepared in just the right way do show a definite architecture [*see top illustration on opposite page*]. This high degree of order indicates that what we are seeing is not just coagulated cell sap but a specialized structure.

Similar structures are visible in the particles produced when the product of gene No. 21 is nonfunctional [*see bottom illustration on opposite page*]. These particles are smaller than normal virus heads and contain no DNA or only a very small amount of it. They have a similar prolate shape, however, and each of them has a well-organized core.

One other point is pertinent in this connection. In the past the fact that virus preparations always contain some empty particles has led some observers to conclude that capsids can be built without the help of a core. The existence of empty shells does demonstrate that cap-

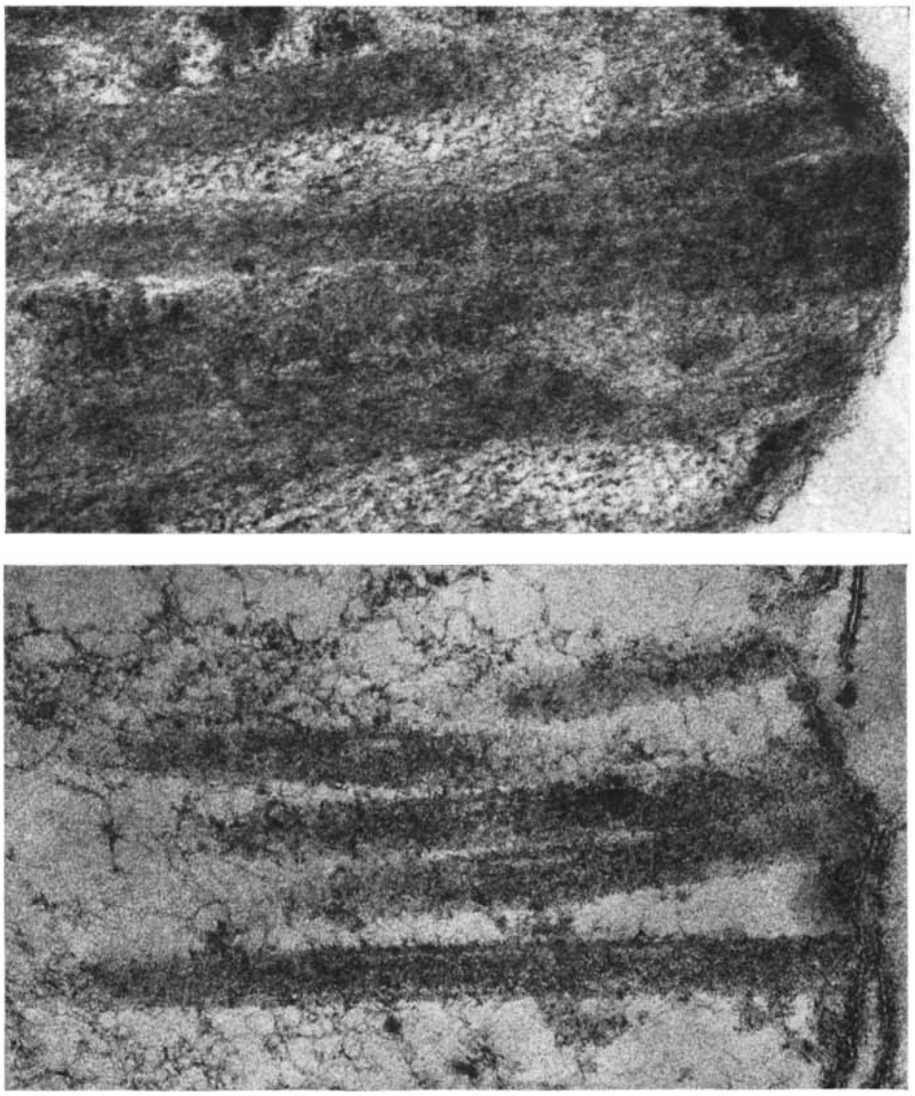
MUTANT GENES	POLYHEADS PRODUCED (MICRONS PER BACTERIUM)
20	30–100
20, 21	26
20, 22	24
20, 23	NONE
20, 66	VERY FEW, MALFORMED
20, 24	20
20, 31	NONE

DOUBLE-MUTANT experiment showed which genes must contribute their product to form polyheads. When only gene No. 20 was mutated, 30 to 100 microns of polyhead were formed per bacterium. Polyheads were formed in spite of double mutants except in the cases of genes No. 23, 66 and 31, so clearly those three genes are needed to make polyheads.

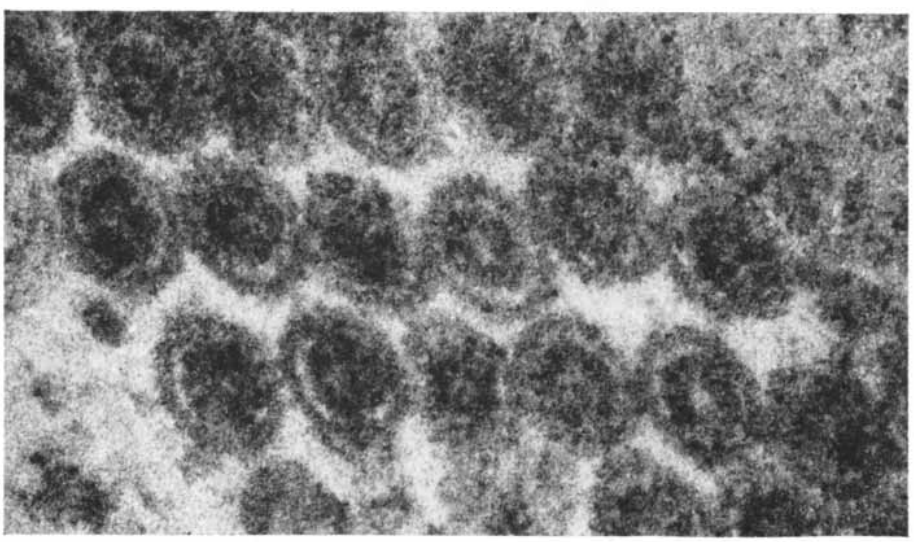
sids can remain stable without the permanent aid of a scaffolding device, but it does not rule out the need for such a device during the process of assembly. The emptying of a capsid is an experimental artifact that occurs frequently and is hard to avoid. The presence of empty viruses in electron micrographs therefore has no weight in any argument about the possibility that capsids can be built without a core.

To sum up, the larger a virus capsid is and the more elaborate its shape is, the more independent bits of information are required to prescribe the shape. Only the simplest virus shells can be the result of a single bit of information contained in subunits of a single type. For more complex shells such as the capsid of the T4 virus more information is necessary, and that information is stored in morphopoietic genes. In the T4 virus the functions of three such genes are known. Gene No. 23 is responsible for the major protein subunit, No. 66 for elongation and No. 20 for closing the prolate icosahedron. Although the pathways by which this information is expressed have yet to be defined, the idea of a structural scaffolding is supported by the observation of organized cores inside virus head structures. At this point we have a good idea of what problems remain to be solved and how to attack them.

The mechanism of shape-making in virus capsids is probably common to all structures made up of protein molecules. What we learn should therefore apply to such protein structures as the whiplike flagella and cilia possessed by many cells. The next important problem in this area is to understand the assembly and functioning of biological membrane, the principal structural element of cells and many of their components. Membranes consist of a double sheet of lipids, or fatty molecules, layered with one or two sheets of protein. If these proteins exist in lattice structures, whatever we learn about capsids will be applicable to membranes. Knowledge of the genetic control of shape in protein structures will not be enough, however, to explain the origin of shape in higher organisms. In multicellular systems cells differentiate into specialized groups. The shape of such an organism depends on the differential growth of specialized cells, and that growth is regulated in part by the interaction of cells. For such regulation one must look to more complex mechanisms, including genes that control the activity of other genes.



CORE MATERIAL is difficult to observe in polyheads. Bacteria were infected with T4 mutant in gene No. 20, then fixed and embedded with various techniques. With good preservation the content is seen to fill the polyheads homogeneously (*top*). In the best micrographs the content is seen to have fine structure (*bottom*), implying that it represents a specialized structure. The micrographs were made by Boy de la Tour; enlargement is 130,000 diameters.



ORGANIZED CORES are also visible in the headlike bodies called "21 particles" that are synthesized by viruses mutant in gene No. 21. The particles in this micrograph made by Boy de la Tour, enlarged 280,000 diameters, are in a bacterium infected by such a mutant.

The Problem of the Quasi-stellar Objects

The observational evidence on these strange celestial objects presents many mysteries. The central question is still whether they are at the edge of the universe or relatively close to us

by Geoffrey Burbidge and Fred Hoyle

It is now nearly four years since certain starlike objects, previously identified as strong sources of radio energy, were shown to be receding at velocities comparable to those of the most distant galaxies. The combination of small size, enormous energy output and apparent remoteness quickly made these quasi-stellar radio sources, as they first were called, the most interesting and widely discussed subject in astronomy. As they were observed more closely a further mystery developed: many of them were found to vary in brightness and in radio output over periods as short as months, weeks or even days. If they were as distant as they seemed to be, and therefore so enormously radiant, how could their energy output fluctuate so rapidly? Some astronomers began to question if the quasi-stellar objects were really as far away as the observational evidence seemed to indicate. Perhaps they were not at such "cosmological" distances at all but were comparatively close to us—objects ejected, perhaps, at high velocity from our own or neighboring galaxies.

The evidence that the quasi-stellar objects are receding from us at high velocity is inferred from their spectra, which show that the light they emit is shifted in wavelength toward the red, or long-wavelength, end of the spectrum. This can be determined because each chemical element, when heated to incandescence, emits light at a series of characteristic wavelengths. If the radiating elements are in a star or other object that is moving away from the observer, these characteristic wavelengths will appear to have lengthened. If, on the other hand, the object is approaching the observer, the wavelengths will appear to have shortened and thus to have shifted toward the blue end of the spectrum. So far no quasi-stellar object has exhibited a blue shift. As we shall explain, if a blue shift were to be detected, a large part of the mystery surrounding these objects would be dispelled.

As matters stand, all one can be sure of is that the quasi-stellar objects, remote or not, are powerful emitters of radiant energy. They are so small as to be almost indistinguishable from stars, and if they are indeed very remote, they are smaller by far and much brighter than normal galaxies observed at the same distance.

The problem of quasi-stellar objects arose just six years ago this month when Allan R. Sandage of the Mount Wilson and Palomar Observatories announced that his photographic plates showed what seemed to be a star at the precise position assigned to a strong radio source known as 3*C* 48 (source No. 48 in the Third Cambridge Catalogue). If Sandage's object was indeed a star, it would be the first radio star ever discovered. Most radio sources are either galaxies or extended regions of very hot gas within our own galaxy. To see what they could learn about this strange object, Sandage and subsequently other astronomers recorded its spectrum and found it to be quite unlike that of any known star.

In early 1963 another radio source, 3*C* 273, was identified with a starlike object even brighter than the one identified with 3*C* 48. The accurate radio position for 3*C* 273 that made possible this second discovery was provided by Cyril Hazard, then at the University of Sydney, and his colleagues, who worked with the 210-foot radio telescope of the Commonwealth Scientific and Industrial Organisation in Australia [see "Locating Radio Sources with the Moon," by R. W. Clarke; SCIENTIFIC AMERICAN, June]. Maarten Schmidt of Mount Wilson and Palomar obtained a spectrum of 3*C* 273 and perceived that several faint lines in the spectrum occupied positions that would coincide with those of a well-known series of hydrogen lines (the Balmer series) if they had been shifted toward the red by 16 percent. With this clue he identified lines of magnesium and oxygen similarly displaced. Immediately Jesse L. Greenstein and Thomas A. Matthews of Mount Wilson and Palomar identified the features in the spectrum of 3*C* 48 that had been so puzzling and showed that the object had a red shift of 37 percent [see "Quasi-stellar Radio Sources," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, December, 1963].

Since 1963 the identification of quasi-stellar objects has proceeded so rapidly that more than 120 such objects are now known. By the latter part of 1965 only about 10 red shifts had been published; today the number of known red shifts exceeds 65.

Nonastronomers should not worry if they have found the terminology confusing. The objects were first called quasi-stellar sources or quasi-stellar radio sources. The term "quasar" was also coined and applied to them, but this rather ugly word has not become popular with astronomers. Along the way Sandage isolated a class of objects that were not listed as radio sources but were in all other respects similar to the quasi-stellar sources. At first he called these objects "interlopers," then "blue stellar objects" and later "quasi-stellar galaxies." In this article we have adopted the term "quasi-stellar objects" to cover all objects that are starlike and have spectra with large red shifts, whether or not they are strong radio sources.

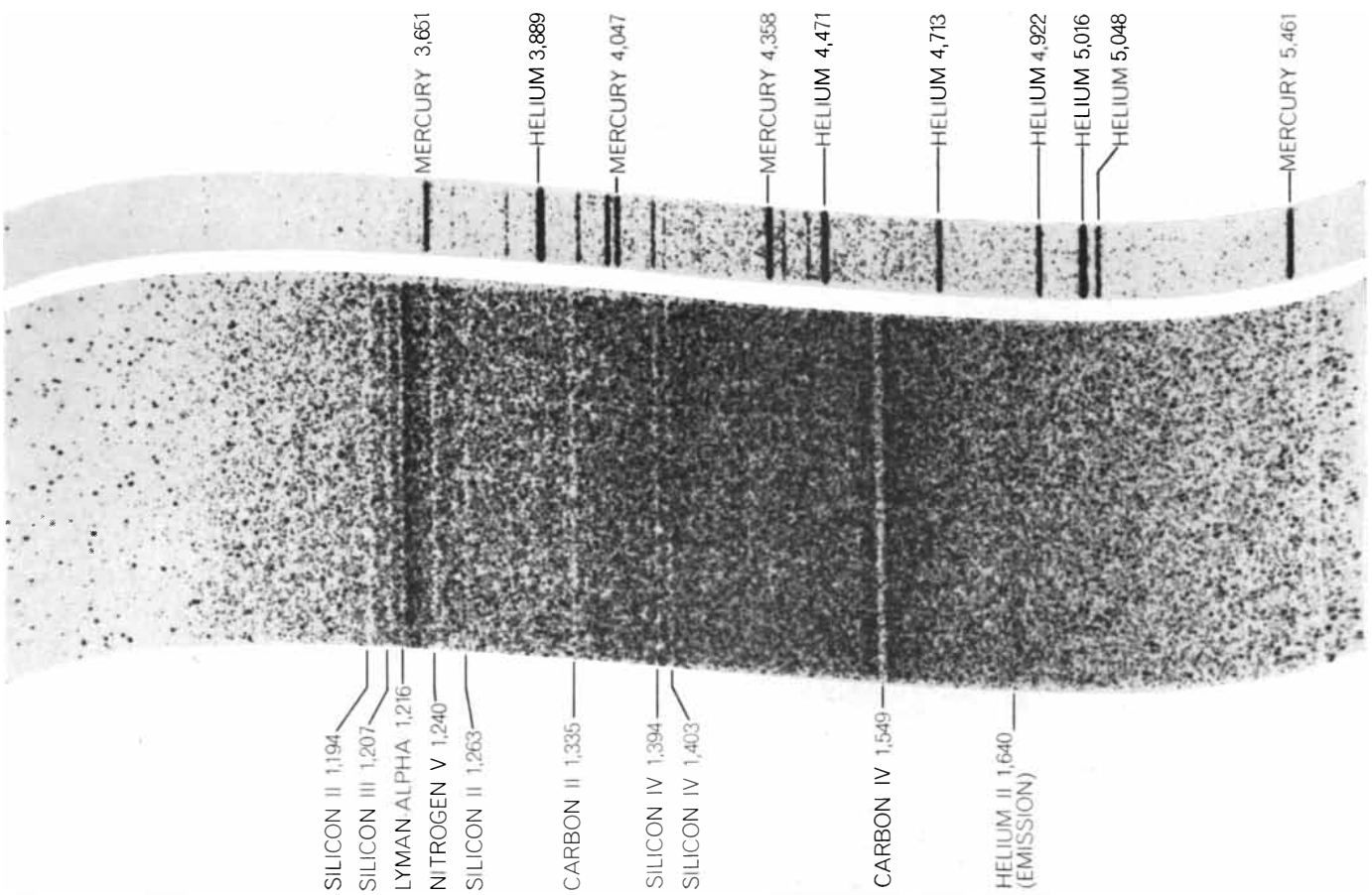
Because quasi-stellar objects radiate strongly in the ultraviolet part of the spectrum, Sandage attempted to make a general search for them using filter pho-

tography and photoelectric photometry to pick out objects with an abnormally strong flux of ultraviolet radiation. The next step was to see if the objects so identified had red-shifted spectra. Of six objects Sandage selected as candidates on the basis of accurate color measurements, three were found to have red shifts, and of these two were sufficiently starlike to qualify as quasi-stellar objects; the third must be disqualified because it has a slightly fuzzy image.

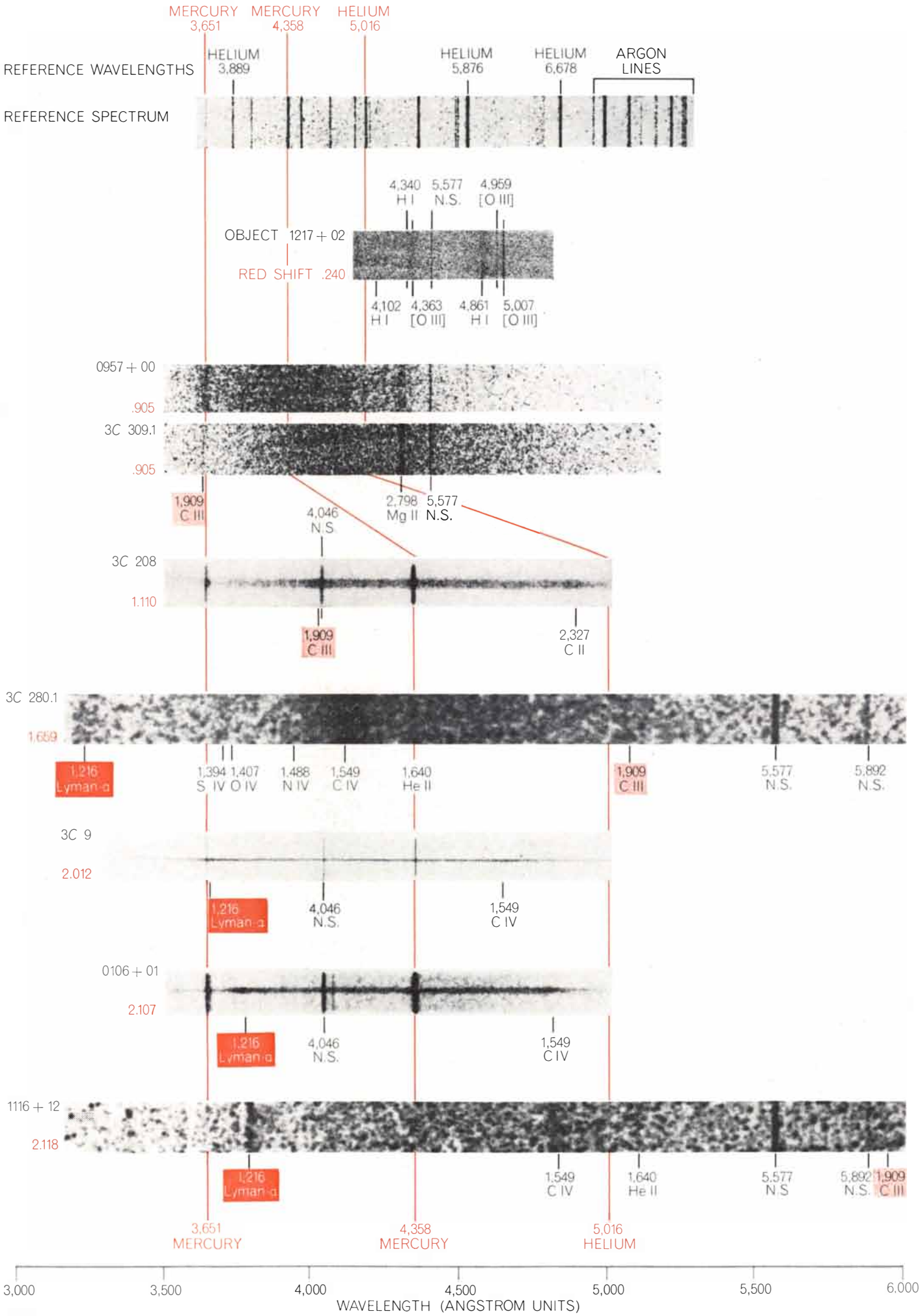
On the basis of coarse sky surveys that had previously been made for blue objects, Sandage estimated that quasi-stellar galaxies (as he referred to them at the time) might be 500 times as plentiful as the quasi-stellar objects that are known to be radio sources. These estimates were severely criticized and it is now generally agreed that Sandage's estimate was too high. A reasonable estimate is that quasi-stellar objects that are not known to be radio sources may be about 100 times as plentiful as the objects that are strong radio emitters. This implies that if one were to count all quasi-stellar objects down to a photographic magnitude of 18, one might find such an object for every square degree of sky, or some 40,000 in all. (A change of five magnitudes represents a hundredfold change in brightness; thus an object of zero magnitude, corresponding to the brightest stars, is 16 million times brighter than one of 18th magnitude.) So far very few of these "silent" quasi-stellar objects have been investigated in detail, and red shifts are still known for only three or four of them. These are included among the 65 or so for which red shifts have been determined.

The known red shifts range from the 16 percent found for 3*C* 273 up to values greater than 200 percent. (The greatest red shift yet observed for a non-quasi-stellar object is about 46 percent.) A 200 percent shift means that the Lyman-alpha line of hydrogen, which has a laboratory wavelength of 1,216 angstrom units in the ultraviolet part of the spectrum, is shifted to a wavelength of 3,648 angstroms (1,216 plus 2 × 1,216), which lies in the ultraviolet just beyond the extreme blue end of the visible spectrum. The shortest wavelength normally recordable by a spectrograph attached to an optical telescope is about 3,100 angstroms. Thus a red shift of at least 145 percent is needed to make the Lyman-alpha line observable. During the first year following Schmidt's discovery of the red shift of 3*C* 273 all the spectroscopic work on quasi-stellar objects was carried out with the 200-inch telescope on Palomar Mountain. Starting in 1964, however, E. Margaret Burbidge and T. D. Kinman began recording the spectra with the 120-inch reflector at the Lick Observatory and C. R. Lynds and his associates began using the 84-inch reflector at the Kitt Peak National Observatory near Tucson, Ariz.

What are the characteristics of the spectra of quasi-stellar objects? In general they exhibit broad, weak emission lines [*see illustration on next page*].



SPECTRUM OF QUASI-STELLAR OBJECT 3*C* 191 was among the first to show strong absorption lines, raising the question of where the absorbing material is located. The spectrum indicates that the absorbing material is a shell of cooler gas expanding outward from the central object. The absorption lines are shifted to the red end of the spectrum only slightly less than the emission lines in the spectrum, which are less easily seen. The numbers beside the names of the various elements give the laboratory, or undisplaced, wavelength in angstrom units for the various absorption lines. Because 3*C* 191 is evidently receding from us at nearly 80 percent of the speed of light, these lines are all red-shifted sharply, as indicated by the wavelengths in the reference spectrum (*top*). The magnitude of the red shift is normally computed by dividing the line displacement by the undisplaced wavelength; for 3*C* 191 this value is 1.946. This can also be regarded as a red shift of 194.6 percent. The spectrum was made by C. R. Lynds and A. N. Stockton of the Kitt Peak National Observatory, who used an image-tube spectrograph attached to the observatory's 84-inch reflecting telescope.



Among the elements identified in these spectra are hydrogen, helium, carbon, oxygen, nitrogen, neon, magnesium, silicon, argon and sulfur. The strength of the lines provides a crude indication of the temperature and density of the gas in which the lines are produced. The temperatures indicated by the electrons in the gas are on the order of a few tens of thousands of degrees Kelvin (degrees centigrade above absolute zero). The density of the gas ranges from about 10^4 to about 10^7 particles per cubic centimeter. For purposes of comparison, the temperature of the surface of the sun is about 6,000 degrees K. and the density of particles in the same region is about 10^{16} particles per cubic centimeter. One unexpected feature of quasi-stellar objects is that they appear to have a normal composition of elements, rather like that found in stars and gaseous nebulas in our own galaxy.

An important new feature of the quasi-stellar objects, discovered only in the past year, is that some of their spectra show absorption lines, indicating that radiation is being absorbed by cooler material lying somewhere between the emitting source and our galaxy. As we shall see, the location of this absorbing material is of fundamental importance. It bears directly on the nature of the quasi-stellar objects and may help to decide whether or not they are at cosmological distances.

Let us therefore describe briefly the possibilities concerning the nature of the quasi-stellar objects. When their large red shifts were first discovered, it was realized that there were only two possible explanations compatible with the known laws of physics. The red shifts meant either that the objects were receding at high speed or that the light was being emitted in gravitational fields far stronger than any previously known. The second possibility follows from the general theory of relativity, which predicts that radiation must "do work" in escaping from a gravitational field and is thereby lengthened in wavelength. The kind of gravitational fields needed to produce the observed reddening would result if the mass of the sun were compressed into a sphere a few kilometers in diameter. In that case, however, the gravitational field would be so enormous that the particles would be drawn quickly into a sphere of smaller and smaller radius, the phenomenon known as gravitational collapse. As an explanation of the red shift observed in quasi-stellar objects, gravitational collapse is unsatisfactory on two main counts. First, the duration of the phenomenon would be too short. Second, the density of the objects would far exceed the 10^4 to 10^7 particles per cubic centimeter indicated by the spectroscopic evidence.

Thus the red shifts almost certainly indicate that the quasi-stellar objects are receding from us. Since the time of the pioneering work on Mount Wilson of Edwin P. Hubble and Milton L. Humason, who showed that the red shifts of galaxies increase with their distance, it has been clear that the galaxies are receding from us and from one another as part of the general expansion of the universe. The constant in the velocity-distance relation is called the Hubble constant. The most distant galaxy we know (the radio galaxy 3*C* 295) shows a red shift of 46 percent, indicating that it is about five billion light-years away.

It was natural, therefore, that the large red shifts of the quasi-stellar objects were quickly taken to mean that some of the objects were even more distant in time and space than the faintest galaxies for which red shifts had been measured. It follows that they must be extraordinarily bright, since they are similar in appearance to the fainter stars in our own galaxy. If their red shifts are taken as a measure of their distance, they must be emitting on the average about 40 times as much energy in the photographic part of the spectrum as the brightest galaxies. This is most astonishing, since a typical large galaxy contains 100 billion stars.

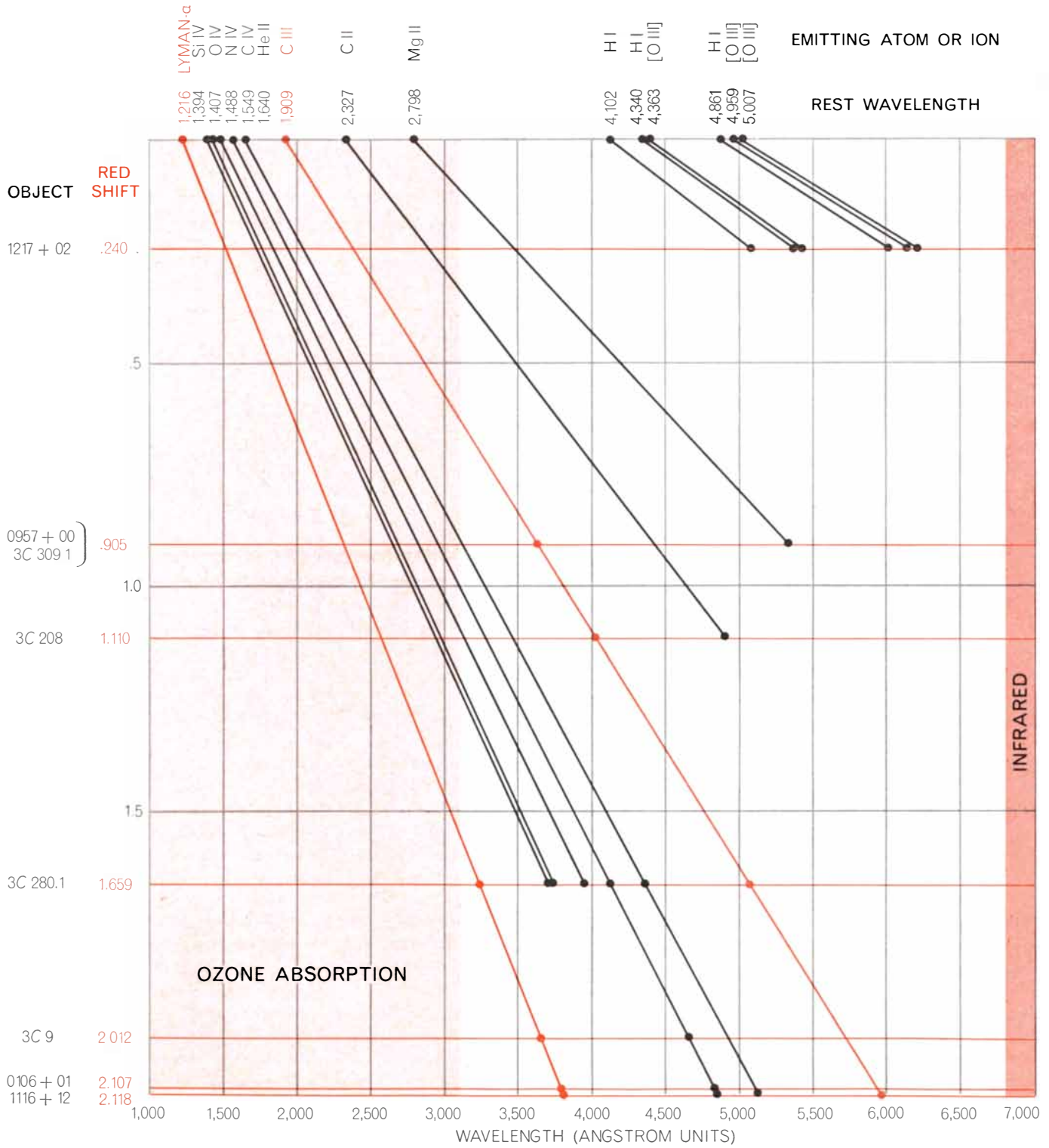
There is, however, another explanation of the red shifts that does not require the quasi-stellar objects to be so luminous. In 1964 James Terrell of the Los Alamos Scientific Laboratory proposed that they might be comparatively nearby objects that somehow had acquired enormous speed. The "somehow" is not a trivial matter; an object with a red shift of 200 percent must be flying away from us at 80 percent of the speed of light. Terrell proposed that the quasi-stellar objects had been ejected by some unknown force from the center of our own galaxy. In this connection, we had ourselves suggested somewhat earlier that an explosion had occurred in the center of our galaxy about 10 million years ago.

About a year ago we were led to consider this "local" hypothesis from a different standpoint and suggested as an alternative to the cosmological hypothesis that perhaps the objects were ejected from one or more of the nearby radio galaxies in which there is evidence that highly energetic explosions have occurred. We accordingly suggested that the quasi-stellar objects might lie at distances measured only in millions or perhaps tens of millions of light-years rather than in billions of light-years. On this hypothesis they would be less luminous by a factor of at least 10^4, that is, they would have the brightness of only about 100 million suns or less. Obviously the local hypothesis presents its own problems.

In any case it is clear that what we need is an observational test that can show unambiguously whether quasi-stellar objects are local or cosmological. Schmidt's discovery in 1965 that the Lyman-alpha emission line was shifted to 3,663 angstroms in the spectrum of 3*C* 9 immediately raised the hope that such a test was at hand. Peter Scheuer of the University of Cambridge and two investigators at the California Institute of Technology, James E. Gunn and Bruce Peterson, pointed out that if 3*C* 9 is indeed very distant, some of its ultraviolet radiation shorter than 1,216 angstroms (or 3,663 angstroms as received) would be absorbed in traveling through the intergalactic medium, provided that the medium contains neutral atoms of hydrogen. These atoms, being in a low-energy state, would readily absorb photons whose wavelength on reaching them corresponded to that of the Lyman-alpha wavelength of 1,216 angstroms. For regions of space close to 3*C* 9 the radiation absorbed by the intergalactic hydrogen would have left 3*C* 9 at a wavelength only slightly shorter than 1,216 angstroms. But the hydrogen just outside

SERIES OF SPECTRA of quasi-stellar objects is arranged from top to bottom in order of increasing red shift. The magnitude of the red shift and the name of the object are given at the left of each spectrum. A reference spectrum appears at the top of opposite page. Note that the scale of the first three spectra is different from that of the last five. The first, second, third, fifth and eighth spectra were made by Lynds and Stockton at Kitt Peak. The others were made by E. Margaret Burbidge, using the 120-inch reflector at the Lick Observatory. The letters "N.S." stand for "night sky" and indicate lines emitted by the earth's upper atmosphere and by gases in city lamps. The quasi-stellar object 3*C* 280.1 is the first in this series that has a red shift large enough so that the Lyman-alpha line of hydrogen (rest wavelength, 1,216 angstroms) is shifted into the visible region. It appears at 3,233 angstroms. In the three succeeding spectra it is shifted still farther: to 3,663, 3,776 and 3,792 angstroms. These three quasi-stellar objects have the largest red shifts yet recorded: 2.012, 2.107 and 2.118.

our galaxy would absorb radiation that had originally been much shorter (in the vicinity of 400 angstroms) and that had been reddened to 1,216 angstroms as a consequence of the expansion of the universe during the several billion years from the time the radiation began its journey. Thus what one should see in the spectrum of 3*C* 9 is a general deficiency of ultraviolet radiation shorter than 3,663 angstroms. After examining spectra of 3*C* 9, Gunn and Peterson thought they could detect the beginning of this long absorption trough in the region between 3,663 angstroms and about 3,100 angstroms, where the ultraviolet absorption of the earth's atmosphere intervenes and cuts off the record. The absorption trough was significantly less than expected, however, so they concluded that only a fantastically small amount of intergalactic gas was in the form of neutral hydrogen: about one atom per 10,000 cubic meters, or 10^{-34} gram per cubic centimeter. Most theoretical models of the universe require a density roughly 100,000 (10^5) times higher for the inter-



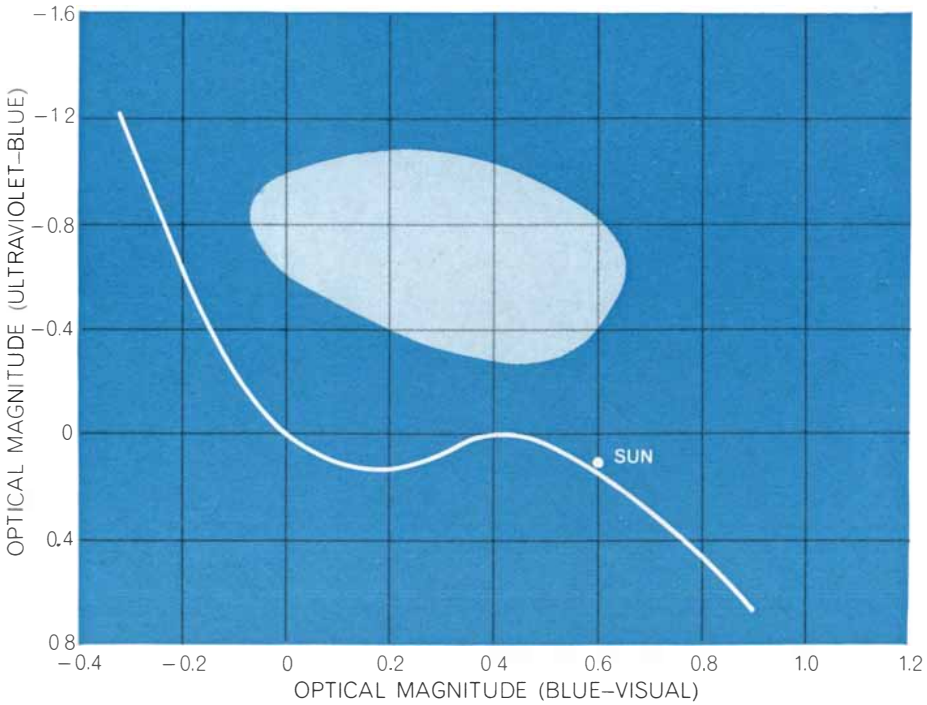
RED-SHIFT DISPLACEMENT for the principal emission lines found in the spectra on page 42 can be more easily visualized with the aid of a diagram in which the undisplaced wavelengths are plotted along the top and the displacements, corresponding to various red shifts, are plotted below. The Roman numerals indicate the state of ionization of the emitting element; the numbers are one greater than the number of electrons missing from the atom. Lyman-alpha and carbon III lines (*color*) show up in four spectra.

galactic medium, unless large amounts of matter are present in a form not easily detected, for example in stars too dim and too dispersed to be seen. The Gunn-Peterson finding might also be explained if the intergalactic gas were present not as neutral hydrogen but as ionized hydrogen, which cannot absorb Lyman-alpha radiation. Indeed, some theoreticians have accepted the Gunn-Peterson results as evidence that most of the hydrogen is in ionized form.

Subsequent observations of 3C 9 and other quasi-stellar objects with comparable red shifts have led to the conclusion that there is really no evidence for Lyman-alpha absorption at all and that the early interpretation by Gunn and Peterson is incorrect. The new studies indicate that the density of intergalactic neutral hydrogen is incredibly low (less than 10^{-35} gram per cubic centimeter); this implies either that virtually all of it is ionized or that the quasi-stellar objects are so near that no significant absorption can be expected. To some the improbability of the first alternative would seem to provide a convincing argument that the objects are local and not cosmological, but enough other possibilities remain so that the debate continues.

One such possibility was pointed out by John N. Bahcall of the California Institute of Technology and E. E. Salpeter of Cornell University. They suggested that the intergalactic gas might not be distributed uniformly but might exist as condensations, for example in association with clusters of galaxies. In that case one might find a number of separate absorption lines in the spectra of quasi-stellar objects, indicating where their radiation had intersected one or more clusters. One might also expect to find absorption lines due to energy transitions in atoms other than hydrogen.

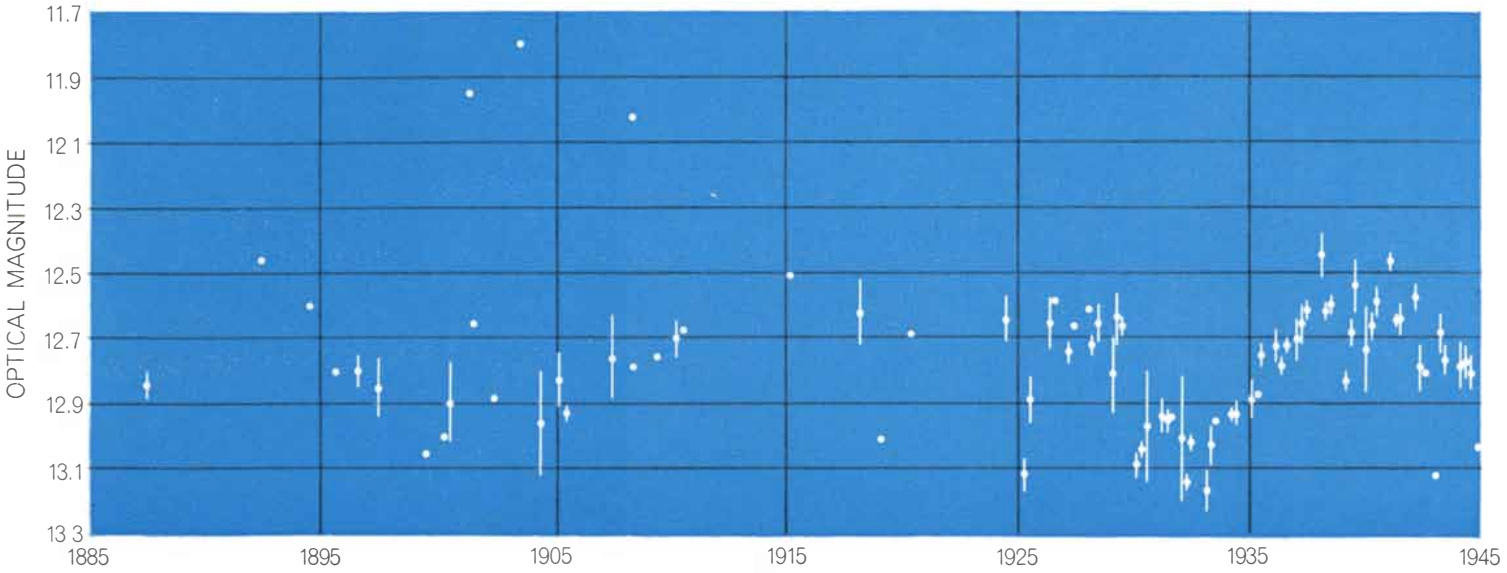
Soon after this proposal was made the quasi-stellar object 3C 191 was observed for the first time by Margaret Burbidge at the Lick Observatory and by Lynds and A. N. Stockton at Kitt Peak. Its spectrum exhibits many absorption lines, and it was thought at first that they might support the Bahcall-Salpeter hypothesis. It was shown, however, that all the lines could be attributed to absorption by ionized atoms associated with the object itself [*see illustration on page 41*]. The evidence for this conclusion was that the absorption lines and the emission lines had almost the same red shift: 195 percent. Evidently the absorption lines are produced in a slightly cooler envelope of material that is part of 3C 191, probably a shell of gas that has been ejected from the quasi-stellar object.



COLOR-MAGNITUDE DIAGRAM shows the general location of quasi-stellar objects (*light area*) compared with the general location of normal stars (*white curve*). Astronomers measure the magnitude, or brightness, of stars through three filters: ultraviolet, blue and yellow (or visual). When differences between the ultraviolet and blue magnitudes are plotted against differences between blue and visual magnitudes, the normal stars over the entire range of temperatures lie on or near a well-defined curve. The hottest stars lie at the upper left corner of the curve, the coolest at the lower right. The quasi-stellar objects lie well above this curve, separated from it by their intense ultraviolet radiation, which moves them upward in the diagram. Some white dwarfs also lie in this region, but since they do not have large red shifts they can be distinguished from quasi-stellar objects.

Absorption lines have now been seen in other quasi-stellar objects. In all cases but one the lines can be interpreted as being produced by a shell of gas whose velocity differs from that of the emissive core by no more than a few thousand kilometers per second—velocities that are no larger than those observed in the explosions of supernovas. The one exception is a spectrum in which the velocities appear to be considerably higher, presenting the possibility that the absorbing medium is not part of the quasi-stellar object but is somewhere in intergalactic space. The arguments for this possibility are in our opinion not conclusive. Thus although absorption features may eventually demonstrate that quasi-stellar objects are at cosmological distances, all the evidence to date is compatible with the conclusion that they are nearby and that when absorption lines are seen, they are due to material associated with the object.

We turn now from the spectroscopy of the quasi-stellar objects to their very important property of variability. Following the initial identification of 3C 273, Harlan J. Smith and E. Dorrit Hoffleit, then at Yale University, examined the Harvard College Observatory collection of astronomical plates, which dates back more than 70 years, to see if the "star" now identified as 3C 273 had varied in brightness. They found not only that it had varied significantly over the years but also that some bright flashes had lasted a month or less [*see top illustration on next two pages*]. Apart from 3C 273 and 3C 48 (also found to vary), none of the quasi-stellar objects is bright enough to be traced back in a similar fashion. In the brief period since they have been discovered, however, almost all the quasi-stellar objects that have been observed on several occasions have exhibited variations in brightness. In one extended study Kinman and D. Goldsmith of the Lick Observatory followed 3C 345 from June to October, 1965, and found that its brightness varied as much as 40 percent in a period as short as a few weeks. A single observation made later in October by Sandage showed its brightness to be three times the brightness measured in June. Subsequently Sandage observed that another quasi-stellar object, 3C 446, has brightened by three magnitudes, or a factor of about 15, in a few months. Recently Kinman and his colleagues at the Lick



BRIGHTNESS CHANGES IN 3C 273, the second quasi-stellar object to be identified, were plotted by examining plates of variable stars in the collection of the Harvard College Observatory. The record of fluctuations in 3C 273, the brightest quasi-stellar object yet found, was traced back more than 70 years by Harlan J. Smith and E. Dorrit Hoffleit, then at Yale University. The ver-

Observatory have observed a twofold change in brightness in 24 hours.

In the summer of 1965 a variation in the radio emission of 3C 273 was reported by William A. Dent of the University of Michigan. (An earlier Russian report of a variation in another quasi-stellar object, CTA 102, was not confirmed by other observers and is generally discounted.) Dent's measurements, made at a wavelength of 3.75 centimeters, showed that the intensity of 3C 273 had increased by about 40 percent in two and a half years. Since then it has been found that quite a number of quasi-stellar objects show variations at wavelengths of a few centimeters [*see illustrations on pages 48 and 49*].

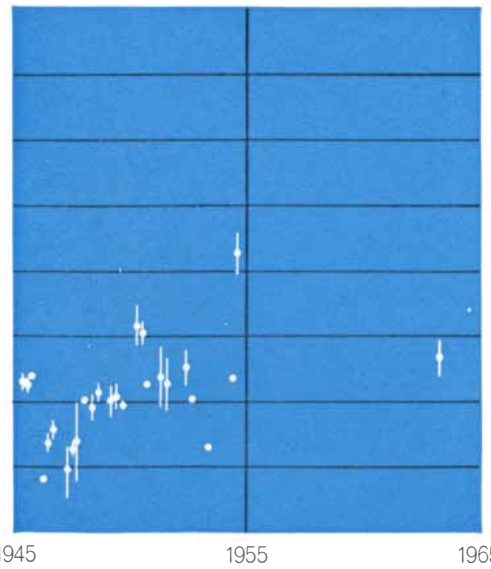
Only 3C 273 is bright enough so that its radiation can be measured in the infrared region of the spectrum. Harold L. Johnson and Frank J. Low of the University of Arizona, who have studied 3C 273 at wavelengths of 2.2 and 10 microns (a micron is 10,000 angstrom units), have detected no variation in its infrared luminosity. Surprisingly their measurements show that a large part of the object's total energy is being emitted in this region of the spectrum. In the adjacent millimeter-wavelength region of the spectrum, which has been observed by Eugene E. Epstein of the Aerospace Corporation and his colleagues, the emission of 3C 273 is again found to be varying rapidly.

The importance of the observed variability in quasi-stellar objects is that it sets an upper limit to the size of the region from which their energy can be emitted. Unless the objects are in a state of continuous explosion at enormous speeds (and there is no hint of this in their spectra), the period of variation is fixed by the time it takes for light to travel the diameter of the radiating object. The observed variations in quasi-stellar objects mean that the size of the region where much of their radiation originates must be no greater than the distance light can travel in a month—in the case of 3C 446, in a day. A light-month is equal to about 10^{17} centimeters, or roughly 100 times the diameter of the solar system. Moreover, this dimension is independent of distance; it is the same whether quasi-stellar objects are nearby or extremely remote, and thus it has a great bearing on the models one can devise to explain their energy output. If they are remote, they must radiate something like 10,000 times more energy per unit of volume than if they are close to us.

If 3C 273 is a remote object, it is emitting about 1.5×10^{47} ergs of energy per second across the entire electromagnetic spectrum; if, on the other hand, it is a local object, its emission is reduced to about 1.5×10^{43} ergs per second or less, depending on the actual distance. The higher value represents a radiation density comparable to that in a laser, the most intense artificial light source known. The problem of explaining such huge fluxes of energy is very difficult and has not been solved. With rather simple arguments, however, one can limit the models that are compatible with the observations.

From lines in the spectra produced by quasi-stellar objects one can infer the presence of a hot plasma, one whose temperature is perhaps 30,000 degrees K. Although such a plasma will give rise to some continuous radiation as well as to discrete lines, it cannot account for the strength of the background radiation found in the spectra of quasi-stellar objects. And ordinary thermal processes certainly cannot account for the energy emitted by such objects in other parts of the electromagnetic spectrum. The bulk of the energy is almost certainly emitted by the "synchrotron" process, in which highly energetic electrons emit radiation while spiraling around the lines of force in a magnetic field.

Now, the conditions under which the synchrotron process can be effective are narrowly restricted if quasi-stellar objects are at cosmological distances in addition to being small in diameter. In this case the density of radiation in them must be extremely high: about 10^{16} photons per cubic centimeter. If high-energy electrons are injected into a radiation field of such high intensity, they may lose most of their energy through collisions with low-energy photons before they can radiate much energy through the synchrotron process. The synchrotron process can be dominant only if the magnetic field is on the order of 100 gauss, or some 50 times as strong as the magnetic field on the surface of the sun. (This is the result if the object has a diameter of about a light-month. If it is only a light-day across, the field would have to be about 10,000 gauss.) Moreover, the electrons injected into such a strong field will radiate for only a few seconds or minutes before their energy is depleted by the synchrotron process. That is far too brief a time for them to



tical bars show the range in brightness for series of plates taken within 100-day periods. Single dots represent isolated observations.

travel across the diameter of a quasi-stellar object, a trip that would take from one to several weeks. This means that quasi-stellar objects must contain not one or even a few hundred but millions of separate points where electrons are injected into a strong magnetic field.

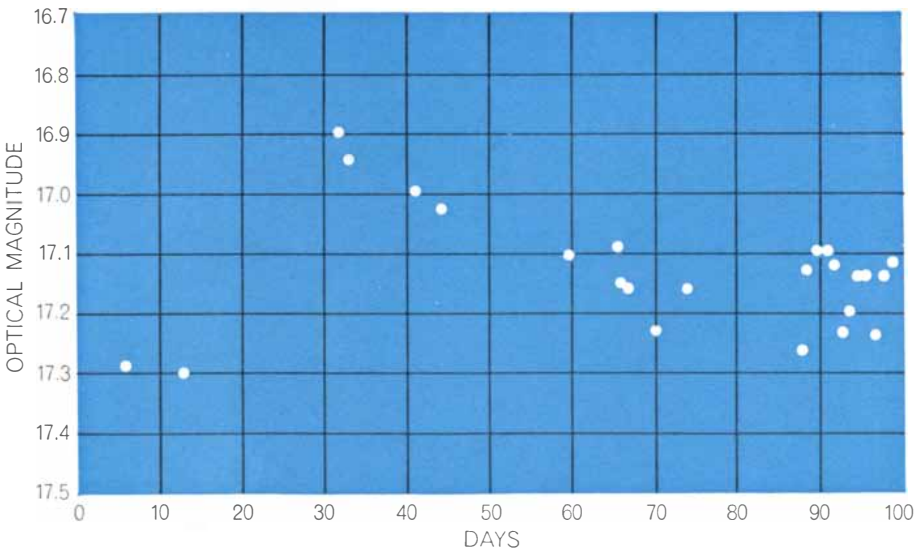
It is possible, of course, that the synchrotron process is not responsible for the bulk of the energy radiated by quasi-stellar objects. One can imagine that some kind of strange "machine" generates a radiation field of low-energy photons even more intense than the one we have described. If enough electrons with the right spectrum of energy were injected into such a field, collision processes alone might give rise to the required flux. This appears to us, however, to be a most unlikely possibility.

Before considering the theories that have been proposed to account for the quasi-stellar objects, we should like to touch briefly on other observational data that bear on the fundamental point of whether they are local or cosmological objects. At one time it was hoped that by plotting the red shift of quasi-stellar objects against their apparent optical brightness one might be able to tell something about the large-scale structure of the universe and the kind of cosmological model that best fits the observations. To be useful such a plot would have to yield a more or less straight-line relation between red shift and brightness, and would itself provide prima facie evidence that the red shifts are indeed a function of distance. It has turned out, however, that the plot has a large scatter in which only a weak trend is apparent [*see top illustration on page 50*]. The scatter evidently arises from the fact that quasi-stellar objects differ greatly in intrinsic brightness. Therefore no simple relation between red shift and brightness can be expected, even if the objects are at cosmological distances.

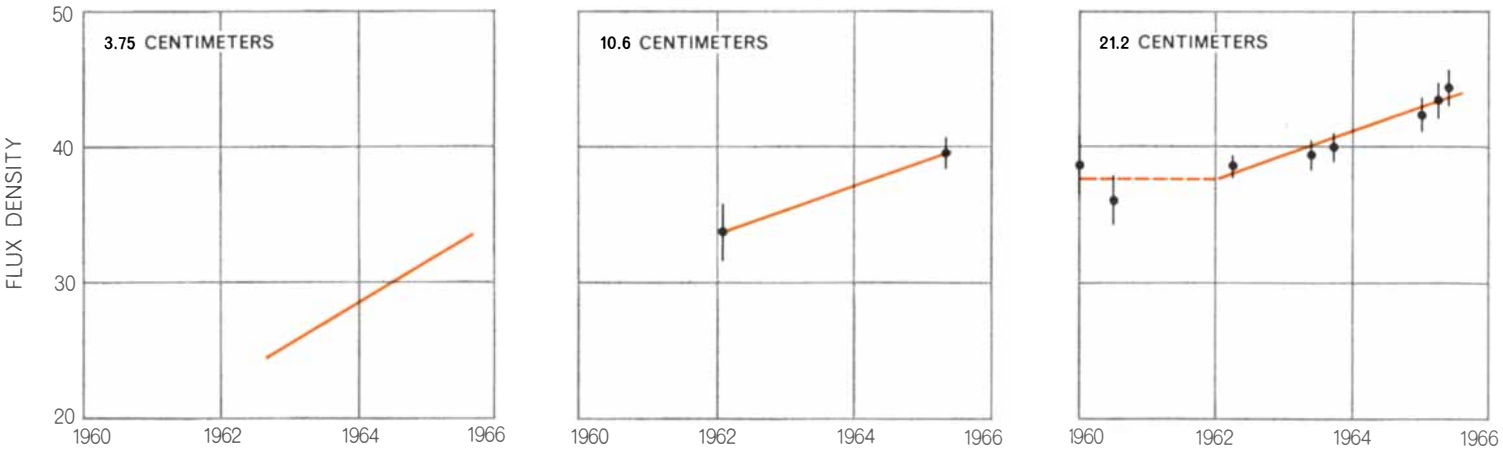
The scatter does not necessarily lend support to the local hypothesis, because then one must account for the absence of blue shifts. One way to do this is to imagine that most, if not all, of the quasi-stellar objects were ejected from a nearby radio galaxy. If enough time has elapsed since the explosion, even those objects initially headed in our direction will have passed through (or close to) our galaxy and will now be receding on the other side. It should be noted, however, that if blue-shifted objects exist, it may be more difficult to identify their spectral lines than is the case for red-shifted objects. There are fewer lines in the red than there are in the blue part of the spectrum and they are intrinsically weaker; thus they would be more easily hidden by the continuous radiation in the background.

Recently Halton C. Arp of the Mount Wilson and Palomar Observatories has presented evidence indicating that radio sources, including several quasi-stellar objects, tend to lie in the vicinity of certain unusual-looking galaxies called "peculiar" galaxies. He suggests that the quasi-stellar objects were ejected from them. One consequence of Arp's suggestion is that we should see more blue-shifted objects than red-shifted ones, even if equal numbers were headed toward us and away from us. The explanation is that those approaching should appear brighter than those receding and thus seem to be more numerous when counted down to the same limiting magnitude. Since no blue-shifted objects have been seen at all, some astronomers have summarily rejected Arp's idea. The rejection may be too hasty. One must consider the possibility that an object may not radiate spherically in symmetrical fashion if it is moving through the intergalactic medium at relativistic speed: a speed close to the velocity of light. Then there would be no guarantee that approaching objects will be easier to see (that is, brighter) than receding ones. If Arp's hypothesis were to be rigorously established, one might be forced to find still other explanations for the absence of blue shifts. It is possible, for example, that the red shifts do not represent a recession of the objects but are due to the relativistic motion of gas contained within them.

Another kind of test is to see if quasi-stellar objects are to be found within clusters of galaxies. It has been established, for example, that many radio galaxies lie in such clusters and that they are frequently the brightest objects present. If even a few quasi-stellar objects were found in clusters, one could try to see if the red shift of the quasi-stellar object matched that of the cluster. If so, the cosmological nature of these objects would be established. The observational difficulty associated with this test is that the fainter quasi-stellar objects are so much brighter than the clusters of galaxies in which they might be situated that the surrounding galaxies would be difficult to detect and their spectra more



BRIGHTNESS CHANGES IN 3C 345, a quasi-stellar object some 4.5 magnitudes fainter than 3C 273, were recorded over a period of about 100 days in mid-1965 by T. D. Kinman and D. Goldsmith at the Lick Observatory. The maximum variation is about 100 percent.



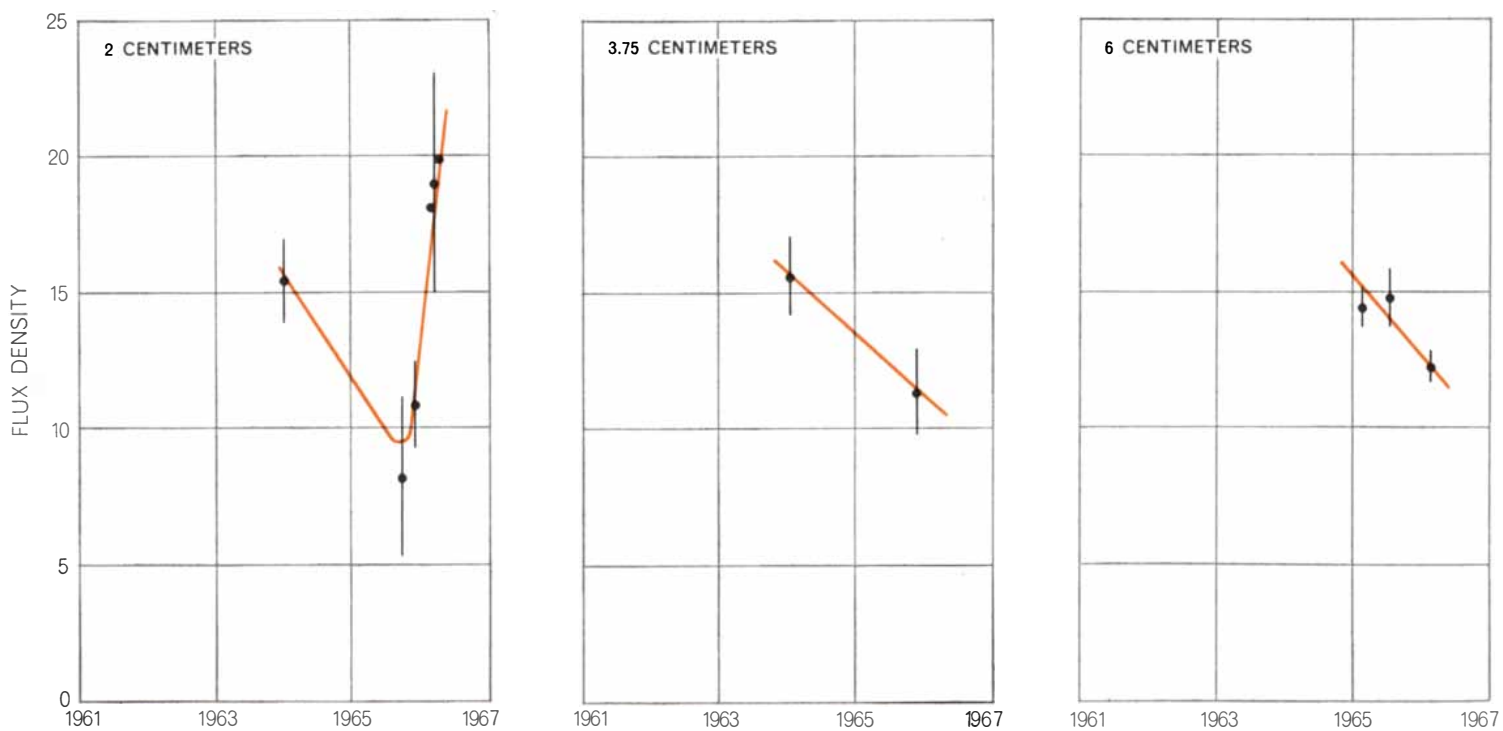
RADIO-FLUX CHANGES IN 3C 273 were compiled from a number of sources by Alan T. Moffet and P. Maltby of the California Institute of Technology. The measurements at 3.75 centimeters were made by William A. Dent of the University of Michigan, who

difficult still to record. In the case of the brighter objects such as 3C 273 and 3C 48, however, the test can be made. It is negative: the objects are not associated with clusters of galaxies. There is optimism that the test can be extended to fainter objects by using sensitive new photographic plates that enable the 200-inch telescope to photograph objects with an apparent magnitude of 24.

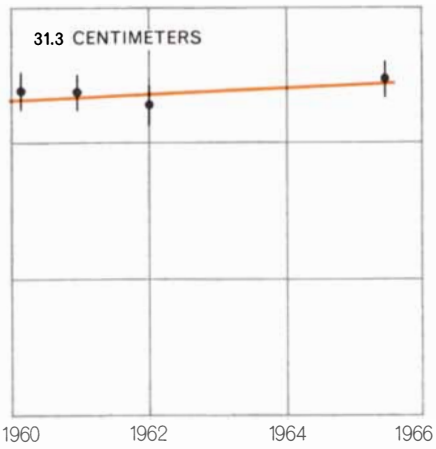
We turn now to a discussion of diagrams in which one plots the red shift of quasi-stellar objects against radio magnitude, expressed as the radio flux (S) at a particular frequency. We have selected a frequency of 178 megacycles because the most extensive catalogues of radio sources have been compiled at that frequency. One can see from the diagram at the bottom of page 50 that there is little or no correlation between red shift and radio magnitude. This is understandable on the basis of the local hypothesis because it implies no strong correlation between red shift and distance, unless all the quasi-stellar objects were ejected at one particular moment from one galaxy.

How can the diagram be understood if one assumes the cosmological hypothesis? The fact that there is no significant drop in radio flux with increase in red shift can be interpreted to mean that the more distant objects are intrinsically more powerful than the nearer ones. If this is true, it should have important significance for cosmological theories. Let us see if it is a realistic possibility.

For some years now radio astronomers have made counts of sources and presented them in the form of "log N–log S" curves, where N is simply the number of galaxies with a radio flux greater than some value S. As one would expect, there are many more galaxies of weak flux than there are of strong flux. In fact, radio astronomers have found an essentially



RADIO-FLUX CHANGES IN 3C 279 were recently reported by K. Kellerman and K. Pauliny-Toth of the National Radio Observatory in Green Bank, W.Va., who assembled their own measurements with those made by Dent. The sharpest change took place at a



obtained the first conclusive evidence that quasi-stellar objects vary in radio emission.

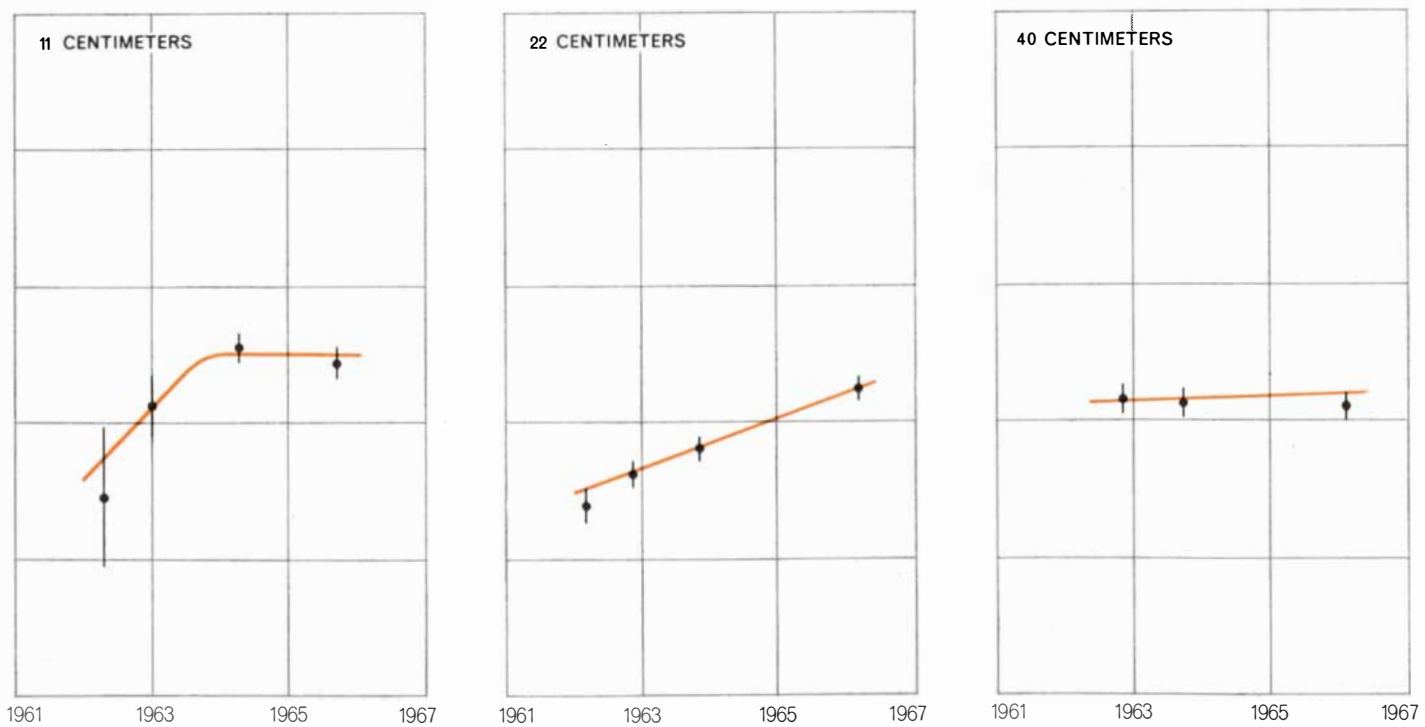
straight-line dependence between the logarithm of N and the logarithm of S. The precise slope of this line is of great interest because it should help to provide a test between different models of the universe. For example, a slope of -1.5 is the one expected if all sources had the same intrinsic power and were uniformly distributed in a Euclidean universe. The value -1.5 results from the following considerations. The number N of sources brighter than a particular value of S is proportional to the volume of space, that is, to d^3, where d is such that a source at distance d has a flux equal to the assigned S. The flux S, in turn, varies according to the inverse square law; thus S is proportional to d^{-2} (that is, to one over d^2). The ratio of log N to log S, therefore, is simply the ratio of the exponents of d, or the ratio of 3 to -2. This gives the value -1.5.

It is easy to show that the same value, -1.5, is also the one to be expected in a steady-state universe. The slope that is actually observed for all extragalactic radio sources is about -1.8, and although this value is hard to explain it has been used as evidence against the steady-state cosmology.

One of us (Hoyle), who has been closely associated with the steady-state cosmology, has always objected to this argument on the grounds that a counting of a class of objects whose physical nature is unknown cannot be regarded as a satisfactory procedure. Before the discovery of quasi-stellar objects, however, it could be argued that all radio galaxies were more or less alike and thus could be counted as objects of a single class. This position is no longer tenable. One must consider the slope of the log N–log S curve for radio galaxies alone and for quasi-stellar objects alone. When that is done, what is the result?

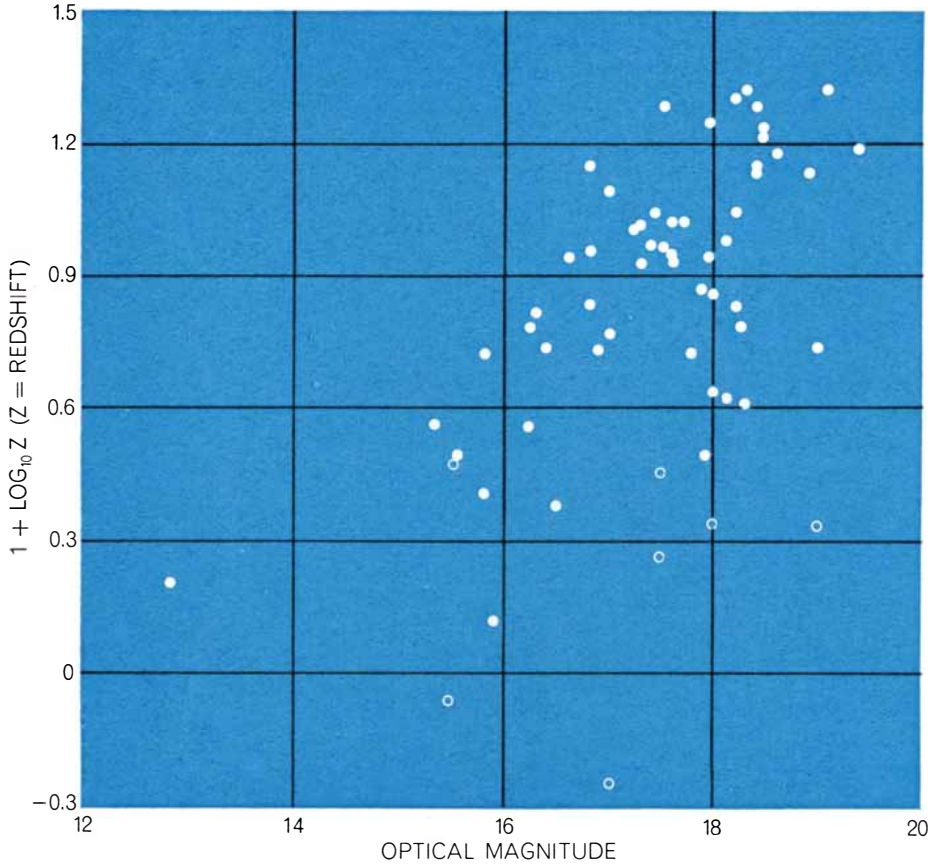
A critical study of this kind was recently conducted at the Mount Wilson and Palomar Observatories by the French astronomer Philippe Véron. He classified all the sources in the Third Cambridge Catalogue according to the nature of their optically visible counterparts in every case where an optical identification had been made. The revised version contains 328 radio sources, of which 32 probably lie within our own galaxy and another 42 are so obscured by galactic absorption that little of value can be deduced from them. Among the remaining 254, Véron finds 144 radio galaxies (100 certain and 44 probable) and 60 quasi-stellar objects (39 certain and 21 probable), leaving only 50 sources that have not yet been identified. One can safely assume that these 50 objects, since they are only 20 percent of the total, are not likely to upset Véron's conclusions regardless of their ultimate classification. We should like to emphasize, moreover, that Véron's study embraces the only "first class" data that exist at the moment relevant to the source-count problem. By "first class" we mean data that are both reasonably complete and technically good.

Véron's finding is this. The radio galaxies, certain and probable together, essentially fit a slope of -1.5. Since the radio galaxies are not extremely far away (maximum red shift, 46 percent), this is the slope to be expected in any cosmological theory. The steep slope of -1.8 shown by all 3*C* sources is due in large measure to the quasi-stellar component, which has the very steep slope of -2.2 [*see illustration on page 51*].

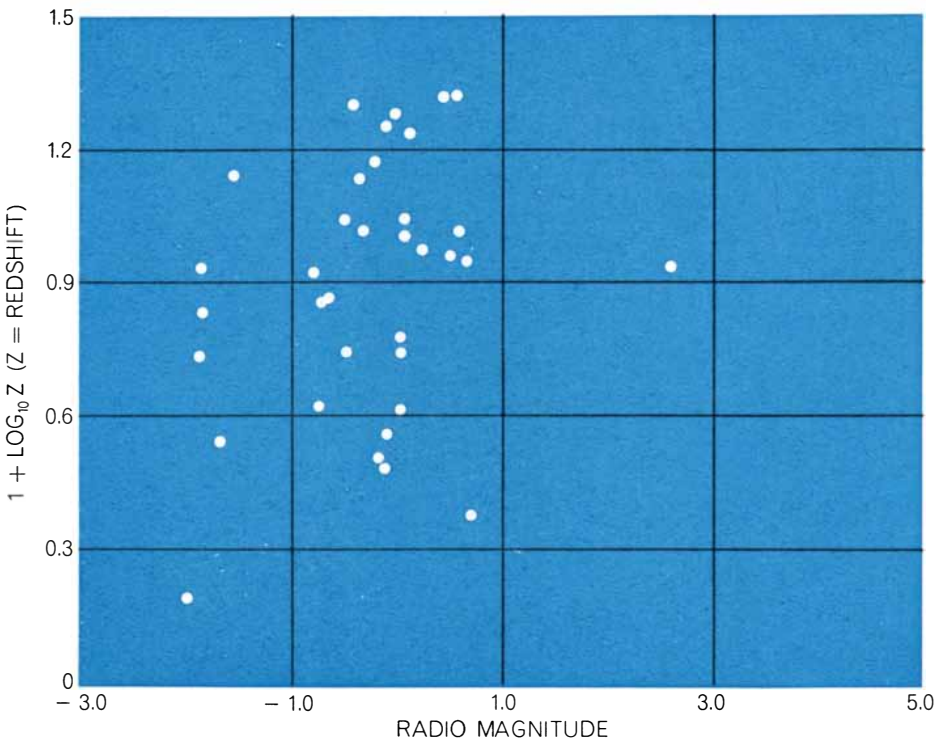


wavelength of two centimeters; the radio flux approximately doubled over a period of a few months between late 1965 and early 1966.

In this illustration and in the one at the top the flux density is given in units of 10^{-26} watt per square meter per cycle per second.



RED SHIFT V. OPTICAL MAGNITUDE is plotted for all quasi-stellar objects (*dots*) and *N*-type galaxies (*open circles*) for which data are available. *N*-type galaxies resemble quasi-stellar objects in spectral features and in having large red shifts, but they are not quite star-like. According to the cosmological hypothesis the greater the red shift of quasi-stellar objects, the more distant they are. Thus if quasi-stellar objects all had about the same intrinsic brightness, one would expect to see a strong correlation between red shift and apparent magnitude. Its absence suggests that the objects differ considerably in intrinsic brightness. An alternative hypothesis suggests that they are not distant objects at all but local ones, in which case the scatter could indicate either variations in brightness or random distribution.



RED SHIFT V. RADIO MAGNITUDE is shown for 35 quasi-stellar objects, most of those for which information exists. The correlation is slim between red shift and magnitude.

It is obvious that if quasi-stellar objects are actually nearby, their slope of −2.2 has no bearing on the cosmological problem.

But—and this is the surprise toward which we have been working—the slope is equally irrelevant to cosmology even if quasi-stellar objects are at cosmological distances. This follows from the scatter diagram at the bottom of this page, which shows that there is at best only a weak correlation between the radio flux of quasi-stellar objects and their distance —assuming now that distance is proportional to the observed red shifts. It follows that the −2.2 slope of the log *N*–log *S* curve for quasi-stellar objects cannot be interpreted as a distance effect. Rather the curve exhibits a "luminosity function" effect, which can be described as follows.

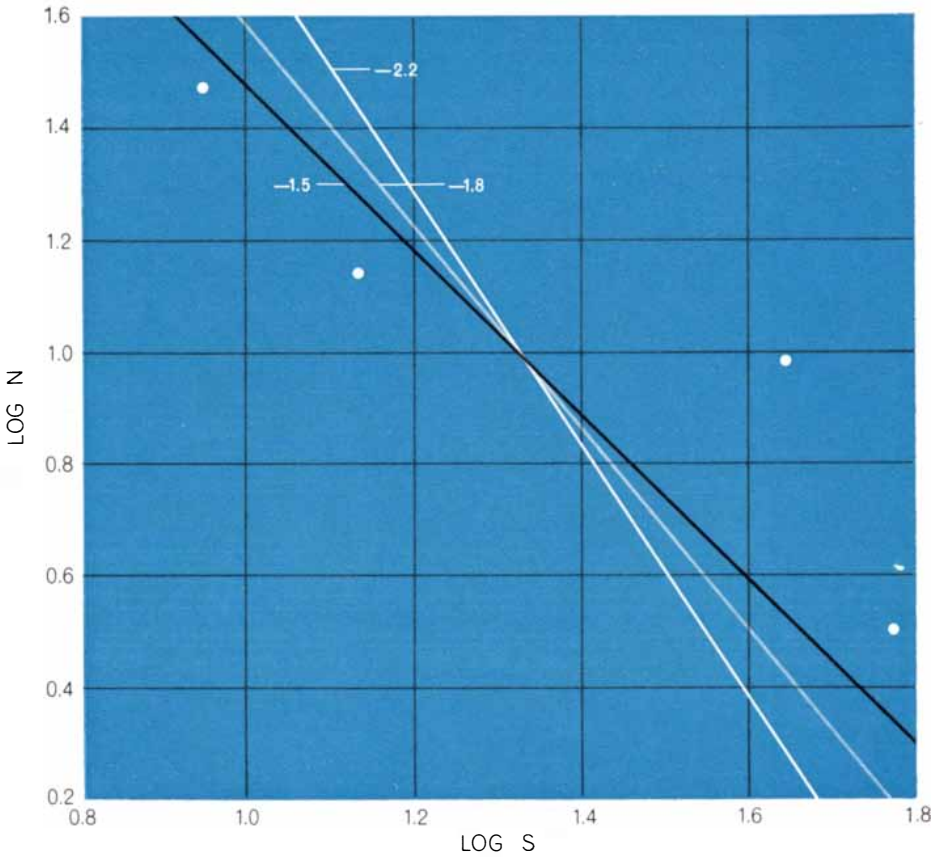
Imagine a group of objects of different intrinsic brightness all placed at exactly the same distance from our galaxy. If there are many more faint objects than there are bright ones, *N* will be significantly larger for a small observed radio flux, *S*, than it is for a large flux, and we shall obtain a curve that runs from lower right to upper left in the log *N*–log *S* diagram. By adjusting the distribution of objects with respect to brightness (that is, the luminosity function) we can indeed obtain any slope we please. The fact that quasi-stellar objects are actually arrayed at various distances (in all likelihood) does not alter the principle involved; it is important only that they have a spread of intrinsic luminosities. In fact, they can have a spread that produces a slope of −2.2 in a log *N*–log *S* curve.

Finally we turn to the theoretical models that have been proposed to explain the quasi-stellar objects. We should first say something, however, about ordinary radio galaxies. By 1956 it was shown that these sources frequently lie in clusters of galaxies whose red shifts are well established; radio galaxies are therefore cosmological objects. The source of their radio emission is assumed to be the synchrotron process. On this basis one can calculate that the minimum total energy released by a large radio galaxy is on the order of 10^{61} ergs. To obtain that much energy by the most efficient conversion process known—the annihilation of matter—would require the disappearance of a mass equivalent to the mass of 10^7 suns for the duration of the outburst. Moreover, there are a number of reasons why it is probable that far larger amounts of energy are actually released.

A variety of processes were suggested to explain energy releases of such magnitude. The earliest suggestion was collisions between galaxies, but this could be ruled out on observational grounds. A later idea was that multiple explosions of supernovas might be responsible. This does not seem to be efficient enough. Then in 1962, before the discovery of quasi-stellar objects, one of us (Hoyle) and W. A. Fowler of the California Institute of Technology considered how the collapse of a large mass might account for the energy released in strong radio sources. It was supposed that the energy released in such a gravitational collapse might be a significant fraction of the rest-mass energy.

With the discovery of 3*C* 273 in 1963 Fowler and Hoyle proposed that such objects, if cosmological, might represent objects with a mass of about 10^8 suns—superstars—whose luminous energy results from standard thermonuclear processes. (The stability of such giant stars and their possible evolution have since been considered by Fowler and others.) It was suggested that the superstar spends about a million years in this highly luminous phase and then collapses, releasing a large amount of gravitational energy that in some fashion is converted into high-energy electrons together with a suitable magnetic field so that the synchrotron mechanism can operate. According to this model a quasi-stellar object is really two objects: a still-burning superstar to provide luminosity and a collapsed superstar to supply the vast flux of particles needed to account for the radio emission. The proposal presents many difficulties, chief among which is understanding how a collapsing object can emit energy amounting to a significant fraction of its rest mass. Since the conventional theory of relativity suggests that this cannot happen, Hoyle and J. V. Narlikar have considered modifications of the field equations that may permit the possibility.

A number of theorists have considered how a superstar of the type needed might be formed. George B. Field, now at the University of California at Berkeley, has proposed that quasi-stellar objects are galaxies in the process of formation and that much of the radiation we observe is gravitational energy released by the contraction of a vast cloud of gas. Along the way stars form, release thermonuclear energy and finally explode as supernovas. The quasi-stellar object, Field believes, is a manifestation of all these processes and at the end the mass will probably condense to form a superstar. It does not appear to us, however, that this model can supply the required energy.



"LOG *N*–LOG *S*" CURVES tend to show a simple straight-line dependence between log *N*, the number of objects above a certain radio magnitude, and log *S*, the selected magnitude in units of radio flux. Thus the lowest point on the quasi-stellar curve (*black*) shows that there are only two objects with a radio magnitude, or flux, above 60 units ($\log_{10} 60 = 1.778$). The point at upper left shows that there are 30 objects with a flux above 9 units ($\log_{10} 9 = .954$). The slope of the log *N*–log *S* curve for these 30 objects is close to −1.5. For all quasi-stellar objects, however, the slope is about −2.2. For all radio sources in the Third Cambridge (3*C*) Catalogue the slope is −1.8. In a simple Euclidean universe the expected slope is −1.5. Evidently the −1.8 value for all radio sources reflects the steeper slope of the quasi-stellar component. The implications of these slopes are discussed in the text.

Another provocative idea is the one proposed by Thomas Gold and W. Ian Axford of Cornell University and Stanislaw M. Ulam of the Los Alamos Scientific Laboratory. They suggest that in some galaxies the density of stars in the nucleus has become so high that the stars begin to collide with increasing frequency. Conceivably the energy released in such collisions could account for cosmological quasi-stellar objects. We do not consider this very likely for a number of reasons; for one, the time during which these events might take place would be quite short. On the other hand, the collisions might lead to an agglomeration process that could produce the kind of superstar we have in mind for our model.

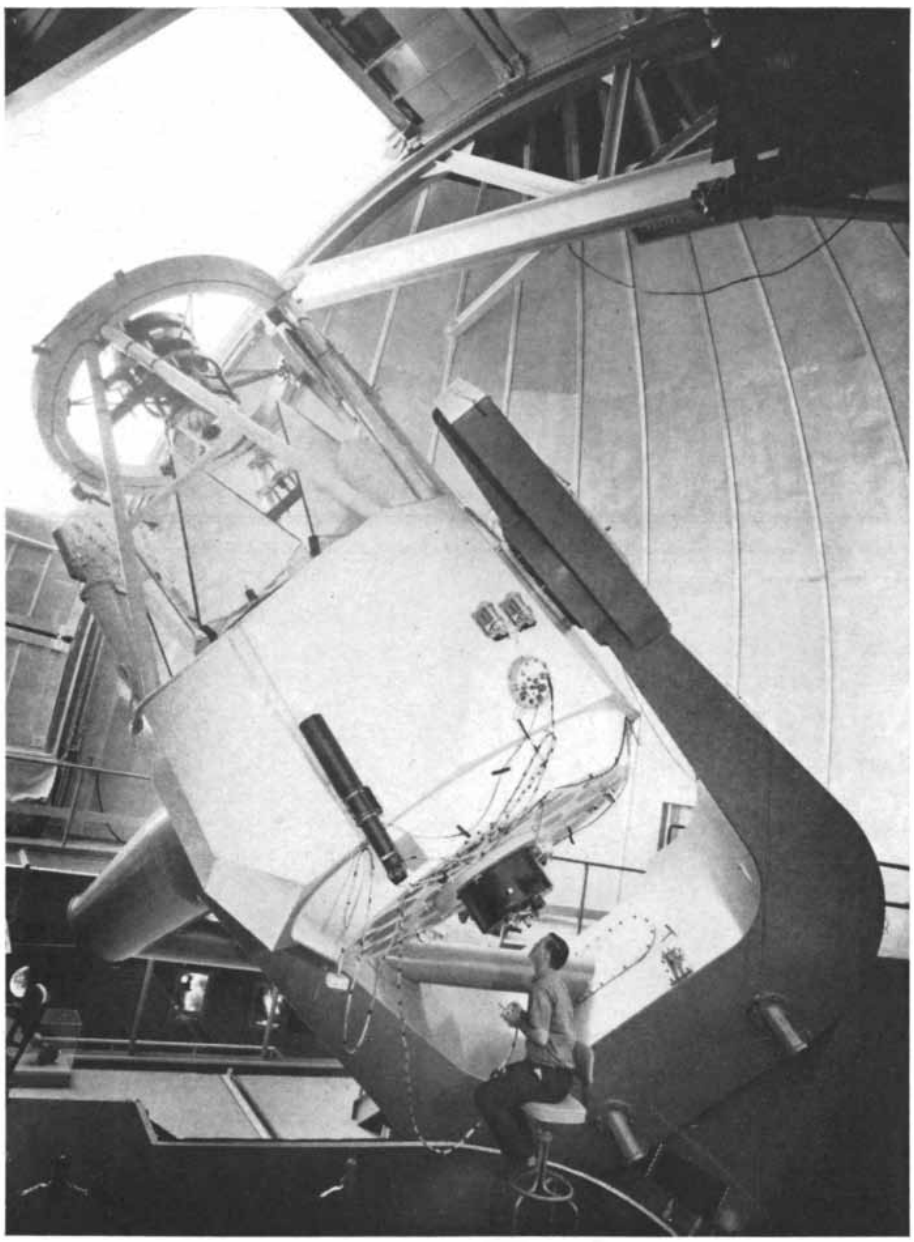
Recently Stirling A. Colgate of the New Mexico Institute of Mining and Technology has proposed a model in which large stars (about 10 solar masses) are formed by the collision of smaller ones. These giant stars evolve and finally explode as supernovas. Colgate believes that such explosions might release much more energy—through gravitational collapse—than is normally observed in a supernova explosion and that the sum would be enough to explain the energy released by quasi-stellar objects placed at cosmological distances. According to Colgate, however, the initial density of small stars that is required in this model is about 500 million per cubic light-year.

In all these theories it is recognized that quasi-stellar objects are both small and very massive. No one really knows if such an object can be formed from low-density matter spread throughout the universe. Thus some people have suggested that quasi-stellar objects are truly cosmological in the sense that their origin is connected with the way in which matter enters the universe. For example, they may be miniature expanding "universes" that have only recently begun to expand. Alternatively, on the steady-state hypothesis, matter may be created in regions of the highest

density, such as the nuclei of galaxies; according to this model quasi-stellar objects are blobs of new matter that have been ejected from galactic nuclei. A radio galaxy might be a galaxy that is giving birth to such objects. Models of this kind would serve to explain quasi-stellar objects whether they were at cosmological distances or much closer.

It is still necessary, however, to explain how the energy released is chiefly in the form of particles moving at relativistic speeds. An attractive possibility is to suppose that matter as originally created, whether in a single "big bang" or in a steady-state universe, is largely in the form of the hypothetical massive particles known as quarks. It has been suggested that such particles may form the basic building blocks of the more familiar elementary particles: the baryons that decay into nucleons and the various mesons. If quarks do exist, they are more massive than baryons; three quarks are needed to create a baryon and a quark-antiquark pair is needed to create a meson.

If primordial matter appears in the form of quarks, one can see how immense energy is released when the quarks give rise to lighter particles, including photons and neutrinos. The particles will be endowed at birth with tremendous amounts of kinetic energy, which could account for the relativistic speeds of matter that are observed in quasi-stellar objects.



KITT PEAK 84-INCH REFLECTOR is the one used by Lynds and Stockton in studying the spectra of quasi-stellar objects. Examples of their work appear on pages 41 and 42. Margaret Burbidge records quasi-stellar spectra with the 120-inch reflector at the Lick Observatory. The first quasi-stellar object, 3*C* 48, was discovered in 1960 by Allan R. Sandage with the 200-inch Hale telescope on Palomar Mountain. Working with the same instrument in 1963, Maarten Schmidt established the first red shift in a quasi-stellar object, 3*C* 273.

What if the quasi-stellar objects are local rather than cosmological phenomena? In that case the energy they release can be less by a factor of about 10^4, a condition much easier to satisfy. Now, however, a plausible model must offer a mechanism for setting the objects in motion at the velocities indicated by the red shifts—and this requires considerable energy. Let us imagine that galaxies explode from time to time and in the process are transformed into radio galaxies. Conceivably the explosion could throw a cloud of objects out into space, and it is these we see as quasi-stellar objects. Such a process might require on the order of 10^{62} ergs per explosion; moreover, the energy must be emitted in coherent lumps so that each object is provided with a dense enough core to hold itself together when ejected at relativistic speeds. We do not know precisely how this can occur, but it seems that in the process of gravitational collapse very large amounts of energy must be released in relativistic form, and this is required in any case to explain the radio galaxies.

Some have objected to this admittedly sketchy model on the grounds that when they calculate the energy required to explain the cloud of objects moving at relativistic speeds, it is too high by some criterion (of unspecified nature) concerning what is reasonable. We reply that any theoretical arguments marshaled for or against one or another quasi-stellar hypothesis on the basis of energy considerations are entirely fallible. In the absence of any real understanding of the mechanism that gives rise to the colossal energy output of radio galaxies, which are known to be at cosmological distances, we are in a poor position to say what is reasonable or even possible.

There can be no doubt that at present most astronomers would like to conclude that the quasi-stellar objects are cosmologically distant. As we have tried to emphasize, the question is still open because there is no conclusive argument one way or the other. In fact, we may be in for many more surprises on the observational side. Regardless of the outcome, the problem of understanding the quasi-stellar objects and the immense fluxes of energy they and the radio galaxies release is one of the most important and fascinating tasks in all of physics.

Solvents and solvatochromic compounds

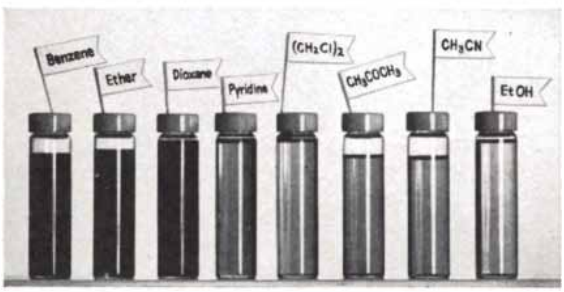
Fifteen years ago we suggested (*J.A.C.S.*, 73:5350)* that certain dyes be used as indicators of solvent polarity, but it fell to another investigator (*Ibid.*, 80:3253) to bring the idea off.

The dye he chose, *4-Carbomethoxy-1-ethylpyridinium Iodide*, we now offer as EASTMAN 9765, which shifts its absorption band toward the blue with increasing solvent polarity. Put it into some solvents, look through a band-pass filter that removes the distractions of color, and arrange in the order of decreasing wavelength instead of by dielectric constant. You

now have a series that may relate better to the intermolecular forces that govern solvation behavior than does dielectric constant (*Angew. Chem., internat. Edit.* [*English*], 4:29).

A dye that shifts its absorption band in the opposite direction, i.e., toward the red with increase in solvent polarity, is the merocyanine, *N,N-Dimethylindoaniline* (EASTMAN 9766).

Here is another solvatochromic dye, *Pyridinium Cyclopentadienylide* (EASTMAN 10009), seen through a filter that passes only one of its four absorption bands, the one that is most sensitive to a change in solvent polarity (*J.A.C.S.*, 81:856):



There is also [*Bis*(*2-hydroxyethyl*)*amino*]-*p-benzoquinone* (EASTMAN 9967). Not only is it solvatochromic but also piezochromic, thermochromic, fluorescent, and soluble in both acid and base (*J.O.C.*, 30:4107).

There must be plenty of occasions in chem labs when it would be handy to look into an eyepiece to find out whether Solvent A is more polar than Solvent B. If this pops an idea into somebody's head, he'd better note that the compounds here mentioned can be ordered from Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company), which has recently issued a new catalog of its EASTMAN *Organic Chemicals.*

What's an opticist, Pop?

Many employers are seeking persons qualified in optics and optical engineering. But for fear of sacrilege, they'd pray heaven to send them. In relation to demand, applied optics and optical engineering seem among the most severely undermanned of professions. Bright kids in school don't seem to find out about this (or to believe it if told) until after committing themselves to other disciplines. As a result, many of today's optical designers and engineers have to admit to themselves in black moments that they really aren't.

To spot a genuine pro in the field, try asking him if he knows a man named Rudolf Kingslake. Most reassuring would be a reply to the effect that not only does he know Dr. Kingslake but has taken courses under him and made good grades.

Kingslake came to the University of Rochester in 1929 from Imperial College of Science and Technology in London. In 1937 he also joined us and has been our full-time head of optical design since 1939. In the past two years he and his staff have been far busier than ever before, though we are not at liberty to disclose on what. Nevertheless, by skillfully using what little time his industrial and teaching undertakings leave him, he has managed during these same two years to bring out the first three volumes† of a five-volume comprehensive treatise entitled "Applied Optics and Optical Engineering" (Academic Press, New York and London).

Under his editorship, 29 of the projected 50 chapters are now in print, a few written by him and the rest by people from our own and 17 other organizations. Where this crew found the ambition and the devotion to scholarly obligation remains a mystery explicable only in terms of the resilience of the human spirit. Probably it is too much to hope that their effort could retread any significant numbers of physicists, electrical engineers, or mechanical engineers into opticists.

We could use a few more opticists ourselves. Indeed we could. They'd be in stimulating company. The address of our Director of Technical Personnel is simply Eastman Kodak Company, Rochester, N.Y. 14650.

Clean out your paper

The little box can hold 49,000 pages of reports, journal articles, and whatever other forms of technical information normally stuff bookcases and cabinets when on paper. Inside the little box it is on sheets of film around 4¼″ x 6″, known as filmcards or microfiches. The upper part of each microfiche may carry an abstract of the item that can be read comfortably without optical aid, while the lower part carries the complete text and illustrations for reading on devices that we offer in a range between $147.95 and $212.50. The exact dimensions and arrangement of the material can conform to the COSATI specification now required for all Federal agencies and their contractors, or to any other specification you please.

You can get yourself all wound up in the complexities of this subject without really being interested in it. We hope you have other uses for your time and energies. We therefore offer you the following service:

You can turn all the paper over to a nearby branch office of ours, and we'll put it on RECORDAK *Filmcards of size and format you suggest or ask us to suggest. If the material is of a nature to require frequent change, we can set up a system to make and distribute replacement microfiches for you every time you send us new paper. If you would rather not let the paper out, we can sell you equipment to make it unnecessary. Write Eastman Kodak Company, Business Systems Markets Division, Rochester, N.Y. 14650.*

Prices subject to change without notice.

*For a more recent publication on the subject from our laboratories, see *J.A.C.S.*, 87:2443.

†Volume I:
photometry
light sources for optical devices
filters
atmospheric effects
optical materials
basic geometrical optics
diffraction
interference and coating
polarization
projection screens
precision and accuracy

Volume II:
the eye and vision
stereoscopy
the photographic emulsion
combination of lens and film
illumination in optical images
electro-optical devices
television optics
infrared detectors
infrared equipment

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lens design
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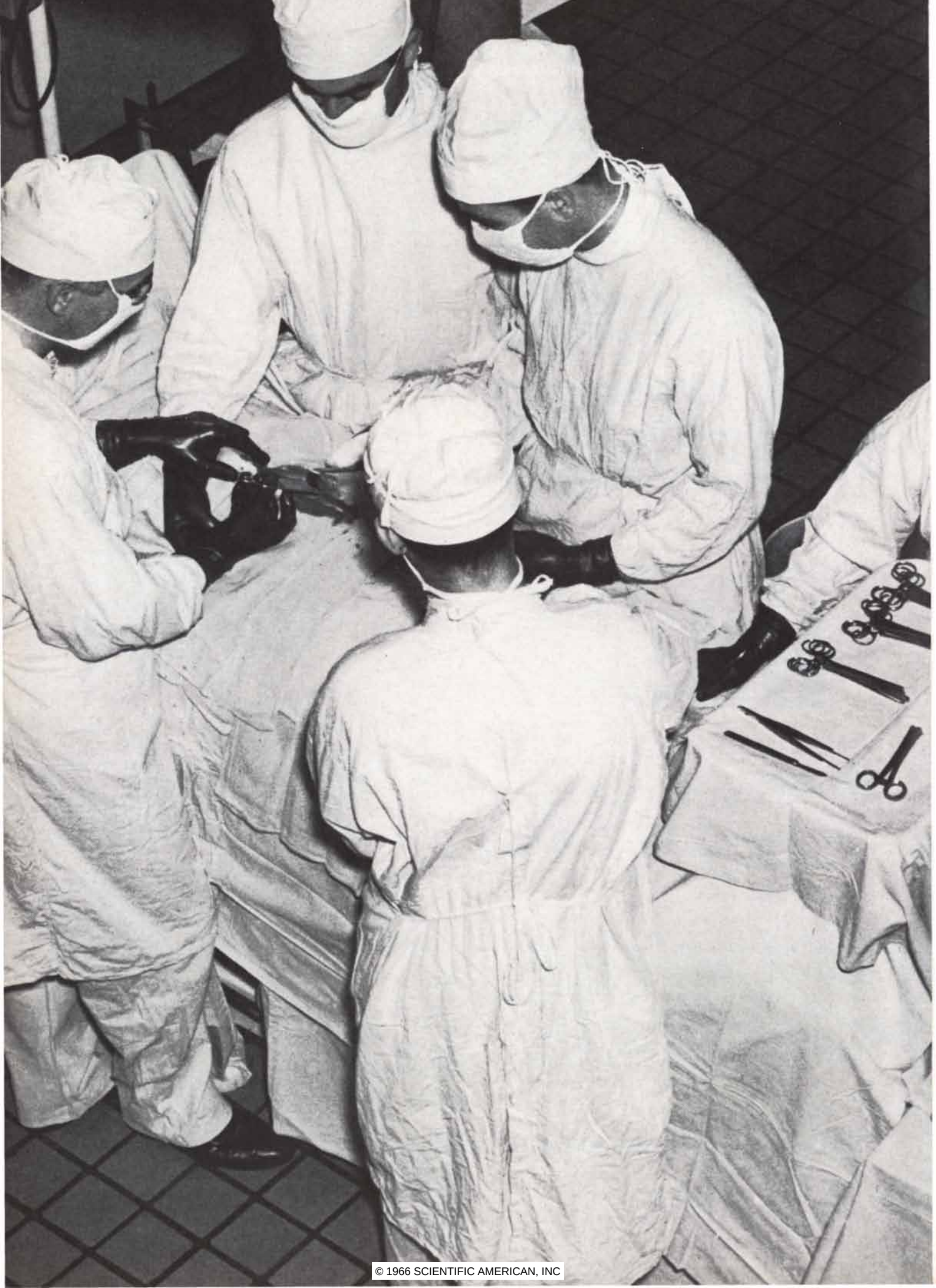
Kodak



"Anesthetic . . . clamp . . . diamond."

Diamonds, the workhorses of industry, are now finding intriguing uses in the operating room.

A Wilmington ophthalmologist and a New York plastic surgeon have uniquely and successfully used diamond instruments. The ophthalmologist, Dr. Davis G. Durham, developed a new technique in cataract surgery. The technique is based on a surgical knife with a microscopically perfect cutting edge formed from gem-quality diamond. The blade measures less than 100 Angstroms in thickness.

"The advantage of the diamond knife," says Dr. Durham, "is that it makes a perfect beveled corneal incision, which results in faster healing." To date he has performed over 70 successful cataract removals with the diamond knife.

Dr. James W. Smith, a plastic surgeon, specializes in the repair of peripheral nerves. He uses precision forceps whose tips have been embedded with diamond dust. These new forceps can grasp very fine tissue firmly, without damaging it. Also, the surgeon can grip sutures more securely when tying damaged tissues together.

But you don't have to work in an operating room to reap the benefits of diamond tools. Natural and synthetic diamond tools are routinely used for a multitude of jobs in optics, metalworking and road-building.

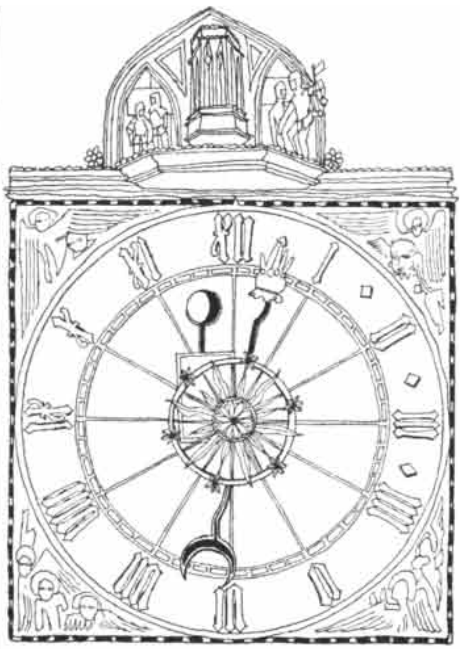
Don't be frightened by the cost of diamond tools. Because if you cut, sharpen, or smooth *anything* in your business, you can probably use diamonds profitably. Your tool and wheel maker can show you how. Or write to this magazine for more information.

De Beers

World's leading source of natural *and* synthetic diamonds for industry . . . backed by the Diamond Research Laboratory

Shannon, Ireland

SCIENCE AND



The Nobel Prizes

The will of Alfred Nobel, which established the Nobel prizes, specifies that the prizes be given "to those persons who shall have contributed materially to benefit mankind during the year immediately preceding." This has never been practical for the prizes in science. Indeed, the science prizes have seemed to fall into two general categories: those awarded for recent work (although seldom for work during the year immediately preceding) and those given for work that was done many years ago and has already become part of the tradition of science. This year the prizes are almost entirely of the latter kind.

The prize for physiology and medicine was shared by Peyton Rous, 87, of Rockefeller University and Charles B. Huggins, 65, of the University of Chicago. The chemistry prize was awarded to Robert S. Mulliken, 70, also of the University of Chicago, and the physics prize to Alfred Kastler, 64, of the École Normale Supérieure in Paris.

In 1910 Rous, who had just been invited to the Rockefeller Institute, began studying sarcomas, a type of malignant tumor, in hens. He wanted to see if the tumors could be transmitted from one hen to another. He soon discovered that a cell-free filtrate obtained from ground tumors would induce sarcomas when injected into healthy hens. The infective agent was evidently a virus—a type of organism then little understood. For some 40 years viruses appeared to be an oddity among cancer-causing agents. In 1951, however, a type of leukemia in mice was traced to a virus. Since then, according to the committee that awarded the prize, "the significance of Rous's initial discovery... has been enhanced with every passing year."

Huggins' work was also concerned with cancer. In the early 1940's he found that female sex hormones would effectively retard the growth of prostate cancer in men by causing the prostate tissue to atrophy. This was the first nonradioactive substance to be effective in the control of cancer and launched a general search for chemotherapeutic agents.

Mulliken's contributions to chemistry are embodied in some 200 papers dating back to 1919. His principal work involves "molecular orbitals," the concept that the valence electrons in molecules are not bound to a particular atom but travel in orbits around two or more atomic nuclei.

Following the rise of quantum mechanics in the late 1920's Mulliken began applying its teachings to the understanding of the chemical bond. He is credited with unraveling the complex spectra of molecules by means of arguments based on symmetry principles, aided by an intuitive feeling for molecular structure. At about the same time John C. Slater of the Massachusetts Institute of Technology developed a parallel interest in molecular orbitals and developed their mathematical theory. Because Slater published exclusively in physical journals his work is less well known to chemists than Mulliken's is. Prior to the development of high-speed computers the theory of molecular orbitals was too complex to apply to problems of practical interest to chemists. In the past 10 years, however, the theory has been used successfully to predict molecular behavior and has been confirmed by experiment.

Kastler received the physics prize for his development of "optical pumping," a method for raising atoms to particular energy levels previously inaccessible for detailed study. Normally when atoms absorb energy they are raised to a variety of excited states from which they subsequently fall at random to lower states. Optical pumping provides a method for obtaining a large population of atoms in a particular excited state so that one can study the spectrum of the radiation they emit in falling to a lower energy state.

THE CITIZEN

Basically Kastler's method involves shining circularly polarized light into a rarefied gas of the atoms to be studied. After being pumped to higher energy states the atoms fall to lower states, which gives rise to a population distribution that is no longer the equilibrium mixture that existed before pumping. By applying radio-frequency energy to this nonequilibrium mixture it is possible to alter the population again, thereby acquiring information about the fine structure of atomic spectra. In describing his work some years ago Kastler generously credited a 1949 paper by Francis Bitter of the Massachusetts Institute of Technology with providing "the starting point of all research on optical detection of radio-frequency resonance."

Optical pumping not only proved fruitful for studying the fine structure of atomic states but also, in the hands of others, contributed to the development of precise atomic clocks, to sensitive magnetometers now used in space exploration and to lasers.

Congress and Science

A Congressional subcommittee, while calling attention to the growing role science and technology must play in meeting national problems, has emphasized the need for "careful and improved methods" of utilizing technical knowledge. "Otherwise," according to the House Subcommittee on Science, Research, and Development, "we may strangle in the coils of an unplanned, unwanted, but unstoppable technocracy." In a report to the parent Committee on Science and Astronautics the subcommittee, whose chairman is Emilio Q. Daddario of Connecticut, summarized its first three years' activities. Then it went on to delineate 12 major problem areas, each of which "will demand a greater appreciation by the public and a greater understanding by public servants before it can be treated with logic and effect." These were some of the areas:

Protecting the natural environment—controlling pollution, understanding weather, developing natural resources. "The rate at which we are altering our environment and consuming our resources," stated the subcommittee re-

port, "may be the most serious blight affecting contemporary civilization."

Application of computers and providing the new computer management systems with "more efficient coupling to human control."

Stimulating industrial research and development, which the subcommittee finds has lagged in relation to the total U.S. effort.

Diminishing urban congestion and developing, through technology and the social sciences, ways of maintaining a dignified living environment and "a reasonable degree of personal freedom and living room."

Upgrading the quality of education. "Too often individual needs are neglected.... Technology is partially responsible for some of the systems that produce this result—but better technology... should be able to overcome it."

The seven other areas were providing new sources of energy, managing information storage and retrieval, innovating in transportation, providing adequate housing, improving food production and distribution, alleviating crime and protecting national health, with particular attention to mental health and geriatrics.

Governmental effectiveness in such areas, the report suggested, requires two special attributes. One is a new ability to deal with problems whole rather than treating symptoms. The other is the linking of social sciences with physical sciences and engineering: "We need to know a great deal more about the behavior and motivations of humanity... to apply our growing technology with accuracy and maximum results."

The subcommittee warned that there is no longer time to deal with "the dangerous side effects" of applied technology after they appear; they must be foreseen and forestalled. The report listed some "obvious" examples:

Technology has produced automatic machines; the side effects include not only unemployment but also fundamental shifts in demands for skills, imbalances of manpower and even the concentration of population in urban centers. Technology has produced pesticides; the side effects are chemical pollution of the soil and trace concentrations of pesticides in human beings—possibly with adverse effects. Technology has enormously improved the efficiency of lumbering and of fishing; the side effects are the depletion of forests and fishing grounds.

Some less obvious examples were cited as being of even greater significance. Progress in utilizing nuclear energy has not been matched by techniques for disposing of toxic by-products, so that widespread use of nuclear fuels may be impractical; should we be working harder on radioactive waste disposal or developing alternative new energy sources? Such diverse factors as highway construction, strip-mining and increased numbers of automobiles, airplanes and human beings may be upsetting the earth's balance between oxygen and carbon dioxide; might this affect life cycles or alter weather patterns?

The subcommittee proposed the consideration of two procedural innovations. One is the establishment in Congress of science and technology "study groups" that would make comprehensive surveys of broad problems before individual House committees consider legislation on aspects of those problems. The other is the establishment of an early-warning system for new technology: a Technology Assessment Board to keep tab on "the potential dangers, as well as the benefits, inherent in new technology."

Pleistocene Overkill

What caused the extinction in North America of large mammals such as the mammoth, the mastodon, the giant sloth and the camel? A change in climate has been the favored hypothesis. Now Paul S. Martin of the University of Arizona has undertaken to show that the cause was another change in the animals' environment: the coming of man.

The remains of 35 mammal genera, Martin writes in *Nature,* have been recovered from California's Rancho La Brea tar pits; they are some 15,000 years old. By 6,000 years ago none of these animals had survived. There is no evidence, however, that there was any catastrophic change in grazing conditions in that period. Moreover, the changes in vegetation that did accompany the last retreat of the Pleistocene ice sheet in the same period had taken place several times before without affecting North America's mammal population. Martin argues that the significant event was not the warming climate but the arrival in the New World of well-armed hunting bands from Asia about 11,000 years ago (see "Elephant-hunting in North America," by C. Vance Haynes, Jr.; SCIENTIFIC AMERICAN, June).

An argument that has been advanced against the view that man was responsible for the disappearance of North America's largest animals is that Africa, a continent long inhabited by human hunters, still has abundant big game. What this argument overlooks, Martin writes, is the fact that at least 25 genera of large mammals (including two genera of primitive elephants and seven or more genera of cattle) became extinct in Africa between 50,000 and 100,000 years ago. The antiquity of this event rules out any possibility that a late Pleistocene change in climate could have been a factor in it.

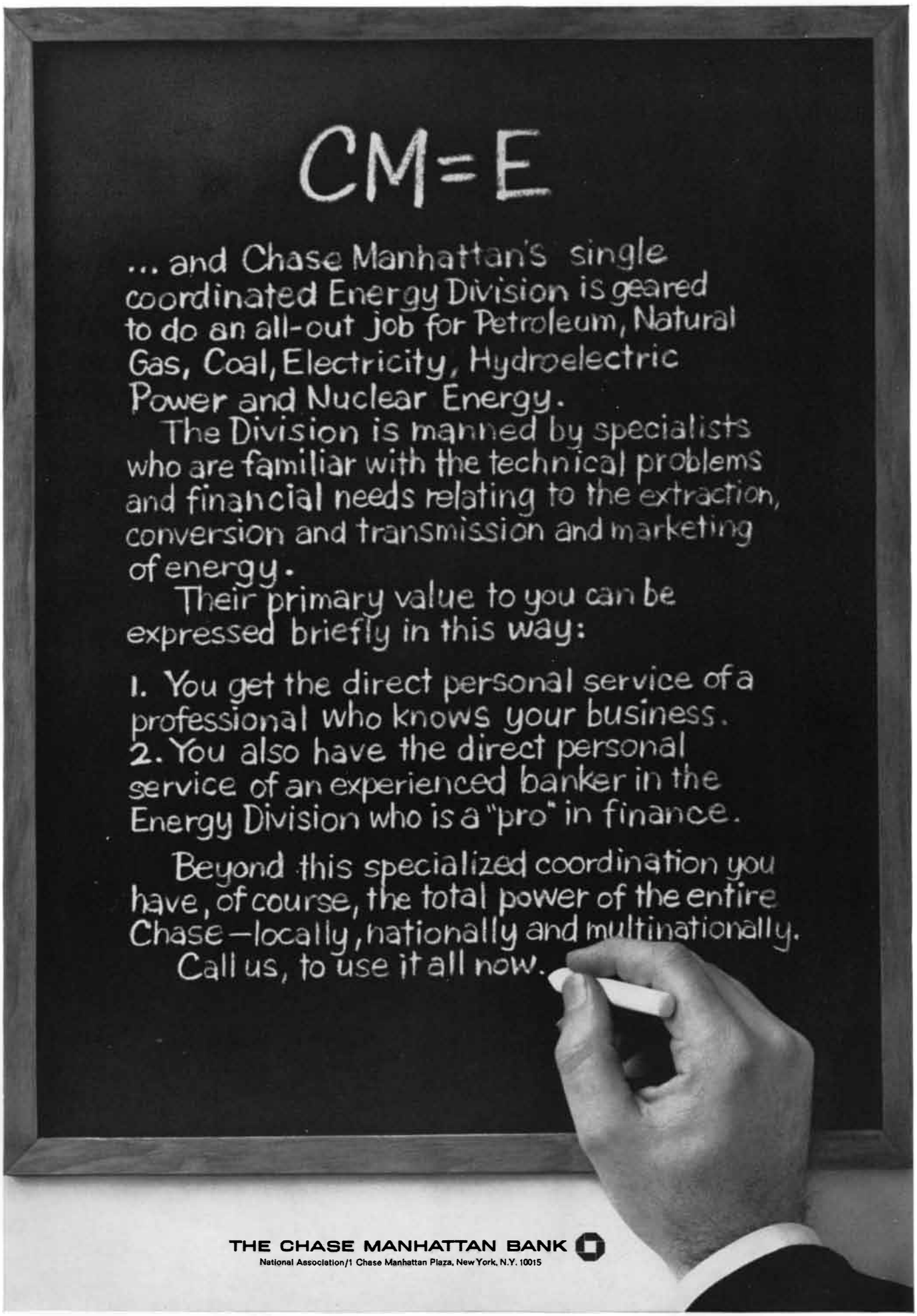
In recent years the remains of many extinct African mammals have been found in association with large, crude stone hand axes, scrapers, cleavers and other tools. These tools, which are among the earliest specialized human artifacts, belong to a stone-tool industry named the Acheulean (after Saint Acheul, an early Paleolithic site in France). Acheulean industries seem to have disappeared from Africa about 50,000 years ago—at about the same time by which all but three of the extinct African genera of large mammals had vanished. Proposing that hunters armed with Acheulean weapons did to the fauna of Africa what Paleo-Indian hunters appear to have done in the New World, Martin concludes that in both cases the primary instrument of extinction was "Pleistocene overkill."

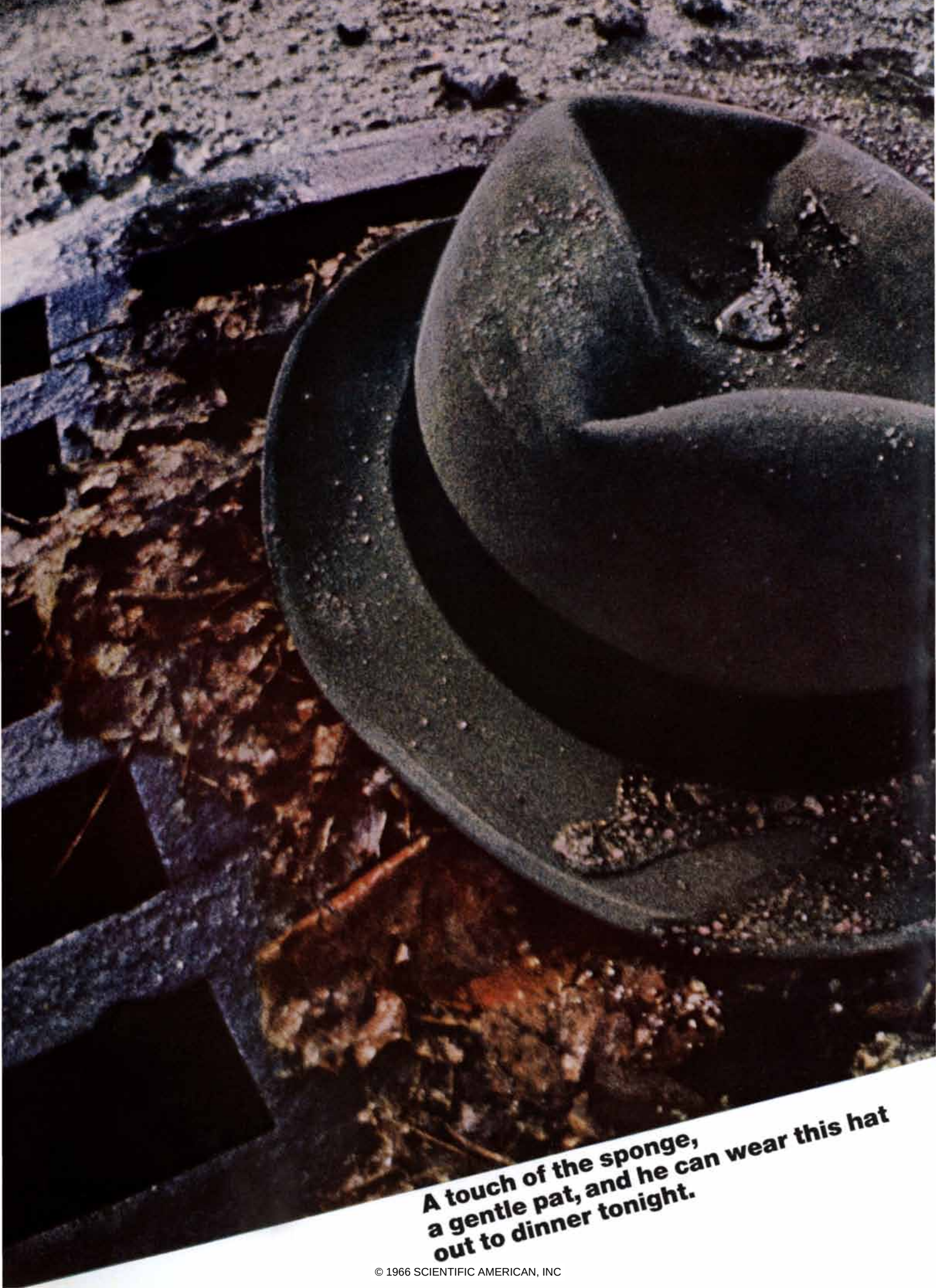
Automatic Insulin

Insulin has been synthesized by an automatic process. The sequence of amino acid units in the insulin molecule had been determined by Frederick Sanger in 1954; the molecule consists of two linked peptide chains, one of 30 amino acid units and the other of 21. In the past three years the hormone has been synthesized by groups in Germany, the U.S. and China. Now it is the first complex protein to be synthesized by the "solid phase" method of peptide synthesis developed by R. B. Merrifield and his associates at Rockefeller University.

The problem in peptide synthesis is to form a series of peptide bonds between the successive amino acid units of the chain while at the same time preventing unwanted reactions involving various sites on each amino acid. In standard methods the most difficult part of the process is isolating and purifying each intermediate product before it can be used for the next step in the synthesis; the separations take time and painstaking effort, and they sharply reduce the final yield. The German process for insulin synthesis, for example, required 221 steps and took many months.

In the solid phase method the growing peptide chain is formed with one end of the chain attached to an insoluble solid support: a tiny bead of polystyrene. The peptide itself thus becomes insolu-





A touch of the sponge,
a gentle pat, and he can wear this hat
out to dinner tonight.

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It's a revolutionary, new kind of hat made from Surfel®, a synthetic, high-polymer fabric from Union Carbide.

Surfel will survive almost any accident. You can smear it with catsup or plaster it with jelly, and it will wipe clean with soap and water. Wear a Surfel hat through a soaking rain, and sit on it, and it will still return to its original shape.

Developed with the Hat Corporation of America, under the Knox and Dobbs labels, Surfel is just one of the hundreds of new developments Union Carbide files with the U.S. Patent Office every year. Just in the last six or seven years, Union Carbide has spent almost half a billion dollars developing new products and processes. Which is why we say our real business is discovering things.

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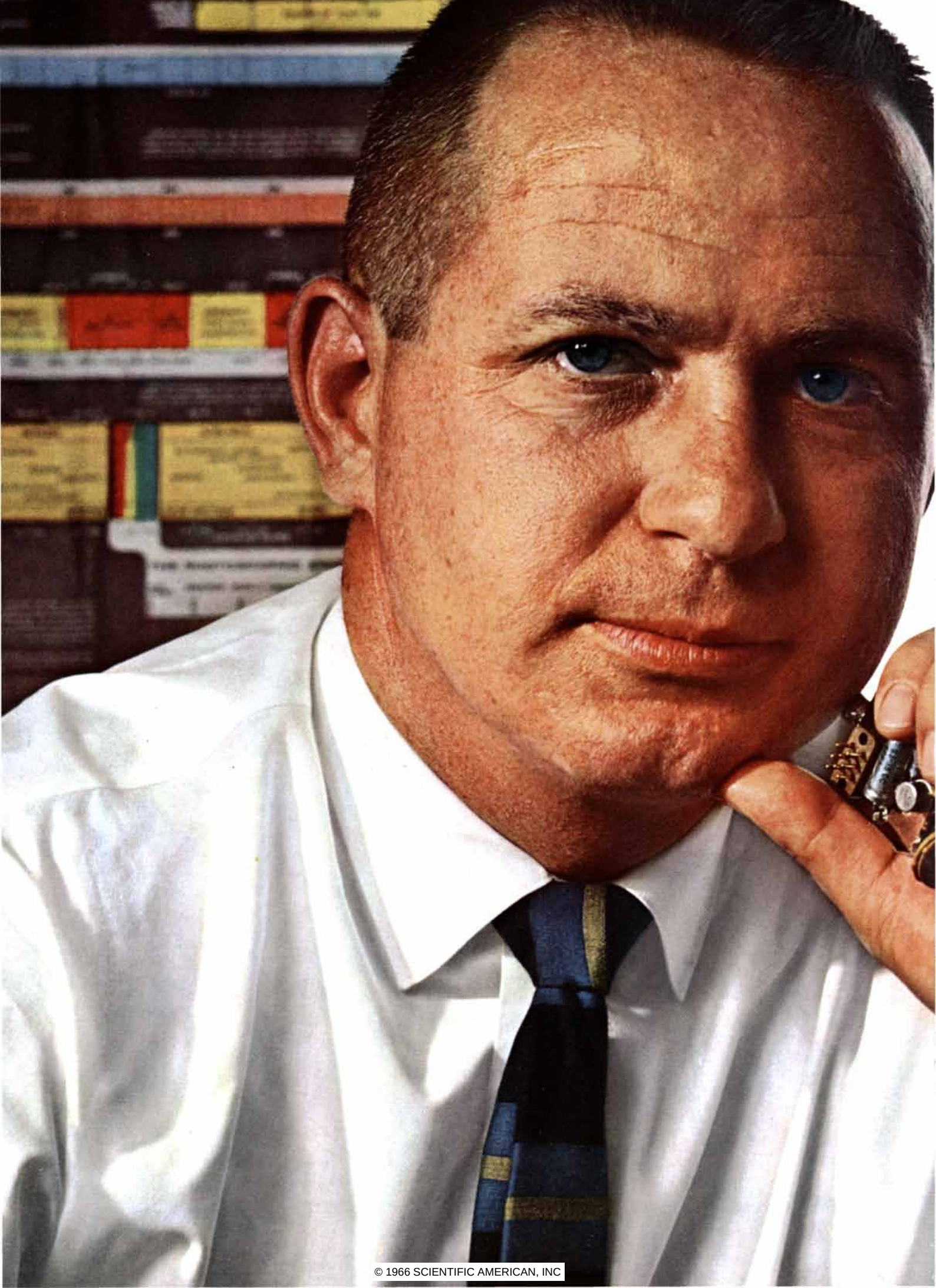

This engineer is developing a way to send talk down a pipeline of light.

What's he doing at IBM?

The usual channels of long-distance communication, namely, wires, radio and microwave, aren't looking so roomy these days.

At the rate we are transmitting talk, pictures, and information between our cities and into space we may one day need new means of communicating.

One new means appears to be the laser.

A laser beam, in theory, can transmit more information than all the radio channels currently in use.

The engineer in our picture is one of IBM's team which is inventing ways to get information on the beam at one end and off at the other.

IBM's interest in the laser grows out of its interest in anything that makes information more useful for people.

IBM has already demonstrated a laser device that can shoot check-out signals directly into a launch vehicle standing on the pad. Another IBM team is developing a laser for communicating with the astronauts, earth to spacecraft, planet to planet.

It all comes under the heading of making information easier to get, which is step one in making it more useful.

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ble and is able to withstand simple filtering and washing operations that purify it as it is formed; the completed chain is simply cleaved from the supporting plastic chemically. The solid phase method lends itself to automatic control because the reactions can all take place within one vessel. Merrifield's group devised an automatic system in which the proper reagents and solvents are pumped into the vessel and out again on schedule by an automatic programmer. The device methodically adds one amino acid after the other at the rate of six a day.

By this method several short, biologically active peptides were synthesized, and now Arnold Marglin and Merrifield have reported in the *Journal of the American Chemical Society* the synthesis of the two chains of cattle insulin, which closely resembles human insulin. The 30-unit chain was produced "by hand" and the 21-residue chain by the fully automatic process, but the method was essentially the same in both cases. A compound containing the first amino acid in a chain, with its reactive sites "protected," was bound to a particle of the plastic. Then the protective group was removed from the site at which the first peptide bond was to be formed and a compound containing the second amino acid was allowed to react with the first. To make the 30-unit chain the process was repeated 28 times, after which the completed peptide chain was cleaved from the plastic. This portion of the process took 11 days; the yield at that point was 64 percent (based on the amount of the first amino acid that had been bonded to the plastic). After further steps to remove protective groups the yield was 21 percent. The other chain took eight days to synthesize and showed a final yield of 37 percent. To test the chains the investigators combined them with each other and with complementary natural chains and tested them for biological activity. The chains compared well in this respect with chains synthesized by standard methods. Marglin and Merrifield suggest that "the remarkable simplicity of operation, the short time required for the synthesis and the high yields" emphasize the advantages of their method.

The Seduction of Bark Beetles

The bark beetle, an insect that annually destroys five times more timber in the U.S. than all forest fires combined, can be added to the list of insect pests subject to biological controls. The foremost candidates among insects for control by natural processes are the more

than 230 species, distributed among 14 insect orders, that secrete complex volatile substances to attract members of the opposite sex. In 175 species the female produces the sex pheromone; in 60 others the male is the producer. More than 20 of the insects whose sexual behavior is chemically mediated are serious economic pests. Natural or synthetic sex pheromones are now being used both for survey and control purposes against six: the gypsy moth, the pink bollworm, the codling moth, the sugarcane borer, the fall armyworm and the cabbage looper.

Gary B. Pitman and J. A. A. Renwich of the Boyce Thompson Institute for Plant Research (working with Jean Pierre Vité of the University of Göttingen) and Robert M. Silverstein and J. Otto Rodin of the Stanford Research Institute in California have announced their independent isolation and identification of the sex attractant produced by bark beetles of the genus *Ips*. Silverstein and Rodin reported at a recent meeting of the Canadian Entomological Society at Banff that they have also synthesized the *Ips* pheromone. The male bark beetles secrete the substance in the hind gut as they feed on host plants; their excretions then attract the females. Several other genera of bark beetles do the same, sometimes the male producing the pheromone and sometimes the female. Identification and synthesis of other bark beetle pheromones should greatly enlarge the opportunities for using pheromones to lure the insects into traps.

Enzymes on the Rocks

The notion that freezing offers the key to the preservation of biological materials, including human organs, is thrown into question by experiments showing that certain enzymatic processes go faster in frozen solutions than in liquid solutions. N. H. Grant and Harvey E. Alburn of the Wyeth Laboratories report in *Nature* that a number of reactions that are catalyzed by the enzyme trypsin proceed faster at −23 degrees centigrade than at 1 degree C.

Grant and Alburn were prompted to make their study by earlier reports that a wide range of catalyzed reactions, including hydrolysis, aminolysis, dehydration and oxidation are accelerated by freezing. In those experiments the catalysts were not enzymes but inorganic compounds of various kinds.

As a result of their findings Grant and Alburn conclude "that enzyme reactions may speed up or change their pathway in the frozen state, despite decreased kinetic energy and probable restricted diffusion. Between zero C. and −70 degrees C. the liquid-water component in frozen systems is highly structured. We are now testing the idea that frozen solutions might offer a useful model for investigating how agents which make and break water structure influence biological processes."

The Electric Automobile (Cont.)

Further evidence that the electric automobile is being seriously considered as an alternative to the internal-combustion car is provided by the recent announcement by the General Motors Corporation that it is working on electric vehicles. Other companies, notably the General Dynamics Corporation and the Ford Motor Company, have stressed the development of novel batteries for such vehicles (see "The Electric Automobile," by George A. Hoffman; SCIENTIFIC AMERICAN, October). General Motors has produced two actual machines.

The two vehicles are a battery-powered Corvair and a small truck that gets its electricity from a fuel cell. The "Electrovair II" has a top speed of 80 miles per hour and a range of between 40 and 80 miles. Its 286 silver-zinc batteries cost $15,000 and can be recharged only about 100 times. The truck has a range of between 100 and 150 miles; thereafter the liquid oxygen and liquid hydrogen of its fuel cell must be replenished. General Motors is investigating an alternative power source: a battery utilizing lithium and chlorine that might prove both inexpensive and efficient.

Photocopying by Radioactivity

Neutron activation, the technique by which nonradioactive atoms are made radioactive by neutron bombardment, has found an unusual application in the restoration of early photographs. Faced with the severe deterioration of a number of century-old prints made by the pioneer photographer W. H. F. Talbot, the Smithsonian Institution has successfully copied several of them by rendering the silver of the images radioactive. The process, described in *Science* by Eugene Ostroff, was used instead of more conventional methods of restoration because the chemical characteristics of the prints were not known.

Each print was exposed to a fairly intense flux of neutrons in a nuclear reactor. The bombardment converted some of the silver atoms in the image to the radioactive isotope silver 108, which has a half-life of 2.3 minutes and emits high-energy beta rays. The irradiated print was then placed in contact with a fine-grain high-contrast X-ray negative, which captured the original image even though little or nothing remained visible on the print itself.

Against Streptococcus

An experimental vaccine has been developed that shows some promise of combating streptococcal infections. These infections can lead to rheumatic fever, rheumatic heart disease and kidney disease. The process by which they do so is still not clear, but it is thought to involve a form of hypersensitivity (see "Rheumatic Fever," by Earl H. Freimer and Maclyn McCarty; SCIENTIFIC AMERICAN, December, 1965). Antigens in the streptococcus apparently stimulate antibodies that attack certain tissues of the infected host as well as the bacterium itself; the presence of these antigens has made it impossible to develop a vaccine by using the whole bacterium.

In the cell wall of the streptococcus, however, there is a so-called *M* protein that accounts for much of the germ's virulence: it inhibits phagocytosis, the process by which defending white blood cells dispose of invading organisms. Specific antibody to this *M* protein neutralizes the protein and renders the bacterium vulnerable to the body's defense system. Unfortunately there are some 50 different types of *M* protein, and antibodies to one are not effective against another. Moreover, it is hard to isolate *M* protein in a form that is potent but not harmful to the host's tissues.

In the *Journal of Immunology* Eugene N. Fox of the University of Chicago has reported making vaccines with *M* proteins that do not damage heart tissue, according to tests performed at Rockefeller University. By combining three different proteins he made a vaccine that, when tested in animals, appears to offer protection against three types of streptococcus; one of the three strains is currently responsible for many streptococcal infections and for most streptococcal kidney disease. Another vaccine, which has had a preliminary test in human beings, conferred protection against only one type of streptococcus. Fox and his associates, Albert Dorfman and M. K. Wittner, hope to make a vaccine that will protect against four to six types, which they feel would account for nine out of 10 infections. Several years of testing with large numbers of human beings will be necessary to prove the safety and efficacy of such a vaccine.

NOISE

There is widespread concern that the noisy environment of modern man not only is distracting but also causes damage to the ear. What are the facts of the matter, and how can noise be brought under control?

by Leo L. Beranek

Mankind seems destined to live in an increasingly noisy environment. The growth of population and the proliferation of machines are steadily raising the noise level, not only in our cities but also in the countryside. More and more we are exposed to a babel of technological noises that disturb our sleep, make conversation difficult, create anxiety and in many cases may result in a permanent impairment of hearing.

Although the noise problem has been widely discussed and studied for many years, it has not yet been dealt with in any thoroughgoing way. In several sectors of our technology, however, it has recently presented itself in an acute form. A crisis was precipitated for a considerable part of U.S. industry by a court decision in the state of New York in 1948. Matthew Slawinski, a drop-forge worker, had filed a claim against his employer for compensation for partial deafness caused by the high noise level in the shop where he worked. Eventually the New York State Court of Appeals upheld his plea that he had suffered an occupational disability (although he was able to continue at full pay as a drop-forge worker), and he was awarded $1,661.25. The decision was soon followed by the filing of hundreds of claims against employers by workers in noisy industries in many other states. Management alarm in these industries—textile mills, drop-forge and metal-fabricating shops, steel mills, metal-container plants and others—rose to near-panic proportions, and a member of the Wisconsin Industrial Commission estimated that the total of claims for occupational loss of hearing in the U.S. might rise to billions of dollars.

Industry was given a reprieve by later judicial elaboration, in New York and elsewhere, of the original ruling. It is now held that to establish a claim a worker must retire from his noisy occupation for some months in order to determine whether or not his hearing loss is permanent. Since most workers do not wish to give up months of wages (or their occupation) for the chancy opportunity to sue for a compensation award, the surge of claims has subsided.

Nevertheless, industry has not entirely recovered from its scare, and other noise sources—notably the rising din of automobile and airplane traffic—are creating active public concern and demands for remedies. It is clear that the basic problem is essentially incurable; noise is an unavoidable price we must pay for a machine civilization. But if we cannot eliminate the noise of modern technology, we can at least control it to minimize its effects. The problem of control has three main aspects: technical, economic and political.

Effects on Hearing

Let us consider first what has been learned about the effects of noise on the human organism. The most obvious effect, of course, is on the hearing organ. Everyone knows that a very loud noise, such as the explosion of a large firecracker, will produce momentary deafness. Permanent hearing loss, however, develops only from repeated or continuous exposure to high noise levels. The relation between such exposure and hearing impairment has been investigated carefully in a number of studies.

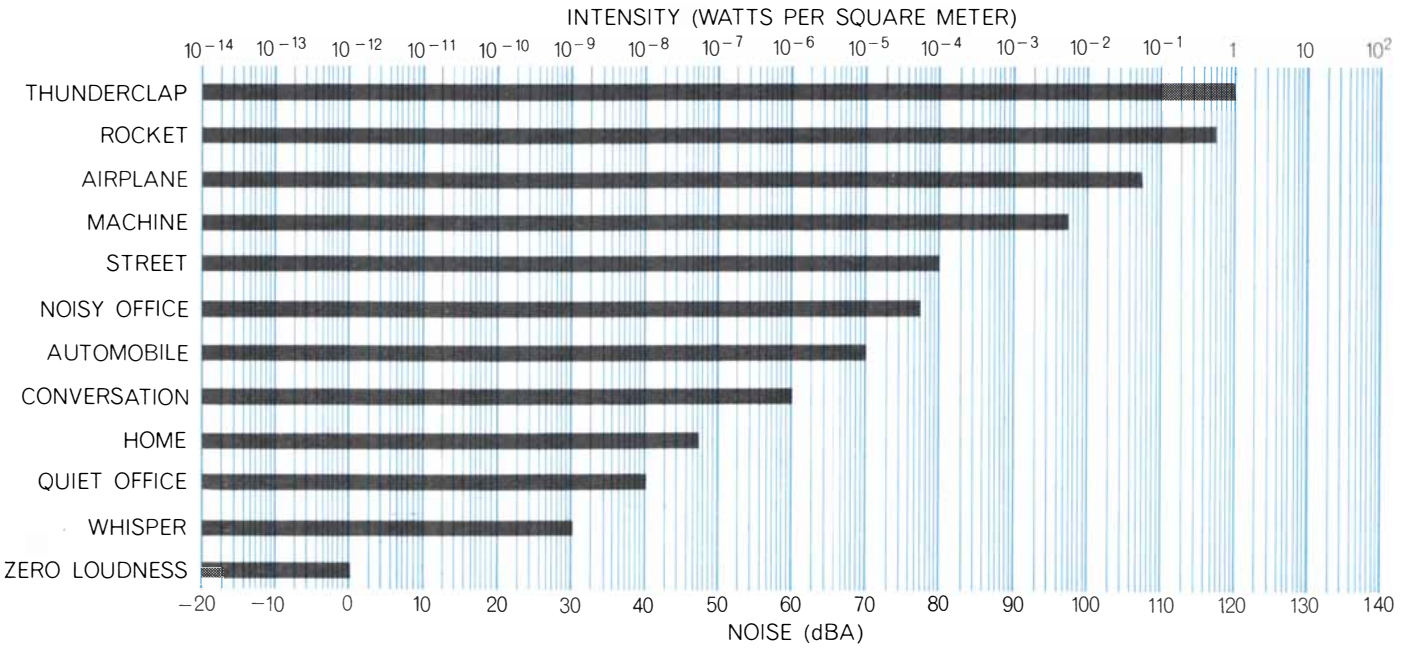
To understand the results of these tests one must know something about the methods of measurement. The intensity of sound is measured in decibels, and a person's hearing is measured in terms of the threshold decibel levels at which his ear can detect sounds at given frequencies. The amount of an individual's "hearing loss" can therefore be gauged by comparing his acuity with an average or standard of hearing sensitivity; if, for instance, a sound must be raised to 15 decibels above the standard for him to hear it, he is said to have suffered a 15-decibel hearing loss. In the U.S. the standard for average hearing has been established by the American Standards Association on the basis of tests of a large group of people between 18 and 30 years of age without hearing difficulties.

As is well known, the audibility and quality of sounds depend a great deal on frequency. The frequencies up to 3,000 cycles per second are the most important for understanding speech. Higher frequencies are generally judged "noisier" and more annoying (although they are essential for full enjoyment of music). It is at the higher frequencies that hearing losses become most marked with advancing age or in the impairment due to exposure to noise. Hearing tests generally examine the subject's sensitivity in a series of bands; each band consists of an octave, that is, the highest frequency in it is twice that of the lowest.

Here are the results of a classic study of 400 men engaged in a noisy occupation. They had worked daily at a noise level averaging 90 decibels in each of the six octave bands between 100 and 6,000 cycles per second, some of them for periods of up to 40 years. On the average the men suffered substantial hearing losses, particularly at the higher frequencies and during the early years of their exposure. Some of those who had been exposed for 10 years, even young men of 30, had so much impairment that they found it difficult to understand speech.

The study showed that individuals differ considerably in their vulnerability

SONIC BOOM, one of the many new noises plaguing man today, is produced when an airplane that is traveling at supersonic speed generates a cone-shaped shock wave such as the one seen in this schlieren photograph. When such a shock wave drags along the ground, it causes an abrupt change in air pressure that may exceed two pounds per square foot. The photograph, which shows a test model of an airplane nose, was made in a high-speed wind tunnel at the research center of the Lockheed Aircraft Corporation.



COMPARATIVE INTENSITIES of a variety of common sounds are arrayed from bottom to top in order of increasing sound pressure, expressed both in "*A*"-scale decibels, or dBA (*bottom scale*), a unit that emphasizes higher frequencies, and in watts (*top scale*).

to noise: among those who had been exposed for 25 years or more there was a spread of about 30 decibels in the amount of hearing loss at the higher frequencies. The variation in vulnerability suggests that it should be possible to discover at a fairly early stage those persons who are particularly susceptible to hearing impairment and transfer them to quieter jobs. The damaging effect of noise is especially marked and prompt in showing itself at the frequency of 4,000 cycles per second; hence this test should be a good indicator for identifying noise-susceptible people. By way of comparison, a separate study of individuals who pursued quiet occupations has shown in detail how hearing at the high frequencies deteriorates with age. Among men in their 60's the average loss of hearing at these frequencies is about 30 decibels, and in the 70's the loss rises to some 40 decibels or more.

Psychological Effects

When we move into other realms of noise effects, such as the psychological consequences, it is hard to find a basis for measurement. The noises of our daily life have been blamed variously for the high divorce rate, social conflict, indigestion and other organic disabilities, nervous breakdown, high blood pressure, heart failure and even insanity. Most of these allegations arise from overvivid imaginations, but one cannot rule out the possibility that some people are particularly sensitive to noise just as others are allergic to nuts, eggs or household dust. As far as controlled social observations go, however, we can only say that the demonstrable and important biological effects of loud noise are—in addition to the impairment of hearing—interference with speech communication, distraction of people from work requiring concentration, interference with sleep and a subjective reaction of annoyance.

Studies of the annoyance effect have been conducted among people living in noisy areas: in central London, near the London airport and in several U.S. cities, some of them near military air bases. Thousands of people were interviewed, and some interesting statistics have emerged. In any noisy environment, whatever the intensity of the noise, about a fourth of the inhabitants say they are not perturbed by the noisy activities. These people apparently are able to live happily next to elevated railroads, trucking routes, airplane flight paths and other loud noise sources. At the other extreme, about a tenth of those interviewed seem to be disturbed by almost any noise not of their own making, regardless of how faint it may be. (The interviews elicited the fact that the same people were dissatisfied with many other things in their environment.)

In areas where a specific source (such as airplanes) produces a constant din, about a third of the people said they tended to get used to the noise; on the other hand, a fourth said they were increasingly bothered by the noise as time went on. Personal reactions to noise did not appear to be correlated to any significant extent with age, sex, income or education. Many people were, however, influenced by specific fears: many of those who lived next to traffic routes said they were sensitive to the noise because of fear for the safety of their children; many of those near airports dreaded the noise because of the possibility of plane crashes. We should not minimize the annoyance effect of noise. Some physiologists assert that annoyance is a biological protective mechanism (like the discomforts of fatigue, hunger or cold) that impels the organism to avoid noise as it does other signals of disturbance.

Noise Control

Let us turn now to what has been done, and what can be done, to control noise in the areas of greatest concern. Foremost among these areas, of course, is industry, where continual exposure may seriously damage the workers' hearing.

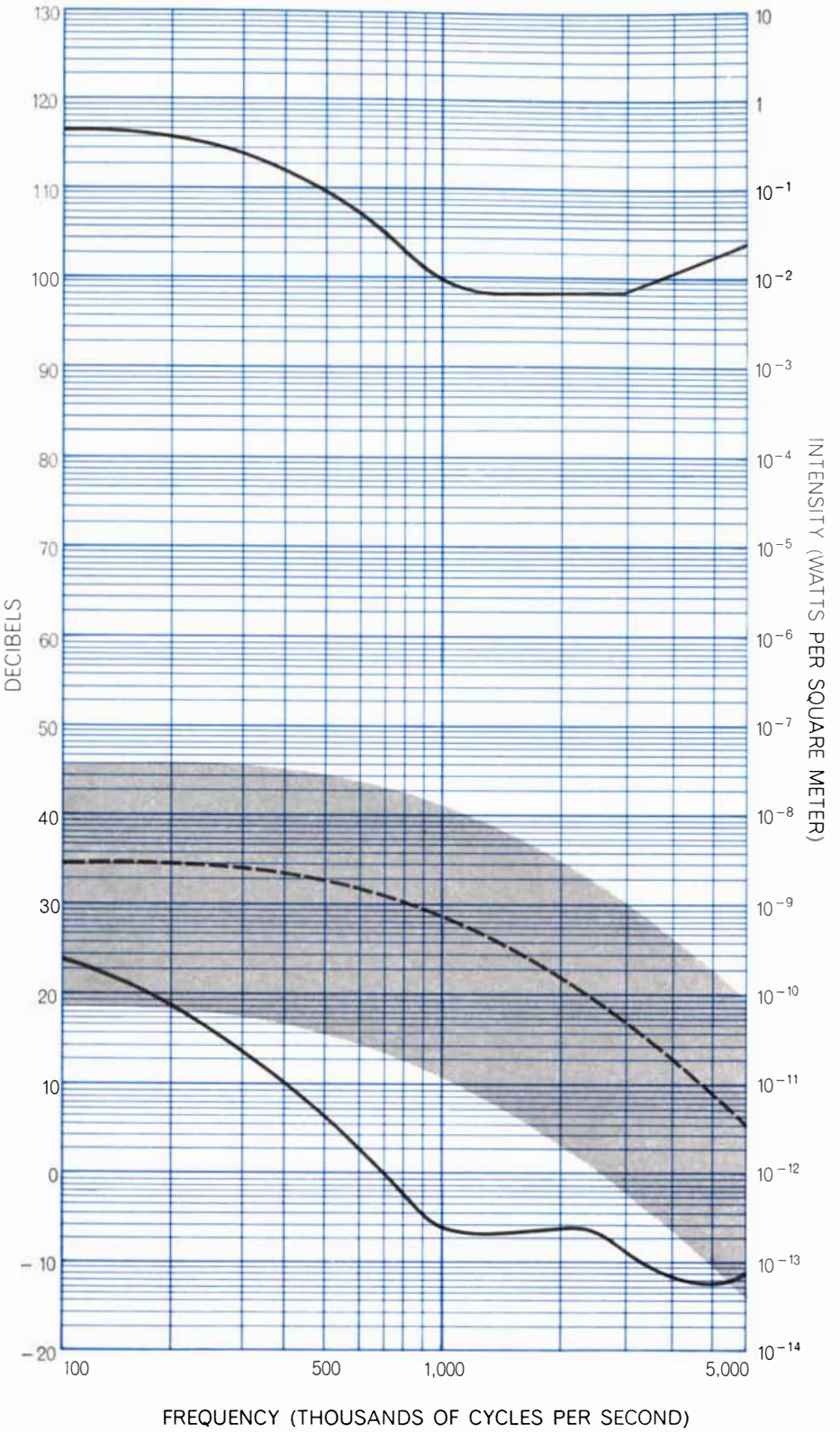
The first need is to determine what the tolerable levels are, and a number of studies have been devoted to this question. A committee of the American Standards Association, in an investigation that is still under way, has arrived at some preliminary ideas on permissible limits of noise exposure for a worker at his daily job. The test applied by the committee is that after 10 years of the daily exposure a worker should not have suffered any appreciable impairment of his ability to understand speech at nor-

mal voice levels. On the basis of this criterion the committee investigators have determined permissible daily "quotas" of exposure, that is, the number of minutes of exposure per day that can be tolerated at various decibel levels and for various sound frequencies. The committee's tentative conclusion is that over an eight-hour working day 85 decibels (for each of the octave-band frequencies above 700 cycles per second) is about the limit people can tolerate without substantial damage to their hearing. A study by the U.S. Navy has suggested that a higher figure is permissible; testing naval personnel, it found that daily exposure up to 90 decibels did not impair the men's ability to understand speech.

The noisy industries themselves have begun to take steps to reduce the risk of hearing loss. Most of the employers in these industries now test the hearing of workers when they are hired and at intervals afterward. They often require workers in the noisy locations to wear earplugs, earmuffs or both. Many factories are applying mufflers and other noise-reducers to their machines, building enclosures around them and covering the room walls with sound-absorbing materials. Some companies go so far as to specify, when buying new machinery, that the machines must not generate noise above a stated level.

At the political level a few states have adopted legislation requiring employers in noisy plants to provide earplugs or earmuffs for their workers. In California the state Department of Industrial Relations has issued a noise-control safety order specifying the circumstances under which ear protection must be worn. It is required, for example, if the worker is exposed for more than five hours a day to 95 decibels or more in any one of the octave-band frequencies above 300 cycles per second.

A number of states now have laws that give workers the right to claim compensation if they have suffered a loss of ability to understand speech, even though this may not have meant the loss of their jobs. The Council of State Governments has recommended a uniform law for all the states that would specify the conditions for compensation claims. It defines noise-induced hearing loss as a compensable disability and establishes a disability scale based on the average of the hearing loss measured at 500, 1,000 and 2,000 cycles per second. The compensable loss would be that beyond 15 decibels, after deducting the natural loss due simply to aging (which is specified as half a decibel per year after the age of



HUMAN HEARING extends over a considerable range of frequencies and can accommodate to a surprisingly wide range of sound pressures. The sound pressure is measured in decibels, or tenths of a bel (a logarithmic unit used to express ratios). Zero on the decibel scale indicates the barely audible sound produced by a pressure of .0002 microbar (one microbar equals one dyne per square centimeter, or about a millionth of a standard atmosphere) alternating at the rate of 1,000 cycles per second. Sound intensity increases exponentially: a 10-decibel sound is only twice as loud as a one-decibel sound, but a 20-decibel sound is four times louder and a 100-decibel sound is 1,000 times louder. The light gray area includes the range of frequencies and intensities that the normal human voice produces; the broken line dividing this area follows the average speech level for a male standing three feet away. Signals with pressures below the bottom curve are usually inaudible. Signals with pressures above the top curve, in turn, so overload the human ear as to be unintelligible.

EAR COVERS protect a pharmaceutical-plant employee from the 100-decibel din of a pulverizing machine. Hearing protection is recommended for all workers who are consistently exposed to noise louder than 85 decibels in frequency bands above 150 cycles per second.

40). The recommended legislation also includes provisions designed to protect employers: workers could file claims only after six months of separation from exposure to noise and the employer's responsibility would be limited to the amount of hearing loss incurred by the worker with this employer (that is, excluding losses in previous jobs).

Noise and Speech

I want at this point to discuss in a little more detail the loss of the ability to understand speech, to which I have already referred so often in this article. The word-comprehension test has proved to be a remarkably useful aid to noise research, not only because it provides a convenient way to measure hearing loss but also because it serves as a criterion for establishing permissible noise limits in almost all types of situation. The analysis of speech sounds and of effects of noise on speech comprehension has therefore given us invaluable information.

Laboratory studies with sound-recording devices tell us that speech is made up of a great variety of sounds at various frequencies and intensities. Each letter or syllable, as normally enunciated, carries a mixture of tones, each with a certain characteristic intensity. Consider the word "sit." The sound of "s" consists of relatively high-pitched tones at a moderate intensity level; "i" is lower-pitched and stronger in intensity; "t" is made up mainly of high-frequency tones at low intensity, so that its sound is comparatively faint. Now, to understand the word when it is spoken a listener must hear and unambiguously identify each letter. If he fails to catch the "t," he may mistake "sit" for "six"; if he misses the "i" sound, he cannot tell whether the word is "sit" or "sat." Laboratory tests have in fact demonstrated that to understand English speech perfectly one needs to hear essentially all its sounds over the frequency range from 200 to 6,000 cycles per second. It has been found that this spectrum can be divided into some 20 bands, all of which prove to be equally important for speech intelligibility. It also turns out that within each band the intensity of the various speech sounds (for letters and syllables) as they are ordinarily enunciated varies over a range of about 30 decibels (from the faintest to the most intense). We can therefore plot on a graph the region of speech intelligibility, in terms of the necessary decibel levels for the various frequencies.

As a standard for reference we can plot the "speech region" in the case of a young male speaker talking at a normal voice level and standing about three feet from the listener. If the speaker talks softly, the entire speech region moves down about six decibels (that is, all the sounds are that much fainter); if he raises his voice above the normal level, the region rises six decibels above the standard; if he shouts, the region moves up another six decibels. The sound level for the listener also varies with distance between the speaker and the listener: for each doubling of the distance the speech sounds become six decibels fainter, and for each halving of the distance they become six decibels louder.

Now, if we plot on the same graph the threshold levels of audibility of sounds for persons with average or normal hearing, we can readily measure the effects of loss of hearing ability. Whenever a person's hearing loss is such that his audibility threshold rises into the normal speech region, he will fail to hear the speech sounds at the affected frequencies and to that extent will suffer a loss of speech comprehension.

The effects of interfering noise can be shown even more graphically. Noises at decibel levels within the speech region will mask, or blot out, the speech sounds. There are continuous-spectrum noises, such as those of a waterfall, a jet engine or a moving train, that will overwhelm the speech region at all frequencies. Thus a railroad train approaching a station where two persons are talking makes it more and more difficult for the two to understand each other, and at its peak the train noise may make speech impossible. By raising their voices and moving closer together, thereby elevating their speech region, the two speakers may be able to achieve a slight measure of communication. There is a level, however, at which speech can be too loud to be understood. A person shouting into a listener's ear may so overload the ear that the speech sounds become unrecognizable.

From the type of analysis I have been describing we can derive information that enables us to set up definite criteria for noise control in our various working and living spaces: offices, conference rooms, shops, homes and outdoor locations. In our laboratory at Bolt, Beranek and Newman, Inc., we have worked out a scale of speech-interference level (SIL) that can be used as a guide for determining the permissible limits of background

noise in given situations. The scale defines background noise in terms of a kind of decibel specially created for the purpose: the SILdB. This unit is an average of the decibel readings in the three octave bands between 600 and 4,800 cycles per second. For instance, in the case of two persons six feet apart outdoors, one speaker will readily make himself understood by speaking in a normal voice if the interfering noise level is no louder than 49 SILdB; against a background of 55 SILdB he will have to raise his voice; at 67 SILdB he must shout.

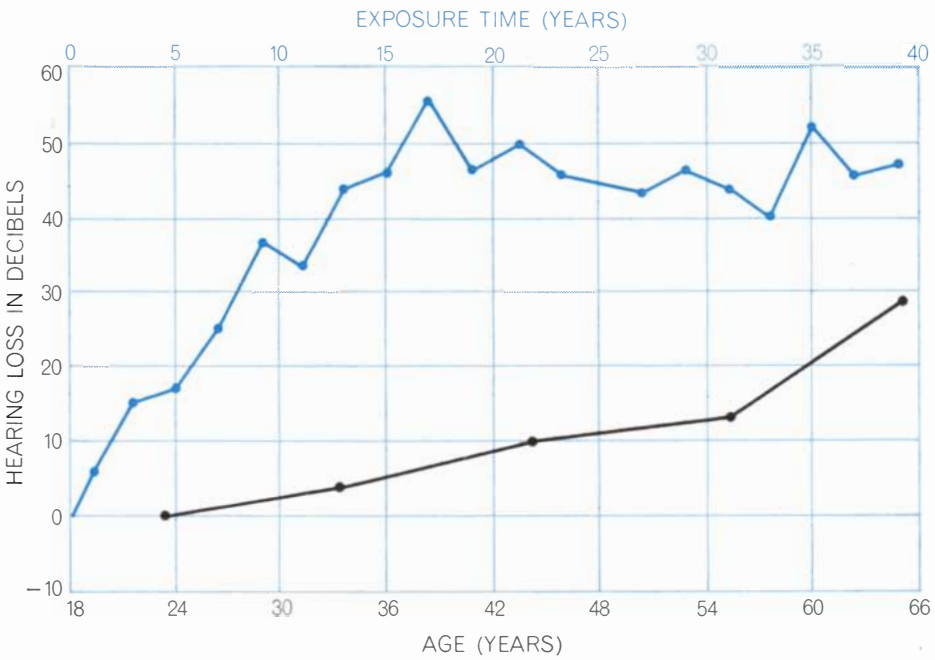
Using this scale, we have derived the following criteria for specific situations. In a private office or small conference room, where the people may be separated by distances of 10 to 25 feet, the speech-interference level of the background noise should be no higher than 30 to 35 SILdB, so that conversation can be carried on at normal voice levels. In large engineering and drafting rooms, where people may stand closer together (about six feet apart) and be willing to raise their voices, a noise level of 40 to 50 SILdB is tolerable. In the home, if we apply a standard of quietness that would allow the television or radio to be understood comfortably at moderate levels of loudness, the interfering noise level should be no more than 30 to 35 SILdB. For telephone conversation the interfering noise should be no more than 45 SILdB; above that level background noise begins to make telephone communication difficult, and when it reaches 75 SILdB use of the telephone may become impossible. In all situations the highest noise level that will allow any intelligible communication is about 90 SILdB; against this background the speaker must shout into the listener's ear from a distance of three to six inches.

Quieter Buildings

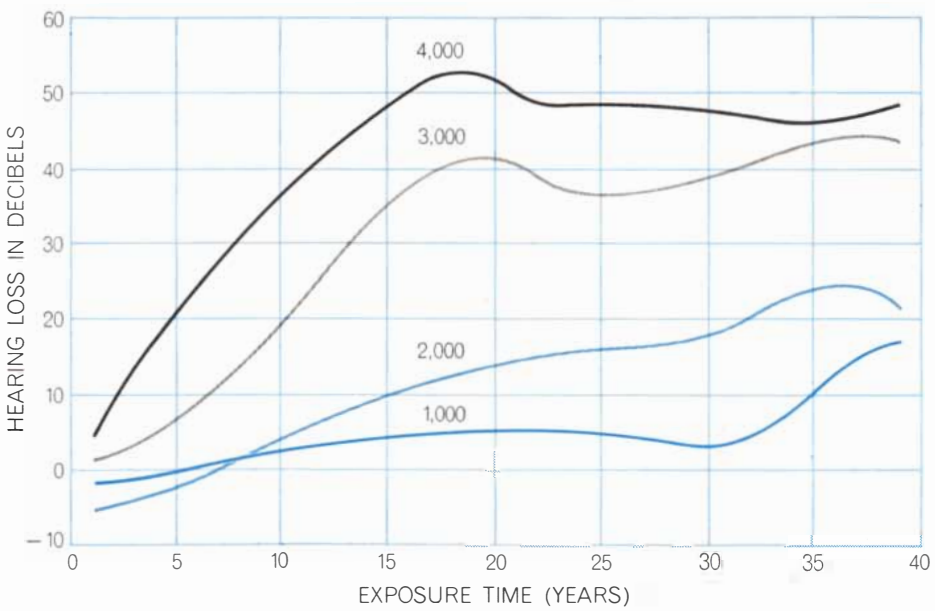
What can be done to make our buildings, particularly dwellings, quieter? Certainly we must give more thought to their basic design. In contemporary architecture the primary emphasis seems to be not on function but on aesthetics. Two of the principal ideals are transparency and continuity—in physical terms, glass and the open plan. Unfortunately continuous structures and open plans are inimical to quiet living. Many modern dwellings are acoustical torture chambers!

In apartment buildings the errors of design are compounded by economic pressures that have resulted in a too flimsy separation between apartments. Many new high-rise apartment buildings in New York are so noisy that their occupancy rates have fallen below the profitable level. Apartment hunters have been known to carry portable radios with them so that they can test the noise transfer from one apartment to the next. Some owners of cooperative apartments are compelled to spend large sums to insulate their dwellings more satisfactorily against the noise of their neighbors.

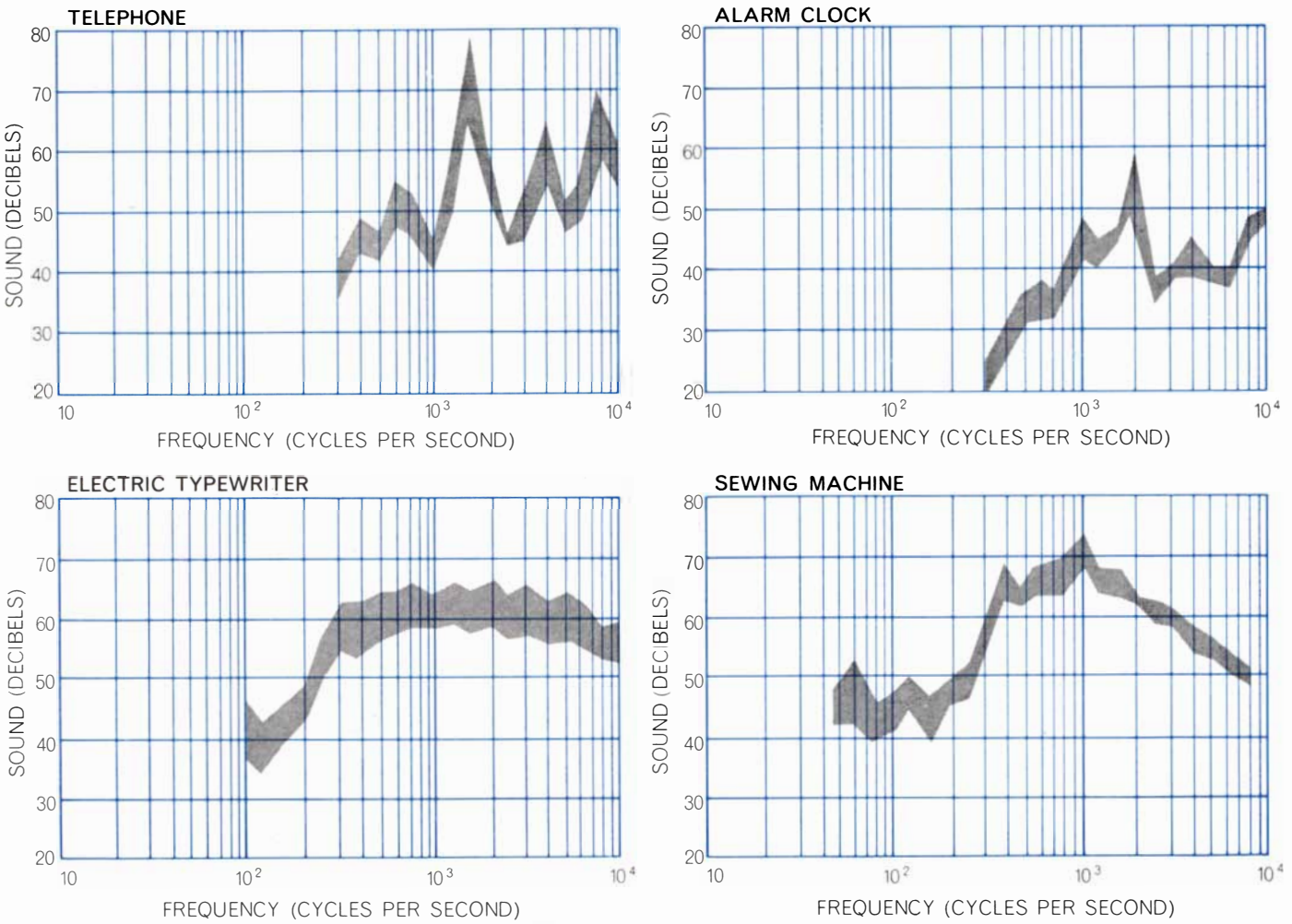
The difficulty is not that techniques for making dwellings quiet are unavailable. Noise can be controlled by erecting heavier or multilayered walls between apartments, by floating floors or hanging ceilings from vertical structural members, by installing nearly silent bathroom fixtures, by designing ventilation ducts to minimize the transmission of noise and by using quiet systems of air conditioning. Indeed, it is possible with present techniques to build apartments (or offices, libraries and hospitals) that



LOSS OF HEARING is a natural result of aging (*bottom curve and scale*), but a much more severe loss can result from exposure to an excessively noisy environment (*top curve and scale*). High-frequency hearing suffers the most. Both curves are for 4,000 cycles per second.



CUMULATIVE DEAFNESS, due to years of exposure to a noise level averaging 90 decibels in each frequency band, shows two peaks. The maximum hearing loss at frequencies of 3,000 cycles per second and above is reached in about 15 years. Loss of hearing at frequencies of 2,000 cycles and below, however, does not reach its maximum until after 30 years or more.



INTENSITY OF COMMON NOISES at various frequencies is demonstrated for the bells of a telephone and an alarm clock and the various moving parts of an electric typewriter and a sewing machine. The most intense noise of all is one peak (between 1,000 and 2,000 cycles per second) of the telephone bell: it reached 76 decibels at the loud setting. The bell of the alarm clock shows five peaks of noise, as does the telephone bell, and one of these is higher in frequency. The typewriter proves to be uniform in noise level over most of its range. The sewing machine rivals the telephone bell in sound pressure and outdoes it in range. Ray Donley of Goodfriend-Ostergaard Associates in Cedar Knolls, N.J., recorded the noises and made the sound-pressure analyses shown here.

are actually too quiet—so silent that even faint noises from outside become obtrusive and disturbing. In that case there is a simple and pleasant remedy: one can introduce a gentle, steady, "white" noise —a noise "perfume" that masks the intrusive noises and has a soothing effect.

In Europe long experience in apartment living and a popular taste for gracious living (in preference to gadgets) have led to careful attention to noise control in the construction of multiple-family dwellings. Britain, the Netherlands, Germany, Sweden and the U.S.S.R. have well-developed acoustical building codes that have been applied to the large-scale program of the rebuilding of housing since World War II.

Studies have shown that the noises apartment dwellers consider most annoying are radio or television noise from neighboring apartments and impact noises, as from people moving about on the floor above. It is not possible to achieve accurate control of the transmission of such noises simply by specifying construction requirements for walls and floors, because noise can travel from one room to another along continuous walls and through cracks, ventilation ducts, electric boxes, pipes, conduits or medicine cabinets. Therefore the codes focus on specifying limits for the amount of noise that may be transmitted, leaving it to the builders to devise means of complying with these limits. The amount of transmission is tested by devices such as a pounding machine that hammers on a floor so that the reception of noise in a room below can be measured. A general formula for rating the insulating value of floors, ceilings and walls has been devised: it is based on the difference in noise level (at 16 significant frequencies) between the room where the noise originates and the one where it is received.

The Netherlands code specifies, for example, that a loud noise must be so muffled that the noise level at 2,000 cycles per second is 54 decibels lower in the receiving room. (Less attenuation of noise is required, however, at lower frequencies.) In Britain, which has separate standards for Grade I and Grade II (less expensive) structures, the minimum absorption requirements for noise at 2,000 cycles per second are 56 and 51 decibels respectively.

In the U.S. such codes are entirely lacking, and only New York is seriously considering one. A proposed code for that city would set the insulation requirement (at 2,000 cycles per second) at 45 decibels—six decibels less satisfactory than even the Grade II code in Britain. Even so, the proposed New York standard would be an improvement over present conditions there. In many of its present apartment buildings the noise insulation is 10 or more decibels worse than the proposed code.

The control of apartment noise in the U.S. will be a most difficult matter. Building codes are strictly local; each of the nation's 6,000 cities and towns writes

its own code. Labor is slow to accept new building techniques. Builders, under the pressure of competition, are governed primarily by economic considerations. Many argue that to attain in the U.S. the standards of quietness now enjoyed in modern apartments in Europe (where building costs are much lower) would require the development of new types of lightweight apartment structures that would be cheaper to build in terms of materials and labor costs.

Nevertheless, it seems that the time is near when we can expect noise-control codes throughout the nation. The Federal Housing Administration is supporting a comprehensive study of the control of noise in multiunit dwellings. This study may in time lead to Federal noise-control requirements for housing built under FHA mortgages. Moreover, if New York adopts a noise code, other cities undoubtedly will follow its lead. It seems likely that public demand, expressing itself through codes and in the marketplace through a deliberate search for quiet in apartment-hunting, will compel increasing attention to noise control in apartment construction. Among other things, it should stimulate research on reducing the cost of building quiet into our dwellings.

Vehicular Noise

We consider next the noise of our vehicles. In retrospect the clip-clop of horses and the rumbling of carriages seem the sounds of an idyllic way of life. Our drive to be continually on the move and to travel ever more rapidly has created a noise nuisance that already has reached awesome proportions and becomes increasingly difficult to live with. In a British government survey of residents of central London, in which some 1,400 people were questioned, traffic noise stood at the top of the list of things in the environment that people would most like to change. The din of motor-vehicle traffic was considered more annoying than all other noises put together; four to seven times as many people were disturbed by this noise as by the noise of airplanes, trains or industry.

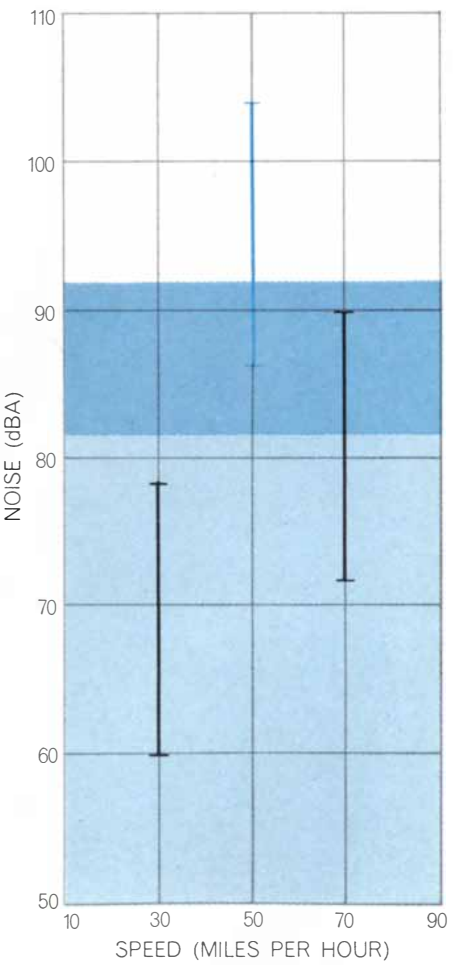
It is abundantly clear, therefore, that if city living is to be made tolerably quiet, the first efforts must be directed to reducing the noise of motor traffic. We cannot banish the automobiles, buses and trucks; they are a necessary part of our lives. It does not follow, however, that we must put up with all the noise now created by these machines.

The levels of noise produced by various types of motor vehicle have been measured carefully on the basis of their irritating effect on hearers. This measure depends not only on the physical energy of the noise but also on the hearer's perception of its loudness, or "noisiness." Noise-measuring instruments have a standard setting—the "*A*" scale—that gives extra weight to the higher frequencies; these variations in sound pressure are recorded in special units called dBA. Using the *A* scale, a study of motor traffic on California freeways showed that the noisiness level of passenger cars (for a hearer nearby) ranges from about 60 to 78 dBA at 30 miles per hour and rises to about 72 to 90 dBA at 70 miles per hour. The wide spread is due to the fact that old cars, with their worn mufflers, are considerably noisier than new ones. The study showed in quantitative terms that the main noisemakers on the freeways are trucks, buses, motorcycles and sports cars. The average truck at 60 miles per hour is about twice as noisy as a steady stream of passenger-car traffic, and its noise may be well above 100 dBA. The irritating effect of these vehicles is heightened by the startling impact of their loud bursts of noise as they arrive at unpredictable intervals in the traffic stream.

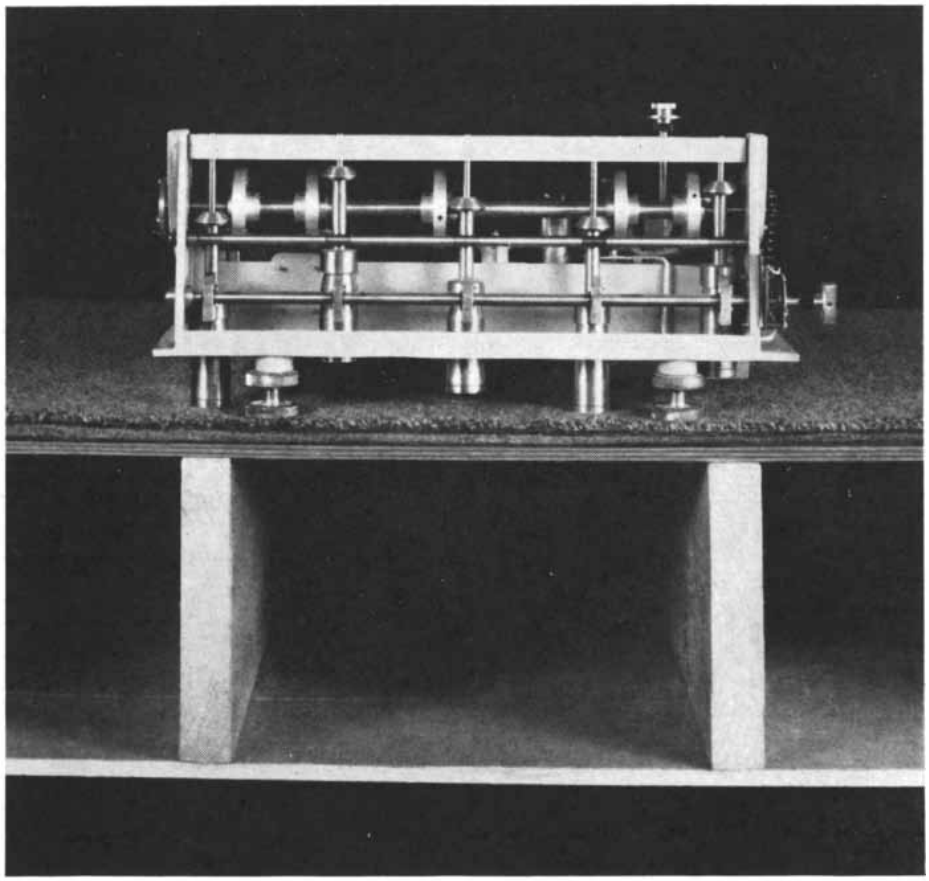
The state of California is considering legislation that would prohibit noise levels above 82 dBA for passenger cars and 92 dBA for trucks and buses. In Britain the national government proposes to limit the maximum permissible noise to 85 dBA for passenger cars and trucks and 90 dBA for motorcycles and other two-wheeled vehicles. France has already established limits of 83 dBA for passenger cars and small trucks, 86 dBA for motorcycles and 90 dBA for large trucks and buses.

It must be said that leaving the problem to state and local legislation in the U.S. would not be effective. So much motor traffic, particularly trucking, is interstate today that national laws are plainly called for. Motor-vehicle noise is one form of hubbub that should not be too difficult to control. Highway builders today have available materials for producing quiet road surfaces. The latest passenger cars generally have effective mufflers and quiet tire treads. Trucks can be equipped with adequate mufflers and noise-damping housing for their engines. We can have quieter as well as safer vehicles.

What can be done about airplane noise? There is no doubt that we shall soon be exposed to a greatly increased volume of noise from this source as air traffic and airports multiply, helicopters become more widely used and supersonic airplanes usher in an era of sonic booms. It is difficult to determine what the tolerable levels of airplane noise are, because they vary widely among individuals and are conditioned by people's attitudes, such as their fear of crashes, their feelings on the subject of whether or not the airlines and airports are concerned about their welfare, and so forth. My own interpretation of the studies that have been made among people living near airports is that for most people the noise begins to become unbearably annoying when the airplane noise peaks (in 20 to 40 daytime flyovers per day) exceed a "perceived noise" level (measured in another special unit) around 115 PNdB. Annoyance rises (or toler-



AUTOMOBILES on a California throughway make noises heard at a distance of 25 feet with the indicated range of intensities. Cars moving at 70 miles per hour are from two to four times noisier than at 30 miles per hour. At 50 miles per hour trucks (*color*) were as noisy as planes at takeoff. The colored blocks mark the maximum allowable noise levels proposed by highway officials for cars (*light*) and trucks (*dark*).



POUNDING MACHINE is used to determine the amount of insulation against impact noise that is provided by floor-ceiling construction in multiple dwellings. Each of its hammers weighs 1.1 pounds; they fall 1.6 inches in succession and deliver 10 impacts per second.

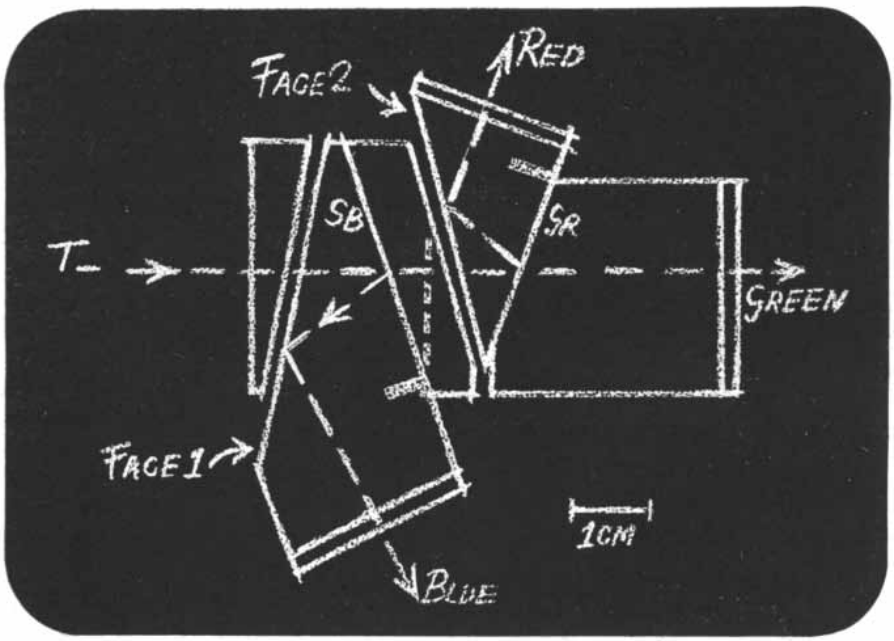
ance declines) if the number of flyovers or the duration of noise in each flyover is increased, and tolerance also drops sharply at night. Some studies indicate that a flyover seems to sound 10 or more PNdB noisier after 10:00 P.M. than it does during daytime hours.

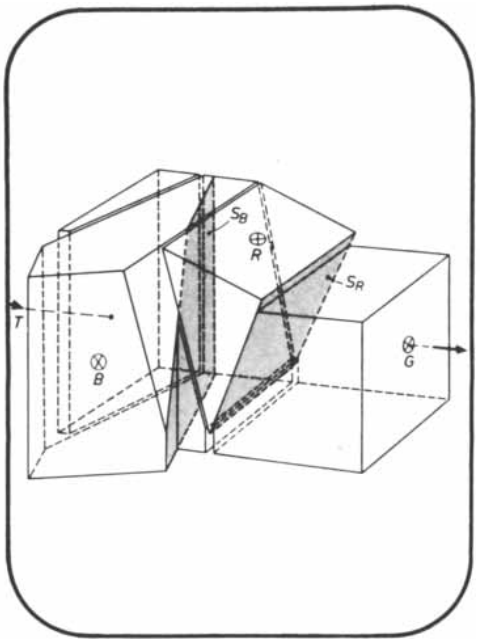
The London airport and Kennedy International Airport in New York have set up noise limits for jet airplane takeoffs (but not landings) that are in accord with these figures. In London the takeoff is supposed not to exceed 110 PNdB during the hours between 7:00 A.M. and 11:00 P.M., and after 11:00 P.M. the allowance is lowered to 102 PNdB. At Kennedy the permissible limit for takeoffs over land is 112 PNdB; at night the jets are usually required to take off over water.

The Federal Aviation Agency, which operates the Washington National Airport, has been experimenting with takeoff patterns designed to minimize noise in the surrounding residential areas. Jet airplanes are required to climb as steeply as possible to an altitude of about 1,500 feet and then coast on minimal power up to 3,000 feet. To avoid flying directly over houses in the early part of the takeoff the plane is also required to follow the Potomac River as it climbs.

For the noisy landings of jet airplanes, made particularly irritating by the whine of their engine-intake compressors, ameliorating maneuvers are not yet feasible. Most pilots believe for safety's sake they must come in to the landing strip at a low glide angle. To approach at a steeper angle—say six or eight degrees instead of three degrees—would require, they insist, several improvements in airplane design: better instrumentation (perhaps computer control of the landing), better engine response and better plane-handling qualities.

Many things could be done to design airplanes for less noisy operation. Prompted by regulations of the Port of New York Authority, operator of Kennedy and other airports, airplane manufacturers have fitted silencing devices to the exhaust ports of turbojet engines. The new turbofan type of engine has increased thrust greatly without a proportional increase in noise (but unfortunately it cannot be quieted appreciably by silencers). Some manufacturers of jet airplanes are studying the possibility of mounting the engine nacelles above instead of under the wings, so that the wings will prevent much of the noise





How to make a television camera human

(from a lecture by Dr. H. de Lang of Philips Research Laboratories, Eindhoven, The Netherlands)

Science and Technology are constantly trying to improve on Nature. But when it comes to color discrimination, the plain old-fashioned human eye takes a lot of beating.

In the early days of color television (a couple of years ago), many people viewed it with a jaundiced eye. There tended to be a harshness in the tinted images, an over-emphasis of strong color and a washing out of the lighter ones. One of the main reasons was that the color separation in the cameras depended largely on a system of dichroic mirrors consisting of interference layers deposited on flat glass plates. There are a number of inherent drawbacks with this system: the mirrors take up a relatively large amount of space, the objective fitted to the camera has to have a fairly large back focus, the support plates cause aberrations, the mirrors are exposed to damage, and large angles of incidence have to be reckoned with. This last named drawback is associated with spurious color gradation across the image, unsatisfactory color separation and unfaithful color rendering when the incident light is polarized.

To overcome these problems, Bouwhuis and I developed a new system in which the color interference layers are enclosed in a cemented assembly of prisms and which appreciably reduces the effective angles of incidence.

The whole idea of this camera was to match the color discrimination of homo sapiens - since homo sapiens was the species that was going to do the viewing (sundry cats and dogs excluded).

Our camera contains three Plumbicon* pick-up tubes, one for each primary color, with spectral sensitivities approaching that of the human eye. Each pick-up tube has the same sort of surface area as the human eye and - apart from noise in the amplifier chains - is just about as sensitive. The scene to be transmitted is conveyed by three „optical" channels to the photosensitive layers consisting of a vapour-deposited porous film of tiny lead monoxide crystal plates with dimensions in the order of 1 micron or less. The blue, green, and red target images of the scene are all observed from the same point, having a common entrance pupil (like the human eye) to avoid parallax phenomena which would affect the congruity of the three images. For the actual focussing of the target images, similar objective lenses are used to those for black and white television.

For separation, use is made of color-selective interference filters having the property of reflecting a pre-determined part of the spectrum, and transmitting the complementary part. Such filters consist of a number of very thin transparent layers of alternatingly high and low refractive indices deposited on a glass surface by evaporation in vacuo. In our device the glass surfaces are those of a prism system. A number of such systems were designed and one of them is shown on the blackboard above. The colour-selective interference layers are at S_B and S_R, where the faces of the prism sections are cemented together to protect the layers against dust and moisture. To keep the angle of incidence on the interference filters as small as possible, thin air layers are provided that cause total reflection of the blue and red rays at faces 1 and 2 respectively. The green rays pass straight through the system. For each of the colored beams the system behaves as a plane-parallel plate placed at right angles to their optical axes. Before leaving the system, each component passes through an absorption filter, which is cemented on to the prism, to remove any unwanted wave length that might still be present. In this compact design we take special precautions against glare from spurious reflections.

One practical form of this prism system is shown above. Here the part at the right of the vertical dotted line in the blackboard version has been rotated 90° with respect to the part on the left. The shaded faces carry the interference layers.
In actual practice we use a system which reduces the effective angle of incidence for the most critical separation - red/green - from 40° to 20°.

How effective this innovation is can be easily seen when Plumbicon television cameras swing into action. There is no harshness in the tinted images, there's a nice subtlety in the color balance and some beautifully subdued tones.

So the camera sees eye to eye with its viewers... humanly speaking, that is.

*Registered Trade Mark of N.V. Philips' Gloeilampenfabrieken of The Netherlands for television camera tubes.

The Philips Research Laboratories carry out research in many fields of fundamental science. Among these: Acoustics, Chemistry, Cryogenics, Perception, Plasma, Material testing, Nuclear physics, Solid state physics, Telecommunications.

from reaching the ground. Designers can also think of ways to control noises by modifications of the engines, nacelles and wings, and it is believed refinements of design would allow airplanes to climb and land at steeper angles. These cost-incurring antinoise improvements are not likely to be undertaken, however, until the Federal Aviation Agency forces their adoption by spelling out limits on the noise that will be tolerated from new airplanes.

Supersonic-Airplane Noise

Ahead of us lies the prospect of sonic booms from the next generation of airplanes—the supersonic transport (SST). The coming of supersonic travel is inevitable; we must prepare to control its effects. The tests that have been conducted so far suggest that sonic booms need not be destructive and that people may be more apprehensive about the phenomenon than they need to be.

When an airplane moves faster than the speed of sound, it produces shock waves that trail in the wake of the plane like the disturbances in the water wake of a rapidly moving boat. The shock waves generate a pressure wave that constitutes the sonic boom. On the ground a typical sonic boom from a high-flying airplane represents a series of rapid changes in air pressure lasting half a second: the pressure suddenly rises by as much as two pounds per square foot, then drops below atmospheric pressure by about the same amount and finally jumps back to normal pressure. The noise of the boom usually consists of two closely spaced, explosive reports.

The sonic-boom "wake" behind the airplane, fanning out in the shape of a cone, spans an area on the earth below that depends on the height at which the plane is flying. Typically the path of the boom on the ground is about 33 miles wide when the plane is at an altitude of three and a half miles and 50 miles wide when it is flying at a height of nine miles. The higher the plane flies, the weaker is the intensity of the boom at the ground.

The U.S. Government has conducted a number of studies of the effects of sonic booms, the most elaborate of which was a six-month test, from February to July of 1964, in the Oklahoma City area. The area was subjected to a total of 1,250 sonic booms from airplanes (during daytime hours). The average intensity of the booms in the early weeks of the test was 1.13 pounds per square foot and eventually it was raised to 1.6 pounds per square foot. Samplings of the public reaction showed that most of the people living within eight miles of the center line of a boom path were disturbed by the sonic booms. About a fourth of the people interviewed at the end of the six-month trial said that eight booms a day at the intensity of 1.6 pounds per square foot was more than they could learn to accept.

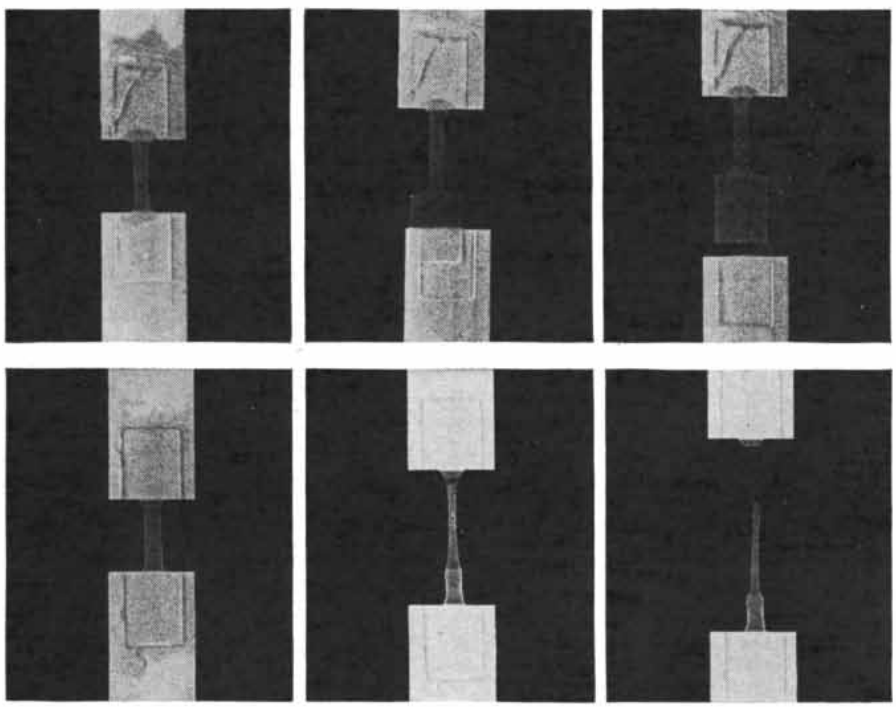
It appears that the main source of complaint was fear of damage to structures—cracks in plaster walls, weakening of the construction and so forth. More than 40 percent of the people interviewed in Oklahoma City believed their homes had been damaged by the sonic booms. Yet careful surveys of many houses showed no visible evidence of damage. In areas of the country where military airplanes regularly carry out supersonic flights, often producing strong sonic booms of more than two pounds per square foot, few damage claims have been filed by residents. On the whole the available evidence suggests that public apprehensiveness about sonic booms will be greatly reduced if people receive credible guarantees that their homes will not be damaged within specified limits of exposure and if these limits are strictly enforced. It is important, therefore, that the Federal Government prepare for the arrival of supersonic travel by establishing tolerable limits for sonic booms—limits that will not damage property or be seriously disturbing to people's peace of mind.

For man in the present "advanced" stage of civilization noise is no longer a trivial problem. It is ironic that the U.S., with its genius for creating technical marvels and solving technological problems, allows this most unpleasant affliction to debase its culture. We could improve the quality of our environment enormously by allocating a portion of our energy and wealth to controlling noise. With some ingenuity and at moderate cost we can hush our noisiest industries to save the hearing of workers. We can mitigate the roar of traffic—on the ground and in the air—by instituting and enforcing noise codes, by improving the design and operation of vehicles, interposing buffer zones to separate residential areas from airports and superhighways (through zoning and condemnation) and by sealing buildings against noise where proximity to noise is unavoidable. With a willingness to pay the extra price in construction costs we can also have quiet homes. It appears that we shall have to pay these costs if we are to make a tolerable adaptation to the noises of civilization.

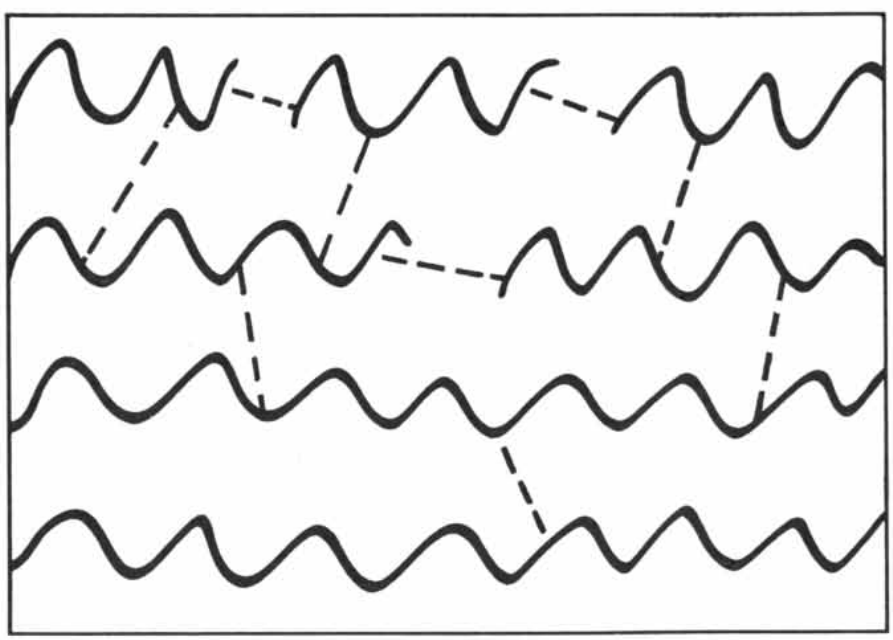
Report from

BELL LABORATORIES

On joining "non-stick" plastics



Untreated polyethylene sample (top three photos) and CASING-treated sample (bottom three photos) joined to metal plates. As tension is applied, left to right, untreated sample quickly pulls away from lower piece of metal. With treated sample, however, polyethylene-metal joints hold as plastic stretches and breaks.



Simplified cross-section shows relatively short molecules at surface of a plastic (wavy lines at top in drawing) and longer molecules underneath. CASING process strengthens surface layers by cross-linking (dashed lines), forming tough surface "skin."

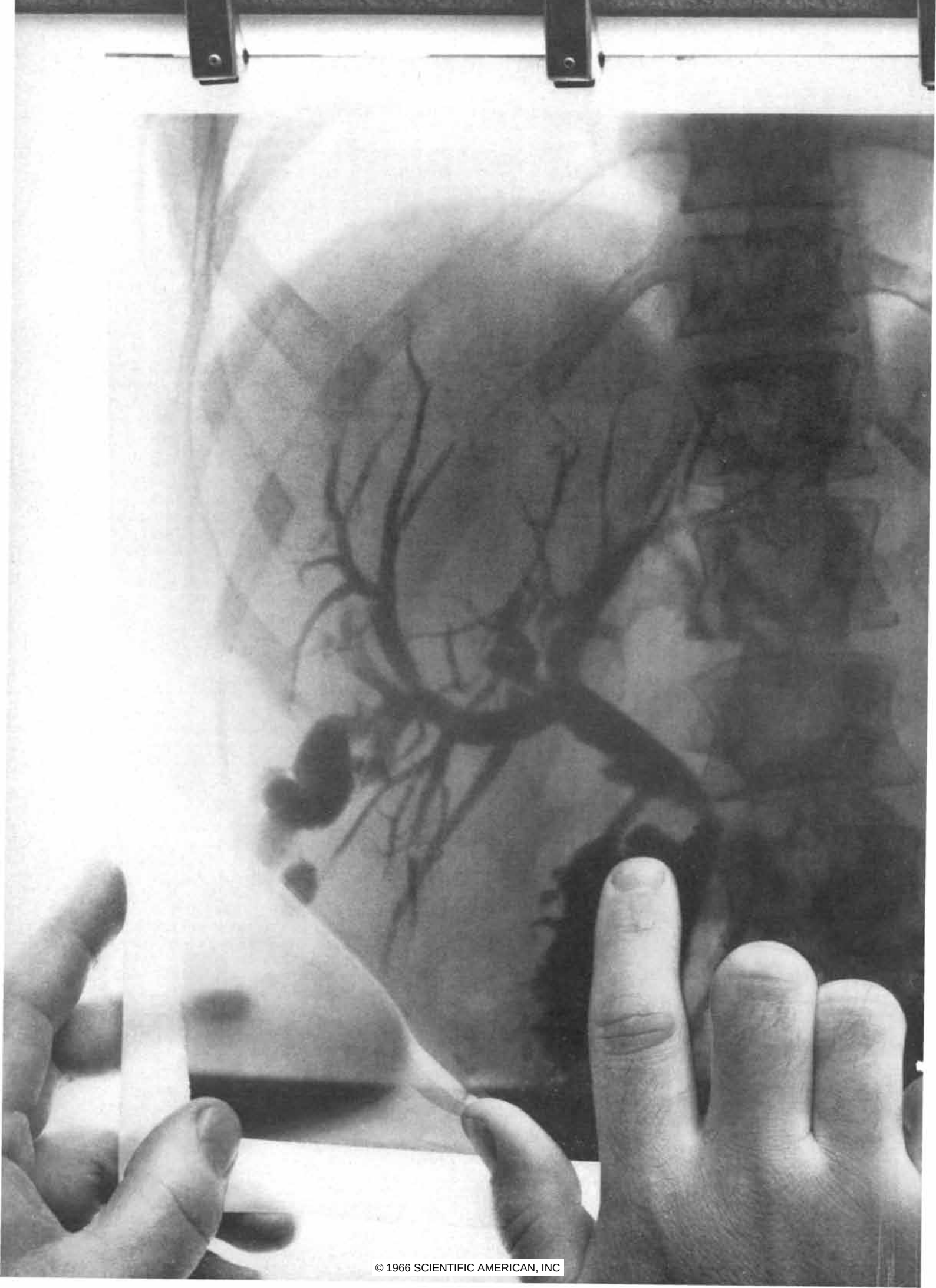
Two Bell Telephone Laboratories scientists have found a way to greatly improve the joint strength between ordinary adhesives or printing inks and PTFE (polytetrafluoroethylene), polyethylene, and certain other plastics. The process is a safe, fast, and inexpensive surface treatment for these plastics . . . one which does not affect the tendency for them to be wet by liquids, and which permits the formation of strong joints without melting the plastics. Also, it does not change their unique bulk chemical, physical, or electrical properties.

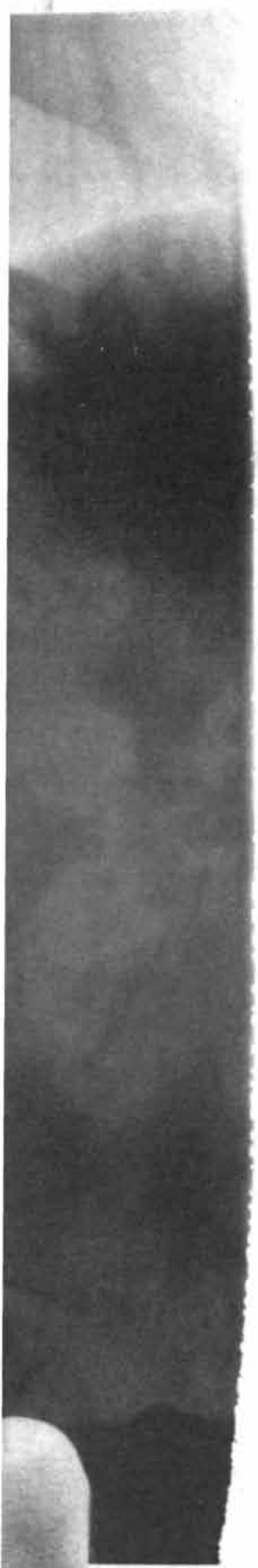
The difficulty with such plastics has been the tendency of relatively short polymer molecules to collect near the surface. This results in a weak layer that cannot produce a strong joint. The answer is to strengthen this region. In the new process, this is done by exposing the plastics to a flow of electrically excited inert gases. The gases remove some hydrogen or fluorine atoms from molecules near the surface, which thus become polymer radicals. The chemically reactive sites in these radicals combine, by cross-linking, to form a strong surface layer.

With this new method, conventional epoxies will adhere to such surfaces on PTFE with up to 1500 psi tensile shear strength; for polyethylene the figure is 3500 psi. These strengths are about ten times those of untreated plastics.

The inventors, R. H. Hansen and H. Schonhorn, call this process CASING (cross-linking by activated species of inert gases).

Bell Telephone Laboratories
Research and Development Unit of the Bell System





The New Instant X-Ray.

Polaroid now has a translucent X-ray film that develops in 45 seconds.

In the operating room, not the darkroom.

Polaroid's latest X-ray film, Type TLX, is a 3000-speed film that produces a 10x12-inch *translucent* radiograph in 45 seconds. (Our earlier instant X-ray films produced opaque prints.) Because it is translucent, the picture is sharply detailed and can be read from a light box. Because of its sensitivity, exposures can be made with about half the radiation required for conventional X-rays.

The importance of TLX film is that it brings the advantages of instant radiography—rapid viewing, minimal radiation—to many more medical procedures. Instant X-rays can now be used as a diagnostic tool where detail analysis is critical. And most important, they can provide detailed X-ray information in the operating room.

The surgeon can now use instant radiography to examine the bile ducts during gallbladder surgery (this is the type of X-ray you see here). And in operations that require accurate X-ray control of surgical maneuvers (many neurosurgical procedures and orthopedic surgery such as hip pinnings).

In these latter procedures, where each surgical move is determined by a continuing series of pictures, the advantages of TLX film are most dramatic. A move is made. Then a picture is taken. Then studied. And the next move is made. And so on. TLX film reduces the pauses to at least half the time needed for the fastest-developing wet-process X-ray film (which also requires bulky, expensive processing equipment). A hip pinning can be shortened by half an hour.

Now that TLX is here, many existing surgical procedures have been made easier, faster, and safer. We believe it will also make new procedures possible.

Polaroid TLX X-Ray Film Polaroid Corporation, Cambridge, Massachusetts

The Visual World of Infants

Does an infant see things in the same general way adults do, or must he learn to do so? The question is taken up by means of conditioning experiments with infants, in which the reward is a cheery "peekaboo"

by T. G. R. Bower

What does an infant see as he gazes at the world around him—an ordered array of stable objects or a random flux of evanescent shadows? There are proponents of both answers. Some psychologists have maintained that the ability to perceive the world is as much a part of man's genetic endowment as the ability to breathe; others have contended that perception is an acquired capacity, wholly dependent on experience and learning. The nativists have argued that a baby sees about what adults see; empiricists have held that an infant's visual world must be—in William James's words—"buzzing confusion."

At the heart of the argument there is a genuine scientific question: how to account for the discrepancy between the richness of perception and the poverty of its apparent cause—the momentary retinal image. First of all, there is the problem of space perception. The world as perceived seems to have one more dimension—the dimension of depth—than the retinal image does. Then there are the spatial "constancies," the tendency of an object to retain its size regardless of changes in viewing distance (even though the size of the retinal image changes) and to retain its shape even when its orientation (and therefore its retinal image) is changed. In other words, perception seems faithful to the object rather than to its retinal image.

Most psychologists have given empiricist answers to the problems of space perception and constancy. They have assumed that the infant's perceptual world mirrors the sequence of momentary retinal images that creates it. The chaotic two-dimensional ensemble of changing shapes is slowly ordered, in this view, by various mechanisms. The retinal image contains many cues to depth; for example, far-off objects are projected lower on the retina than nearby objects (which is why they appear higher to us). Supposedly a baby learns that it must crawl or reach farther to get to such a higher image, and so comes to correlate relative height with relative distance. A similar correlation is presumably made in the case of the many other distance cues.

Once these theories have accounted for space perception they must go on to endow infants with the constancies. The oldest theory of constancy learning stems from Hermann von Helmholtz. He argued that by seeing an object at different distances and in a variety of orientations one learns the set of retinal projections that characterize it, so that on encountering a familiar retinal projection one can infer the size, shape, distance and orientation of the object producing it. According to this theory, however, there could be no constancy with an unfamiliar object. To avoid this prediction a different (but still empiricist) theory was developed from a suggestion made by the Gestalt psychologist Kurt Koffka. It assumes that a child who has acquired space perception will notice that there is a predictable relation between the distance of an image and its size, and a predictable relation between the orientation of an image and its shape. Once these relations have been inferred the child should be able to predict the size an image would have if its distance were changed and the shape it would have if its orientation were changed. The child could achieve shape constancy by predicting what shape a slanted image would have if it were rotated to lie directly across his line of sight. This means that the constancies could be attained with any object, familiar or not.

Note that this theory makes an assertion about the course of perceptual development that is also an assertion about the sequence of events in perception: Before an infant can attain size and shape constancy he must be able to register distance or orientation and projective size or shape; before an adult can compute true size or shape he must register projective size and shape and distance and orientation. There were many attempts to validate this theory of development by testing adult subjects. In a typical experiment adults were shown shapes in various orientations and asked to report true shape, projective shape and orientation. If the theory were correct, one should be able to predict a subject's true-shape judgments from the other two. This turned out to be impossible. Subjects' judgments of true shape were often far more accurate than any deduction from their judgments of projective shape and slant could have been; they often got the true shape right and, say, the orientation completely wrong. This apparent disproof of the theory was explained away by supposing the process of deduction from retinal projection and orientation to true shape had become so automatic with long practice that the premises of the deduction had become subconscious.

So-called completion effects are another puzzle created by the characteristics of the retinal image. If one object is partly occluded by another, the two-dimensional retinal image of the first object is transformed in bizarre ways. Koffka argued that when an adult looks at a book on a table, he can see the table under the book. Similarly, if one looks at a triangle with a pencil across it, one can still see that there is a triangle under the pencil. In the retinal image, of course, there is a gap in the table and a gap in the triangle. Empiricists argue that ex-

perience and learning are necessary for these retinal deficiencies to be corrected. They argue that one *learns* the shape of a triangle, after which, on seeing a partly covered triangle, one can infer what the hidden parts look like.

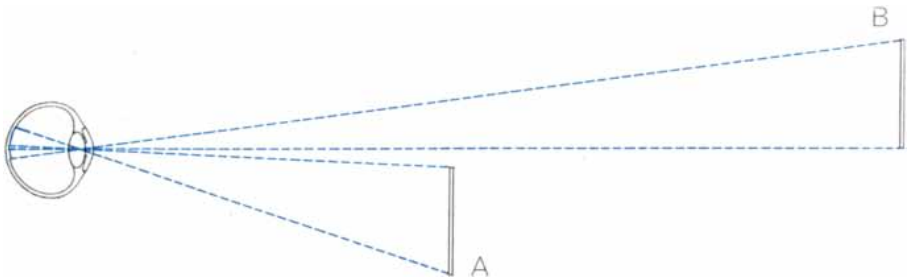
This short review of problems will give the reader some idea of what the perceptual world of the infant should be if empiricist theory is correct. William James's description of it as buzzing confusion is then too mild; it should be a chaotic, frightening flux in which nothing stays constant, in which sizes, shapes and edges change, disappear and reappear in a confusing flow. Yet the theories described above are at least serious attempts to handle the problems of space perception, spatial constancies and completion effects. Nativist theories in contrast make a rather poor showing. Too often a nativist theory has merely been an argument against empiricism, not an attempt at genuine explanation.

The nativism-empiricism issue has remained open largely because there have seemed to be no ways to investigate the perceptual world of infants. How is one to get an answer from an organism as helpless as a young human infant, capable of few responses of any kind and of even fewer spatially directed responses? One obvious solution is the use of the operant-conditioning methods that were devised by B. F. Skinner: one selects some response from an organism's repertory and delivers some "reinforcing" agent contingent on the occurrence of that response. If reinforcement is delivered only in the presence of a certain stimulus, the response soon occurs only in the presence of that "conditioned" stimulus. It is then possible, among other things, to introduce new stimuli to be discriminated from the conditioned stimulus. Using manipulations of this kind, one can discover a great deal about the perceptual worlds of pigeons, fishes and even worms.

For some years, first at Cornell University and more recently at Harvard University, I have been applying operant-conditioning techniques to investigate perception in human infants. The major block to applying these methods to infants had been the necessity of a reinforcing agent. The agent is ordinarily either food or water, and it is usually withheld for some time before the experiment; a pigeon working for grain is kept at 80 percent of its normal body weight. One could hardly inflict such privation on infants. Fortunately less drastic methods are available. As

OPERANT-CONDITIONING technique requires that an infant be trained to respond to the presentation of a certain stimulus. In this experiment in shape perception the stimuli are plywood rectangles and trapezoids placed at various angles to the infant's line of sight. The object is to see how well the infant can differentiate among the shapes and orientations.

"REINFORCEMENT," part of the training program, is delivered when the infant responds correctly. The usual reinforcement in animal experiments is food or water. The author uses a "peekaboo": as shown, an experimenter pops up, cooing and smiling, then disappears.



RETINAL IMAGE varies with distance. Objects *A* and *B* are the same size but *A* projects a larger image on the retina. In spite of this, adults usually see such objects as being the same size. One of the author's objectives was to see if infants too have this "size constancy."

Skinner pointed out, any change in surroundings, even the simple rustling of a newspaper, seems to reinforce an infant's responses. The reinforcement we use is a little game that adults often play with infants called "peekaboo": the adult pops out in front of the infant, smiling and nodding, and speaks to him (sometimes patting him on the tummy if he is unresponsive) and then quickly disappears from view. Infants between two and 20 weeks old seem to find this event highly reinforcing and will respond for 20 minutes at a time to make it occur. The situation can be made even more reinforcing by altering the schedule of reinforcement.

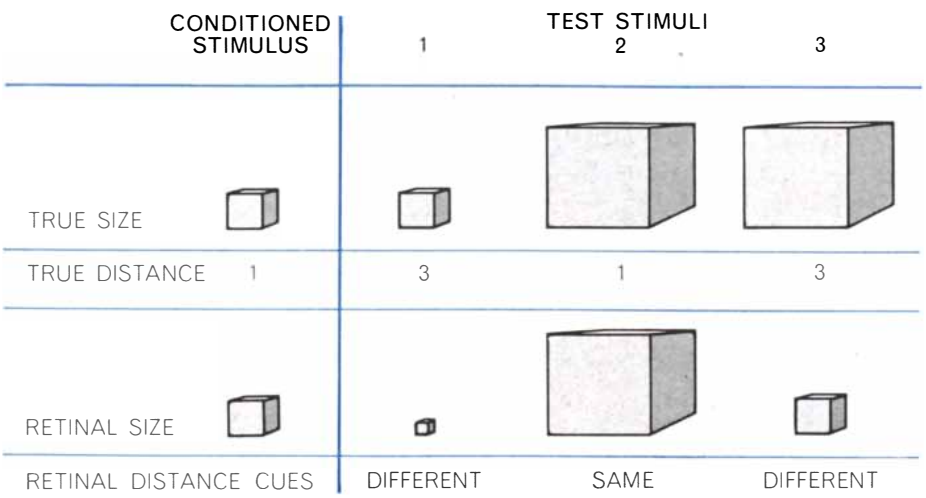
A lesser problem is deciding what response to use. Infants have few responses available; most of these require substantial effort and would quickly tire the subject of an experiment. The one used in the present investigations is a turn of the head. The infant reclines with his head between two yielding pads. By turning his head as little as half an inch to the left or right he closes a microswitch that operates a recorder. This response requires scant effort; even infants as young as two weeks old can give 400 such responses with no apparent fatigue.

The first experiment carried out with these techniques was aimed at discovering whether or not infants can perceive distance and are capable of size constancy. An infant between six and eight weeks old, too young to be capable of the spatial behavior of reaching and crawling, reclined in an infant seat on a table, with the peekabooing experimenter crouching in front of him and the stimuli beyond the experimenter. A translucent screen could be raised for rest periods and stimulus changes. The conditioned stimulus in the first experiment was a white cube 30 centimeters (12 inches) on a side, placed one meter from the infant's eyes.

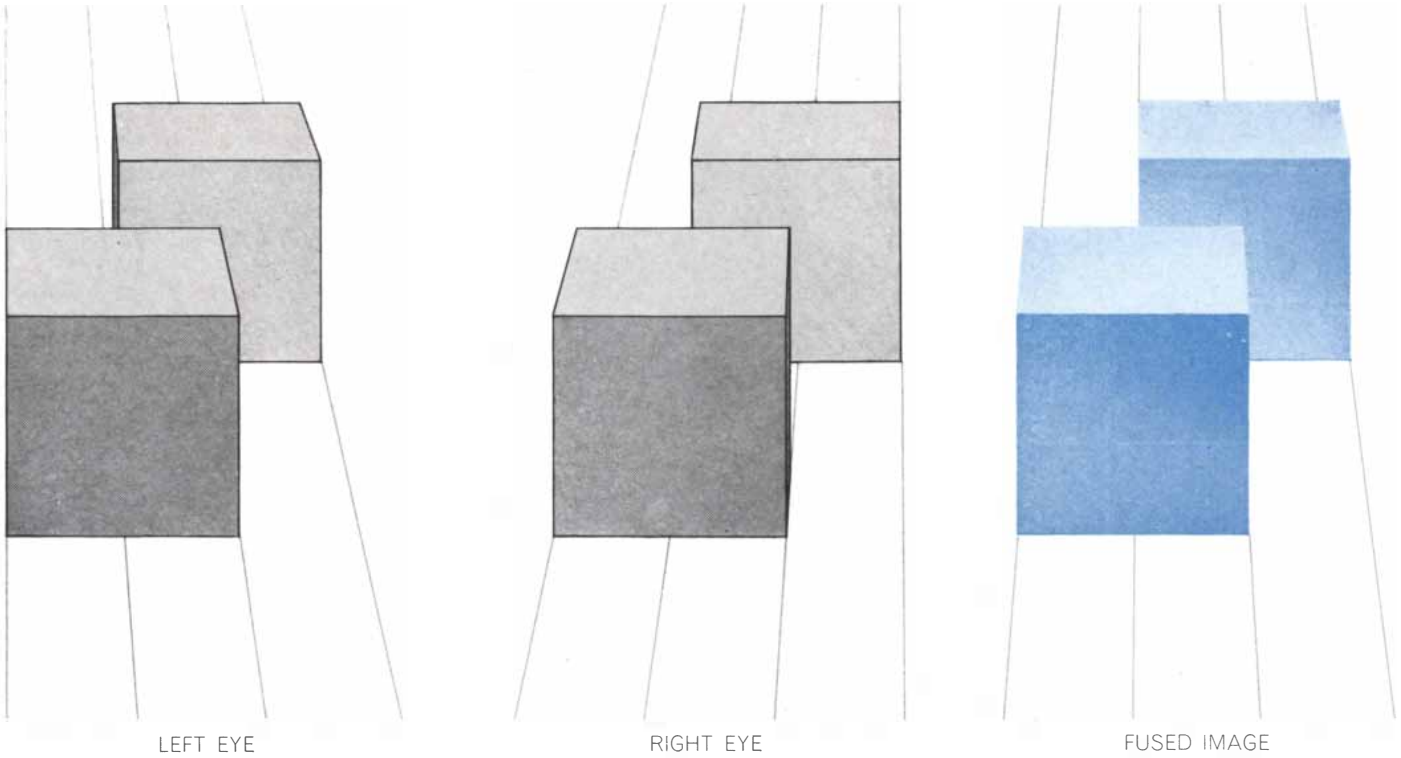
After training an infant to respond only in the presence of the cube, we gradually changed the reinforcement schedule to a variable one in which every fifth response, on the average, was reinforced. After one experimental hour on this schedule we began perceptual testing by introducing three new stimuli. These were the 30-centimeter cube placed three meters away, a 90-centimeter cube placed one meter away and the same 90-centimeter cube placed three meters away. These three stimuli and the conditioned stimulus were each presented for four 30-second periods in counterbalanced order and the number of responses elicited by each stimulus was recorded. During the testing period no reinforcement was given.

On any theory, the conditioned stimulus could be expected to elicit more responses than any of the other stimuli. The stimulus eliciting the next highest number of responses should be the one that appears to the infant to be most like the conditioned stimulus. If the empiricist hypothesis that infants do not perceive distance and do not have size constancy is correct, the stimulus that should have appeared most similar was the third stimulus, the 90-centimeter cube placed three meters away; it was three times the height and width of the conditioned stimulus but also three times as far away, so that it projected a retinal image of the same size. If infants can perceive distance but still lack size constancy, stimulus 3 should still have seemed more like the conditioned stimulus than stimulus 1, the 30-centimeter cube at three meters. Both were at the same distance, but stimulus 3 projected a retinal image with the same area as the conditioned stimulus, whereas stimulus 1 projected an image with only one-ninth the area. If the infants had been unable to discriminate distance at all, stimulus 2 would have elicited as many responses as stimulus 1, since stimulus 2 projected an image with nine times the area of the conditioned stimulus and stimulus 1 projected an image one-ninth as large. If they had been sensitive to distance or its cues but had lacked size constancy, stimulus 2 would have elicited more responses than stimulus 1, since stimulus 2 was at the same distance as the conditioned stimulus. If, on the other hand, the infants had been able to perceive distance and had size constancy, stimuli 1 and 2 should have elicited about the same number of responses, since stimulus 1 differed from the conditioned stimulus in distance and stimulus 2 differed in size; stimulus 3 should have elicited the lowest number of responses, since it differed from the conditioned stimulus in both size and distance [*see illustration at left*].

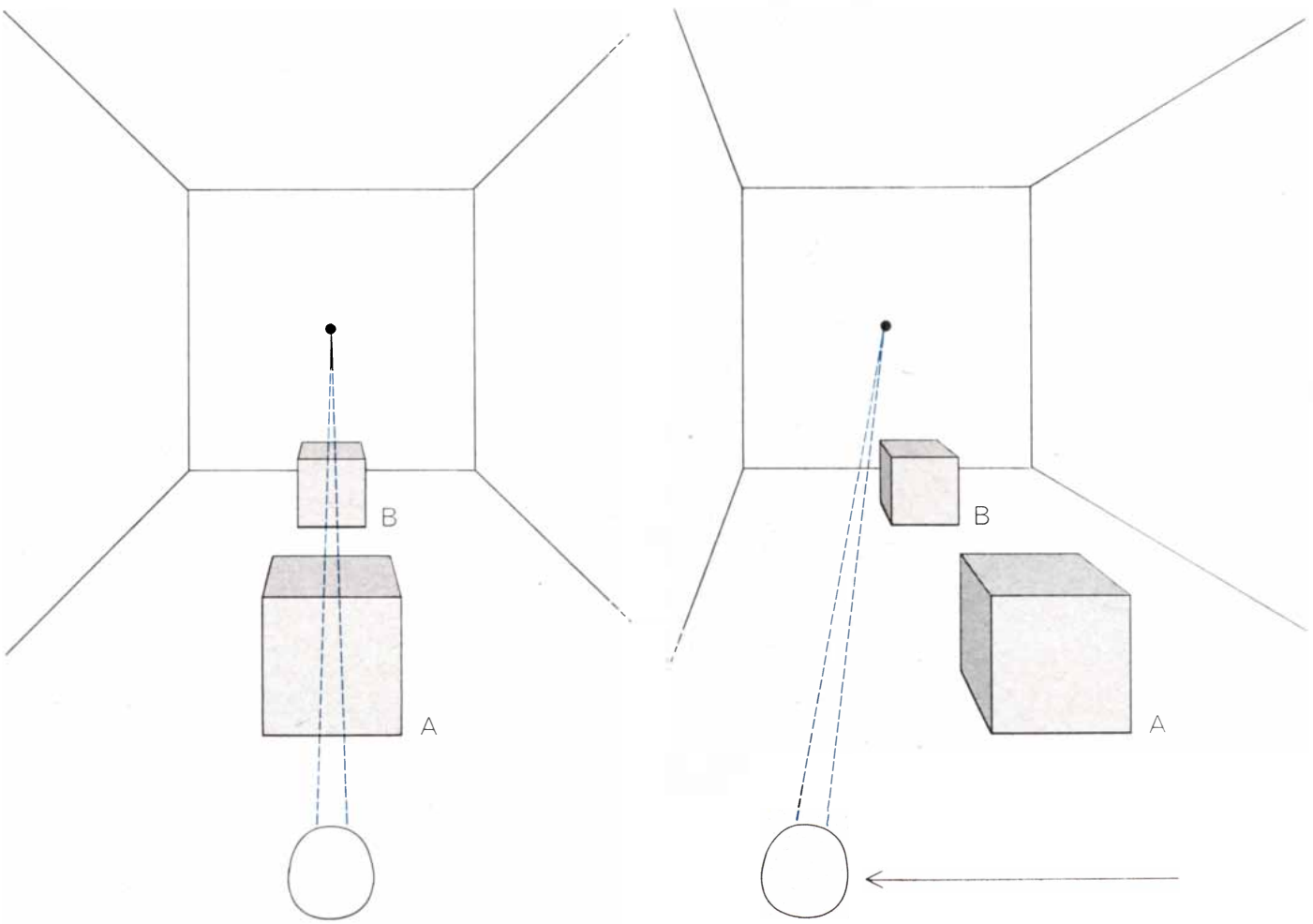
To sum up the predictions, according to empiricism stimulus 3 should be as effective as or more effective than stimu-



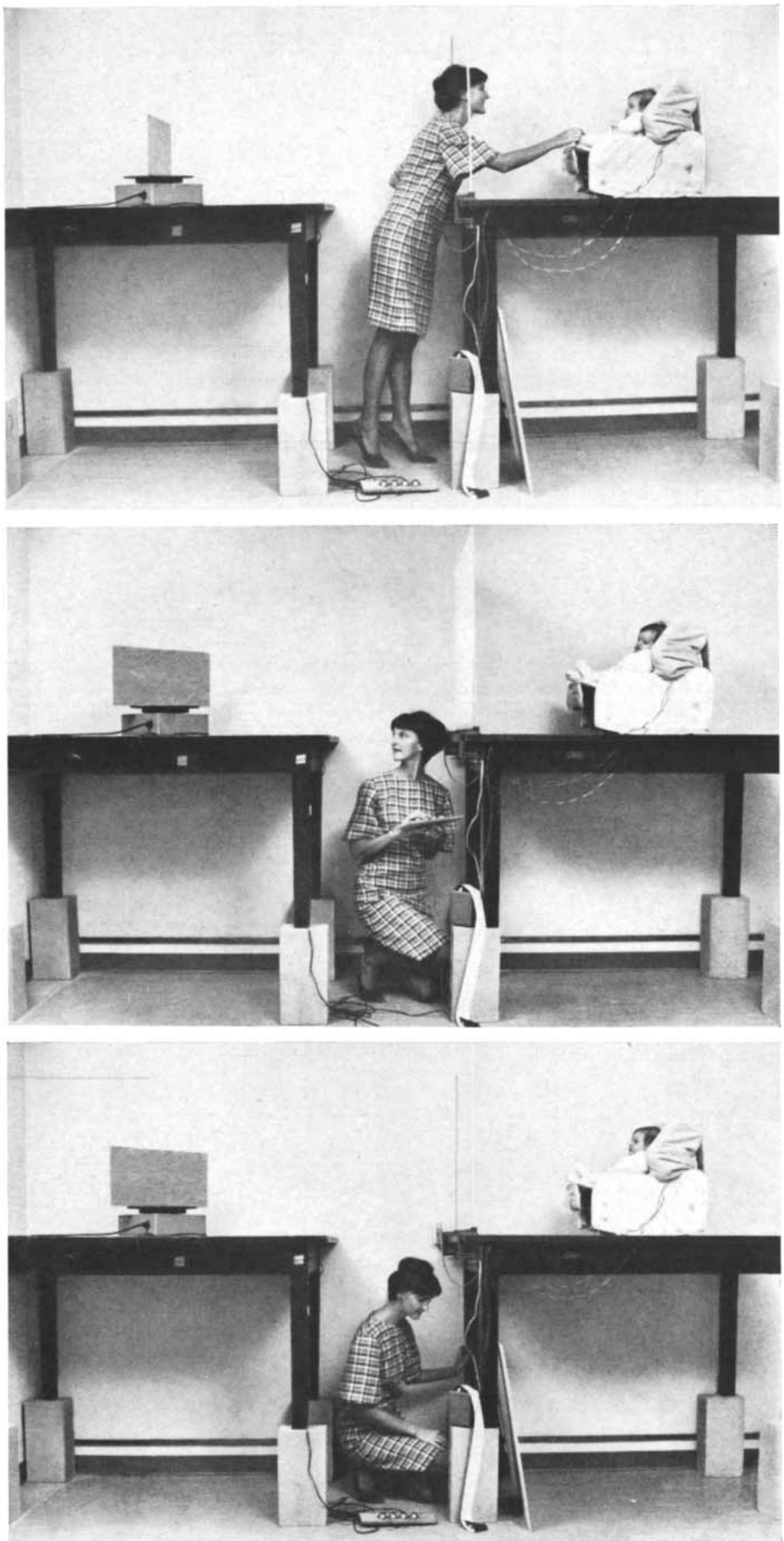
SIZE CONSTANCY was investigated with cubes of different sizes placed at different distances from the infants. The conditioned stimulus was 30 centimeters on a side and one meter away, test stimuli 30 or 90 centimeters on a side and one or three meters away. The chart shows how test stimuli were related to the conditioned stimulus in various respects.



BINOCULAR PARALLAX is one of two "primary" cues to distance. Because the right and left eyes are some distance apart, each registers a somewhat different view of the same scene. In the two drawings at the left the lower, or nearer, cube is farther to the left in the right eye's view than in the left eye's view. If the two images are combined stereoscopically (with the aid of a prism to superpose one image on the other, for example), the scene acquires a third dimension. The result is simulated by the drawing at the right.



MOTION PARALLAX also provides different perspectives that vary with distance. If the head moves left and the eyes are kept fixed on a distant point, the nearer object (*A*) appears to move to the right farther and faster than the more distant object (*B*) does.



EXPERIMENTAL PROCEDURE begins with conditioning. The infant is trained to respond to a rectangle seen in a certain orientation and the response is reinforced by a "peek-aboo" (*top*). Then a screen is interposed between the infant and the stimulus area while the experimenter changes the orientation (*center*). With the screen removed, the experimenter watches a recorder to see whether or not the infant responds to the test stimulus (*bottom*).

lus 2, which should in turn get more responses than stimulus 1; if retinal distance cues are not taken into account, 3 should be clearly superior to 2. According to nativism the order should be the reverse: more responses to 1 than to 2, more to 2 than to 3. What happened was that the conditioned stimulus elicited an average of 98 responses; stimulus 1, 58 responses; stimulus 2, 54 responses, and stimulus 3, 22 responses. It therefore seems that the retinal image theory cannot be correct. These infants' responses were affected by real size and real distance, not by retinal size or by retinal distance cues.

What stimulus variables were being used by these infants to gauge depth? Two cues, binocular parallax and motion parallax, are called "primary" because they are the most reliable of all the cues. The first of these is available because a human being's eyes are set some distance apart and therefore receive slightly different views of the same scene. This binocular disparity produces an immediate impression of distance, at least in adults. Motion parallax is a similar cue: by moving one's head from side to side, one picks up a sequence of slightly differing perspectives of a scene. Moreover, near objects are displaced farther and faster than far objects. Are binocular parallax and motion parallax "primary" in a developmental sense, however? The presumptive cause of perception is the momentary retinal image of a single eye. As soon as two eyes are introduced for binocular parallax there arises the problem of integrating the two images; as soon as a sequence of images is brought in for motion parallax there is the question of how the visual system integrates multiple images spread out over time. Since these presumably complex integration processes must come into play before the two kinds of parallax can acquire spatial meaning, it is little wonder that these variables have seemed poor candidates for development early in infancy. This drawback does not apply to the host of pictorial cues that are implicit in the momentary retinal image of a single eye. These are the cues—shading, perspective, texture and so on—a painter exploits to produce the illusion of depth on a canvas without benefit of the parallaxes. It has seemed possible that these cues are recognized early in development as having differential value and so become endowed early with spatial meaning.

To discover which cues should be called primary, we tested three new

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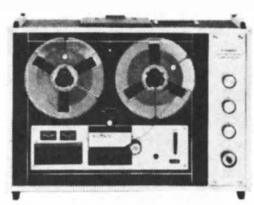

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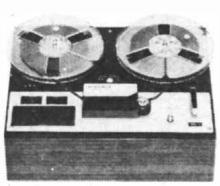

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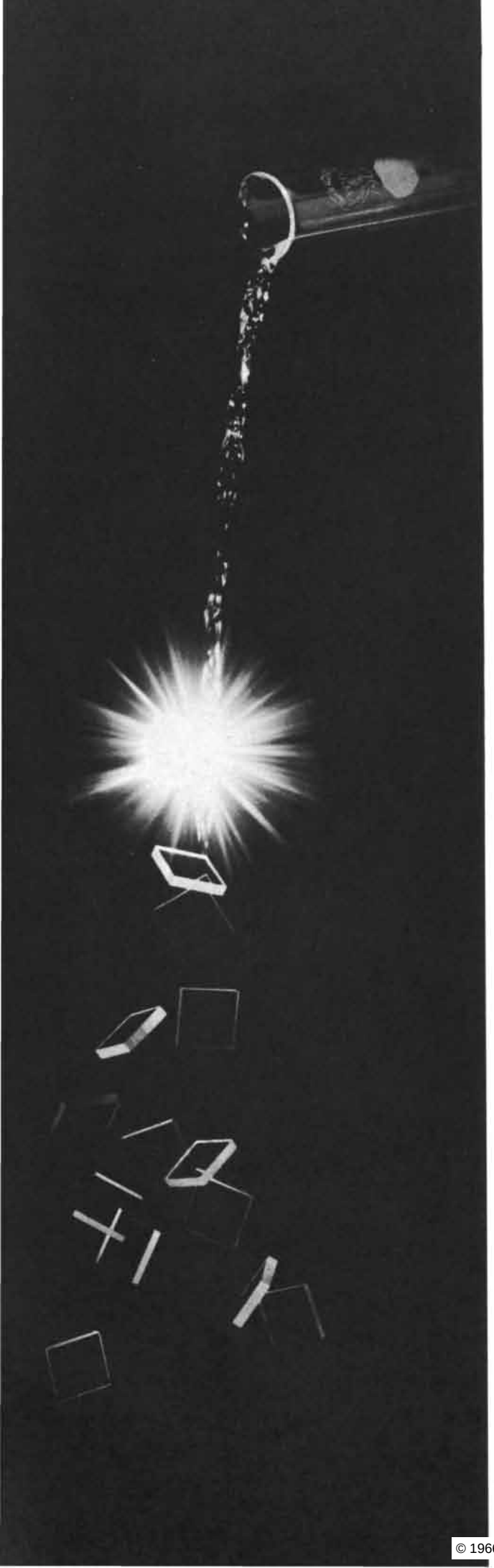


Sometimes it takes a light touch to make plastics.

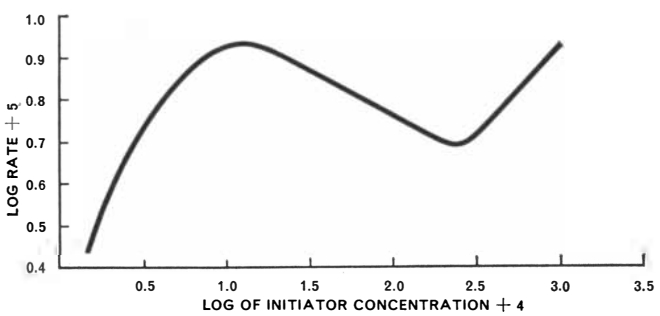
To make a plastic—take a monomer, add an initiator, and then add some energy to kick off the reaction. When it's over, you have polymer molecules—a plastic. The needed energy often comes from heat. But heat can evaporate the monomer before it has a chance to polymerize. Or it can damage a material being plastic coated.

A good alternate energy source is light. Just recently, our chemists discovered an initiator that is particularly effective in forming acrylic polymers on exposure to ultraviolet light.

It's triphenylphosphine. Several other triphenyl compounds are known as effective polymerizing agents at about 200°C. But we've found that these, and the phosphorus derivative, can also initiate *photo*polymerization. And triphenylphosphine is effective at room temperature.

Suppose you want to "pot" a delicate electronic circuit that would be harmed by heat. Take a methacrylate monomer to which our new initiator has been added. Drop the electronics into a bowl of this watery liquid and expose it to ultraviolet light. In a few minutes the circuit is encapsulated in a clear, solid plastic that is potentially very stable. (Many initiators leave a residue in the polymer that hastens its degradation. Triphenylphosphine doesn't.)

The suggested explanation of how and why all this happens gets into molecular complex formations and electron exchanges. Detailed discussion is available on request. It's all part of our continuing search for a better way.



Effect of triphenylphosphine concentration on rate of polymerization of methyl methacrylate.

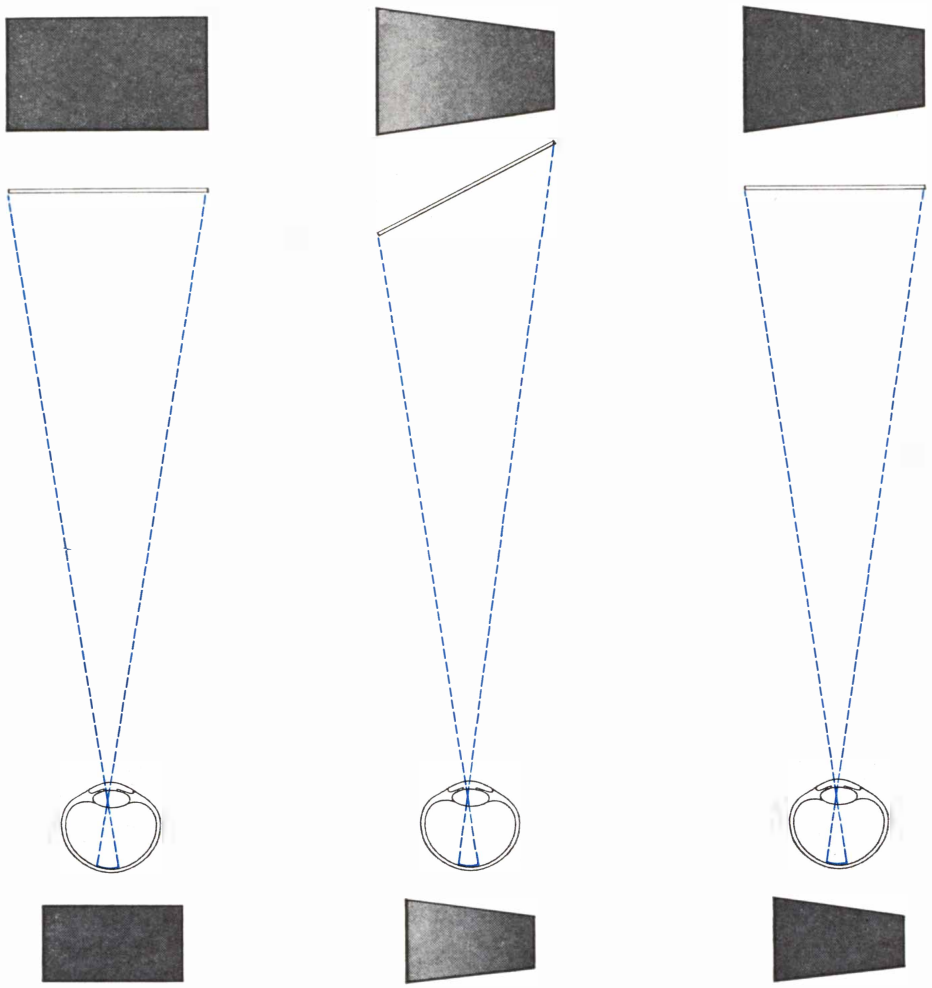
GM **General Motors Research Laboratories**
Warren, Michigan 48090

MARK OF EXCELLENCE

groups of infants on the size-constancy test. Infants in one group wore a patch over one eye so that they could not register binocular parallax but could register only motion parallax and pictorial cues. A second group viewed, instead of the real cubes, projected slides that were rich in pictorial cues but lacked both binocular and motion parallax entirely. A third group of infants wore specially constructed stereoscopic goggles and viewed projected stereograms of the various scenes; their presentation contained binocular parallax and pictorial cues but lacked motion parallax. The results were interesting. The monocular group performed just as the unrestricted group of the first experiment had. The conditioned stimulus elicited an average of 101 responses; stimulus 1 (the same cube farther away), 60 responses; stimulus 2 (the large cube at the distance of the conditioned stimulus), an average of 53 responses; stimulus 3 (the large cube set to be projectively equivalent to the conditioned stimulus), only 22 responses. The infants who viewed the slides performed quite differently: they produced 94 responses to the conditioned stimulus, 52 to stimulus 1, 44 to stimulus 2 and 96 to stimulus 3. Their behavior suggested that their responses were determined solely by the projective size of the cubes

RESPONSE in these experiments was a head-turning motion that operated a switch in the cushions at the infant's head. At first the infants gave exaggerated responses (*left*); later they responded more economically, keeping their eyes on the stimulus (*right*).

PLEASURE at the peekaboo reinforcement was manifest (*left*), and was sufficient to keep infants responding up to 20 minutes between reinforcements. The problem in experiments with infants is boredom; after a while even the peekaboo loses its charm (*right*).



SHAPE CONSTANCY is illustrated by shapes in different orientations. A rectangle presented in the parallel plane (*left*) projects a rectangular image on the retina (*bottom*) and is seen as a rectangle. Presented at a slant, it projects a trapezoidal image (*center*), yet is usually seen as a rectangle. A trapezoid in the parallel plane projects the same shape (*right*).

in the various presentations; the pictorial distance cues in the slides were obviously not even being detected (or stimulus 3 could not have elicited as many responses as the conditioned stimulus), much less serving as cues to distance and size constancy. The infants in the stereogram group were different again. Their responses suggested some size constancy but less than the responses of either the unrestricted infants or the monocular group did. The values were: conditioned stimulus, 94 responses; stimulus 1, 44 responses; stimulus 2, 40 responses, and stimulus 3, 32 responses. It therefore appeared that motion parallax was the most effective cue to depth, followed by binocular parallax. The static pictorial cues in the retinal image seemed to be of no value.

A second set of experiments was carried out to investigate shape constancy and slant perception. The subjects were infants between 50 and 60 days old. The conditioned stimulus in this investigation was a wooden rectangle 25 by 50 centimeters (about 10 by 20 inches) placed two meters away and turned 45 degrees from the "fronto-parallel plane," a plane at a right angle to their line of sight. The test stimuli were (1) the same rectangle placed in the infant's parallel plane, or at a right angle to the line of sight; (2) a trapezoid, placed in the parallel plane, that projected a retinal image of the same shape as the rectangle in the 45-degree position, and (3) this same trapezoid placed in the 45-degree position. The three test stimuli differed from the conditioned stimulus as shown in the bottom illustration on this page.

If infants are capable of shape constancy, stimulus 1 should be more effective than stimulus 3, which should be about the same as stimulus 2. If they are controlled by retinal shape only, on the other hand, stimulus 2 should get more responses than 3 or 1. The results were that the conditioned stimulus elicited an average of 51 responses; stimulus 1, the same rectangle in a different orientation, elicited 45.13 responses; stimulus 2, which projected the same retinal image as the conditioned stimulus, elicited only 28.50 responses, and stimulus 3 elicited 26 responses. There was no doubt that these infants had learned to respond to real shape, not retinal shape. Statistical analysis showed, moreover, that there was no significant difference between the number of responses elicited by the conditioned stimulus and the number elicited by test stimulus 1. It therefore appeared that the infants were responding to true shape and displaying shape constancy *without* having discriminated between different orientations of the same object.

This last result was extremely puzzling and we modified the experiment to examine it in more detail. There were three groups of infants aged 50 to 60 days, each with a different set of stimuli. One group was trained with the rectangle turned five degrees away from the parallel position. The three test stimuli were the same rectangle turned 15 degrees, 30 degrees and 45 degrees from the parallel plane. The second group of infants was trained with a trapezoid placed in the parallel plane whose shape was projectively equivalent to the rectangle in its five-degree position. The three test stimuli were trapezoids set up in the parallel position and projectively equal to the three test stimuli used for the first group. For the third group the

STIMULUS	REAL SHAPE	ORIENTATION	RETINAL SHAPE
1	SAME	DIFFERENT	DIFFERENT
2	DIFFERENT	DIFFERENT	SAME
3	DIFFERENT	SAME	DIFFERENT

TEST STIMULI in the first shape-constancy experiment described in the text differed from the conditioned stimulus as shown. Retinal shape was expected to be the governing factor.

Seeing double at Western Electric

Western Electric isn't in the optical supply business. But we don't back off if a new kind of optical instrument will help us do our job better in any way.

As it happened, we needed a special dual-viewing stereomicroscope that would let two people simultaneously view an object with the same depth perception, magnification and image quality. We wanted a sturdy, portable, reasonably-priced adaptation of a standard 20-80 power stereomicroscope.

But such a microscope wasn't on the market. So engineers at our Engineering Research Center stepped out of their customary roles and built one. They wrote the specs, constructed a prototype, evaluated and tested it.

In our new microscope a simple beam-splitter divides both beams of light transmitted by the primary objective to the primary eyepieces. Three mirrors, four achromatic doublet lenses, and two collector lenses relay each split beam through a 20-inch long tube to secondary eyepieces. Only 14% illumination is lost; distortion is 8.3%; resolution is maintained close to 0.0001 inch, or better than 160 cycles per millimeter.

Today, a number of Western Electric and Bell Laboratories locations use them to train assemblers of microelectronic components; to make time-and-motion studies of microscopic operations; and to obtain agreement between two inspectors, or between the buyer and seller of miniscule parts. Because of our enthusiasm, two optical houses now manufacture models similar to our design to supply unanticipated demand from other companies.

It is with such flexibility and determination that Western Electric engineers help their teammates in the Bell System continue to bring you the world's most modern telephone service at a reasonable cost.

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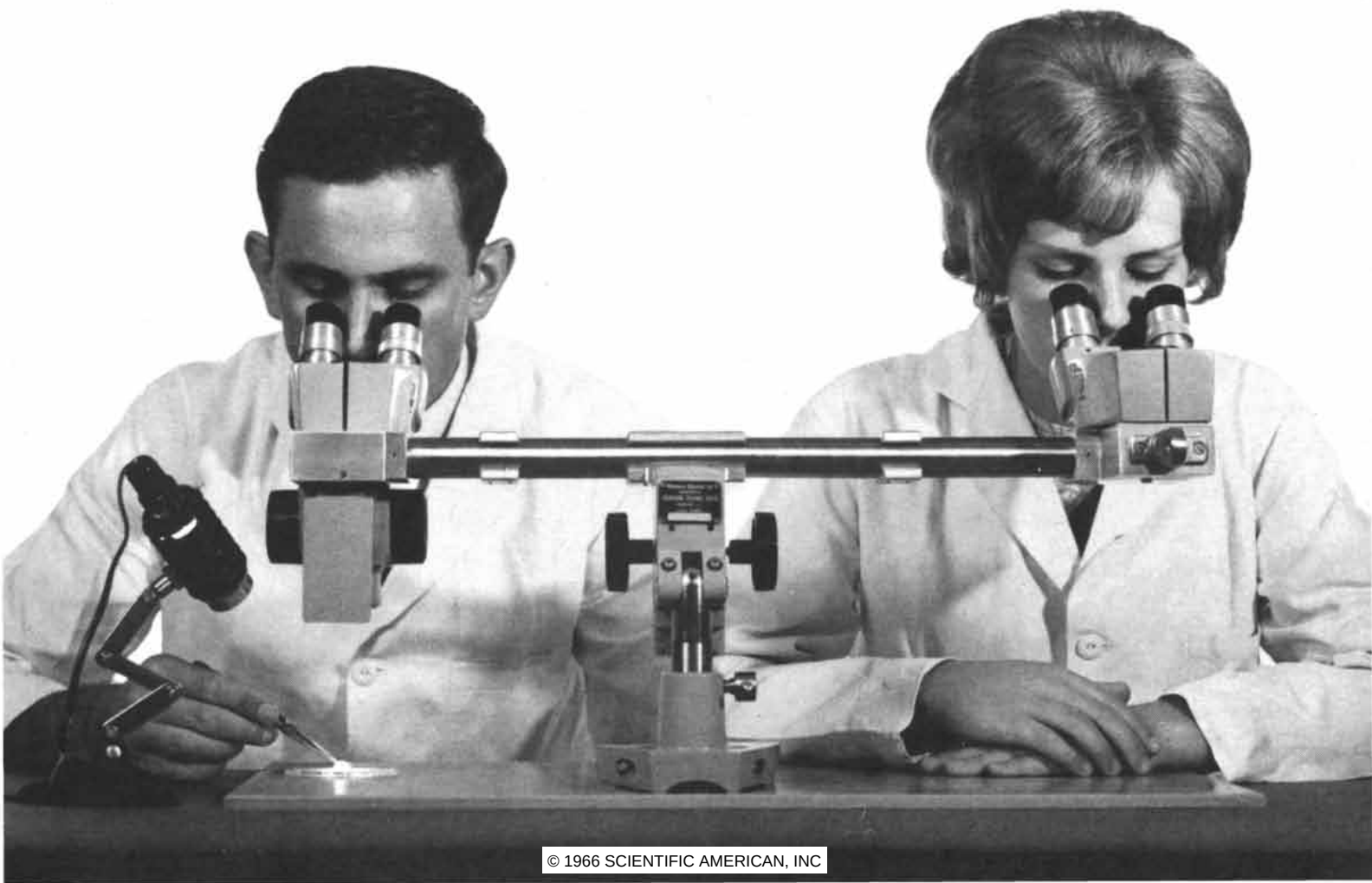


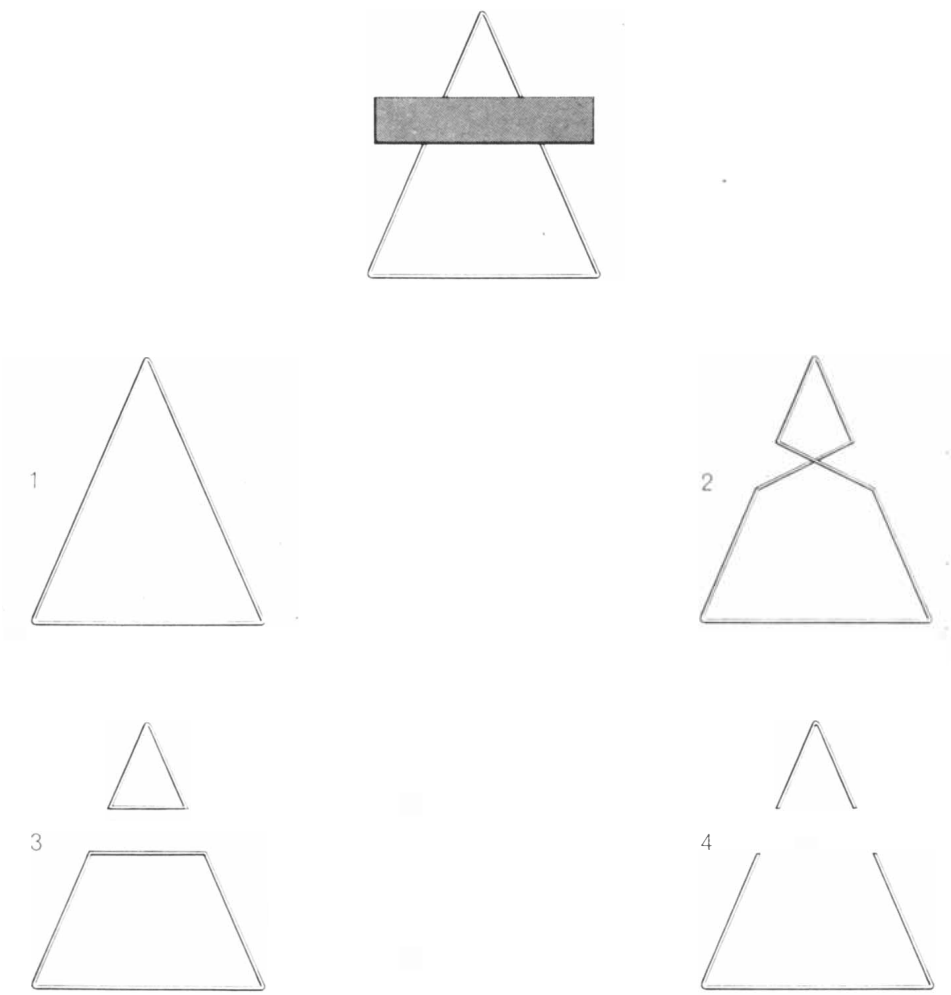
rectangles used for the first group were hidden by a screen with a rectangular hole cut in it so that the body of the rectangle was visible but its edges were not; the only information available on the difference between the conditioned stimulus and the test stimuli was therefore given by variations in orientation. To summarize the three viewing conditions, the stimuli viewed by group 1 varied in projective shape and orientation, with real shape constant. Those viewed by group 2 varied in real shape and projective shape, with orientation constant. Those viewed by group 3 varied in orientation only, with real shape and projective shape remaining constant.

This was a multipurpose experiment. It was intended, first of all, to discover whether or not infants can discriminate among different orientations of the same shape; hence group 1. If the answer to that question were negative, the experiment should show whether or not such infants could discriminate orientation as such; hence group 3. Moreover, a comparison of group 1 with groups 2 and 3 would bear on the idea, mentioned earlier, that spatial constancies are attained by a prediction from one retinal image in a perceived orientation to another image in another orientation. If it were true that infants see an object in space as a projective shape with an orientation, the infants in group 1 would give far fewer responses to the test stimuli than the infants in the other two groups, since the first group, viewing an object rotated in space, would have both projective shape and orientation available to differentiate test stimuli from conditioned stimulus, whereas the other two groups would have only one of these differentiating variables at their disposal.

On the contrary, the infants in group 1 showed the poorest discrimination; they responded as if the three test stimuli looked the same as the conditioned stimulus. The infants in groups 2 and 3 showed good discrimination, indicating that variations in real shape (and therefore in projective shape) can be registered by infants and that variations in orientation can also be registered. The poor discrimination shown by group 1 can only mean that real shape—which was the same in all four of the stimuli—was perceptually more salient than either orientation or projective shape. This finding seems very important, since it is a blow not only against empiricism but also against the idea (common to nativists and empiricists) that perception of simple variables is in some way developmentally earlier than perception of complex variables.

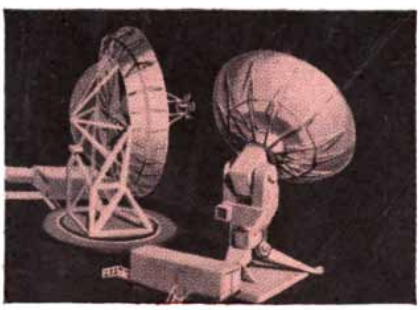
A third set of experiments was concerned with completion problems. Again the subjects were infants between 50 and 60 days old. The conditioned stimulus was a black wire triangle with a black iron bar placed across it. After training as before, four wire test stimuli were presented [*see illustration on this page*]. The complete triangle elicited an average of 42 responses. The other test stimuli elicited 18.25, 17.25 and 20 responses respectively. This can only mean that these infants saw the conditioned stimulus as a triangle with a bar over it. Since none of these infants had ever seen a triangle before the experiment, and since during the experiment it was only seen with a bar over it, the empiricist reliance on learning and experience cannot be justified. In a second experiment in which slides of these triangular objects were presented rather than the wire objects, the result was quite different: there was no preference for one test figure over any other. As in the case of space perception, the infants' performance appeared to depend not on static retinal cues but rather on the information contained in variables, such as motion parallax, that are available only to a mobile organism viewing a three-dimensional array.

Our investigation was originally directed to the nativism-empiricism controversy. The eight-week-old infants certainly were more capable of depth discrimination, orientation discrimination, size constancy, shape constancy and completion than an empiricist would have predicted. On the other hand, the babies were also less capable than a strict nativist would have predicted. They could not discriminate pictorial cues and they could not maintain shape constancy and orientation discrimination simultaneously. It cannot be stated, therefore, that the experiments have resolved the issue one way or another. Nor do they seem merely to indicate that the true position is a compromise—that there are some innate abilities and that these are



COMPLETION EXPERIMENT was conducted with these objects. The conditioned stimulus was a triangle with a bar attached to it, thus interrupting its shape. Of the test stimuli, *3* and *4* are more like the conditioned stimulus than *1* and *2* are. Actually infants seem to complete objects as adults do, as shown by the fact that *1* was the most effective stimulus.

Who built two of the Army's most advanced radar systems?



Sylvania did. We offer total capability for *any* kind of radar. Searching or tracking. Long or short range. Mobile or stationary. Our heavyweight experience assures efficient operation at high resolution—across the spectrum of required frequencies.

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The RONDO system tracks missiles using two mobile 30-foot antennas—plus Sylvania receiving and digital processing equipment.

The ALTAIR system starts with a dish antenna 150 feet across—and ends with precision data processing. This Sylvania system, to be located on Kwajalein Atoll, extends range instrumentation in the far Pacific. It will provide new data acquisition and tracking capabilities—plus greater sensitivity and additional range resolution.

In projects like these, Sylvania works from concept to completion, and provides the full range of logistic support services. From site selection through design, development, construction, installation, operation and maintenance.

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elaborated by experience and learning. My impression is rather that these studies have added to the growing body of evidence that the whole controversy is based on false premises.

The most notable set of false premises stems from the belief that perception is caused by the momentary retinal image. What the experiments seem to show is that evolution has tuned the human perceptual system to register not the low-grade information in momentary retinal images but rather the high-fidelity information in sequences of images or in simultaneous complexes of images—the kind of information given by motion parallax and binocular parallax. The infants in these studies were obviously able to register variables containing complex information. Yet they were unable to use the information in the slide presentations of the first and third sets of experiments. This failure must surely mean that infants are not sensitive to the kind of information that can be frozen on the plane of a picture or locked into a momentary retinal image. A similar conclusion can be drawn from the fact that in none of these experiments did retinal similarity seem to make for more responses. Rather than being the most primitive kind of perceptual ability, it would seem, the ability to register the information in a retinal image may be a highly sophisticated attainment and may indeed have to be learned.

These results suggest a theory of perceptual and perceptual-motor development. It is obvious that an adult is capable of some responses these infants apparently lacked. For example, the infants in the second shape-constancy experiment seemed to be unable to register real shape and orientation simultaneously but able to register orientation in the case of a surface without limiting contours. The most plausible hypothesis is to assume that infants have a lower processing capacity than adults—that their perceptual systems can handle simultaneously only a fraction of the information they register. Infants can register the real shape of an object and they can also register its orientation. If they have limited processing capacity, however, they may be able to process only one of these variables even when both are present and are registered. This makes sense of the discrepancy between the behavior of group 1 and that of group 3 in the shape-constancy experiment. The infants of group 1 were presented with a real shape in various orientations, but they could process only the shape, which remained invariant, and so their discrimination appeared poor. Those in group 3 viewed a surface whose retinal shape stayed the same but whose orientation varied, and by choosing to process orientation and ignore retinal shape they were able to show good discrimination.

If capacity is limited, it also seems plausible that the infant perceptual system should give priority to information that has definite survival value. On this reasoning one would expect the shape of an object to have greater priority than its orientation and the orientation of a surface to have greater priority than its shape. Objects must be responded to, and their shape will often indicate the proper response, whereas surfaces are things to be landed on or used as supports, and their orientation is surely their most important attribute. One would also predict low priority for retinal shape and size, variables that are of no survival value except to a representational artist.

This evolutionarily oriented line of reasoning may also help one to understand the problem of perceptual-motor learning. The fact that infants will initially misreach has often been taken to show that they cannot perceive depth. If they can in fact perceive depth, the misreaching remains to be explained. A clue to an explanation is given by the fact that the most obvious change in an infant as he develops is a change in size. It seems likely that an infant who misreaches does so not because of poor depth perception but because he simply does not know how long his arm is. Since arm length is going to change drastically during development, it would be uneconomical—indeed, positively maladaptive—if the perceptual-motor system were geared at birth for a particular arm length.

The overall picture of perceptual development that is emerging is very different from traditional ones. It has long been assumed that perceptual development is a process of construction—that at birth infants receive through their senses fragmentary information that is elaborated and built on to produce the ordered perceptual world of the adult. The theory emerging from our studies and others not reported here is based on evidence that infants can in fact register most of the information an adult can register but can handle less of the information than adults can. Through maturation they presumably develop the requisite information-processing capacity. If this view is correct, the visual world of the infant may well be overwhelming at times, but it is probably not the meaningless buzz it has long been thought to be.

VACUUM COATED STEELS

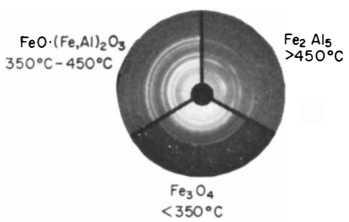
An idea borrowed from the electronics field, "vacuum evaporation", has multiplied the number of potential steel coatings to create a new generation of valuable products.

by R. P. Morgan, Research Manager

As if to emphasize the technological changes which are taking place in many of its processing operations, the steel industry recently borrowed an idea from the electronics field, scaled it up a hundred times and introduced a new steel coating process. The technique, used in the production of transistors and other space age electronic components, consists of evaporating metallic or non-metallic materials in high vacuum and condensing them onto a prepared substrate to form a coating. Youngstown Steel has been working with this process for the past four years, exploring its general utility. In many cases, special surface properties have been obtained on steel strip which could not have been economically achieved by other means, and from this work a new generation of coated steel products has emerged.

Research has reached a stage where a high speed pilot line is being used to prepare coils of steel with different coatings for customer evaluation. A key feature of the system is a series of remarkably effective roll seals. These seals enable a clean strip to pass continuously from the atmosphere into the high vacuum evaporation chamber operating at a pressure below 10^{-4} Torr, and out again. Inside the evaporating chamber, a specially designed crucible containing the coating material is heated by a beam of high energy electrons to some characteristic temperature at which large quantities of vapor are rapidly evolved. For example, with aluminum this temperature is about 1700°C. The vapor is immediately condensed onto the moving steel strip to form the desired coating. A number of individual evaporators is used in order to increase the operating speed and to produce a coating on both sides of the strip ranging in thickness from 0.001 to 1.0 mil. The use of the electron beam as a heating device permits the evaporation of a wide range of coating materials including those with very high evaporation temperatures.

One of the important technical problems in this field is that of obtaining good adhesion between the condensate and the steel substrate. Procedures vary for each material; however, again taking aluminum as an example, the steel must be pickled and subsequently preheated to a temperature of 400°C in vacuum before deposition of the coating. Electron diffraction studies of the interface between the steel and the aluminum have shown that a magnetite film is present at substrate temperatures below about 350°C, (see illustration) and is accompanied by poor adhesion.



VARIATIONS IN INTERMEDIATE LAYER BETWEEN VACUUM DEPOSITED ALUMINUM AND STEEL

As the substrate temperature is increased towards 450°C, an alumina spinel of varying composition is formed and the adhesion and corrosion resistance of the coating increase markedly. At temperatures above 450°C, an Fe_2Al_5 phase can be detected. Adhesion at this point is excellent but rapid total conversion of thin films to the brittle intermetallic can occur. This operating range is therefore generally avoided. Other coating metals of low melting point and high vapor pressure, such as zinc, require more critical control of substrate temperature. In addition, they require the use of an intermediate layer of a second metal to secure acceptable adhesion.

Other aspects of the process are under investigation including those connected with the control of coating properties and those related to the development of new equipment designs for more efficient operation. Data are steadily being accumulated through operation of the pilot facility and this information will eventually be used to further the construction of full scale production equipment.

Much of the work which has already been carried out points to the unusual flexibility of the new technique and the commercial significance of the products. For example, the "tin" can which is, of course, basically a "steel" can could be manufactured by substituting another metal for tin. Aluminum or chromium are contenders in this respect. They provide an attractive finish, are readily available, and have chemical properties which encourage their use in certain food containers.

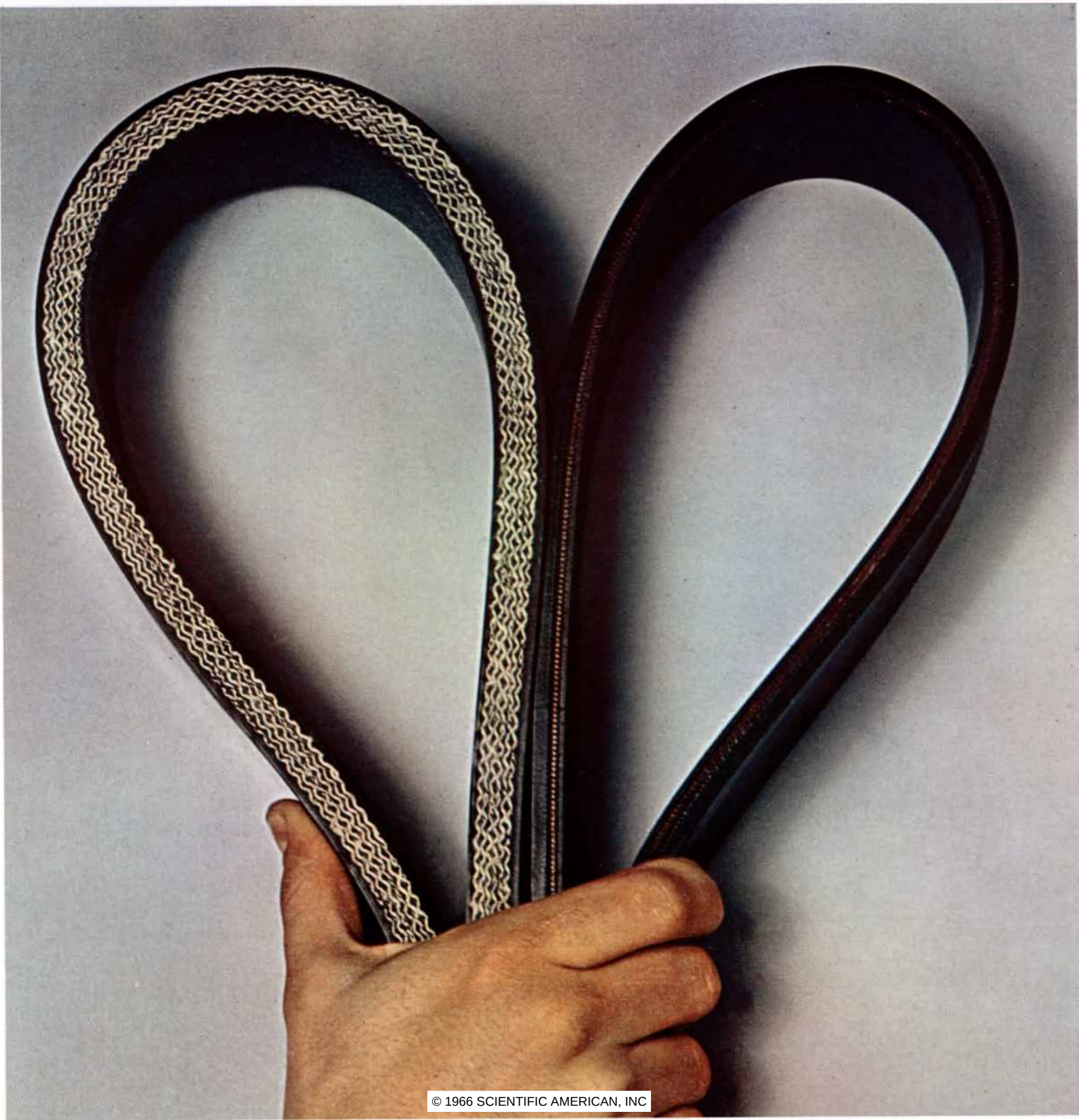
There are many additional examples of ways in which vapor deposited coatings can be used to broaden the performance of a steel product. Zinc, for special automotive applications, and stainless steel for architectural usage are both promising materials. Experiments have already shown that stainless steel compositions can be evaporated and condensed to form finishes with great corrosion resistance. The application of metals such as copper for brazability, or titanium for chemical inertness is also under consideration.

A great deal of additional research and development will be necessary to create the systems which will economically process a hundred thousand tons of these new strip products a year. Nevertheless, it is apparent at this time that the steel industry in its search for effective new techniques has discovered in vacuum evaporation a method with significant potential.

Steel and steel application problems are continually under investigation at Youngstown's research center in support of Youngstown's position as a major supplier of a wide variety of low carbon and low alloy products. The work on coated products represents only a small part of the 24 hour a day research effort. If you think Youngstown can help you, call at your convenience, or write Department 221 E6.

Plies in rubber: the fewer the better.

Single-ply (right) is comparable to six-ply conveyor belting (left). Although 40 percent lighter, single-ply belting lasts longer.



Uniroyal discovered that one ply of heavy cord is better than many plies of lighter fabric. The single-ply conveyor belt is tougher and lasts longer.

To make rubber stronger, manufacturers add "plies" of cotton or synthetic fabrics.

But plies can cause problems, too. Heat build-up at the point where rubber and fabric meet is the reason why rubber products sometimes come apart at the plies. ("Ply separation" is one of the most common reasons for failure of a rubber product like conveyor belting.)

That's why the single-ply conveyor belt was developed by Uniroyal (you might know us as United States Rubber Company).

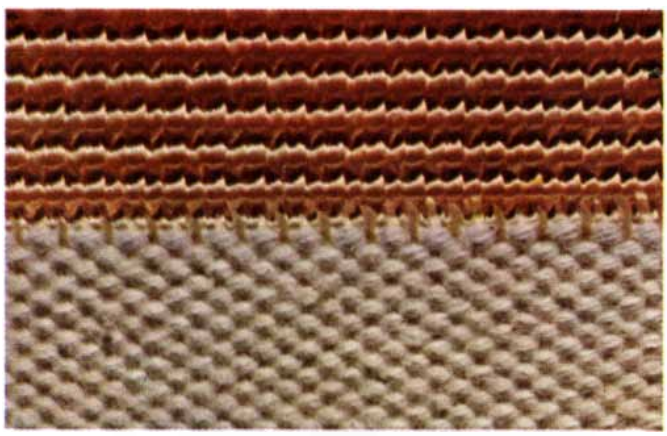
The patented Uniroyal invention shown here made it possible. By arranging fibers in parallel planes, rather than interweaving them, larger diameter fibers can be used more efficiently. A single ply of the new construction can do the job of six and as many as eight plies of conventional design.

Conveyor belts with the new single-ply construction have demonstrated the many customer benefits of the idea. Sold by Uniroyal under the registered tradename of "UsFlex," they are handling some of the toughest jobs in industry. More than 1,500 miles of single-ply belting are moving tons of products like coal, crushed ore, hot coke, sharp rocks, slag, cement, sand and gravel.

A conveyor belt no more than 5 feet wide might move some 600 tons of material an hour as far as one mile in a single "lift" or carry.

Conveyor belting represents a capital investment of considerable magnitude. Belting for a single installation might cost as much as half a million dollars.

That's why industries that use heavy-duty conveyor belting thoroughly investigated Uniroyal claims for single-ply belting before using it. Industries like mining, iron and steel, chemical process, public utilities. Here's what they found:



Unique construction (top) makes single-ply belting practical. Length and crosswise "strength" members are in parallel planes, not interwoven as in conventional ply (bottom).

Strength member from single-ply belt (top) retains much more of its inherent strength because it is not crimped and bent during weaving like conventional ply (bottom).

Although single-ply belting is lighter and thinner than equivalent multiple-ply belting, it consistently gives longer life.

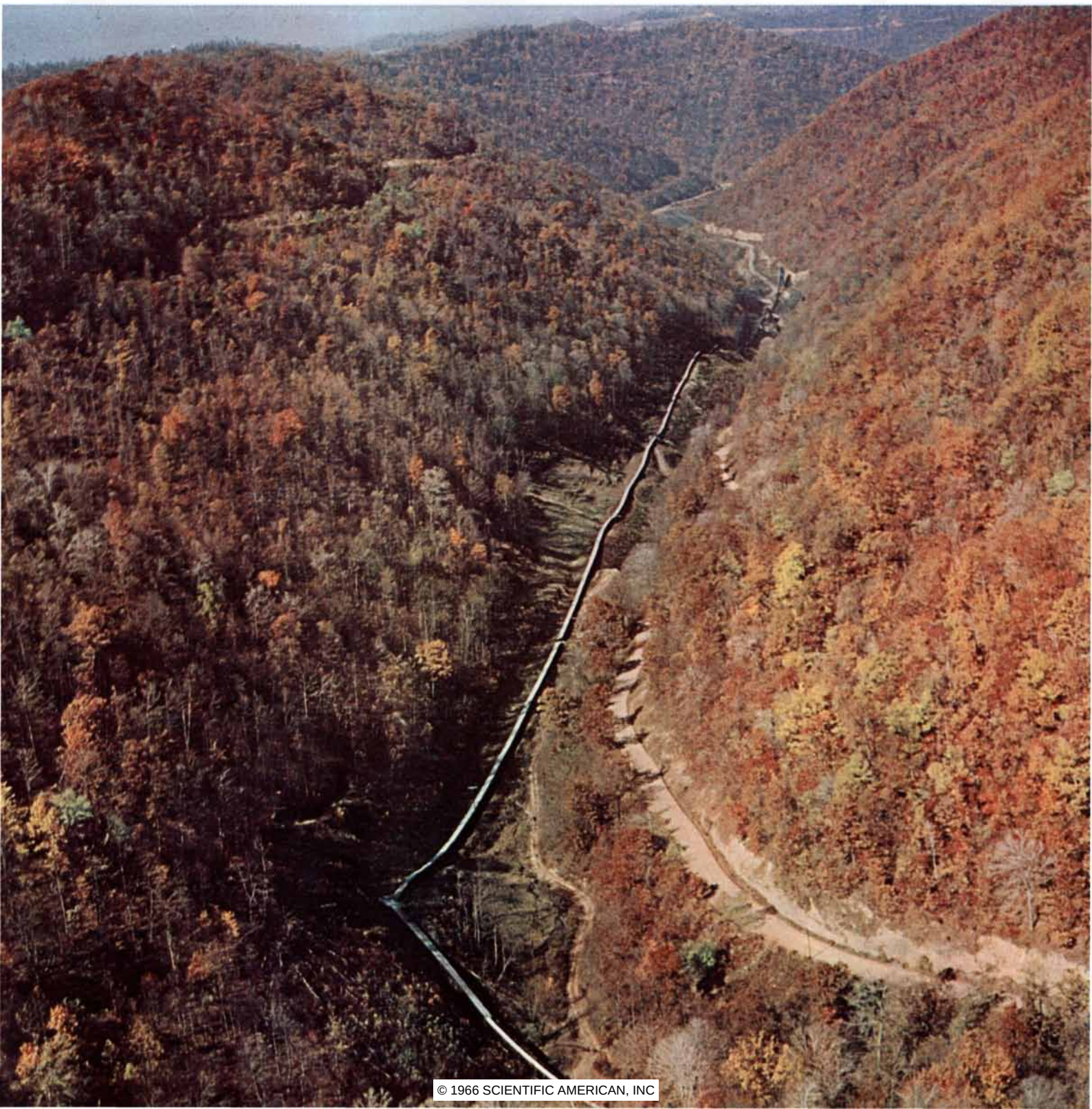
Single-ply belting virtually eliminates problems of separation and delamination.

Single-ply belting is considerably more flexible. A 20-inch pulley may do the job of a 30-inch pulley required by a multiple-ply belt. Capital costs may be reduced by using smaller head and tail pulleys, lighter supporting structures and smaller horsepower motors.

Continued...

Plies in rubber: newest development is a bi-constituent fiber, tougher than nylon.

Single-ply conveyor belting at Amherst Coal Company mine near Logan, West Virginia, spans a distance of more than 1½ miles.



UNIROYAL
U.S. RUBBER

Although other manufacturers have not yet developed a comparable single-ply conveyor belt, Uniroyal is not sitting around waiting for the rest of the industry to catch up.

A new "bi-constituent" fiber developed by Allied Chemical will make Uniroyal conveyor belts more resistant to heat, moisture and chemicals.

Tougher than nylon, this new bi-constituent fiber is actually an intimate mixture of nylon and polyester. (About 70 percent nylon and 30 percent polyester.)

The mixture combines the best properties of both fibers. It combines the strength of nylon with the moisture resistance, heat resistance, and chemical stability of polyester. (Nylon alone loses some of its strength when it's wet.)

Conveyor belting made with the new fiber stretches less than conventional nylon-reinforced belting. This can mean big savings to an operator who counts on running 24-hours-a-day. When a belt stretches beyond the ability of the take-up rollers to compensate, the conveyor line has to be shut down up to eight hours for "resplicing." This can cost thousands of dollars in lost production.

The advantages of this new ply material have been thoroughly proven in the laboratory. And the dynamic belting tester in the Uniroyal laboratory is almost as big as many field installations. Sixty-five feet long, it weighs more than a hundred tons and is capable of testing belts at speeds up to 2,000 feet per minute.

After we were satisfied with our tests, we tried the belting in actual service conditions. After more than a year of duty in a number of trial installations, there hasn't been a single failure. In every way it has outperformed the best belting previously available.

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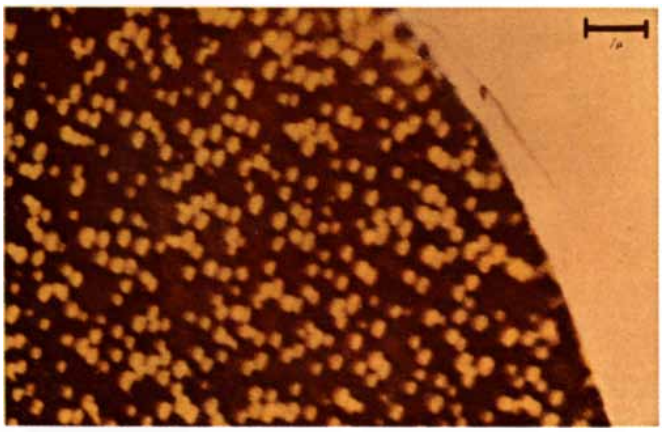


Dyed photomicrograph shows cross section of a single filament of the new bi-constituent fiber. "Fibrils" of polyester (yellow) are embedded in nylon matrix (brown).

Uniroyal holds more patents than any other rubber company.

PELLA: CAPITAL OF ANCIENT MACEDONIA

The city where Euripides died and Alexander the Great was born is gradually being uncovered by Greek archaeologists. Among their most striking finds are mosaics made of pebbles

by Ch. J. Makaronas

For the past 10 years Greek archaeologists have been excavating a city that was once the center of Hellenism but then suffered such a complete eclipse that today its very name is unfamiliar. The city is Pella in Macedonia, where the playwright Euripides died and Alexander the Great was born. Pella was the capital of Macedonia from the time of Archelaos, who ruled from 413 to 399 B.C., until the Roman conquest in 168 B.C. Under a succession of Macedonian rulers, from Archelaos to Alexander, Pella became rich and powerful. Yet when large-scale archaeological work began there in 1957, little remained to mark the city's location. Even after a decade of work only the outline of imperial Pella has begun to emerge. In one of the city's residential districts, however, a series of superb mosaics has been uncovered. Some of these Hellenic works of art may well have originated with one of the master painters of Athens.

Ancient accounts provide some details of Pella's former splendor. When Archelaos succeeded to the throne, the capital of Macedonia was Aegae (today called Edessa), a city that had strong natural defenses but also had the disadvantage of being far inland. Pella, situated near a bay of the Aegean Sea, was much more accessible. To Archelaos, who wanted his growing kingdom to have a centralized administration, this was a consideration that outweighed the site's vulnerability to attack and its proximity to malarial swamps. To compensate for the lack of natural defenses, fortifications were built that gave Pella the reputation of being the strongest city in Macedonia. According to the historian Xenophon, Archelaos sought to make it also the greatest city, and provided it with numerous and varied public buildings. The almost level plain lent itself to city planning and future expansion. Archelaos had his capital laid out on a square-block plan, probably under the influence of the advanced theories of the architect-philosopher Hippodamos of Miletos.

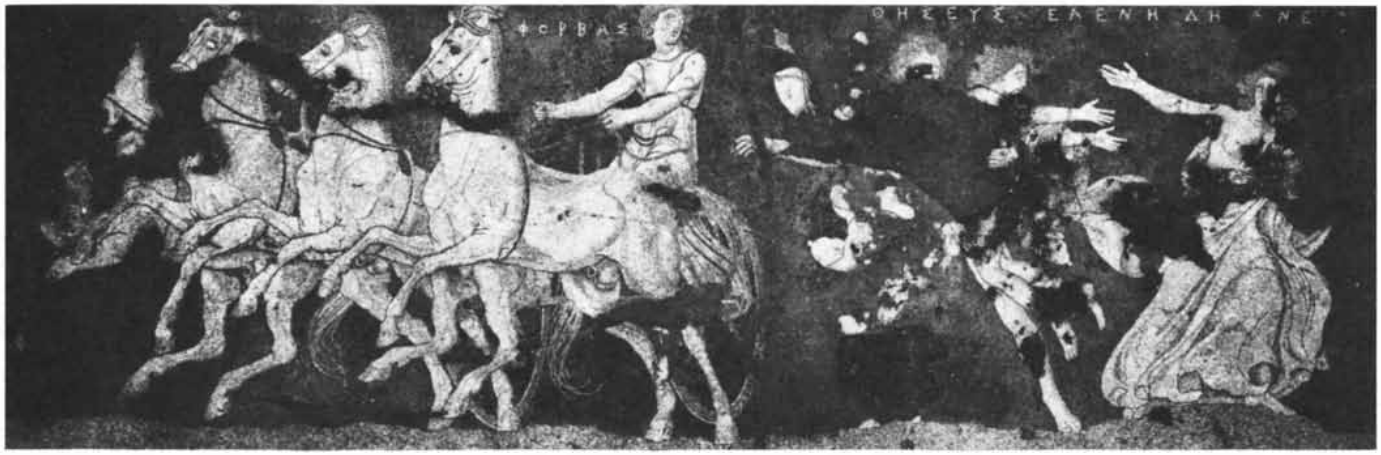
Although the Greeks of the city-states to the south regarded the Macedonians as being rude and uncouth, Archelaos was an active patron of the arts. The royal palace was famous for the paintings done by the Athenian artist Zeuxis, who is said to have been the first to use light and shade to achieve a three-dimensional effect in the painting of figures. Zeuxis' reputation among contemporary painters was such that a charming fable survives: In a contest to see who could paint the most realistically Zeuxis won the prize when his painting of a bunch of grapes attracted passing birds.

Pella had a well-known theater. It is almost certain that the dramas of Euripides were performed there—particularly *Archelaos,* which was of course named for the playwright's royal patron. So presumably were the plays of another of Archelaos' protégés, the tragic poet Agathon. At the height of Pella's career the theater was remodeled so that it could seat 10,000 spectators.

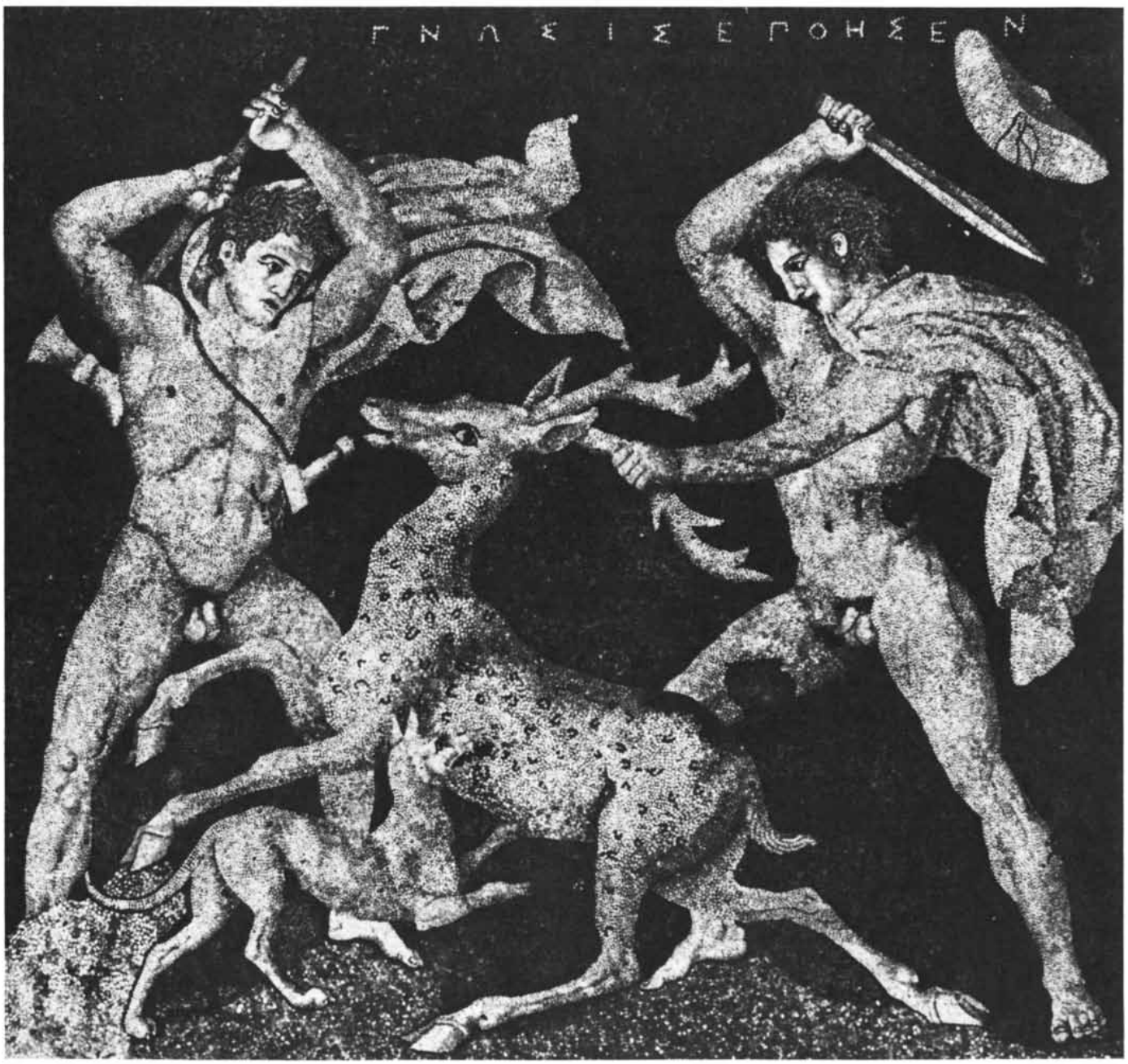
Under the rule of Archelaos the Macedonian kingdom prospered. Commerce thrived, the merchant fleet grew larger and close economic ties were established with nearby colonies of the southern Greek city-states. As Macedonia grew in wealth and power, so did its capital; in the reign of Philip II, Alexander's father, it was the most important city in the Greek world. Even after Alexander's empire broke up, Macedonia and Pella continued to flourish. When Macedonia's Roman conquerors divided it into four districts, however, the decline of Pella began. The city was reduced to the status of a district capital and the most important city in Macedonia became Thessalonike. By the beginning of the Christian era Pella's population was much smaller. Quite apart from its diminished political importance, the city apparently had suffered an encroachment of its surrounding marshes and an increase in malaria. Toward the end of the first century A.D. the historian Dion Chrysostomos wrote that Pella had virtually disappeared; its sole remaining inhabitants were a few impoverished families living amid heaps of broken tiles.

The recent excavations at the site have uncovered significant traces of Pella's ancient glory. First it is necessary to say what we have *not* found; so far nothing has been uncovered of Archelaos' great fortifications, of his palace, of the theater, of any other big public building or, with one exception, of Pella's temples. This is largely an economic problem rather than an archaeological one. There are two major acropolises, or areas of high ground, at the site. The one to the east is covered by the modern town of Palaia Pella, and so it is impractical to dig there. The acropolis to the west is mostly held by private owners and excavation is prohibited. In the parts of the western acropolis where it has been

GOD AND KING are the subjects of pebble mosaics unearthed at Pella, a city that was once the center of the Hellenic world. The top illustration on the opposite page shows the deity of wine, Dionysos, and may be a copy of a painting by the fifth-century-B.C. Athenian artist Zeuxis. The bottom illustration depicts an event in the life of Alexander the Great. Both mosaics, which are composed of water-smoothed pebbles, were made before 300 B.C.



SEIZURE OF HELEN by the Athenian hero Theseus is depicted in another mosaic at Pella, discovered in 1961 and less perfectly preserved than the rest. This event preceded Helen's marriage to Menelaos and her more famous abduction by Paris, prince of Troy.



KILLING OF A STAG is the subject of a second mosaic found at Pella in 1961, which bears the name of its creator, Gnosis. The use of light and shadow and the general three-dimensional quality of the figures suggest that Gnosis was influenced by mural painters.

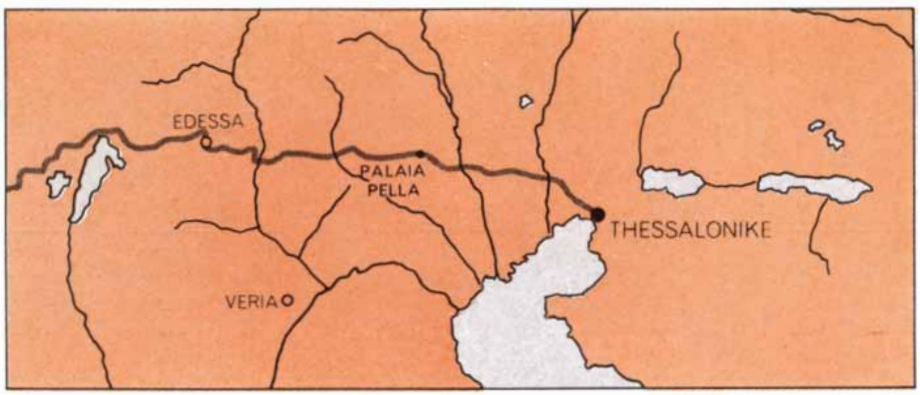
possible to work, wall foundations and other intricate structures have been uncovered. They are evidently the remains of substantial buildings dating from the period after Alexander. In all probability one of these structures was a temple; numerous stone pedestals of the kind used to support devotional monuments and tripods have been found nearby. Before more can be learned about this section of Pella, government action to acquire some of the privately owned land will be necessary.

One feature of Pella that is mentioned by ancient writers has been identified on a rise of ground about a kilometer from the main excavations. This is the Phakos, a small fortress that stood on a knoll completely surrounded by marsh and was connected to the city by a bridge. Archelaos and his successors used the Phakos both as a treasury and as a place of detention for distinguished prisoners and hostages. Trial excavations of this high ground have revealed traces of a fortified enclosure and other structures. They also indicate that the knoll was inhabited by men long before the time of Archelaos; in the lower strata were found potsherds typical of the late Bronze Age (roughly the second half of the second millennium B.C.).

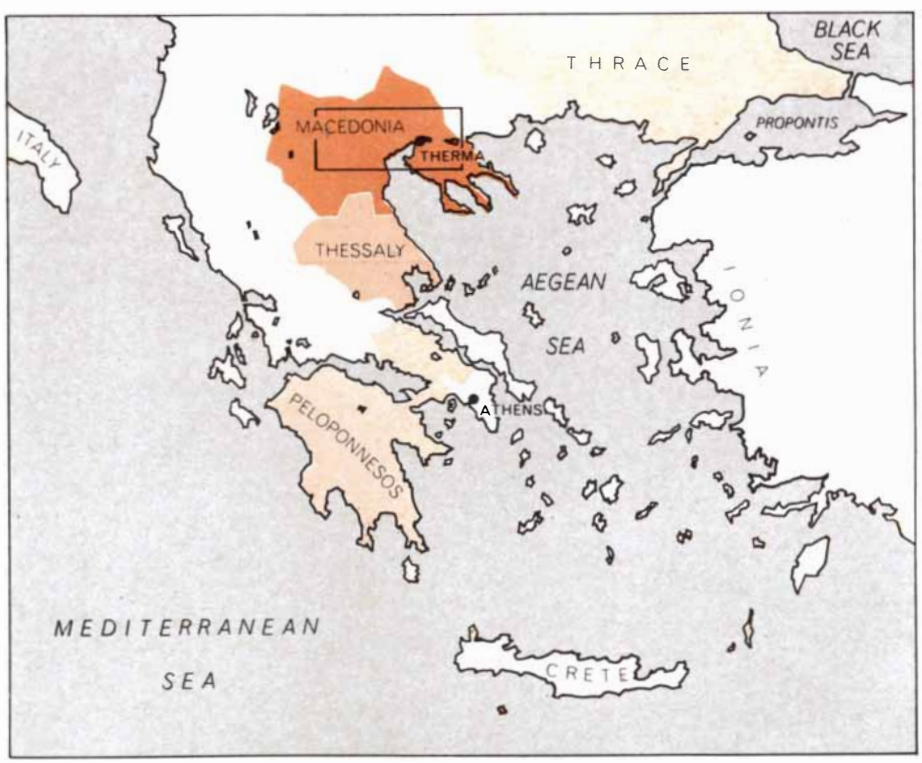
The tract of land lying between the Phakos and the main excavations is currently the focus of much interest. When this was first examined four years ago, a circular edifice 30 meters in diameter was uncovered. Although the building apparently had been roofless, there is evidence that inside it there had been a covered walk, or portico. Along the periphery of the larger structure are the remains of three smaller circular rooms, less than six meters in diameter. These rooms evidently had had roofs. Each has a doorway connecting it to the main structure, and on the floor of one room is a mosaic. The artifacts associated with this strange and as yet unexplained cluster of buildings indicate that it belongs to the period of Pella's ascendancy during the fourth century B.C. Further work at the site may reveal what purpose the structures served.

The main excavation at Pella is 800 meters or so to the south of the modern town, astride the highway that runs from Thessalonike, 40 kilometers to the east, to Edessa [*see bottom illustration on page 104*]. The first few weeks' work here in 1957 clearly showed that this part of the city followed Hippodamos' rectangular plan. The excavation revealed straight streets that intersected at right angles to form oblong blocks. A main street running from east to west was nine meters wide; several north-south streets were six meters wide. Below the surface of the narrower streets were pottery pipelines, equipped at intervals with large clay pots. These were evidently conduits supplying fresh water to the neighborhood; the pots served as settling tanks so that cleaner water would be delivered. Just at the surface of the main street [*street No. 3 in bottom illustration on page 104*] and running down its middle was a stone-lined trench that presumably acted as a sewer.

It was soon clear that each of the oblong blocks was occupied by a house or houses, and that each house was built on a classical plan. An enclosed courtyard formed a central rectangle; surrounding it were stone columns forming a peristyle [*see illustration on next two pages*]. Surrounding the peristyle, in turn, were the house's reception rooms, living quarters, storerooms and the like, their doors opening inward and their blank outer walls facing the street. In some of the houses the peristyle had cylindrical stone columns, Doric or Ionic in manner. In others it had square corner posts, usually made of stone but sometimes of wood. Up to a height of half a meter the walls of the houses were built with stone and above that with sun-dried



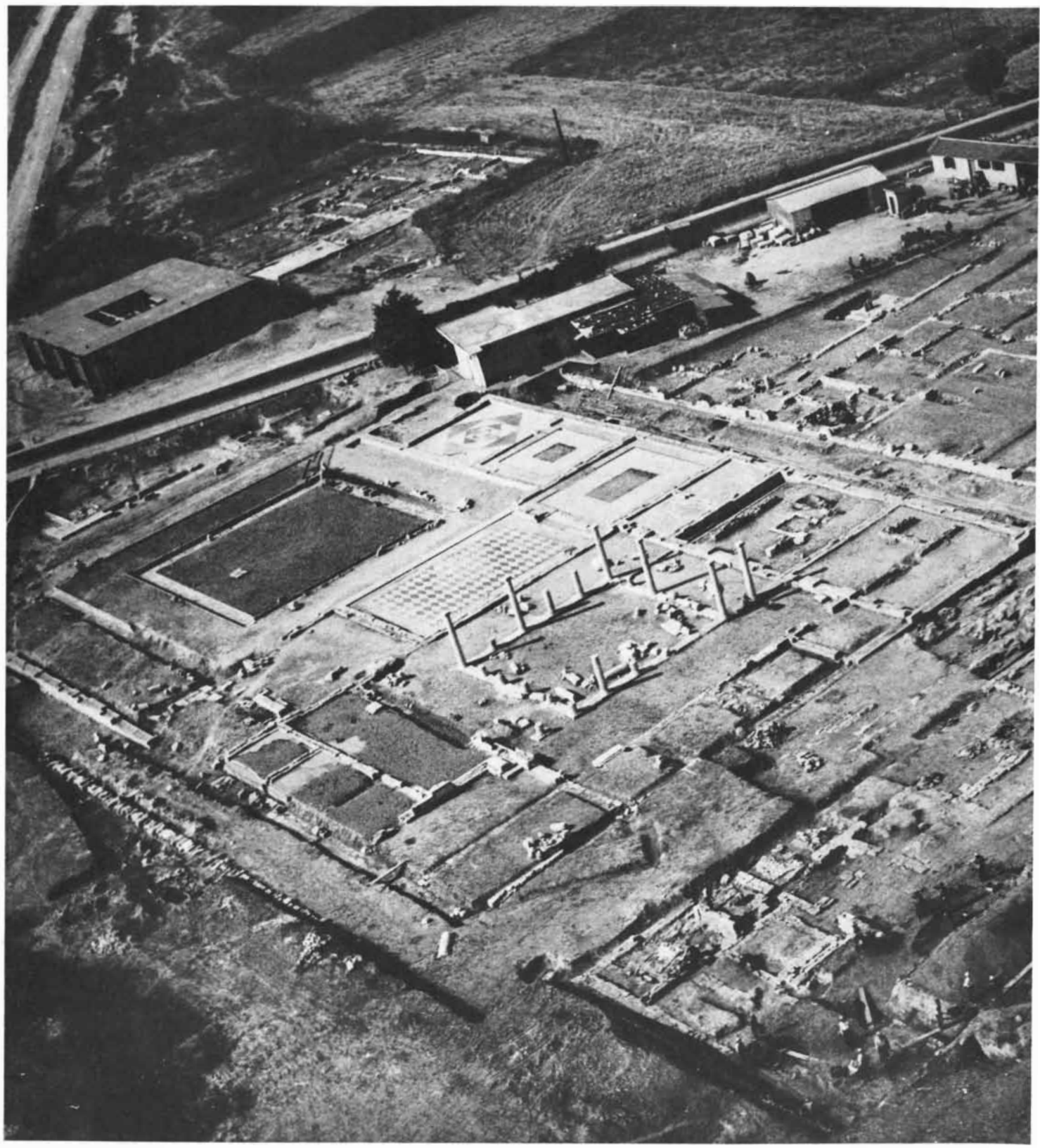
MODERN TOWN of Palaia Pella, 40 kilometers west of Thessalonike on the road to Edessa, covers part of the ancient city of Pella, which King Archelaos made Macedonia's capital.



HELLENIC SPHERE during the rise of Macedonia extended from Crete in the south to the Thracian coast in the north and from the Greek colonies in Italy and Sicily in the west to Ionia, the Propontis and the Black Sea in the east. During the rule of Philip II the Hellenic power center shifted from rival Athens and Sparta northward to the capital of Macedonia.

mud brick. Although mud brick scarcely seems an aristocratic building material, the houses were of good workmanship and were elaborately decorated. The walls were faced with plaster in a variety of vivid colors, the wooden doors bore handsome bronze bosses and the roofs were tiled with slabs of fired clay, some of which had been stamped with the city's name.

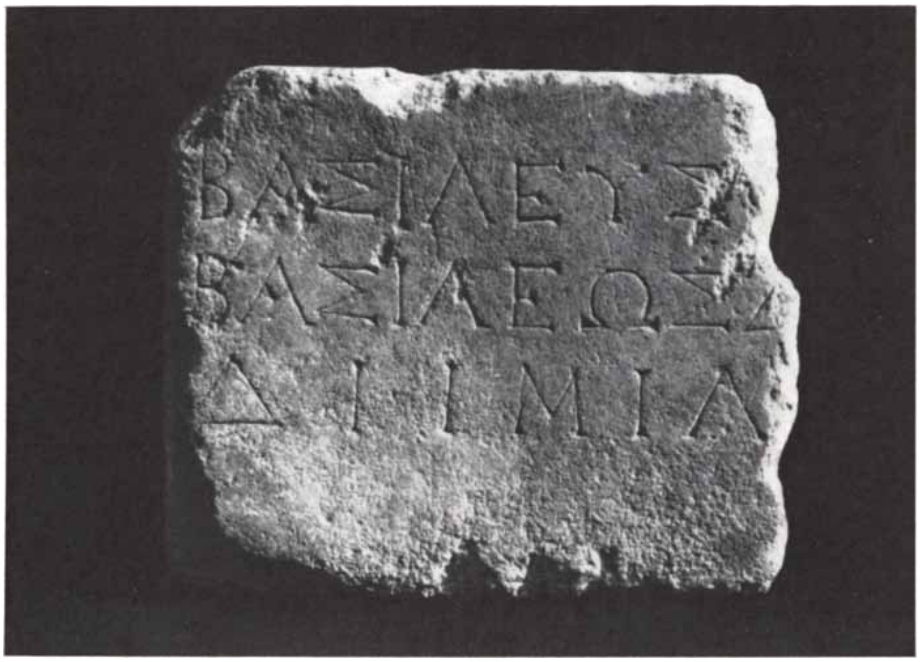
The first buildings to be excavated lay in the block bounded on the east and west by the streets marked No. 1 and No. 2 in the bottom illustration on page 104. In two of the large rooms along the west side of the middle house [*C and D in the illustration*], at an average depth of one meter below the surface of the ground, were floors made of water-worn pebbles of contrasting colors. These pebbles formed elaborate mosaics in which



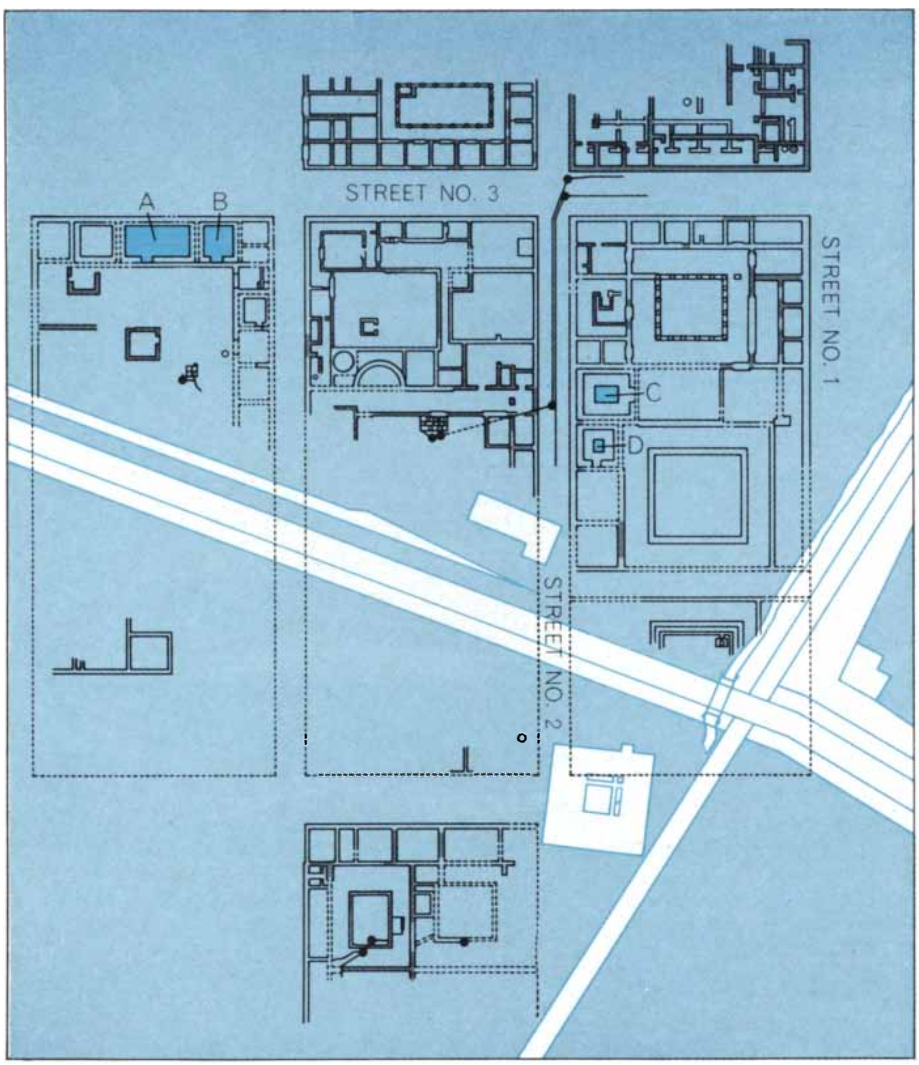
RECTANGULAR LAYOUT of ancient Pella is evident in this aerial photograph (*see plan on page 104*). The house that yielded the mosaics of Dionysos and Alexander is in the foreground. The rooms that held the mosaics are just above the partially restored peristyle;

an ornamental border surrounded a lively scene in the center. Both mosaics are shown in color on page 98; the illustration on the cover of this issue is a detail from one of them. It is apparent in these illustrations that the figures of men and animals are rendered in vari-

the dark rectangle in each room shows the area originally occupied by the mosaic.



ROYAL OFFERING, unearthed at Pella, dates from the years just before the Roman conquest of Macedonia. Philip V (221–179 B.C.) ordered the dedicatory inscription to Zeus.



MAJOR EXCAVATION at Pella has exposed parts of six city blocks, separated by wide east-west streets and narrower north-south streets. Modern roads and buildings are indicated in white. The mosaics discussed by the author were located in the rooms marked by letters: (*A*) Helen's abduction, (*B*) the stag hunt, (*C*) Alexander's hunt and (*D*) Dionysos' portrait.

ous shades of gray against a dark background, and that pebbles of pink or yellow stone are used for color accents. These two mosaics, together with two lesser ones that decorated the thresholds of the rooms, are the oldest that have yet been unearthed at Pella; they were probably executed somewhat before 300 B.C., or soon after the reign of Alexander.

The mosaic that decorates the center of the smaller room represents Dionysos, the god of wine and fecundity, riding on the back of his favorite animal, the panther. His right arm encircles the neck of his mount; in his left hand is the thyrsus, the beribboned ceremonial staff traditionally associated with the deity. Fine details of the mosaic, such as Dionysos' profile, eye, hands and feet, were emphasized by the insertion of strips of lead among the pebbles.

The mosaic in the center of the larger room is not devoted to mythic figures, although the incident it depicts may well be fictional. Two youths are holding a lion at bay; the animal appears to have been on the point of attacking the hunter at the left when his attention was diverted by the hunter at the right, whose sword is raised. Meanwhile the hunter at the left prepares to thrust his spear home. This is no ordinary lion hunt; the mosaic illustrates a tale about Alexander the Great during his years of conquest in Asia. There, as it was related by contemporary writers, Alexander was attacked by a lion and was saved by his friend, the general Krateros. The clue to Alexander's identity is the helmet-like headdress worn by the figure at the left. This headdress, the *kausia,* was worn exclusively by Macedonian kings and princes; here the wearer must be Alexander himself. If the youthfulness of the two figures seems surprising, one needs only to recall that Alexander succeeded his father at the age of 20 and was no more than 22 when he began his Asian campaigns.

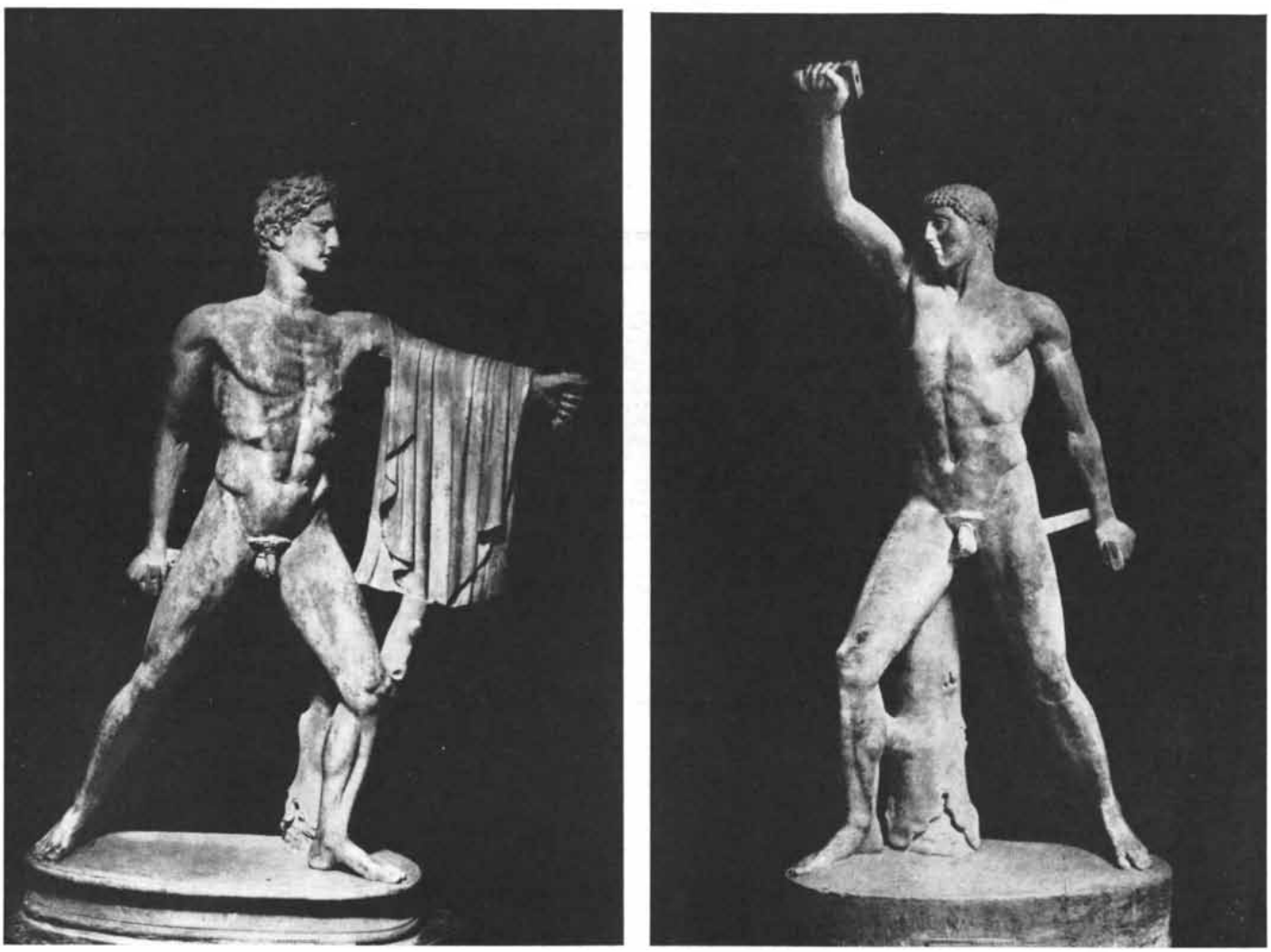
During the 1961 excavating season at Pella other pebble mosaics were discovered on the floor of a house two blocks to the west of the first house. One of these depicts a deer hunt; in composition it is not unlike the lion hunt, even to the point of including another headdress. In this mosaic, however, the headdress is in midair, doubtless dislodged in the excitement of the chase [*see bottom illustration on page 100*]. A hound has buried its teeth in the deer's side and the two hunters are about to dispatch their quarry. Along the upper margin, near the headdress, the artist has written

with understandable pride: "Gnosis created this work." It is intriguing that the hunter to the left wears a sword but is about to strike the deer with a double-bladed axe, a rather unusual weapon for the chase. Perhaps this mosaic, like the one of the lion hunt, portrays a celebrated event of the time. If so, we have no clue to the event or its participants.

The fourth and last of the mosaics from Pella that I shall describe presents no such problem, even though it is somewhat damaged. Twenty-four feet long and nearly nine feet high, it decorates the floor of an adjacent room in the same house. The incident it portrays is the forcible seizure of Helen by Theseus, the legendary hero-king of Athens whose adventures in Crete are among the best-known of the Greek myths. The episode occurred early in Helen's life, before her marriage to Menelaos of Sparta and her abduction by Paris. Each actor in the scene is identified by a name written nearby: from left to right these are the charioteer Phorbas, Theseus, Helen and a friend or relative of Helen's named De[i]ane[ira] (the letters in brackets are missing).

The two mosaics discovered in 1961 are sufficiently different in technique to indicate that they are not both the work of Gnosis. In the deer hunt the landscape is realistic and the ground under the hunters' feet is irregular. The figures are richer in color than those in the mosaic showing the seizure of Helen; they are rendered more in light and shadow and have more three-dimensionality. One has the impression that the mosaic was copied from a painting. In the seizure-of-Helen mosaic the strong outlining and the cautious use of light and shadow suggest that the artist was under the influence of those painters who decorated pottery, using a bold but essentially flat style. In any case, the mosaics discovered in 1961 are more advanced in style and certainly later in date than the ones found in 1957.

Both the question of artistic influences and the possibility that one of the later mosaics was a copy of a painting have added significance when one speculates on the inspirations that gave rise to the mosaics of Dionysos and Alexander's lion hunt. Observing the composition of the lion hunt, for example, one cannot help but be reminded of the famous sculptures called "The Tyrannicides," which were executed in the fifth century B.C. [*see illustration below*]. The Dionysos mosaic too could have been modeled after an earlier work of art. Is it possible that the artist of the mosaic was working from one of the wall paintings with which Zeuxis embellished the royal palace of Archelaos? If so, the mosaics of Pella have done a double service. Not only do they hint at the luxurious life of Macedonia's capital city in post-Alexandrian times but also they have preserved an early work of art that would otherwise have been lost altogether.



TWO TYRANNICIDES, Aristogeiton (*left*) and Harmodios (*right*), were young Athenians who killed the brother of the tyrant Hippias in 514 B.C. Statues were later made in their honor; these, now in the Naples Museum, may be the originals. The author suggests that the postures of Alexander the Great and Krateros in the lion-hunt mosaic may have derived from the tyrannicides' postures.

Numerical Taxonomy

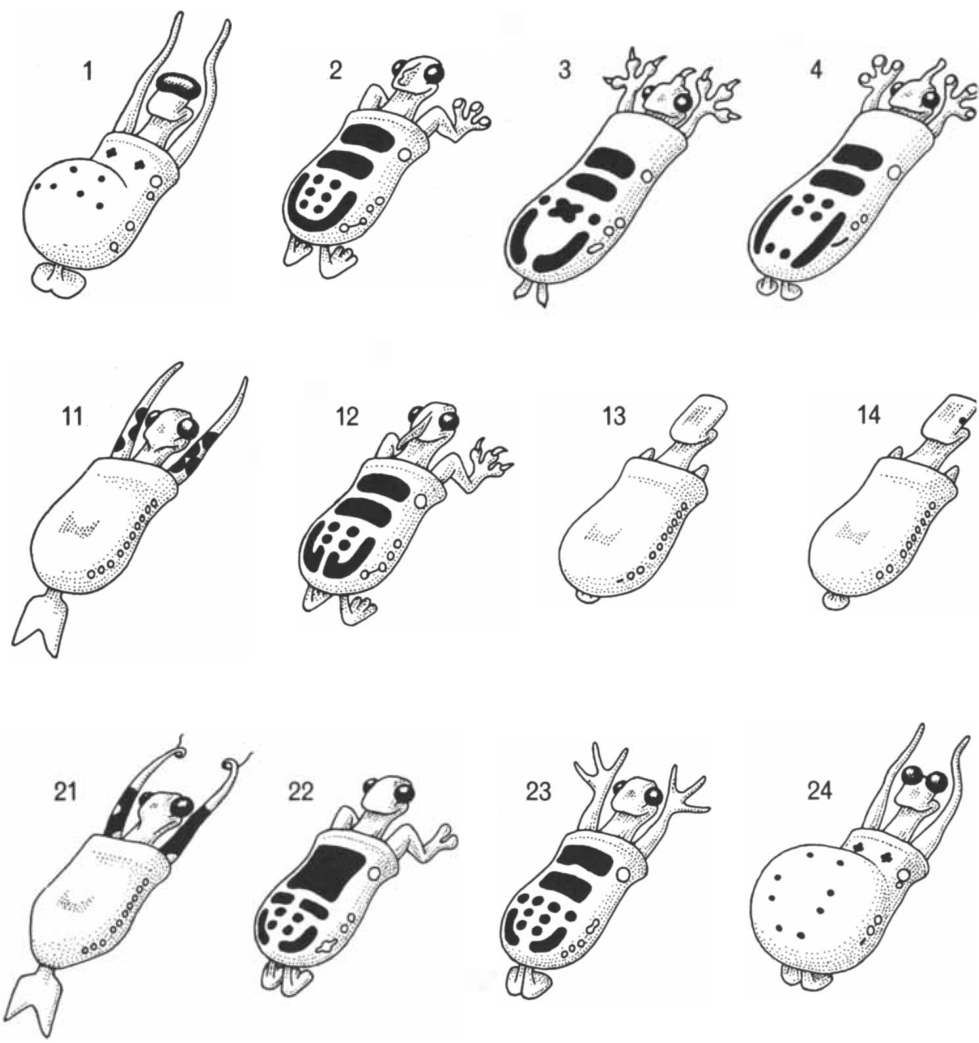
The computer has made it possible to consider large numbers of characteristics in classifying many phenomena, notably living organisms, fossil organisms and even imaginary organisms

by Robert R. Sokal

Classification is one of the fundamental concerns of science. Facts and objects must be arranged in an orderly fashion before their unifying principles can be discovered and used as the basis for prediction. Many phenomena occur in such variety and profusion that unless some system is created among them they would be unlikely to provide any useful information. Chemical compounds (particularly organic ones), groups of stars and the two million or so species of living organisms that inhabit the earth are examples of such phenomena.

The development of high-speed electronic computers has had a profound impact on the methods of classification in many scientific fields. The rapidity of the computer's operation has made it possible for the first time to consider large numbers of characteristics in classifying many phenomena. The writing of computer programs for such work has led to a renewed interest in the principles of classification, reviving such old questions as: What makes one classification better than another? What is a "natural" classification? What is similarity, and can it be quantified? The inquiry has progressed furthest in the field of taxonomy, or biological classification. The methods of numerical taxonomy (as this new field has come to be called), the conceptual revolution it has wrought, the nature of the controversy surrounding it, some future prospects for the field and its relevance to problems of classification in other sciences will be discussed in this article.

Many of the new procedures of numerical taxonomy and their theoretical justification have been the subject of intense disagreement between numerical taxonomists and supporters of traditional taxonomic practices and principles. Controversy, of course, is nothing new in science. Time and again the introduction of a new concept or the development of a new technique has aroused the passions of scientists representing conflicting points of view. Although debate about numerical taxonomy has not been as acrimonious as some debates in the history of science, it has certainly been spirited and continues undiminished. At recent biological conferences the symposiums on numerical taxonomy have been unusually well attended, often by people only remotely interested in the field who have heard that "a



IMAGINARY ANIMALS, called Caminalcules after their creator, Joseph H. Camin of the University of Kansas, are used in experiments on the principles and practices of tax-

good fight" was about to take place in that session. What is all the shooting about?

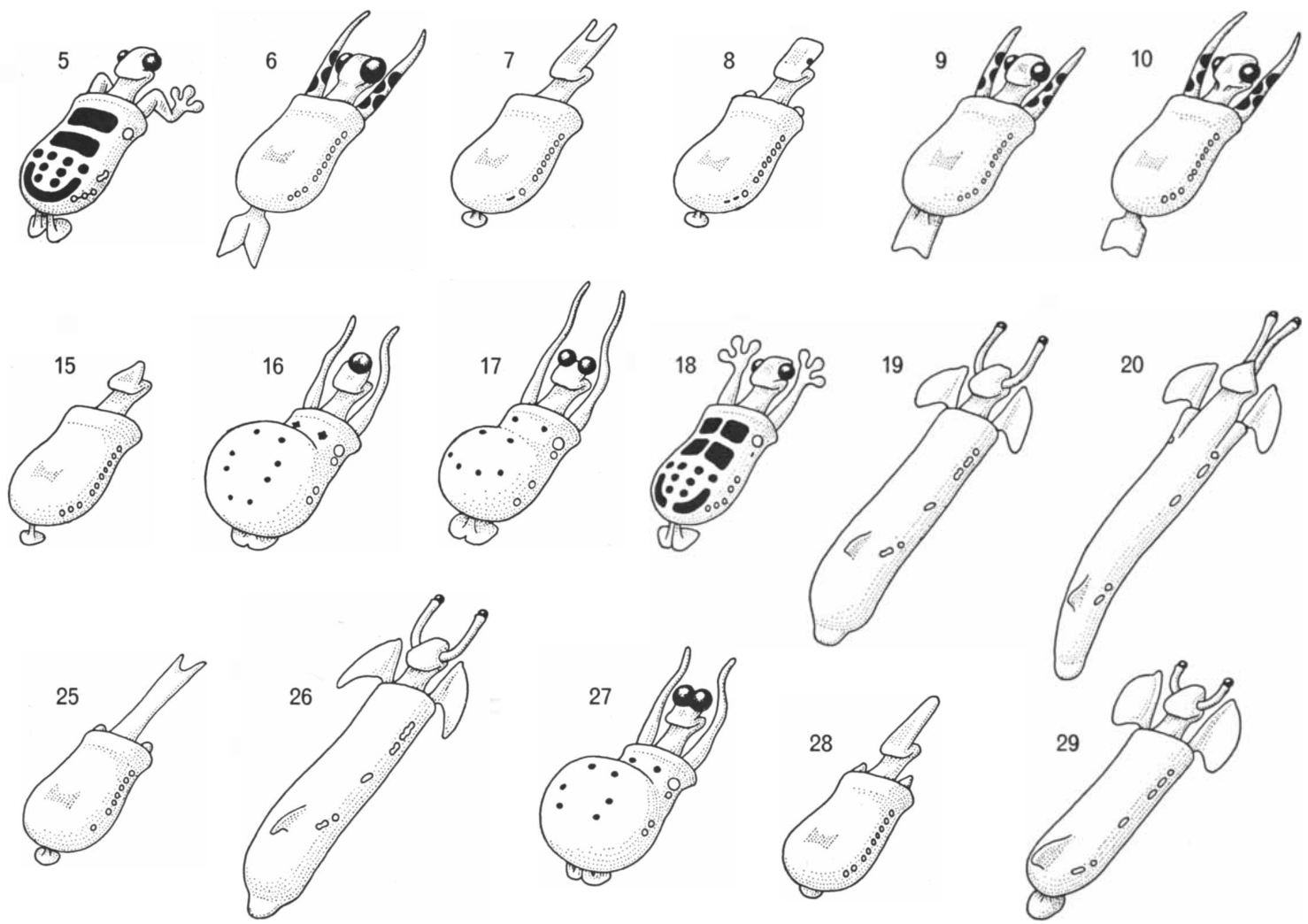
In the early days of modern science, and for special purposes even today, classifications were based on a single property or characteristic, the choice of which might be quite arbitrary. Metals are divided into conductors and nonconductors, other substances into those that are soluble in water and those that are not; organisms are divided into unicellular ones and multicellular ones. Some of these classifications are arbitrary in the sense that there is a continuum of properties—as in the case of solubility, for which the line between soluble substances and insoluble ones is not distinct. In contrast one can almost always say whether an organism is unicellular or multicellular, so that with properties such as these the decisions can be quite clear-cut. Classifications based on one or only a few characters are generally called "monothetic," which means that all the objects allocated to one class must share the character or characters under consideration. Thus the members of the class of "soluble substances" must in fact be soluble.

Classifications based on many characters, on the other hand, are called "polythetic." They do not require any one character or property to be universal for a class. Thus there are birds that lack wings, vertebrates that lack red blood and mammals that do not bear their young. In such cases a given "taxon," or class, is established because it contains a substantial portion of the characters employed in the classification. Assignment to the taxon is not on the basis of a single property but on the aggregate of properties, and any pair of members of the class will not necessarily share every character.

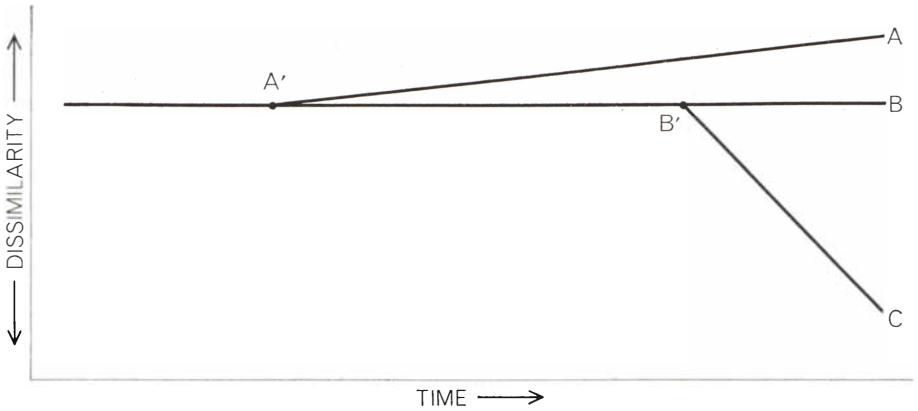
It is obviously much more complicated to establish classifications based on many characters than it is to establish classifications based on only one character. The human mind finds it difficult to tabulate and process large numbers of characters without favoring one aspect or another. The comparative subjectivity of traditional approaches and the inability of taxonomists to communicate to one another the nature of their procedures have contributed to making taxonomy more of an art than a science.

The arrival of the computer has reversed this trend, and a new field with many possibilities for objective and explicit classification has opened up. Computer techniques have indeed been a principal force behind the gradual adoption of an operational approach in taxonomy; in order to use such techniques, classificatory procedures must be outlined in such a form that any scientist or a properly programmed computer can carry out the indicated operations and, given the same input data, arrive at the same results. This would preclude the often arbitrary decisions of conventional taxonomists, epitomized by the statement that "a species is whatever a competent taxonomist decides to call a species."

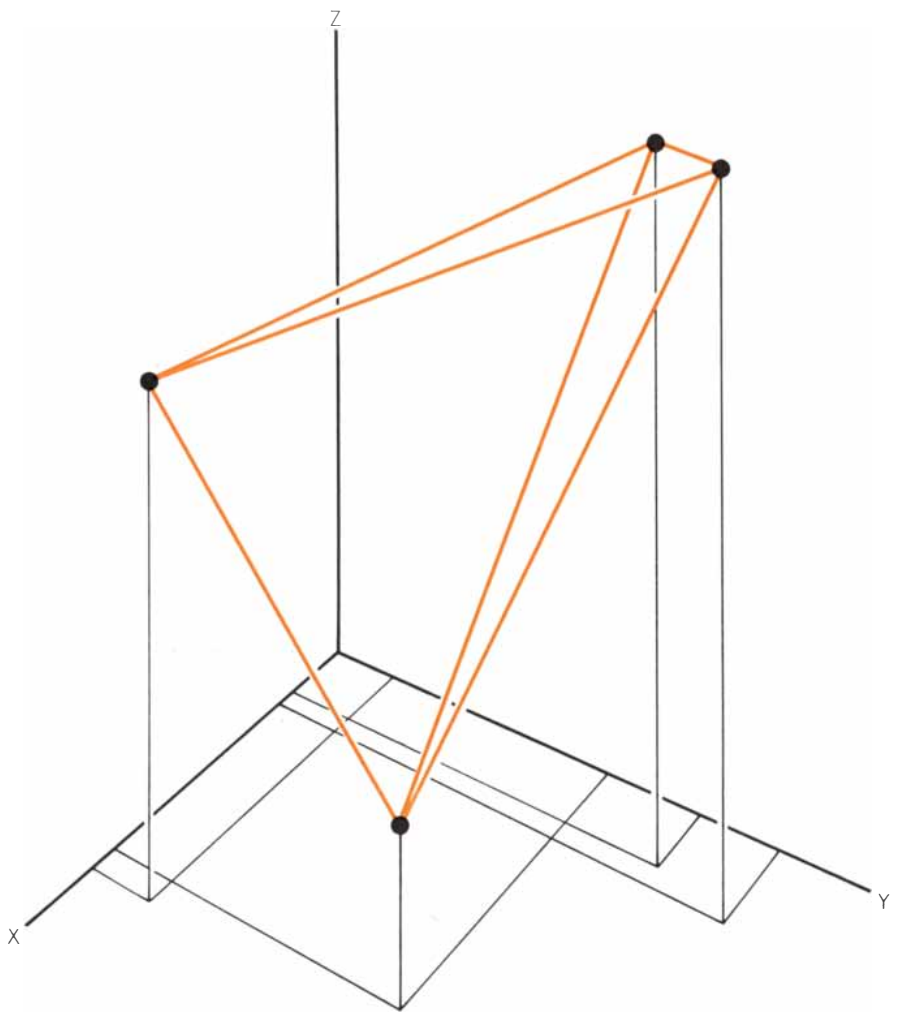
Before proceeding further I should remove a possible source of confusion.



onomy, or biological classification. The 29 "recent" species of the organisms, depicted on these two pages, were generated by Camin according to rules known so far only to him. The drawings are based on Camin's originals, with slight modifications in perspective.



TAXONOMIC RELATIONSHIPS can be viewed from three distinct aspects. "Phenetically" (based on overall similarity among the objects to be classified) organism *B* is more closely related to organism *A* than it is to organism *C*, even though *C* evolved much later than *A* as a branch of stem *B*. "Cladistically" (based on common lines of descent) organisms *B* and *C* are closer to each other than either is to *A*, since they have an ancestor (*B′*) in common before either has a common ancestor (*A′*) with *A*. "Chronistically" (based on time) *A*, *B* and *C* are closer to one another than any of them is to *B′*, since they occupy same time horizon.



SIMILARITY CAN BE REPRESENTED as the distance between the objects to be classified (called operational taxonomic units, or OTU's for short) in a multidimensional space. In this example the similarity between all possible pairs taken from four objects is estimated on the basis of three characters, which are represented by the three coordinates axes *X*, *Y* and *Z*. The OTU's (*black balls*) are then plotted into this three-dimensional space according to their state, or value, for the three characters. Similar objects are plotted much closer to one another than dissimilar ones. In any real case there will, of course, be more than three characters and a multidimensional space—called a "hyperspace"—would be necessary.

This is the difference between the terms "classification" and "identification." When a set of unordered objects has been grouped on the basis of like properties, biologists call this "classification." Once a classification has been established the allocation of additional unidentified objects to the correct class is generally known as "identification." Thus a person using a key to the known wild flowers of Yellowstone National Park "identifies" a given specimen as a goldenrod. Some mathematicians and philosophers would also call this second process classification, but I shall strictly distinguish between the two. Here I am principally concerned with classification in the biologist's sense.

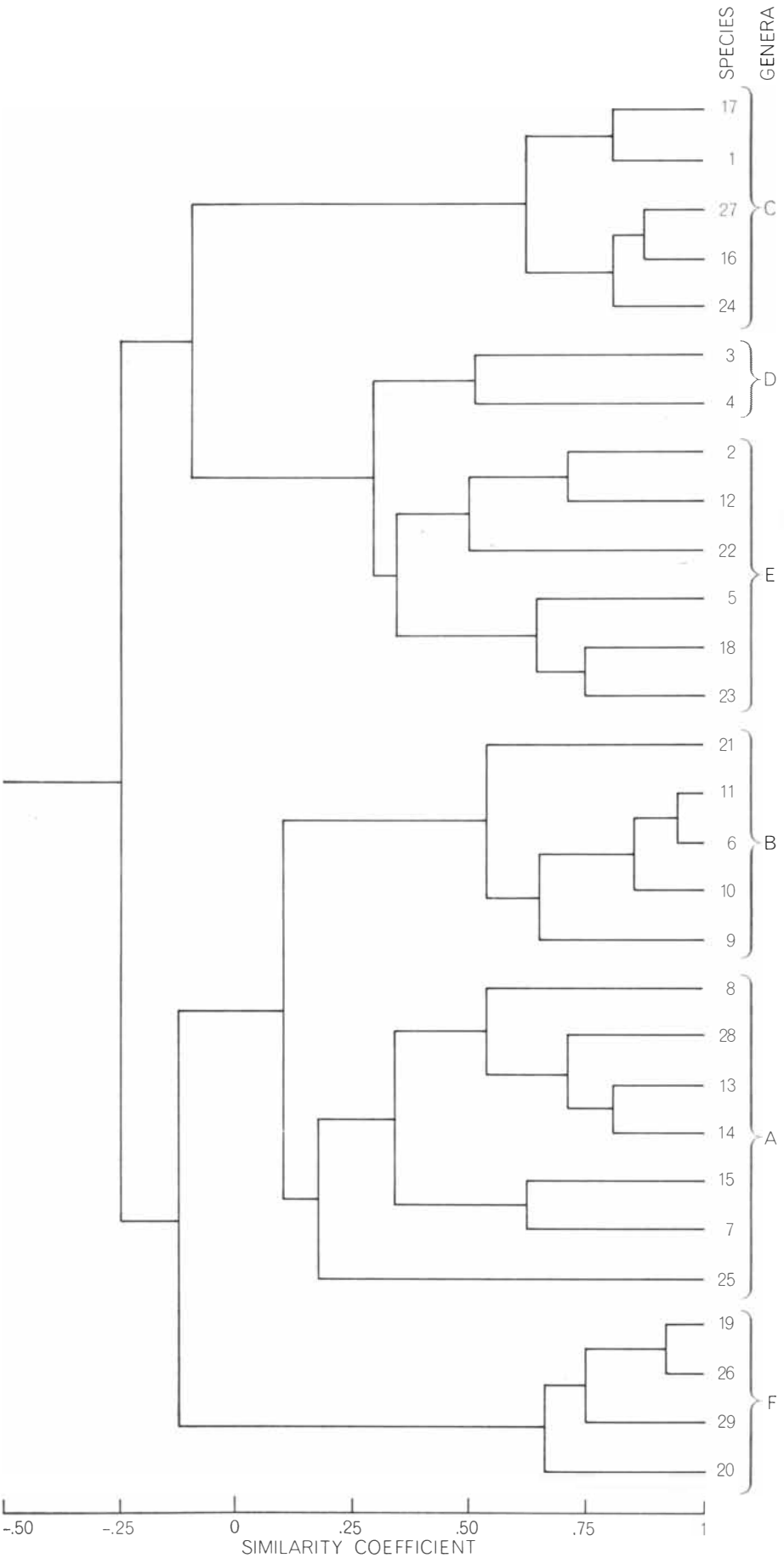
The purpose of taxonomy is to group the objects to be classified into "natural" taxa. Naturalness has been variously defined, but underlying the several definitions is the common idea that members of a natural taxon are mutually more highly related to one another than they are to nonmembers. This leads us to try to define what we mean by "taxonomic relationship." Conventional taxonomists wish to equate taxonomic relationships with evolutionary relationships, but numerical taxonomists have pointed out that taxonomic relations are actually of three kinds. "Phenetic" relationships are those based on overall similarity among the objects to be classified. "Cladistic" relationships are based on common lines of descent. Although close cladistic relationship generally implies close phenetic similarity, it is not always the case. Differences in evolutionary rates may give rise to lineages that diverged long ago but appear more similar than a subsequently diverged pair of stems, one or both of which has undergone rapid evolution [*see top illustration at left*]. The third kind of taxonomic relationship is the "chronistic," or temporal, relation among various evolutionary branches. Cladistic relationships for most organisms are known scantily, if at all, and are generally inferred from phenetic evidence. The "phylogenetic" classifications of conventional taxonomy are usually based on an undefined mixture of phenetic and cladistic relationships, and often merely represent an overall similarity among the classified organisms disguised in evolutionary terminology.

In view of these considerations numerical taxonomists propose to base classifications entirely on resemblance, defining natural classifications as those

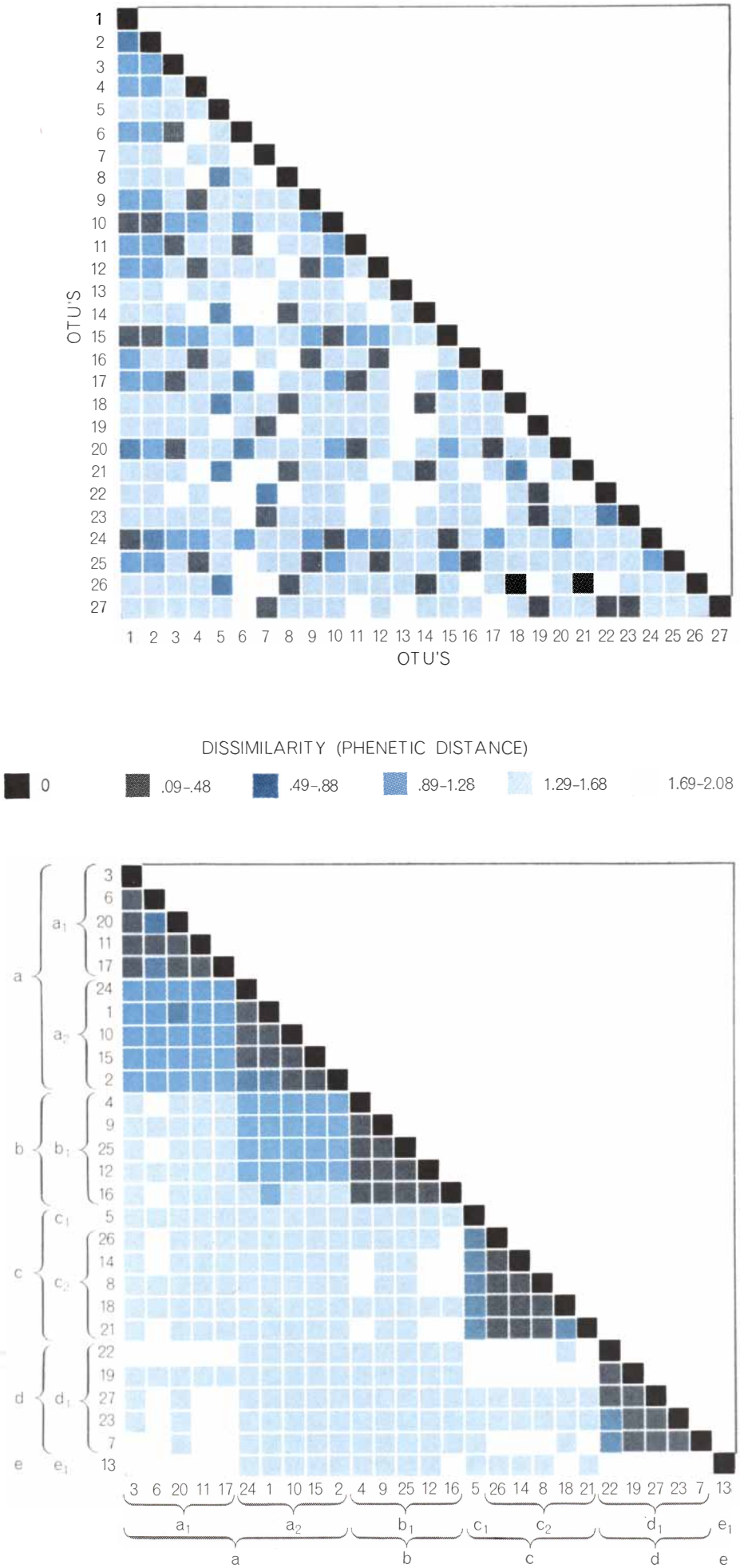
yielding taxa whose members are in some sense more similar to one another than they are to members of other taxa. It follows from this concept of naturalness, which is based on the ideas of J. S. L. Gilmour, a botanist at the University of Cambridge, that a natural taxon will be most predictive. If a classification is based on many correlated characters, predictions about the states of other characters in various groupings of the classification should be more successful than if the taxonomy were based on few characters. Furthermore, it is likely that a classification based on a great variety of characters will be of general utility to biology as a whole, whereas a classification resting on only a few characters is less likely to be generally useful, except for the special purposes relevant to the chosen characters. Thus a classification of animals into "swamp dwellers" and "animals not living in swamps" may be very useful for a study of the ecology of swamps but not for general zoology.

Overall phenetic similarity is based on all available characters without any differential weighting of some characters over others. A substantial part of the controversy about numerical taxonomy has centered on this point. Conventional taxonomists usually employ only a few characters in classification and weight these in terms of their presumed evolutionary importance. Numerical taxonomists contend that evolutionary importance is undefinable and generally unknown and that no consistent scheme for weighting characters before undertaking a classification has yet been proposed. To weight characters on the basis of their ability to distinguish groups in a classification, as is frequently advocated, is a logical fallacy. Since the purpose of employing the characters is to establish a classification, one cannot first assume what these classes are and then use them to measure the diagnostic weight of a character.

The nature of similarity is, of course, a fundamental problem of taxonomy, whatever one's theoretical approach. This ancient philosophical problem has recently become acute in a variety of fields because of the introduction of automata for classification and identification. What is the meaning of the statement "*A* is similar to *B*"? Only when qualified to the effect that "*A* is similar to *B* in such and such a respect" has this statement any meaning. It is one of the underlying assumptions



PHENOGRAM is a convenient two-dimensional representation of the results of a numerical classification, in this case the results of classifying the 29 recent species of Caminalcules depicted on pages 106 and 107. The various species are indicated by the numbers at the tips of the branches. Phenograms tend to distort the original multidimensional relationships.



of numerical taxonomy that quantification of degrees of similarity is possible. The establishment of comparative similarities—for example *"A* is more similar to *B* than it is to *C"*—is fundamental to any attempt at clustering objects into homogeneous groups.

Similarity can be established only on the basis of homologous, or corresponding, characters. Hence it is not possible to compare the forelimbs of vertebrates without prior agreement on what to call a forelimb in each of the vertebrates to be compared, and on the correspondences between constituent parts of the appendages. Homology, as interpreted by numerical taxonomists, is the existing overall similarity in structure rather than similarity due to common ancestry, although this may often be the underlying cause. To describe such essential similarity one needs to base it on numerous "unit characters" of the structures to be compared. Numerical taxonomists regard unit characters as those that cannot be subdivided into logically or empirically independent characters. This is a complex subject, however, since the same set of biological characters can be described in innumerable slightly varying ways. One would not wish to use all these descriptions, yet how can one avoid redundancy by choosing the best ones?

Another problem is how many characters to choose for describing phenetic similarities. Is there an asymptotic similarity among organisms that is approached as more and more characters are measured, or will each additional set of characters contribute a new dimension to similarity, making the taxonomic structure of a group inherently unstable? All the evidence on this complicated question is not yet in. It might be assumed that if one knew the genetic fine structure of organisms, one could then develop an overall measure of similarity among organisms based on similarity of genetic structure.

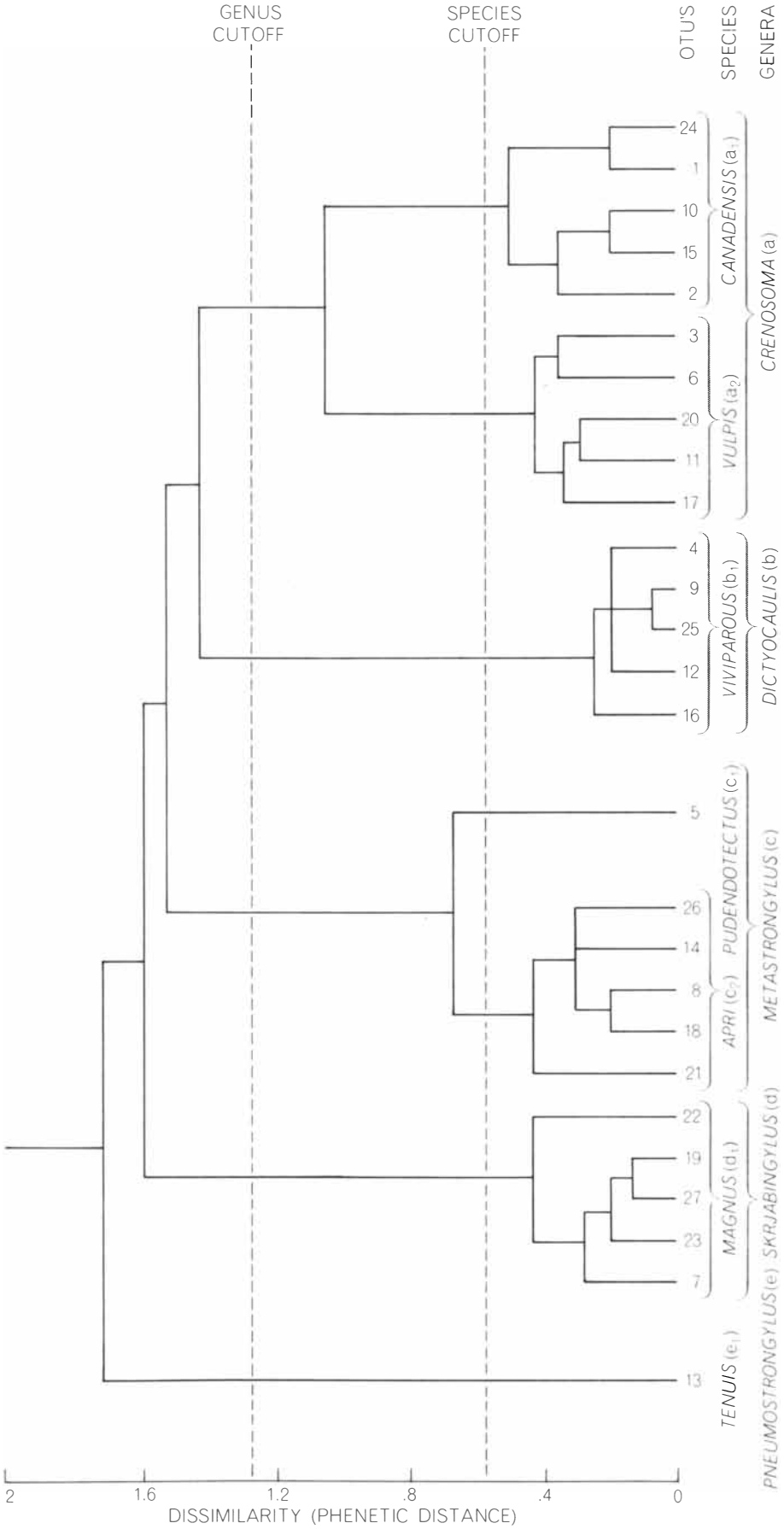
SIMILARITY MATRIXES have been shaded to show the degree of similarity between pairs of 27 OTU's (in this case individuals from seven species of nematode worms). The darker the squares, the greater the similarity. The matrix at top has the OTU's arranged according to an arbitrary sequence of code numbers. The matrix at bottom has been rearranged to yield clusters of similar OTU's. The dark triangles along the diagonal indicate species; larger, less dark triangles represent genera. OTU 13 is not closely related to any of the other OTU's **(*see illustration on opposite page*).**

Yet even this would present complications, since the genetic code as it is now understood is in the nature of a program, certain portions of which come into play at different times during the development of an organism. Similarity in the programs might not reflect similarity in the products, and it is by no means certain whether genes or their effects should form the basis of a classification.

Moreover, since we do not as yet have measures of similarity between different genetic codes (except for certain limited instances), we are forced to resort to the morphological and physiological characters employed in conventional taxonomy. Recently we have found that although different types of characters in a taxonomic study may be correlated, this correlation is not sufficiently strong for a classification based on one set of characters (for example external characters) to agree fully with a classification based on a second set (for example internal characters). Thus a taxonomy of males may differ somewhat from one of females, and a classification of skeletal parts may not agree entirely with one based on soft parts. This is a necessary consequence of phenetic classification, and in order to obtain valid measures of overall similarity one has to use as many and as varied sets of characters as possible.

If classifications are to be established on overall similarity, numerical taxonomy is required to put the procedures on an operational and quantitative basis. Some of the procedures of numerical taxonomy were developed as early as the beginning of this century, but before the introduction of digital computers they never caught on, presumably because of the insuperable computational difficulties. The philosophical origins of the present development in taxonomy derive from the work of Michel Adanson, an 18th-century French botanist, who first rejected a priori assumptions on the importance of different characters and proposed basing natural taxa on his essentially phenetic concept of "affinity."

The recent development of numerical taxonomy starts with the almost simultaneous publication in 1957 of papers advocating this method by Peter H. A. Sneath, a British microbiologist, and by Charles D. Michener and myself, both entomologists at the University of Kansas. Two further independent studies by workers at the University of Ox-

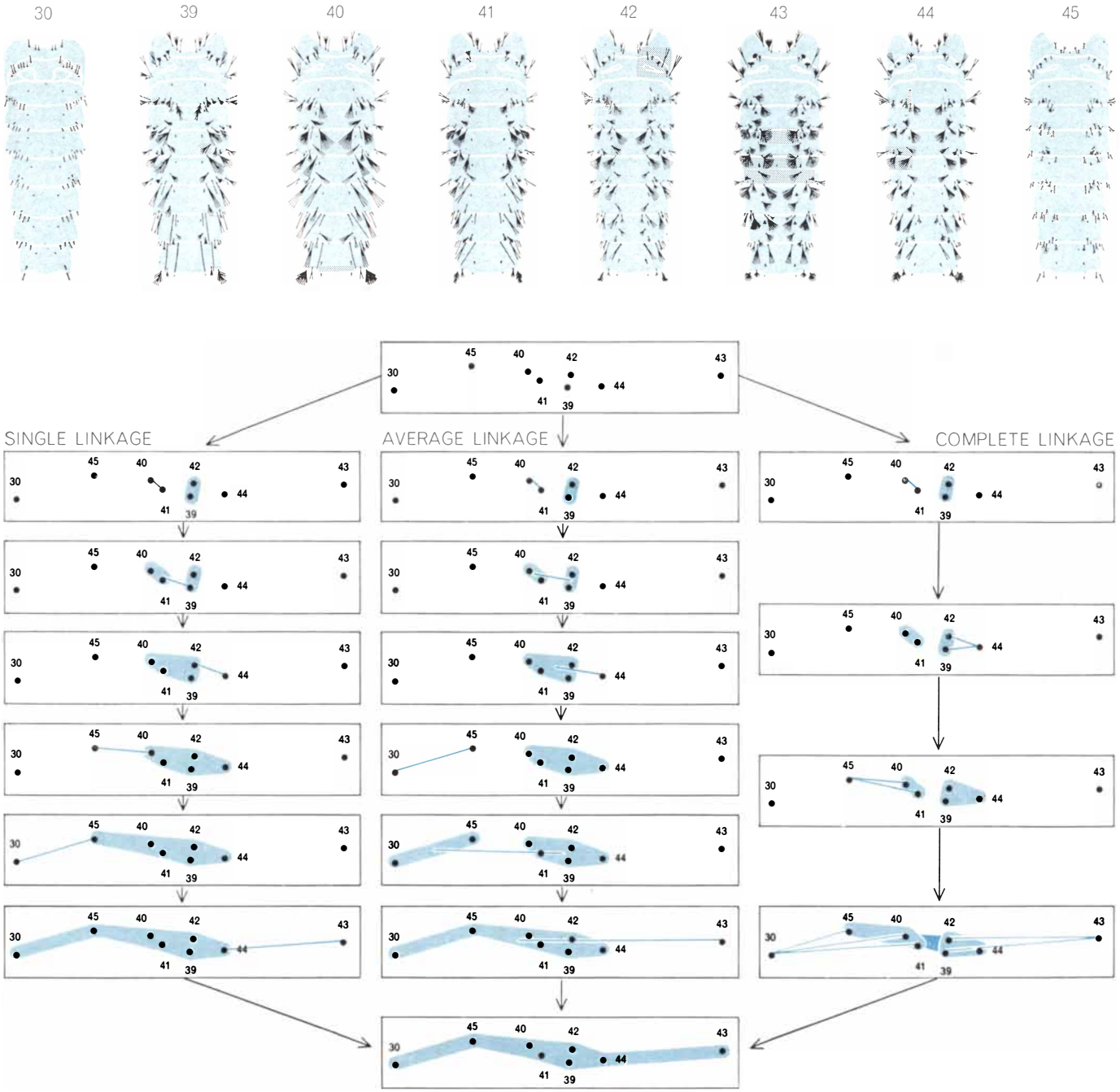


NEMATODE PHENOGRAM is based on the similarity matrix at bottom of opposite page. The brackets and lettering correspond to similar brackets and lettering in the similarity matrix. Broken vertical lines are "cutoff lines" for recognizing species and genera, which are indicated by their full names at right. Code numbers for OTU's are at tips of branches. Rearrangement of first two species has no effect on the taxonomic relationship illustrated.

ford and at the New York Botanical Garden followed in 1958 and 1960 respectively. Since that time the literature and the number of workers in the field have grown rapidly. At last count there were at least 200 published papers on numerical taxonomy, with more than 60 papers applying numerical taxonomy to diverse groups of organisms.

How does one produce a classification by numerical taxonomy? The objects to be classified are called "operational taxonomic units," or OTU's for short. They may be individuals as such, individuals representing species or higher-ranking taxa such as genera or families of plants or animals, or statistical abstractions of the higher-ranking taxonomic groups.

Classifications by numerical taxonomy are based on many numerically

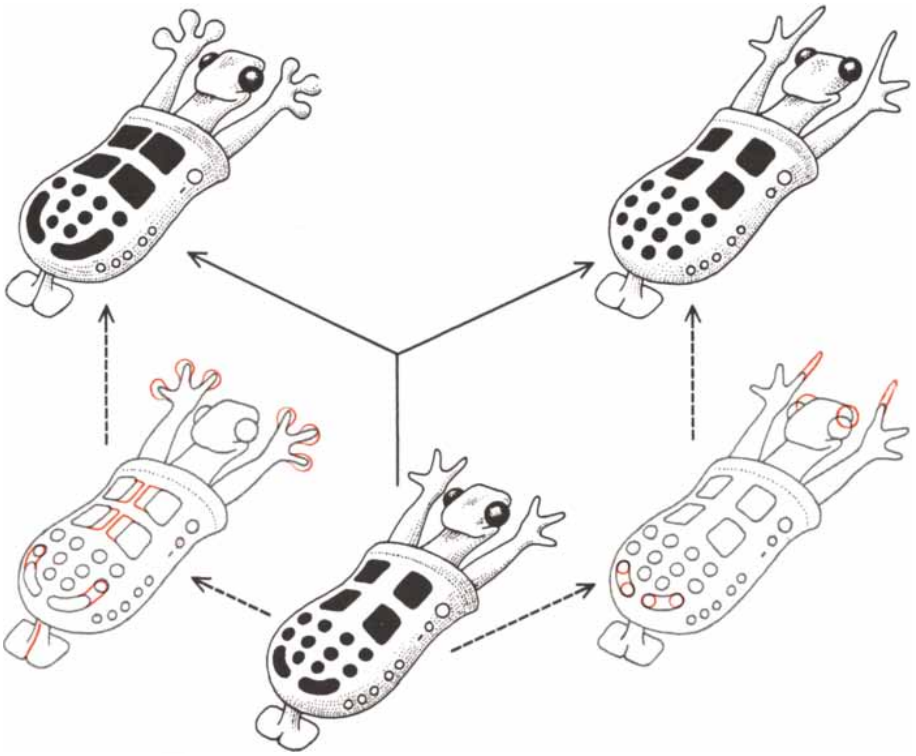


DIFFERENT CLUSTERING TECHNIQUES yield different classifications of the same taxonomic units. The numbered black dots represent eight species of mosquitoes described by pupal characteristics only (*drawings at top*). Species 30 belongs to the genus *Mansonia;* the others are species of *Anopheles*. For convenience of representation, distances among OTU's are shown in two-dimensional space only. Linkages between OTU's and clusters and between pairs of clusters are shown by solid-colored lines, previously established clusters by light-colored shading of the area occupied by the clustered OTU's. As clustering proceeds step by step the criteria for joining become less stringent; in other words, the distances between prospective joiners and established clusters increase. The single-linkage method (*left*) starts with the shortest distance between any pair of OTU's and takes up the other distances in order of magnitude. In average linkage (*center*) an OTU will join a cluster if the average distance between it and the "center of gravity" of the cluster is less than for any other such distance in the study. In complete linkage (*right*) joining takes place only when the relationships between a candidate for joining and established members of the clusters are all at the minimum criterion for a given clustering cycle. Although the initial clustering step is the same for all three methods and the final cluster, including all the OTU's, must necessarily also be the same, the intermediate clustering steps are obviously quite different at roughly equivalent stages. The results depicted here will not necessarily agree with comparable studies that include additional closely related OTU's.

recorded characters. These may be measurements that are appropriately represented numerically, or they may be coded in such a way that the differences between them are proportional to their dissimilarity. For example, a character called "hairiness of leaf" might be coded as follows: hairless, 0; sparsely haired, 1; regularly haired, 2; densely haired, 3. By this coding system we imply that the dissimilarity between densely haired and hairless is approximately three times the dissimilarity between sparsely haired and hairless. In some fields, such as microbiology, characters are almost always expressed by only two states corresponding to the presence (1) or the absence (0) of a given character, for example an enzyme.

All the characters and the taxonomic units to be classified are arranged in a data matrix, and the similarities between all possible pairs of OTU's are then computed based on all the characters. We shall not concern ourselves here with the variety of mathematical coefficients that have been devised to represent similarity between objects. One way of representing similarity (actually dissimilarity) is the distance between OTU's in a multidimensional space. Suppose the similarity between all possible pairs taken from four objects is to be estimated on the basis of three characters. We can visualize these characters as representing three coordinate axes [*see bottom illustration on page 108*]. Each OTU is then plotted into this three-dimensional space according to its state, or value, for the three characters. Those objects that are very similar will be plotted close to each other; dissimilar ones will be considerably farther apart. The computation of such straight-line distances is quite simple. In any real case there will, of course, be more than three characters and a multidimensional space would be necessary. Although it is not possible to represent such a "hyperspace" pictorially, the computation of distances within it is still quite simple. Thus we can view the objects to be classified as clusters of points in multidimensional space.

The similarities between pairs of OTU's are evaluated by a computer and printed out in a "similarity matrix," which shows the similarity value of each OTU with respect to every other one. Rather than give such a numerical table here, I have illustrated it graphically on page 110, indicating the magnitude of the similarity coefficient by depth of shading. Unless the OTU's to be classified have been ordered previously, the pattern of shading in the similarity matrix is likely to be complex. We can attempt, however, to alter the arrangement of the OTU's in such a way that the dark-shaded areas (high-similarity values) will condense in triangular groups along the diagonal of the table. This procedure will yield a rough classification of these OTU's into groups.



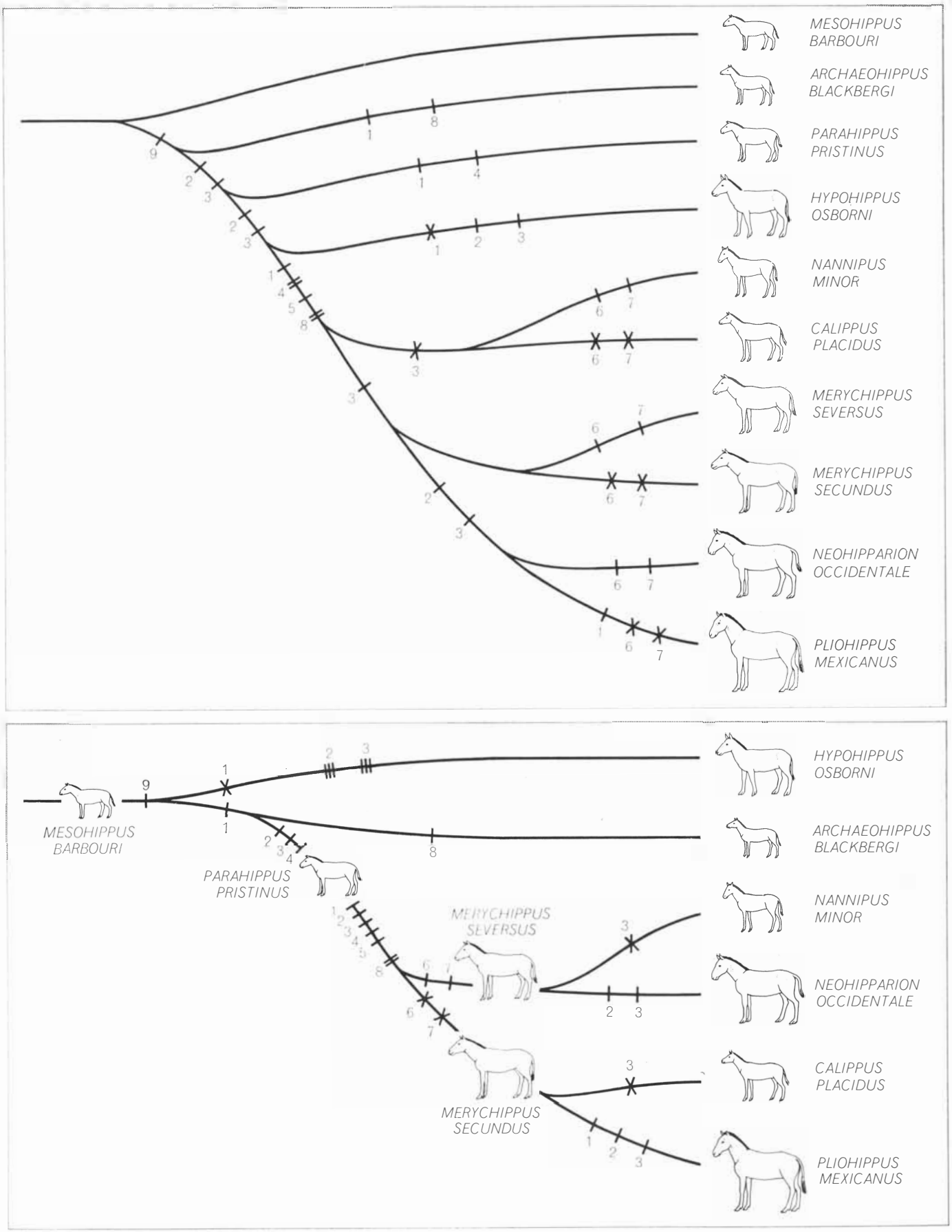
GENETIC CONTINUITY was accomplished in the generation of the Caminalcules by tracing the drawing of the primitive species (*bottom*) from sheet to sheet, making possible the preservation of all characters except for the desired morphological modifications (*color*).

For more precise classifications a variety of numerical clustering procedures have been developed, and these procedures are routinely carried out on the computer after the similarity matrix has been calculated. There is no generally accepted clustering method. Different methods will yield different results, depending on the underlying "similarity structure" of the objects to be clustered [*see illustration on opposite page*]. Attempts are being made currently to define an "optimal" classification mathematically so that the results of a numerical classification can be evaluated by this criterion.

The results of a numerical classification are usually represented by means of a "phenogram." These treelike diagrams indicate the similarity between OTU's or stems bearing more than one OTU along one axis. Because phenograms collapse multidimensional relationships into two dimensions, there is appreciable distortion of the original relationships as shown in the similarity matrix. Estimates of the degree of distortion in a given phenogram are made routinely in numerical taxonomic studies as a precaution. Representing phenetic relationships by three-dimensional models of OTU's avoids some of the distortions encountered in phenograms. Since such models cannot be circulated widely, the possibility of publishing computer-produced "stereograms"—two-dimensional projections of three-dimensional models—is currently being investigated.

Describing the similarities among organisms is only one aim of taxonomy. Another is to trace the evolutionary lineages that gave rise to the diversity of organic life that exists today. To reconstruct the taxonomic relationships and evolutionary trends among a group of organisms one would need to describe their phenetic relationships through all points in time. One would also have to describe the group's "cladistics," the branching sequences in the evolutionary trees. Finally, one must furnish a correct time scale to the evolutionary reconstruction. At the moment there is no known way—short of a multidimensional reconstruction, which is impossible of practical achievement—to incorporate these elements into a unified system without large distortion of the phenetic relationships.

Some substantial recent advances in

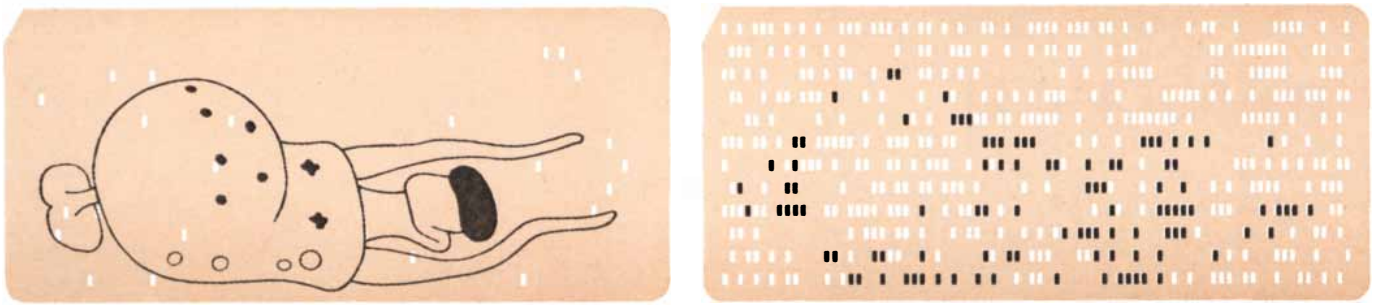


CLADOGRAMS, diagrams that delineate the branching sequences in an evolutionary tree, are shown here for a group of fossil horses. A computer program developed by Camin and the author constructs cladograms with the fewest number of evolutionary steps. The cladogram at top shows an early stage in the procedure; the one at bottom shows the most parsimonious solution, in which the 35 steps at top have been reduced to 31 steps. The cladogram at bottom corresponds to evolutionary branching sequence generally accepted by paleontologists. The evolutionary steps for various numbered skeletal and dental characters are marked on the branches. In the bidirectional evolution of a character one direction is shown by lines across branches, the other by *X* marks.

techniques for reconstructing cladistic sequences grew out of an experiment on the principles and practices of taxonomy carried out by a group of graduate students and faculty members at the University of Kansas. The study was based on a group of imaginary animals generated by Joseph H. Camin according to rules known so far only to him but believed to be consistent with what is generally known of evolutionary principles. Genetic continuity was accomplished by tracing the drawings of the animals from sheet to sheet, permitting the preservation of all characters except for the modifications that were desired. All 29 "recent" species of these "organisms," irreverently named Caminalcules by the graduate students, are shown on pages 106 and 107. Detailed studies of the assemblage of hypothetical animals by orthodox phylogenetic methodology by various team members resulted in differing, but internally consistent, cladistic schemes, the choice among which was not easily apparent. Comparison by Camin of these various schemes with the "truth" led him to the observation that those trees that most closely resembled the true cladistic sequence invariably required for their construction the fewest number of postulated evolutionary steps for the characters studied.

Our experiments were based on three working assumptions: first, that character states could be numerically coded according to their presumed evolutionary trends; second, that evolution is irreversible, so that when a character evolves to state 2, it will not revert to state 1; third, that nature is fundamentally parsimonious, so that the diversity in character states within a given group was achieved at or close to the minimum number of evolutionary steps. From these assumptions Camin and I developed a computational technique that constructs the most parsimonious cladistic tree, or cladogram, from an original data matrix. A computer program carries out these computations. The cladograms on the opposite page illustrate the type of change that is routinely carried out by the computer program. The cladograms estimate the branching sequences that occurred in the evolutionary history of a group of fossil horses. These methods have also given apparently meaningful results in studies of bees, vipers, certain plants, fossil protozoa and the structural rearrangements of chromosomes in blackflies and drosophila.

The computer program also evalu-



AUTOMATIC SCANNING of organisms for the purpose of establishing phenetic classifications was proved to be feasible in a recent experiment performed by F. James Rohlf and the author in which they successively placed 25 punch cards, each perforated with 25 randomly chosen holes, over drawings of a group of Caminalcules. One of the punch cards is shown at left superposed over a drawing of a Caminalcule belonging to species 1. In making the composite at right each of the 625 holes was scored 1 when a black line appeared through it and 0 when no black showed. (Actually fewer than 625 holes are visible here, since many holes on different cards coincided.) The illustrations of the organisms were compared on the basis of matching scores for corresponding masks and holes.

ates the compatibility of each characteristic with all the other characters and weights it in terms of this criterion. It points out inconsistencies and has repeatedly discovered errors in coding, transcription or interpretation of the data.

A major impetus for the development and application of numerical taxonomy is the current introduction of automatic sensing and data-recording devices. The development of such instruments has proceeded very rapidly in recent years. Most prominent among the devices likely to be useful in taxonomy are optical scanners, which digitize drawings, photographs, microscope preparations and results of biochemical analysis. The veritable flood of information that will flow from these automatic sensors will require computer-based processing and classification, since the human mind is not able to digest these data by traditional means.

Recently F. James Rohlf and I have shown that data of this kind, collected in a quite unsophisticated manner, can be used to form adequate phenetic classifications. We employed the straightforward approach of recording agreement in visible structures over randomly selected minute areas of the images of pairs of organisms. Such a procedure would be feasible by means of optical scanners. Random masks, made from 25 punch cards each perforated with 25 randomly chosen holes, were placed over black-and-white drawings of two groups of "organisms." One group consisted of the 29 recent species of the Caminalcules; the second comprised published illustrations of the pupae of 32 species of mosquitoes. Each illustration was overlaid with all the masks, and each of the 625 holes was scored 1 when a black line appeared through it and 0 when no black showed [*see illustration above*]. Illustrations were compared on the basis of matching scores for corresponding masks and holes. A numerical classification of the images was surprisingly similar to studies by conventional taxonomy or by numerical taxonomy based on the detailed description of characters. Whenever phenetic taxonomies are acceptable, automatic scanning and classification may provide a rapid and reliable approach. Problems of the size and orientation of the organisms remain to be worked out, but they should not present insuperable technical difficulties. The implications of the success of this method are that experience and insight into the presumed biological and phylogenetic significance of characters may be less important for obtaining satisfactory classifications than had been generally supposed.

Thus there is every reason to believe that classifications from automatically obtained characters are possible. This finding will, of course, lead not only to automatic classification but also to automatic identification, which should be one of the more exciting prospects for research workers faced with routine identification problems.

Numerical taxonomists working in biological taxonomy are continually surprised and impressed by the applicability of their principles in numerous sciences and other fields of human activity. They marvel at the rapidity with which this knowledge is spreading throughout the biological, medical, geological and social sciences, as well as the humanities. Numerical taxonomy has been employed to classify soils and diseases, politicians and plant communities, archaeological artifacts and oil-bearing strata, socioeconomic neighborhoods and psychological types, languages and television programs—to name just some of the applications. Sneath has even used it to solve a jigsaw puzzle. This broad spectrum of applications for numerical taxonomy should not surprise us. After all, the precise categorization of human experience is one of the foundations for a scientific understanding of the universe. We should not, however, be overly impressed by the similarities in approach in these various sciences. There are appreciable differences in the principles of classification in diverse fields, and it is necessary to know when the problems of one discipline part company with those of another. Nonetheless, the common fund of basic ideas on similarity and classification is great enough to serve as the basis for a general science of taxonomy.

Biological taxonomy will be affected by the computer in many ways besides numerical taxonomy. Automatic data processing will revolutionize the storage and retrieval of taxonomic information for museums and catalogues. The approaches of numerical taxonomy have already done much to de-emphasize the often legalistic and sterile aspects of naming organisms. It is likely that developments in automatic data processing will rapidly relegate problems of nomenclature to the position of relative unimportance they merit. Some of the birth pangs of automation will be felt in taxonomy as in other fields, and traditionally-minded workers will presumably resist the changes. The controversy about numerical taxonomy will doubtless continue for some time to come until a new "synthetic" theory of taxonomy, accepting what is soundest from various schools, becomes established. The revolution the computer has wrought in taxonomy has only just begun.

RECENT findings

RESEARCH LABORATORIES

Ford

Ionic conduction study leads to new concept in energy conversion device at Ford Motor Company.

Heart of the new sodium-sulfur battery recently announced by Ford Motor Company is a highly ionically conducting poly-crystalline ceramic, based on the compound beta alumina $Na_2O \cdot 11Al_2O_3$. This compound exhibits unusual two-dimensional diffusion and ion exchange properties.

A summary of the ion exchange properties of beta alumina when in equilibrium with mixtures of molten nitrates of monovalent cations is shown in Figure 1. The symbol X designates the cation shown with each curve.

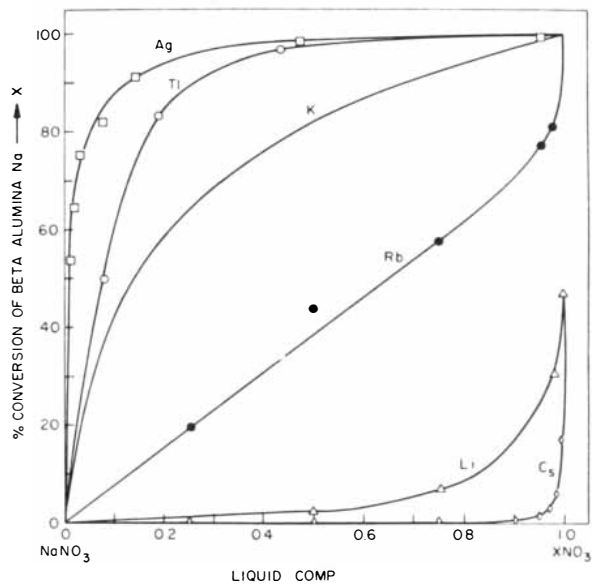


Fig. 1 Equilibria between beta alumina and various bimary nitrate melts containing $NaNO_3$ and another meltal nitrate at 300-350°C.

No anions of the molten salt enter the solid beta alumina phase. The equilibrium is unfavorable with cesium because the cesium ion is larger than the volume available at the cation location in the beta alumina, and is unfavorable for the lithium ion because this small ion can coordinate closer to the anions of melt than of the beta alumina.

In spite of the fact that beta alumina is a robust material with a melting point approaching 2000°C and a demonstrated resistance to molten salts, the diffusion rate of sodium ions in this material is as fast as the best solid inorganic ionic conductors known. For example, when a 2mm diameter single crystal of this material is placed in molten sodium nitrate at 300°C, it will exchange one half of its sodium ions with the sodium ions of the melt in 60 seconds. In more scientific terms, the diffusion coefficient for the sodium ion in the crystal is $\sim 1 \times 10^{-5}$ cm²/sec at 300°C and 4.0×10^{-7} cm²/sec at 25°C.

The two-dimensional character of the diffusion is strikingly shown in Figure 2. The sodium ions of this thin single crystal of beta alumina were originally completely exchanged with the lithium isotope Li^6.

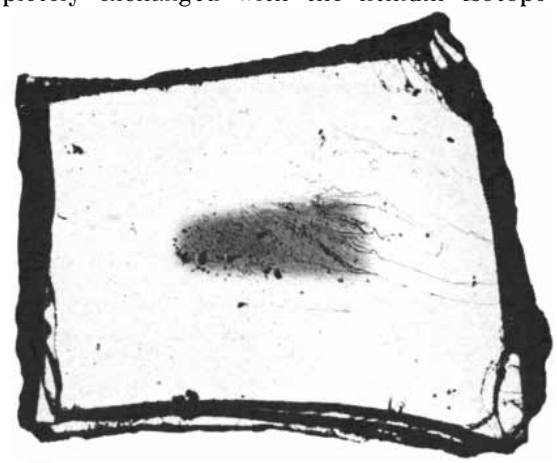


Fig. 2 Partially exchanged ($\sim$60%) Li^6 single crystal of beta alumina. The area of high Li^6 concentration has become dark under neutron irradiation ($\sim 10^{13}$ neutrons per cm² for 1 hour).

The crystal was then exchanged for a short period of time with molten Li^7NO_3 which resulted in a replacement of part of the Li^6 atoms with Li^7 atoms. The crystal was then irradiated with neutrons in the Phoenix reactor of the University of Michigan which caused the area containing a large amount of Li^6 atoms to turn dark in color. As can be seen in the photograph, the center portion contains the unexchanged Li^6. This is a direct visual indication that the exchange is two dimensional in the plane of this thin crystal.

Science is always interested in findings that indicate a potentially new form of energy conversion. The development of this high-energy secondary battery system is a significant step in that direction.

PROBING DEEPER FOR BETTER IDEAS

Ford

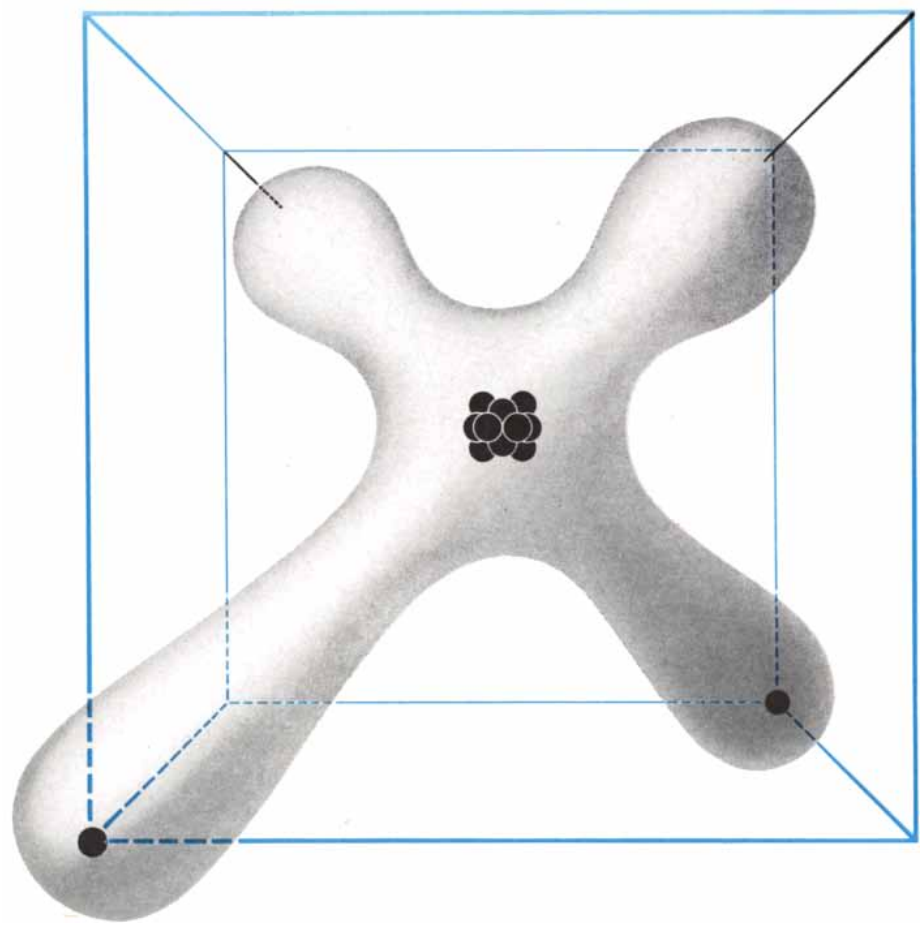
ICE

At the molecular level the seemingly rigid perfection of a crystal of ice is disrupted by an astonishingly busy traffic of molecules and migrating lattice faults

by L. K. Runnels

Ice is a substance that has fascinated many of the foremost scientists of modern times. Chemists, physicists, mathematicians and even biologists have been drawn to the investigation of its somewhat mysterious crystal structure and its peculiar properties. Their exploration of the problems presented by ice have yielded a better understanding of the hydrogen bond (present in many important molecules, including proteins) and of the activity that goes on within a seemingly rigid crystal. The investigation of ice is a good example of how much can be learned from close study of a most commonplace object.

Let us begin by examining the structure of a single water molecule—say a molecule of water vapor in the air. The easiest way to visualize the molecule is to place it in an imaginary cube with the nucleus of the oxygen atom at the center of the cube and the two hydrogen nuclei at opposite corners of the cube's base [*see illustration on this page*]. Actually the shape of the figure is not exactly cubic—the "cube" should be slightly distorted—because the angle of attachment of the hydrogen atoms to the oxygen is 104.5 degrees, whereas in a perfect cube the lines from the corners to the center form an angle of 109.5 degrees. For our purpose, however, the cube figure is accurate enough. Of the oxygen atom's eight electrons two are held near the oxygen nucleus while another pair joins with two electrons from the hydrogen atoms in binding them to the oxygen; this leaves two "arms" of unshared electrons that point from the oxygen nucleus to other corners of the cube, as the illustration indicates.



MOLECULE OF WATER has four "arms" (actually clouds of electrons) extending from the central nucleus of the oxygen atom. Two of the arms contain hydrogen nuclei (protons) and are positively charged. The other two arms contain no protons and hence are negatively charged. In subsequent illustrations the negative arms of molecules will be omitted.

When water molecules are not isolated but packed together, as in the liquid state, these negatively charged arms serve to attach molecules to one another. Each negative arm attracts a hydrogen nucleus in a neighboring water molecule, and the hydrogen atoms thus act to join the molecules with what are called hydrogen bonds. The molecules tend to combine in clusters [see "Water," by Arthur M. Buswell and Worth H. Rodebush; SCIENTIFIC AMERICAN, April, 1956].

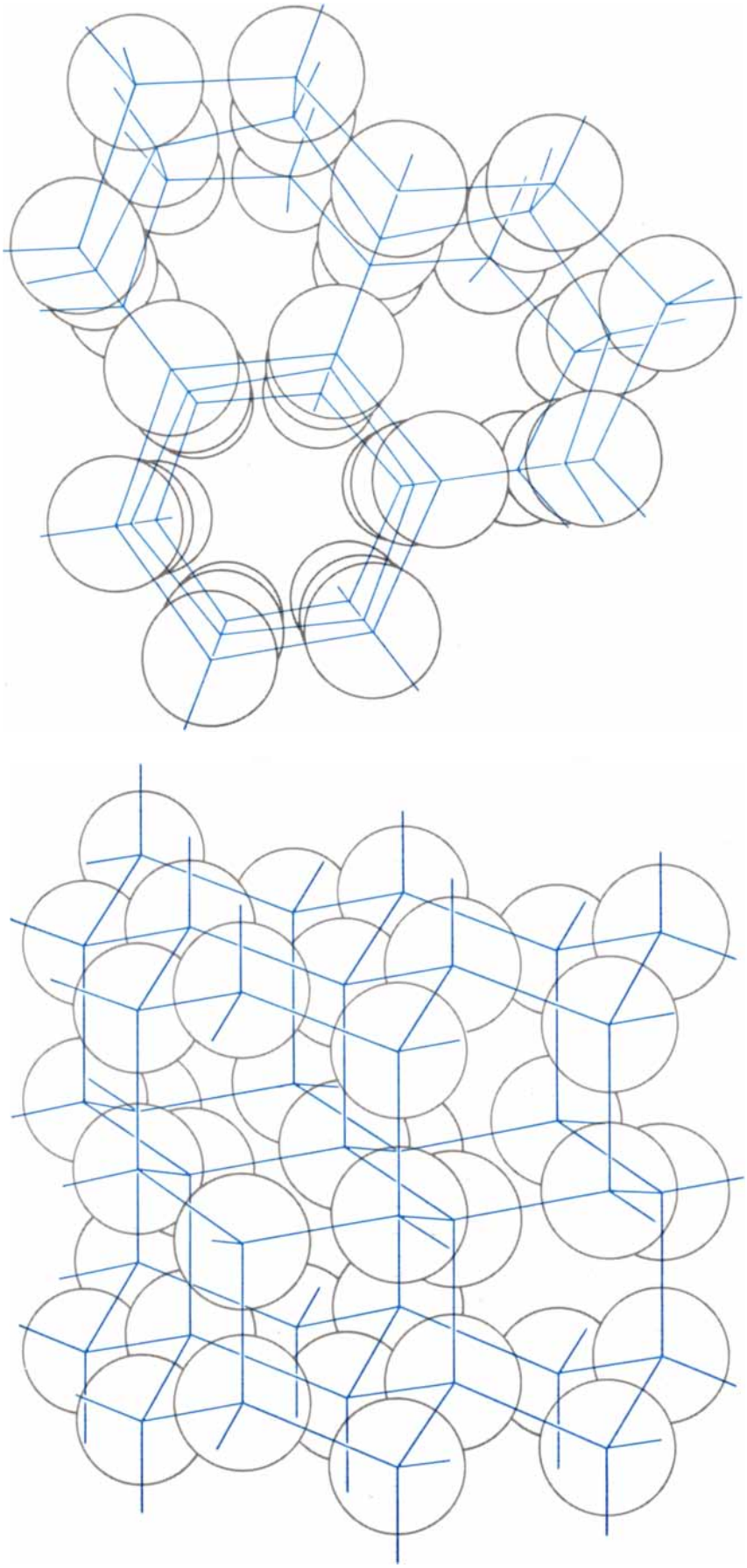
In the liquid state the normal thermal motion of the molecules is sufficient to break the bonds as the molecules jostle one another; consequently the clusters are continually being split up and reformed. When water is cooled to the freezing point, however, the thermal motion is so reduced that the molecules form large, stable clusters: the crystals

of ice. The first thing that interests us about these crystals is their structure. How are the water molecules arranged in an ice crystal?

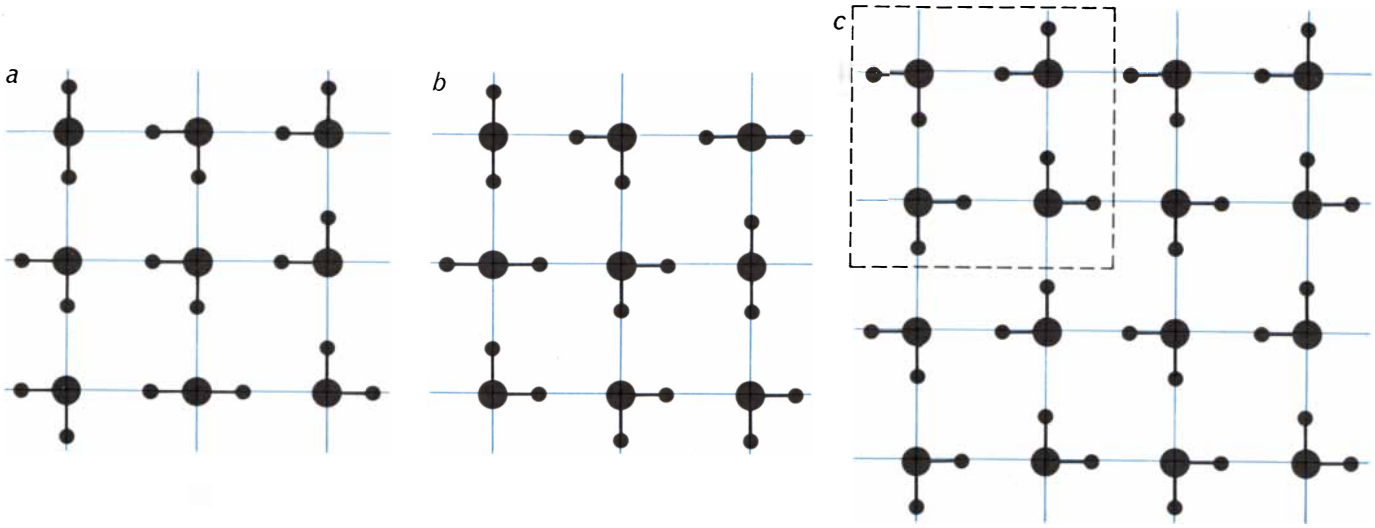
The study of ice by the technique of X-ray diffraction showed many years ago that the molecules in the crystal are arrayed in a hexagonal pattern [*see illustration at right*]. This accounts for the six-sided form of snowflakes. More significantly, the analysis revealed that there is a good deal of empty space between the molecules: the crystal has a rather open structure. This finding clearly explained one of the most unusual properties of ice: the fact that, in contrast to almost all other substances, water is less dense in the solid state than in the liquid state, with the result that ice floats on liquid water. In frozen water, it can be seen, the molecules are more loosely packed than in the liquid. When a crystal of ice melts, the breakdown of its structure allows molecules to fill some of the open spaces.

The X-ray studies succeeded in revealing the arrangement of molecules in ice because the oxygen atoms in the molecules serve to deflect the X rays. The technique failed, however, to locate the positions of the hydrogen atoms; their power to deflect X rays is too low. For more than 30 years investigators in Europe and the U.S. have been pursuing the intriguing problem of finding out just where the hydrogen atoms are in the ice crystal, as this information is crucial to understanding the complete structure of ice and some of its most important properties.

The effort took its cue from a suggestion made in 1933 by the British physicists J. D. Bernal and R. H. Fowler. They argued that in all likelihood the orientation of the molecules in the ice crystal is such that each molecule forms good hydrogen bonds with its four nearest neighbors; that is, in each case the molecule's two hydrogen nuclei (protons) are pointed toward its neighbors' negative arms and its own two negative arms are pointed toward its neighbors' protons. This suggestion was accepted as reasonable. Unfortunately, however, it left the problem wide open. It did not specify any particular arrangement of the molecular orientations; indeed, one could picture many different arrangements that would satisfy Bernal and Fowler's rule. Some of these possibilities are shown in the top illustration on the next page, which for the sake of convenience is presented in only two dimensions (instead of the three dimensions of a real



WATER MOLECULES IN ICE CRYSTAL were shown many years ago by the technique of X-ray diffraction to be arrayed in a hexagonal pattern, viewed here from above (*top*) and from the side (*bottom*). The X-ray analysis revealed that there is a good deal of empty space between the molecules, which explains why ice floats on liquid water. The technique failed to locate the positions of hydrogen atoms, because their power to deflect X rays is too low.

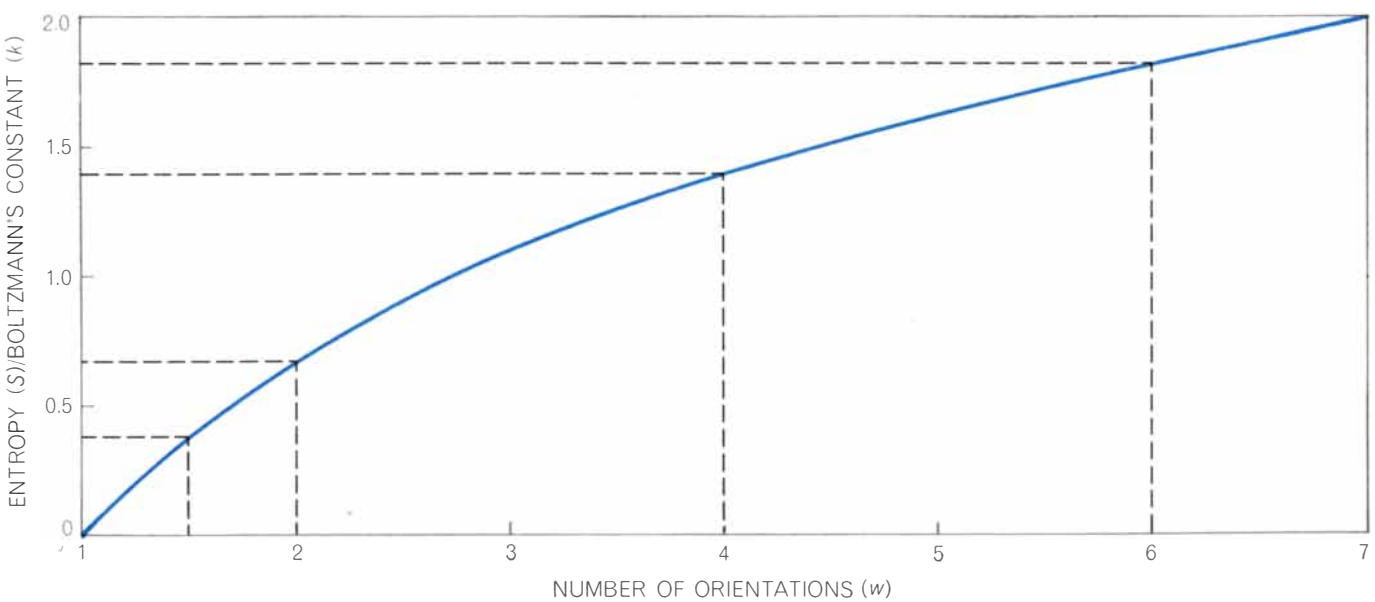


TWO DIFFERENT ORIENTATIONS of water molecules in an ice crystal (*a*, *b*) both satisfy the requirement that every pair of neighbors be joined by a hydrogen bond formed when a positive proton faces a negative arm (the hydrogen-bond rule). For convenience the crystals are presented in only two dimensions instead of the three dimensions of a real crystal. A total of 2,604 different arrangements is possible for such an ice crystal containing only nine molecules. In *c* a hypothetical arrangement is shown with a repeating "unit cell."

crystal) but nevertheless illustrates the essential point.

Does ice have one fixed, invariable structure? In most solids the atoms are arranged in a certain definite order with each type of atom assigned to a particular location in the unit cell, or repeating molecular structure, that makes up the crystal. Experiments on ice soon turned up indirect evidence, however, that its hydrogen atoms are not restricted to a single basic pattern. The evidence had to do with entropy.

The entropy of a system, which fundamentally is defined in terms of its heat capacity (the amount of heat required to raise its temperature), is a measure of the lack of order, or the presence of randomness, within the system. The higher the entropy, the more random the distribution of particles or molecules contained in the system. Now, as a substance is cooled, the reduction of the motions of the molecules within it results in a greater order and a decrease of entropy. At absolute zero the entropy of most substances is zero: they are "frozen" in a certain predictable state of order. Some compounds, however, do not give up all their entropy even when they are cooled to the lowest attainable temperature (almost absolute zero). In one way or another they retain some randomness —a "residual entropy." A good example is carbon monoxide (CO). With a carbon atom at one end and an oxygen atom at the other, this molecule is slightly polarized (the electric charge of one end is slightly more positive than that of the other), but the difference is so small that there is little distinction between the positive and the negative ends of the molecule. Consequently when the substance is cooled to very low tempera-



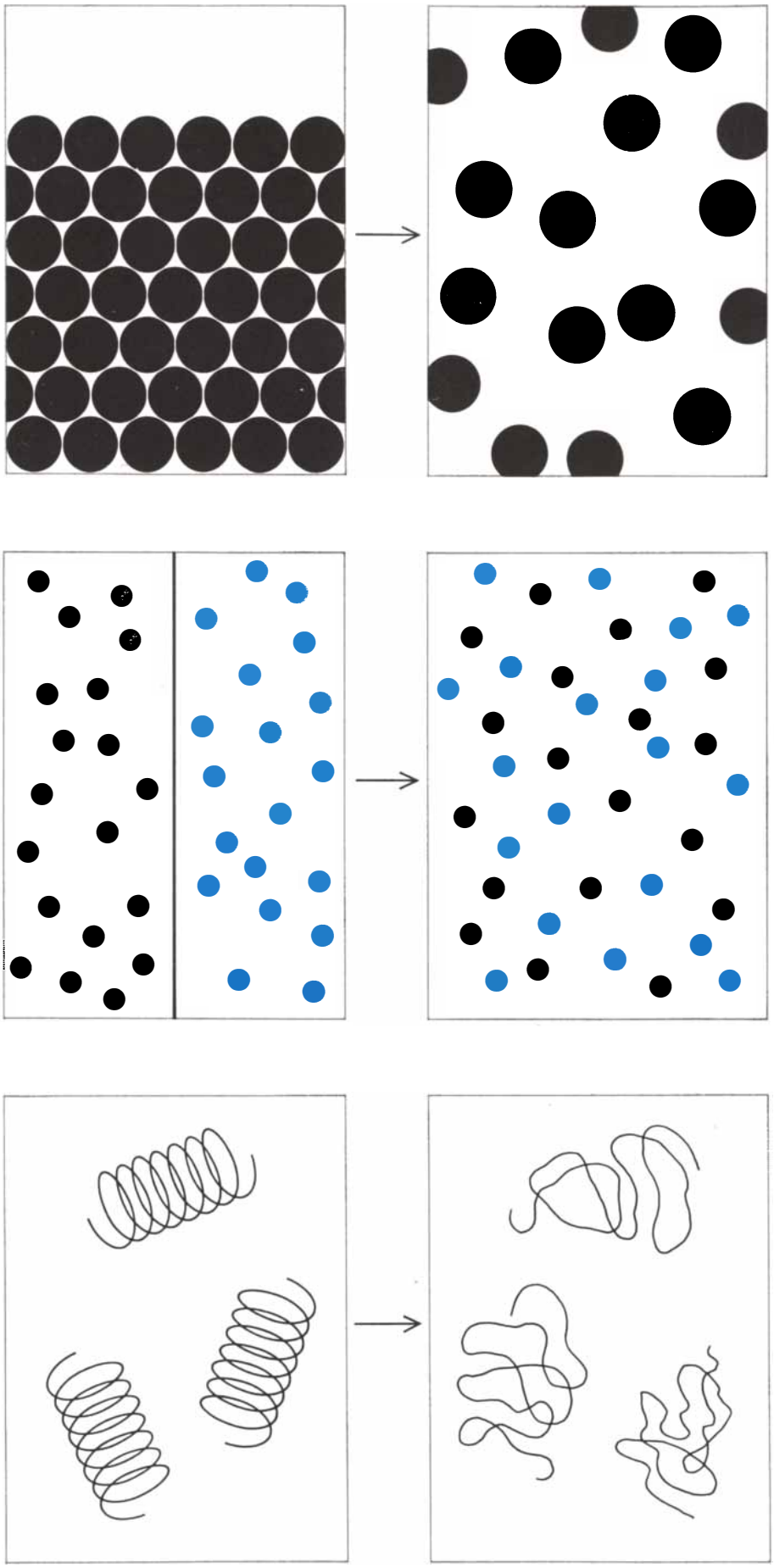
BOLTZMANN RELATIONSHIP, named after the 19th-century Austrian physicist Ludwig Boltzmann, predicts that the entropy (or randomness defined in terms of heat capacity) of any system in which the molecules are independent of one another will be proportional to the natural logarithm of the number of equally likely orientations of the molecules. The values for w of 1.5, 2, 4 and 6 correspond respectively to ice, carbon monoxide, deuterated methane and ice without the hydrogen-bond rule. The experimental value of $S/k = .4$, obtained by measuring the heat capacity of ice to very low temperatures, substantiates hydrogen-bond rule for ice.

tures, the orientation of the molecules in the crystal is ruled largely by chance, some molecules pointing in one direction and others in the opposite direction. For this reason carbon monoxide is said to have a residual entropy at absolute zero.

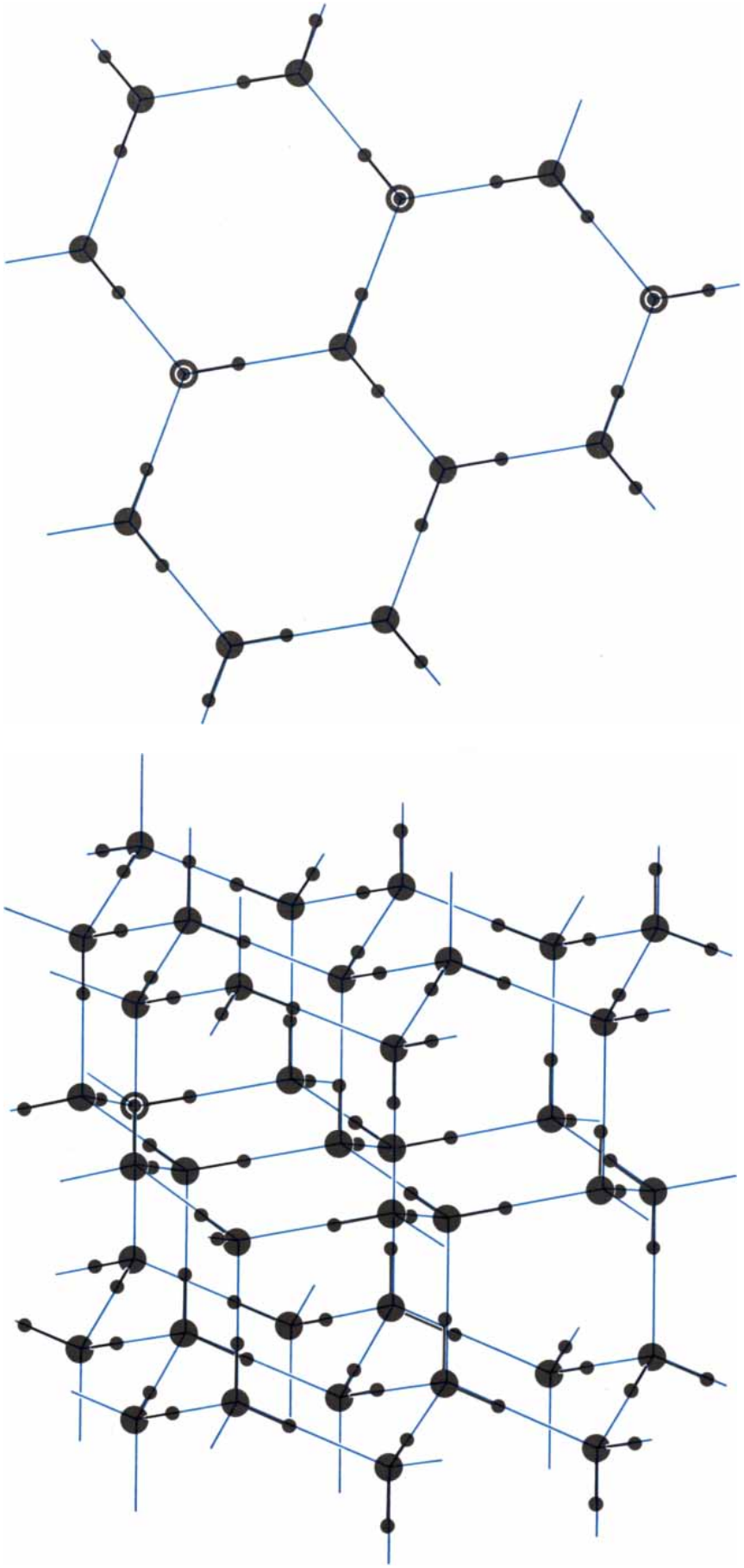
Bernal and Fowler in their discussion of the structure of ice implied that there might be no energy considerations dictating a particular arrangement of the hydrogen atoms. Amplifying this idea, Linus Pauling at the California Institute of Technology argued that ice (like carbon monoxide and a few other compounds) should have a residual entropy at low temperature. Indeed, this had already been observed experimentally by W. F. Giauque and J. W. Stout of the University of California at Berkeley. By measurement of the heat capacity of ice down to very low temperatures they found that the crystals actually did retain a certain amount of entropy.

It became clear, then, that in the crystals of ice the molecules are oriented in more than one way. Could the measured residual entropy shed any light on just how many different arrangements are actually present? A means of tackling this question was available: it was the famous entropy formula of the 19th-century Austrian physicist Ludwig Boltzmann, one of the founders of statistical mechanics. Boltzmann's formula predicts that the entropy (S) of any system in which the molecules are independent of one another will be proportional to the natural logarithm of the number of equally likely orientations of the molecules. In symbolic terms the formula is $S = k \log w$, with w standing for the number of possible orientations and k for the celebrated Boltzmann constant. In the case of carbon monoxide w is 2 (each molecule has two possible orientations), and the formula predicts that the residual entropy divided by the constant (S/k) should therefore be .69. The measured value of carbon monoxide's residual entropy agrees satisfactorily with this figure.

Suppose now we apply the formula to ice. In the ice crystal a molecule has six possible orientations: its hydrogen atoms can be oriented in six different ways. According to the Boltzmann formula, with $w = 6$ the residual entropy (more precisely, S/k) should have the value 1.8 [*see bottom illustration on opposite page*]. Actually in the experimental measurements the value turns out to be only .4. The discrepancy is not surprising; in the Boltzmann formula, as we have noted, w is the number of *independent* alternatives. The orientations of the



ENTROPY AND DISORDER are closely related, the more random arrangement of a system (*right*) having a higher entropy than the more orderly one (*left*). The three typical entropy-increasing processes shown here are the vaporization of a solid (*top*), the mixing of two gases (*middle*) and the helix-to-random-coil transition of protein molecules (*bottom*).



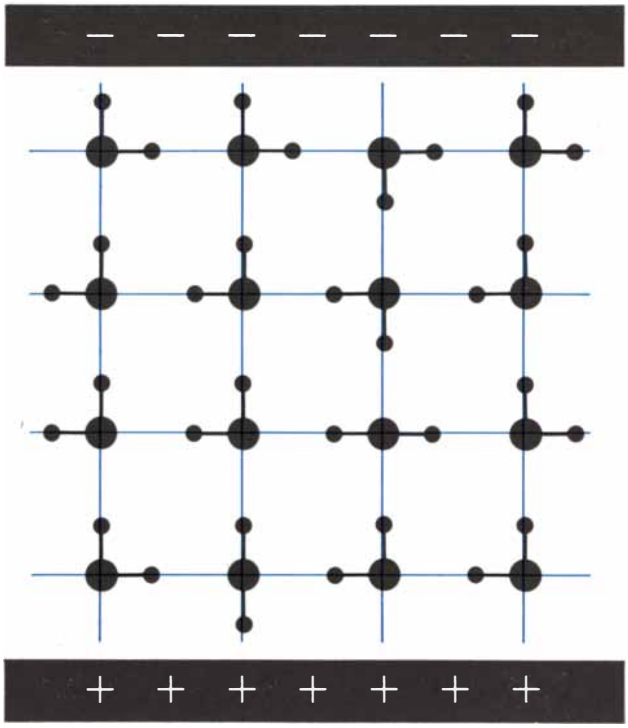
HYDROGEN ATOMS IN ICE CRYSTAL appear to be oriented at random, even at very low temperatures. There is no unit cell in the crystal for hydrogen nuclei. This conclusion is based on measurements of the residual entropy of ice. Crystal is viewed from above (*top*) and from the side (*bottom*). The molecules are somewhat reduced in size for clarity.

water molecules in ice are not independent of one another. Once we have selected a particular orientation for one molecule there are only three possible ways a second molecule can orient itself to form a good hydrogen bond with the first, and the molecules that join up with the first have other neighbors that in turn restrict the orientation choices still further. Pauling calculated that the average number of orientation choices for the system (that is, the value of w) is about 1.5 per molecule.

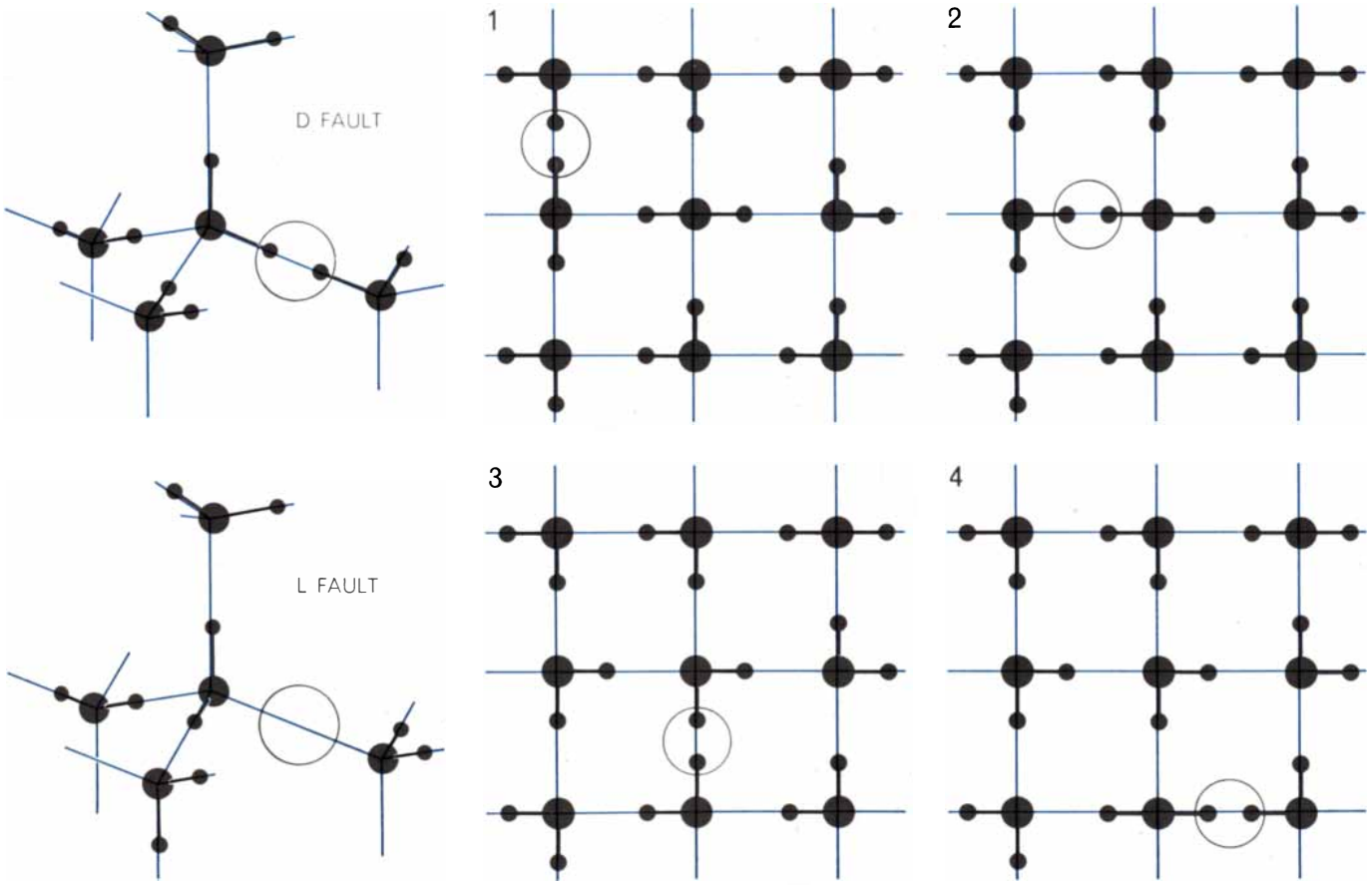
This estimate agreed well with the measurements Giauque and Stout had obtained for the residual entropy of ice; with $w = 1.5$, the value of S/k would be almost exactly .4. Lars Onsager of Yale University suggested in 1939 that it was important to compute as precise a value as possible for the average number of possible orientations. Pauling's estimate of 1.5 was the lower limit for this figure; Onsager noted that the actual value must be somewhat higher. The reason it was important to calculate the number exactly was that, if w turned out to be significantly higher than 1.5, it would indicate that there was some ordering influence within the ice crystals; in other words, that the possible orientations of the molecules were not all equally likely.

For more than 30 years chemists and mathematicians have struggled with this interesting mathematical puzzle, attempting to determine just how many geometric orientations are open to a collection of ice molecules. So far the problem has defied the most sophisticated assaults. Two years ago, however, John Nagle, a student of Onsager's at Yale, pursued some ideas suggested by Edmund A. DiMarzio and Frank H. Stillinger, Jr., of the Bell Telephone Laboratories and arrived at a reliable estimate that narrows the area of uncertainty to very close limits. Nagle found that the exact value must lie between 1.5065 and 1.5068. This result, bringing the theoretical prediction of ice's residual entropy into close agreement with the experimental measurements, shows that if there are any ordering forces in the crystals favoring one arrangement over another, they must be extremely weak.

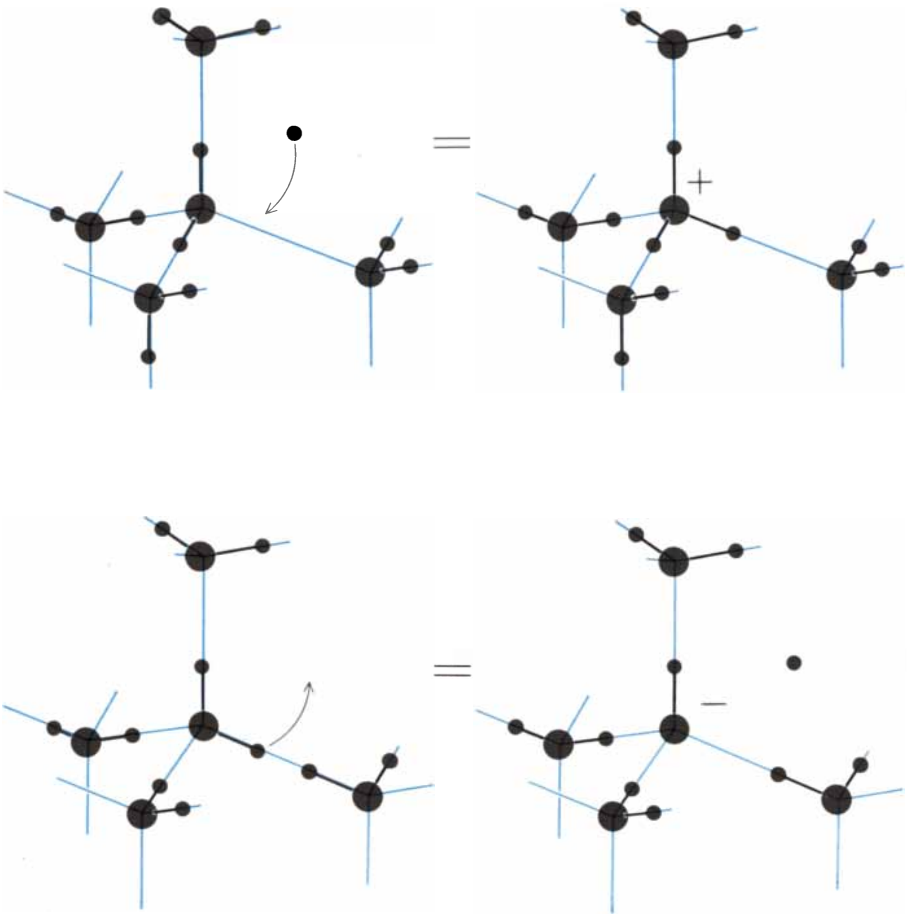
We have been considering an ideal picture in which the structure of ice is governed strictly by the known rules—in particular the hydrogen-bond rule of Bernal and Fowler, which would lock the molecules in a fixed pattern. Now we must look into certain complications that lead to a surprising new view of



ICE CRYSTALS BECOME POLARIZED when they are placed in an electric field between positively and negatively charged metal plates (*left*). When the field is shut off, the crystals gradually return to their normally "relaxed," or depolarized, state (*right*).



IMPERFECTIONS in the crystal lattice of ice explain how the molecules rotate. The two defects at left, proposed by the Danish chemist Niels Bjerrum in 1951, represent occasional violations of the hydrogen-bond rule. In a *D* fault the positively charged hydrogen arms of two adjacent molecules point toward each other. In an *L* fault the two negatively charged electronic arms do so. At right a *D* fault is shown wandering through a hypothetical two-dimensional crystal, leaving behind a chain of reoriented molecules. The decay of polarization (or dielectric relaxation) illustrated at the top of the page results from the migrations of such Bjerrum faults.



MOLECULAR IONS are additional defects present in an ice crystal. The positive ion at top is called a hydronium ion (H_3O^+). The negative ion at bottom is a hydroxyl ion (OH^-).

what actually goes on inside the crystals of ice.

The first of these complications was the discovery many years ago that when ice crystals are placed in an electric field between positively and negatively charged metal plates, the crystals become polarized—negative on the side toward the positive plate, positive on the side toward the negative plate. When the field is shut off, the crystals gradually return to their normally depolarized state. Obviously in the polarized condition a majority of the molecules must point a positively charged hydrogen arm toward the negative plate and a negative electronic arm toward the positive plate, and the orientations must become random again when the crystal is depolarized [*see top illustration on preceding page*]. The late Peter J. W. Debye of Cornell University, a pioneer in the chemistry of polar molecules, concluded that the molecules in ice must be able somehow to shift their orientations!

How could they do so? It was difficult to see how the individual molecules could rotate in the interlocked crystal system, where each molecule's orientation is fixed by the hydrogen bonding with four neighbors. In 1951 the Danish chemist Niels Bjerrum found a reasonable explanation. It is well known that many crystals are subject to imperfections, and Bjerrum suggested a form of imperfection in ice crystals that could account for the molecules' ability to change their orientation. In occasional instances, he said, molecules might violate the Bernal-Fowler rule: hydrogen arms of two adjacent molecules might point toward each other, or electronic arms might do so [*see bottom illustration on preceding page*]. He named the first case a *D* fault (from the German word for "doubled," *doppelt*, signifying a doubling of the bond) and the second case an *L* fault (from *leer*, "empty," indicating the absence of a proton). The presence of these faults would enable the molecules involved to pivot and so change their orientation.

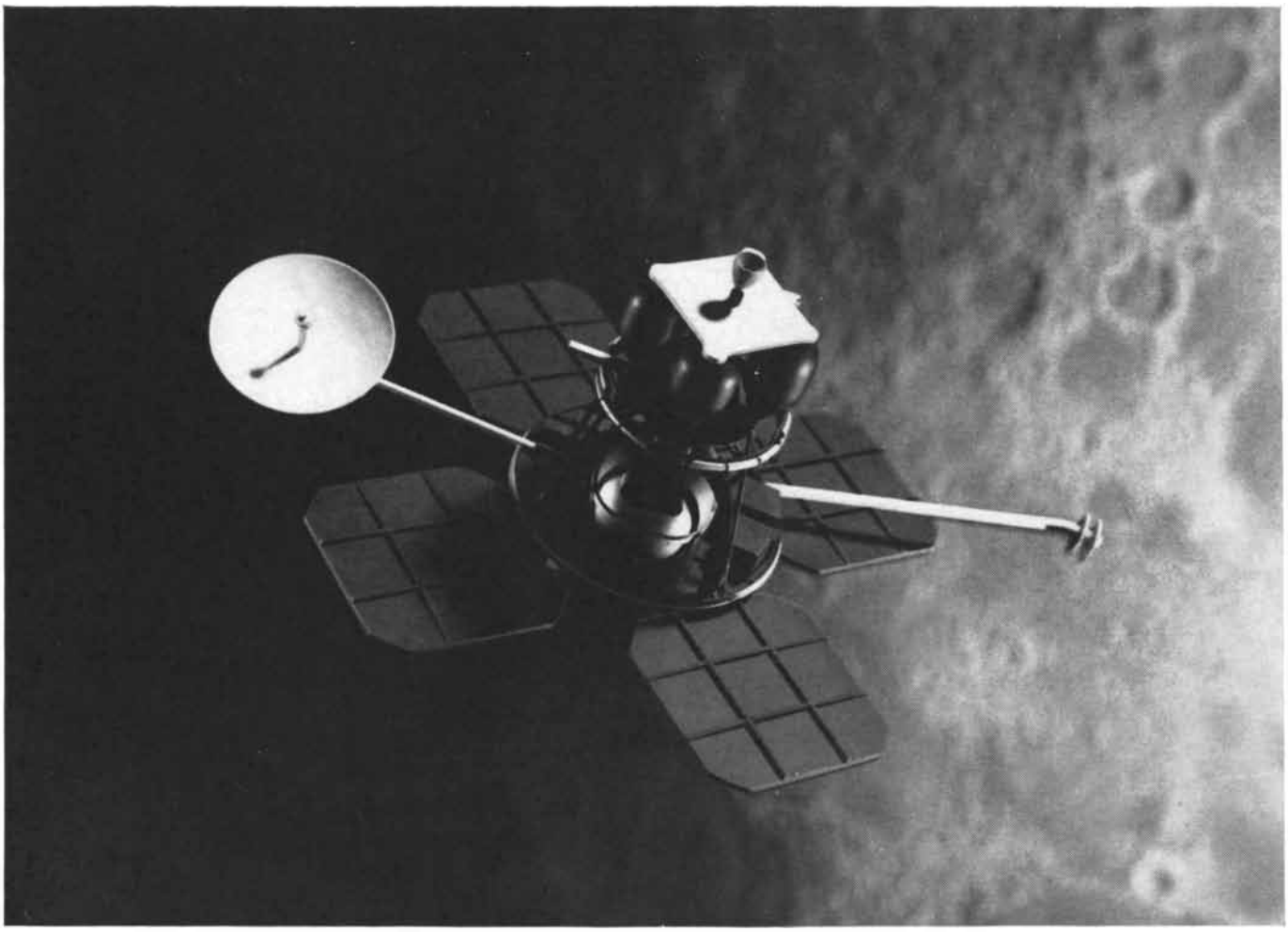
There are some who object to Bjerrum's theory, principally on the ground that the electrical repulsion between hydrogen nuclei is too strong to allow a *D* fault to occur. The hypothesis has proved eminently workable, however, and it seems likely to stand up in its basic features. Among other things, it shows how such a fault, passed from one molecule to the next, can cause many molecules in a crystal to shift their orientation.

Experiments suggest that in ice at a temperature just below the melting point one molecule in a million is likely to be involved in a Bjerrum fault. Because of the rapid migration of faults this is enough to effect the polarization of an ice crystal by an applied electric field, and also the "relaxation," or depolarization, of the crystal after the field has been removed. Indeed, the movement of faults and the attendant rotation of molecules in ice crystals have been detected even without the use of electric fields. It has been found that when the molecular orientations in ice are changed by the application of mechanical pressure, which affects some orientations more than others, the orientations return to the normal distribution after the stress is removed. Measurements of the relaxation time indicate that this form of recovery, like electric depolarization, is brought about by the migration of Bjerrum faults.

The most startling finding in the electric-polarization experiments is that in a crystal of ice just below the melting point the "half-life" of the decay of polarization after the shutoff of the electric field is about a hundred-thousandth of a second. We are forced to the conclusion that every molecule in such a crystal normally rotates at the rate of about 100,000 times per second!

There are other indications that ice, far from being a quiescent system, seethes with activity. One is its electrical conductivity. It is true that ice is not a very good conductor, but there are worse; in fact, the conductivity of pure ice is about the same as that of liquid water, although water is much more abundantly supplied with ions as charge carriers. A potential of 200 volts impressed across a one-inch cube of ice will produce a flow of a millionth of an ampere of current through the cube.

In metals and semiconductors electric current is carried by mobile electrons; in ice, as in some other solids and in liquids, it is carried by charged ions. It is convenient to think of the ions in ice as a kind of defect associated with the Bjerrum faults. The ions in ice are the hydronium ion (H_3O^+) and the hydroxyl ion (OH^-); these are also present in liquid water. Onsager and Marc Dupuis have suggested that their role in carrying current in ice resembles the transmission of Bjerrum faults. The hydronium ion, for instance, can transmit current by transferring its extra proton to the next ice molecule, which in turn will pass a proton to the next and so on [*see illus-*

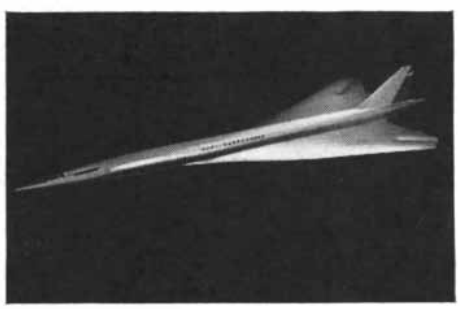


FIRST U.S. spacecraft to orbit the moon, to photograph earth from the moon and to photograph far side of moon, was NASA's Boeing-built Lunar Orbiter, shown above. Orbiter flew and maneuvered flawlessly throughout its mission. It photographed thousands of square miles along moon's equator to help NASA select level, safe landing sites for America's Apollo astronauts. In addition, Orbiter data revealed exact shape of moon and its gravitational characteristics. Astronomers report Orbiter sent back more moon information than had been learned in the past 50 years. Designed and built by Boeing for NASA, Orbiter's first flight began 28 months, 15 days after contract signing, shortest span ever for a major U.S. spacecraft.

Capability has many faces at Boeing

DASH, torpedo-carrying anti-submarine helicopter, operational with U.S. Navy, is powered by Boeing T50 gas turbine engine.

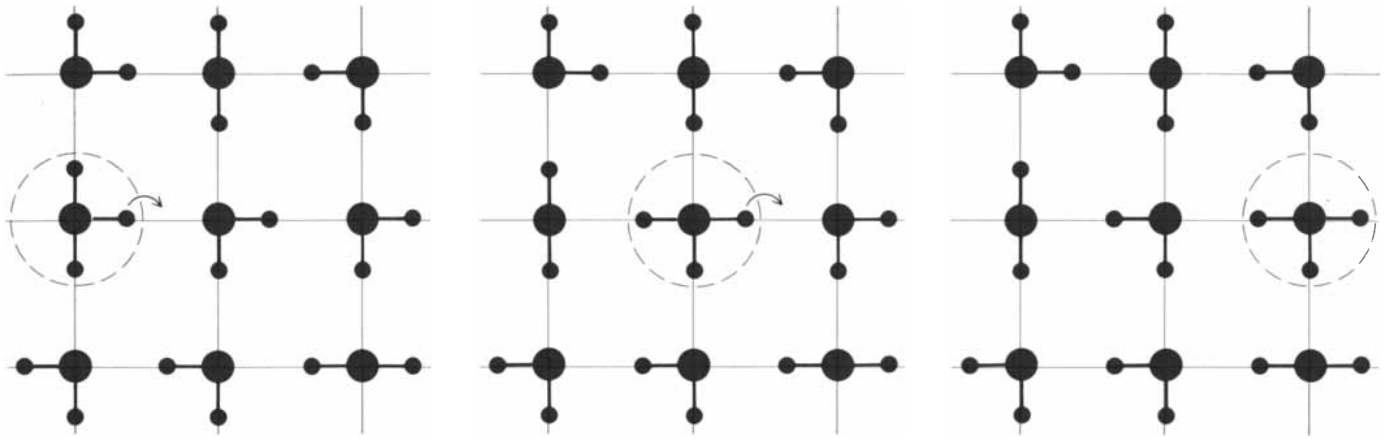
CH-47A, Boeing Chinook helicopters are deployed to Vietnam with 1st Cavalry Division (Airmobile). In its 30-foot payload compartment, the Chinook can transport a fully-equipped combat platoon, combat vehicles, infantry support weapons, or, as in recent rescue operation, 170 refugees.



SST. Boeing supersonic transport design features variable-sweep wing. Retracted, as shown above, wing and horizontal tail form integrated surface for maximum efficiency at supersonic speeds. Extended, wing provides added span and high-lift devices for maximum stability and control during low-speed approaches and landings.

BOEING

1916 * 50th Anniversary Year * 1966



HYDRONIUM ION MOVES at an extremely high speed through the crystal lattice of ice because the entire ion need not jump, just the extra proton (*arrows*). Because of the great mobility of its protons, ice shares many properties with electronic semiconductors.

tration above]. The ions are extremely rare in ice; according to Manfred Eigen and L. De Maeyer of the University of Göttingen, there are only one hydronium ion and one hydroxyl ion for about every million million molecules. The ions move so fast, however, that they convey an appreciable amount of current. Furthermore, in ice a "catcher" is always in position to catch the proton "pitched" by its neighbor, whereas in liquid, amorphous water there may be a wait for a molecule to arrive in a position to receive the pitch. This compensating factor enables ice to conduct electricity about as well as water even though it contains fewer ions.

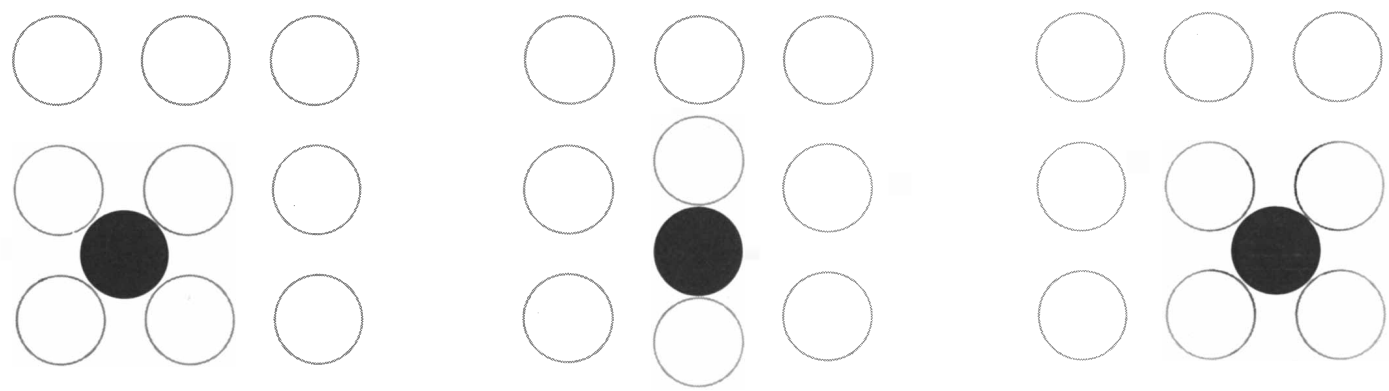
Ice can be called a semiconductor. Since its current-carriers are protons, whereas in the better-known semiconductors the carriers are electrons, Eigen describes ice as a "protonic" semiconductor. Indeed, Eigen has shown that ice can act as a transistor. The usual practice in making a transistor is to "dope" the semiconducting element with traces of impurities to add extra electrons. Eigen doped ice with small amounts of acids or bases (such as hydrogen fluoride, ammonia or lithium hydroxide) that increased the number of mobile protons, and he was able to construct a *p-n* junction device that rectified current.

Several years ago two Swiss chemists, W. Kuhn and M. Thürkauf of the University of Basel, reported a curious finding that has led to the discovery of still another kind of movement in the ice crystal. They used labeled molecules of water, tagged with a heavy isotope of hydrogen (deuterium) or an uncommon heavy isotope of oxygen (oxygen 18), as tracers whose travels in the crystals could be followed. Rather surprisingly it turned out that the rate of diffusion through the crystal was the same in both cases: the spread of deuterium was as rapid as that of oxygen 18. This indicated that the tagged atoms moved about in the crystal primarily as members of intact molecules, not as separate hydrogen or hydroxide ions.

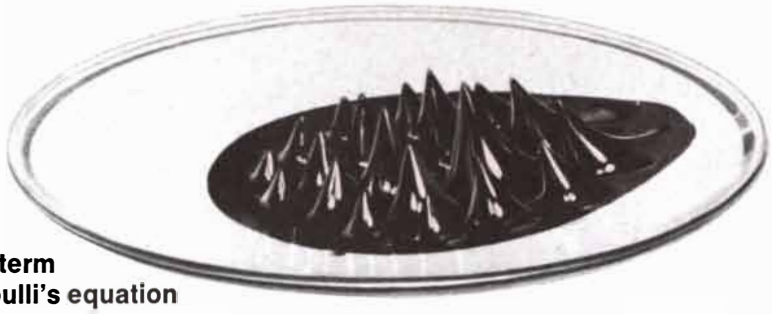
How can complete molecules move in the crystal lattice? The most satisfactory explanation seems to be that they are able to make their way through the open spaces, or channels, within the lattice. The normal thermal vibrations of the molecules may occasionally cause a molecule to jump out of its lattice site into an interstitial space between other molecules. From there it may either jump back or begin to wander about in the interstices of the lattice, perhaps to wind up kicking another molecule out of position and taking its place.

From various experiments, including measurements of the "relaxation" of nuclear magnetic resonance, which is a very sensitive indicator of molecular motion, we can derive an estimate of how often these jumps occur. The calculations lead to the conclusion that in ice at a temperature just below the melting point the average molecule jumps out of its lattice position about once every millionth of a second, and it travels an average distance of about eight molecules before regaining a normal lattice site. Thus the process takes place some 10 times faster than the in-place rotations described earlier!

The placid and symmetrical appearance of a crystal of ice is certainly deceiving. Inside, at the molecular level, the perfection is punctuated by imperfections, the order is disrupted by fascinating varieties of disorder, and an astonishingly busy traffic of molecules and defects is continuously charging about through the lattice. In short, there is a great deal more to ice than meets the eye.



INTERSTITIAL MOLECULE is another type of imperfection in ice crystals. Normal thermal vibrations may occasionally cause a molecule to jump out of its lattice site and begin to wander about through the channels, or open spaces, within the crystal lattice.

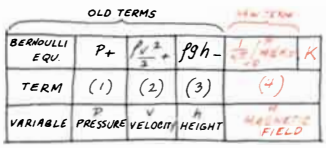


Adding another term to Bernoulli's equation

There is nothing quite as exciting and potentially useful in science as demonstrating experimentally the effect of adding a new term to a familiar old general equation. Avco, for example, has added a magnetic term to Bernoulli's classic equation for behavior of incompressible fluids, with the resulting promise of new advances in control systems, communications, computers and energy conversion.

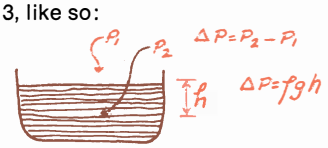
This was made possible when a team of Avco scientists perfected a process that enables us to suspend tiny single-domain magnetic particles in liquids without having the particles stick together or "flocculate."

Here is how the resulting "super-generalized" version of Bernoulli's equation looks:



The new term accounts for the effect of magnetic fields (H) on our ferrohydrodynamic (FHD) fluids with their magnetization properties, M.

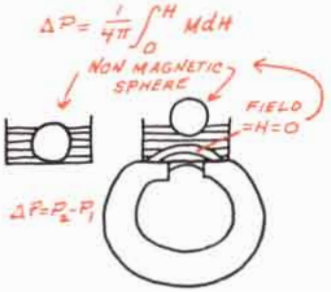
How will the equation predict the behavior of the new fluids? We use the same two-by-two pairing of terms that engineers have always used in applying the Bernoulli equation. Remember, for example, that if you want to find the pressure increase with depth in a tank of still liquid, you pair terms 1 and 3, like so:



Now we pair our new term 4 with the old terms 1, 2 and 3.

1—Increase of Pressure

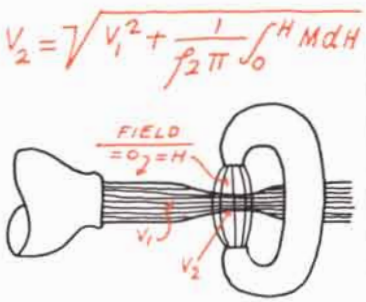
Pair terms 1 and 4 to find out how a magnetic field can increase the pressure of a ferrofluid. The field can float a heavy non-magnetic object that formerly sank to the bottom. The new term's definite integral is taken from zero field to strength of field at any point pressure is desired. The magnetization of fluid may vary as a function of H.



This effect could be used to devise a "no-mechanical-contact" journal bearing, for instance.

2—Increase Velocity

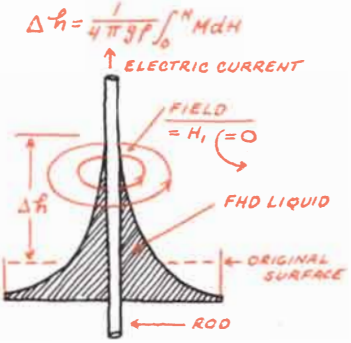
Pair terms 2 and 4 to find how magnetic field can locally speed up the flow of a free jet (like a stream from a hose). The jet will also neck down at speed-up point to maintain constant mass flow.



This effect could be used to provide communication between conventional electronic and new fluidic computers.

3—Increase Height

Pair terms 3 and 4 to find that magnetic field can effect the surface height of ferrofluid. This was responsible for the odd spikes coming up out of the surface of the ferrofluid in the photo at top of these columns. There, the spikes represented the fluid's way of achieving a minimum-energy balance surface energy and the new "fourth-term" energy.



This effect could be used to convert electrical signals into patterns for novel pattern-recognition schemes.

Other uses:

At this time, the FHD application nearest to realization is a hermetically-sealed viscous damper for satellites. But we also see applications ranging from magnetic printing inks to direct thermal-to-mechanical energy conversion.

FHD should provide a field day for inventors.

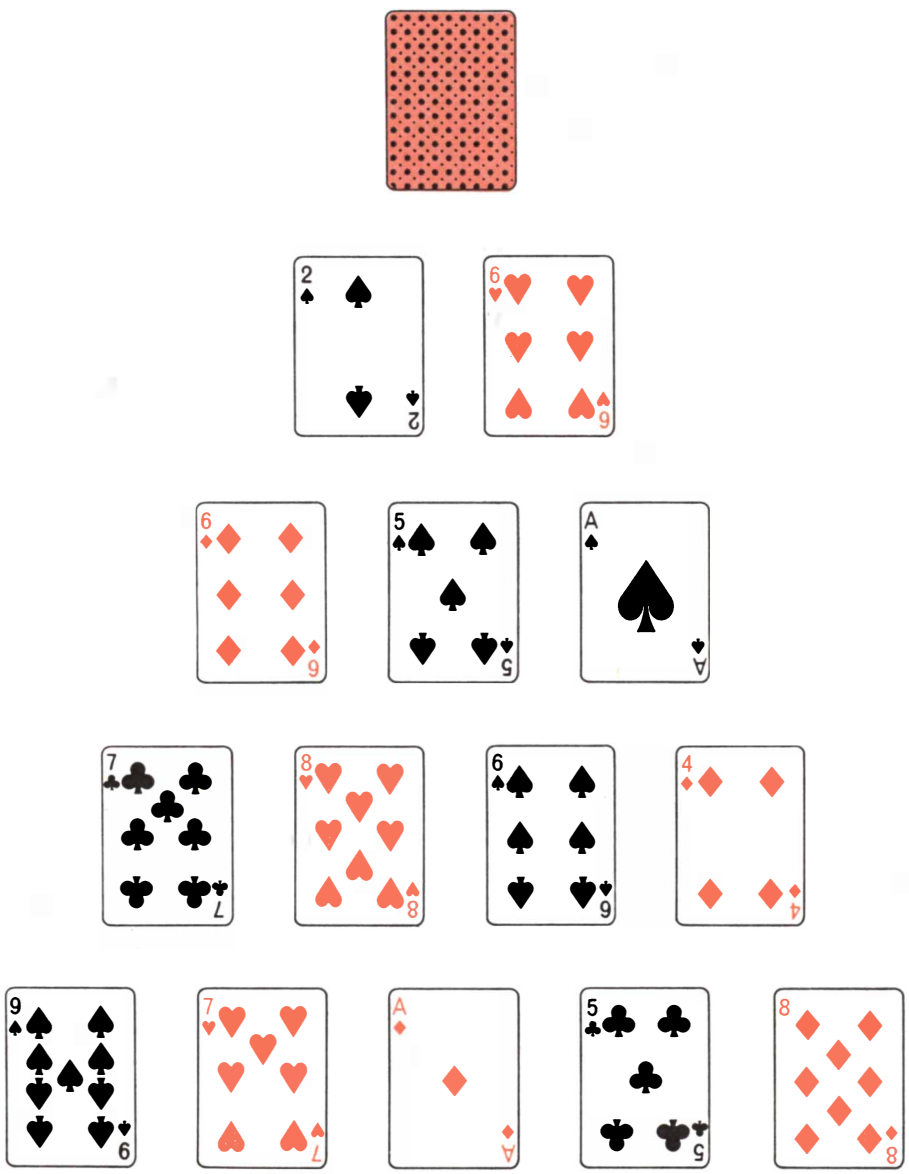
MATHEMATICAL GAMES

The multiple charms of Pascal's triangle

by Martin Gardner

Harry Lorayne, a professional magician and memory expert who lives in New York, has recently been puzzling his friends with an unusual mathematical card trick of his own invention. A spectator is given a deck from which the face cards and tens have been removed. He is asked to place any five cards face up in a row. Lorayne immediately finds a card in the deck that he puts face down at a spot above the row, as shown in the illustration below. The spectator now builds a pyramid of cards as follows:

Each pair of cards in the row is added by the process of "casting out nines." If the sum is above 9, 9 is subtracted. This can be done rapidly by adding the two digits in the sum. For example, the first two cards in the bottom row of the illustration add to 16. Instead of subtracting 9 from 16, the same result is obtained by adding 1 and 6. The sum is 7; therefore the spectator puts a seven above the first pair of cards. The second and third cards add to 8, so an eight goes above them. This is continued until a new row of four cards is obtained, and the procedure is repeated until the pyramid reaches the face-down apex card. When this card is turned over, it proves to be the correct value for the final sum.

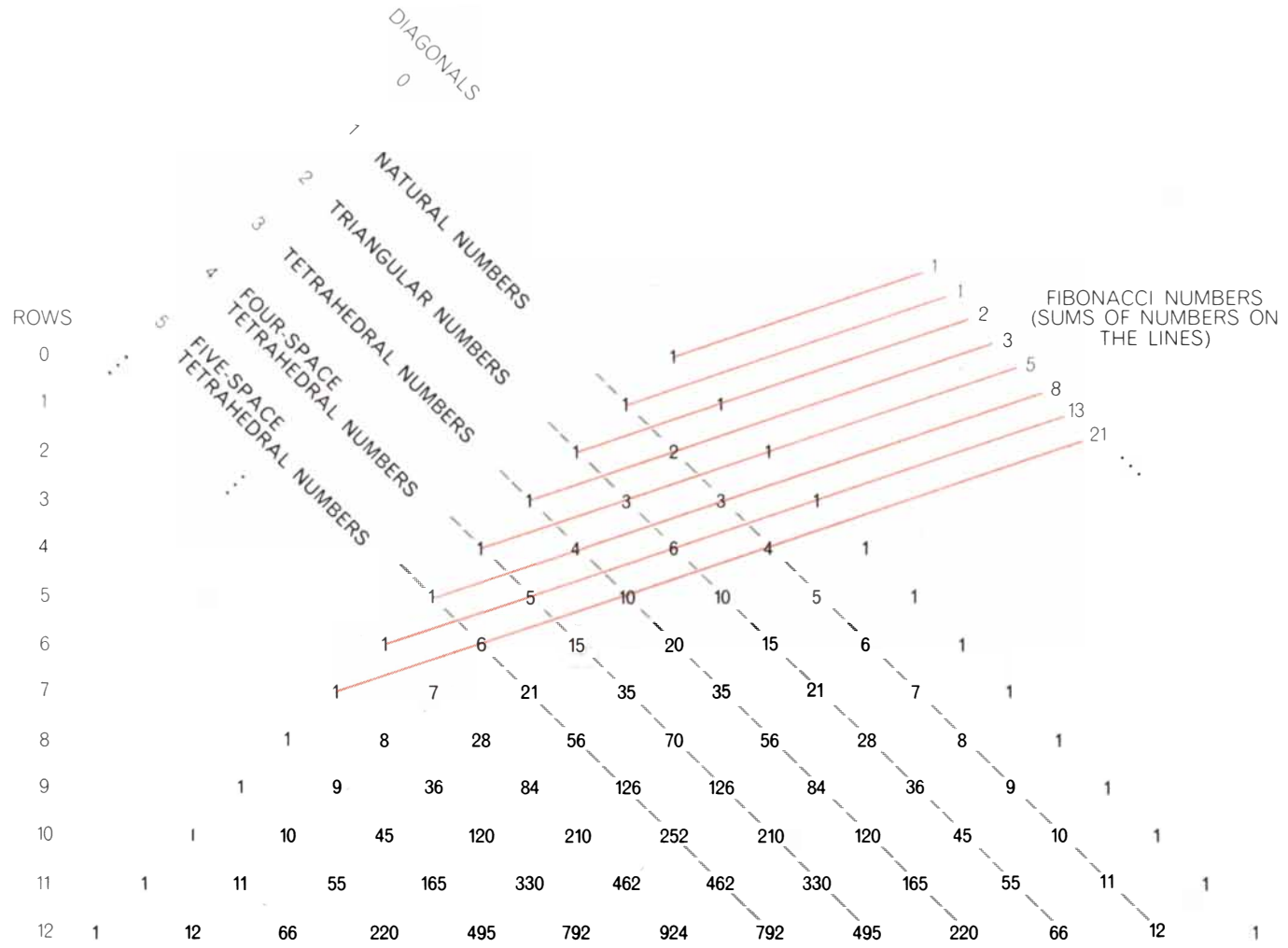


The apex card trick

The trick can be done with any number of cards in the initial row, although if there are too many there may not be enough cards to supply all the needed values for the pyramid. The computations can, of course, always be done on paper. A good version of the trick is to ask someone to jot down a row of 10 random digits. You can calculate the pyramid's apex digit quickly in your head if you know the secret, and it will always turn out to be correct. How is the apex digit determined? One's first thought is that perhaps it is the "digital root" of the first row—the sum of the digits reduced to a single digit by casting out nines—but this is not the case.

The truth is that Lorayne's trick operates with simple formulas derived from one of the most famous number patterns in the history of mathematics. The pattern is known as Pascal's triangle because Blaise Pascal, the 17th-century French mathematician and philosopher, was the first to write a treatise about it: *Traité du triangle arithmétique* (*Treatise on the Arithmetic Triangle*). The pattern was well known, however, long before 1653, when Pascal first wrote his treatise. It had appeared on the title page of an early 16th-century arithmetic by Petrus Apianus, an astronomer at the university in Ingolstadt. An illustration in a 1303 book by a Chinese mathematician also depicts the triangular pattern, and recent scholarship has traced it back still earlier. Omar Khayyám, who was a mathematician as well as a poet and philosopher, knew of it about 1100, having in turn probably got it from still earlier Chinese or Indian sources.

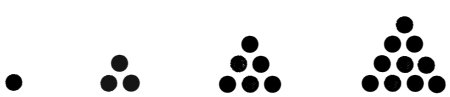
The pattern is so simple that a 10-year-old can write it down, yet it contains such inexhaustible riches, and links with so many seemingly unrelated aspects of mathematics, that it is surely one of the most elegant of all number arrays. The triangle begins with 1 at the apex [*see illustration on opposite page*]. All other numbers are the sums of the two numbers directly above them. (Think of each 1, along the two borders, as the sum of the 1 above it on one side and 0,



Pascal's triangle

or no number, on the other.) The array is infinite and bilaterally symmetric. In the illustration the rows and diagonals are numbered in the customary way, beginning with 0 instead of 1, to simplify explaining some of the triangle's basic properties.

Diagonal rows, parallel to the triangle's sides, give the triangular numbers and their analogues in spaces of all dimensions. A triangular number is the cardinal number of a set of points that will form a triangular array:



This sequence of triangular numbers (1, 3, 6, 10, 15...) is found in the triangle's second diagonal. (Note that every adjacent pair of numbers adds to a square number.) The first diagonal, consisting of natural numbers, gives the analogues of triangular numbers in one-dimensional space. The zero diagonal gives the analogue in zero-space, where the point itself is obviously the only possible pattern. The third diagonal contains tetrahedral numbers: cardinal numbers of sets of points that form tetrahedral arrays in three-space. The fourth diagonal gives the number of points that form hypertetrahedral arrays in four-space, and so on for the infinity of other diagonals. The nth diagonal gives the n-space analogues of triangular numbers. We can see at a glance such curious facts as that 10 cannonballs will pack into a tetrahedral pyramid and also a flat triangle, and that the 56 hypercannonballs in a five-space tetrahedron can be rearranged on a hyperplane to form a tetrahedron (but if we try to pack them on a plane in triangular formation, there will be one left over).

To find the sum of all the numbers in any diagonal, down to any place in the series, simply look at the number directly below and left of the last number in the series to be summed. For example, what is the sum of the natural numbers from 1 through 9? Move down the first diagonal to 9, then down and left to 45, the answer. What is the sum of the first eight triangular numbers? Find the eighth number in the second diagonal, move down and left to 120, the answer. If we put together all the balls needed to make the first eight triangles, they will make exactly one tetrahedral pyramid of 120 balls.

The sums of the more gently sloping diagonals, indicated by colored lines, form the familiar sequence of Fibonacci numbers, 1, 1, 2, 3, 5, 8, 13..., in which each number is the sum of the two numbers preceding it. (Can you see why?) The Fibonacci sequence often turns up in combinatorial problems. To cite one instance, consider a row of n chairs. In how many different ways can you seat men and women in the chairs provided that no two women are allowed to sit next to each other? When n is 1, 2, 3, 4..., the answers are 2, 3, 5, 8... and so on in the Fibonacci order. Pascal apparently did not know that the Fibonacci series was embedded in the triangle; it seems not to have been noticed until late in the 19th century.

And not until late this year was it noticed that by removing diagonals from the left side of the triangle one obtains partial sums for the Fibonacci series. The discovery was made by Verner E. Hoggatt, Jr., a mathematician at San Jose

State College who edits *The Fibonacci Quarterly*, a fascinating journal that has published many articles about Pascal's triangle. If the zero diagonal on the left side is sliced off, the Fibonacci diagonals have sums that are the partial sums of the Fibonacci series ($1 = 1$; $1 + 1 = 2$; $1 + 1 + 2 = 4$; $1 + 1 + 2 + 3 = 7$ and so on). If diagonals 0 and 1 are eliminated from the left side, the Fibonacci diagonals give the partial sums of the partial sums ($1 = 1$; $1 + 2 = 3$; $1 + 2 + 4 = 7$ and so forth). In general, if k diagonals are trimmed, the Fibonacci diagonals give the k-fold partial sums of the Fibonacci series.

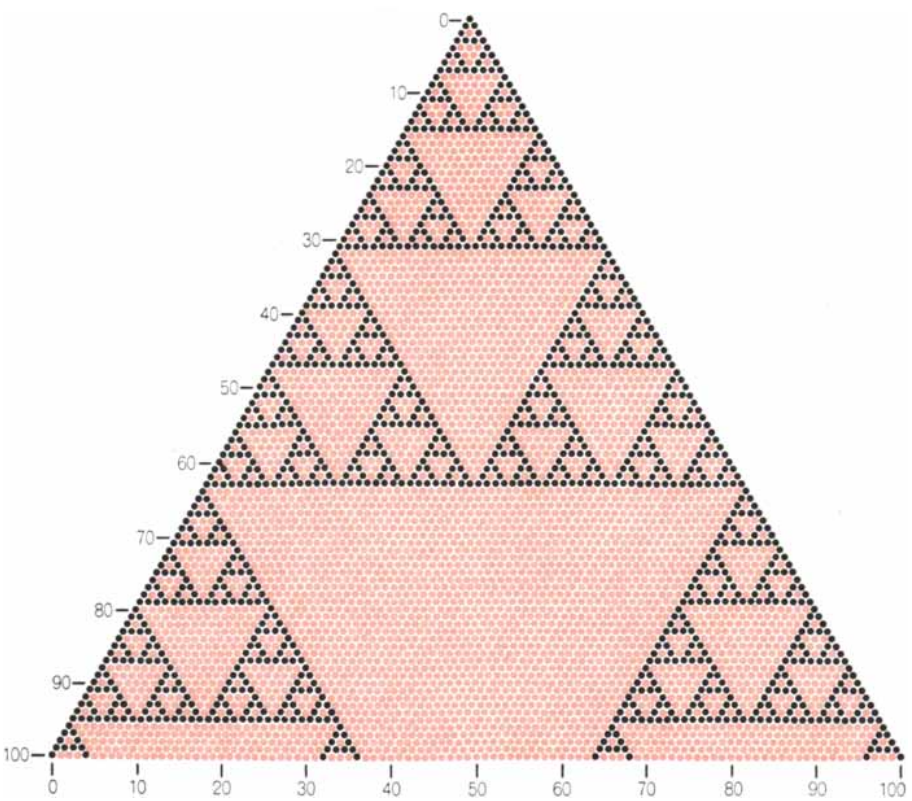
Each horizontal row of Pascal's triangle gives the coefficients in the expansion of the binomial $(x + y)^n$. For example, $(x + y)^3 = x^3 + 3x^2y + 3xy^2 + y^3$. The coefficients of this expansion are 1, 3, 3, 1 (a coefficient of 1 is customarily omitted from a term), which is the third row of the triangle. To find the coefficients of $(x + y)^n$, in proper order, merely look at the triangle's nth row. This basic property of the triangle ties it in with elementary combinatorial and probability theory in ways that make the triangle a useful calculating device. Suppose an Arab chief offers to give you any three of his seven wives. How many different selections can you make? You have only to find the intersection of diagonal 3 and row 7 to get the answer: 35. If (in your eager confusion) you commit the blunder of looking for the intersection of diagonal 7 and row 3, you will find that they do not intersect, so that the method can never go wrong. In general the number of ways to select a set of n elements from a set of r distinct elements is given by the intersection of diagonal n and row r.

The connection between this and probability is easily seen by considering the eight equally possible outcomes of getting heads or tails when flipping three pennies: HHH, HHT, HTH, HTT, THH, THT, TTH, TTT. There is one way to get three heads, three ways to get two heads, three ways to get one head and one way to get no heads. These numbers (1, 3, 3, 1) are, of course, the triangle's third row. Suppose you want to know the probability of exactly five heads showing if you toss 10 pennies in the air. First determine how many different ways five pennies can be selected from 10. The intersection of diagonal 5 and row 10 provides the answer: 252. Now you must add the numbers in the 10th row to obtain the number of equally possible cases. You can short-cut this addition by remembering that the sum of the nth row of Pascal's triangle is always 2^n. (The sum of each row is obviously twice the sum of the preceding row, since every number is carried down twice to enter into the numbers of the row below; therefore the sums of the rows form the doubling series 1, 2, 4, 8. . . .) The 10th power of 2 is 1,024. The probability of getting five heads is 252/1,024, or 63/256. (There is a mechanical device for demonstrating probability, often exhibited at science fairs and museums, in which hundreds of small balls roll down an incline through a hexagonal array of obstacles to enter slots and form an approximation of the bell-shaped normal-distribution curve. For a picture of such a device, and a discussion of how Pascal's triangle underlies it, see "Probability," by Mark Kac; SCIENTIFIC AMERICAN, September, 1964.)

If we represent each number of the triangle by a small dot and then blacken every dot whose number is not exactly divisible by a certain positive integer, the result is always a striking pattern of triangles. Patterns obtained in this way conceal many surprises. Consider the binary pattern that results when the divisor is 2 [*see illustration on this page*]. Running down the center there are colored triangles of increasing size, each made up entirely of even-numbered dots. At the top is a "triangle" of one dot, then the series continues with triangles of 6, 28, 120, 496... dots. Three of those numbers—6, 28 and 496—are known as perfect numbers because each is the sum of all its divisors, excluding itself (for example, $6 = 1 + 2 + 3$). It is not known if there is an infinity of perfect numbers, or if there is one that is odd. Euclid managed to prove, however, that every number of the form $2^{n-1}(2^n - 1)$, where $(2^n - 1)$ is a prime (primes of this form are called Mersenne primes), is an even perfect number. Leonhard Euler much later showed that all even perfect numbers conform to Euclid's formula. The formula is equivalent to

$$\frac{P(P + 1)}{2},$$

where P is a Mersenne prime. The above expression happens also to be the formula for a triangular number. In other words, if the "side" of a triangular number is a Mersenne prime, the triangular number is also perfect. Going back to the even-odd coloring of Pascal's triangle, it can be shown that the formula for the number of dots in the nth central triangle, moving down from the apex, is $2^{n-1}(2^n - 1)$, the formula for perfect numbers. All even perfect numbers appear in the pattern, therefore, as the number of dots in the nth central triangle whenever $2^n - 1$ is prime. Because $2^4 - 1 = 15$, which is not a prime, the fourth colored triangle is not perfect. The fifth triangle of 496 dots *is* perfect because $2^5 - 1 = 31$, a prime. (The sixth



Pascal's triangle with numbers represented by dots, the odd numbers by black dots

colored triangle is not perfect, but the seventh, with 8,128 dots, is.)

One final curiosity. If rows 0 through 4 are read as single numbers (1, 11, 121, 1,331 and 14,641), they are the first five powers of 11, starting with $11^0 = 1$. The fifth row *should* be $11^5 = 161{,}051$, but it is not. Observe, however, that this is the first row with two-digit numbers. If we interpret each number as indicating a multiple of the place value of that spot in decimal notation, the fifth row can be interpreted (reading right to left) as $(1 \times 1) + (5 \times 10) + (10 \times 100) + (10 \times 1{,}000) + (5 \times 10{,}000) + (1 \times 100{,}000)$, which gives the correct value of 11^5. Interpreted this way, each nth row is 11^n.

Almost anyone can study the triangle and discover more properties, but it is unlikely they will be new, for what is said here only scratches the surface of a vast literature. Pascal himself, in his treatise on the triangle, said that he was leaving out more than he was putting in. "It is a strange thing," he exclaimed, "how fertile it is in properties!" There are also endless variants on the triangle, and many ways to generalize it, such as building it in tetrahedral form to give the coefficients of trinomial expansions.

If the reader can solve the following five elementary problems, all to be answered in this department next month, he will find his understanding of the triangle's structure pleasantly enriched:

1. What formula gives the sum of all numbers above row n?

2. How many odd numbers are there in row 256?

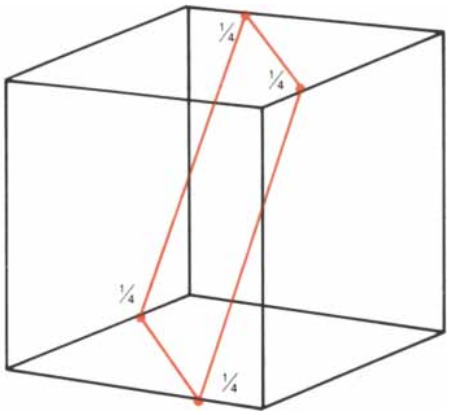
3. How many numbers in row 67 (in honor of the coming year) are evenly divisible by 67?

4. If a checker is placed on one of the four black squares in the first row of an otherwise empty checkerboard, it can move (by standard checker moves) to any of the four black squares on the last (eighth) row by a variety of different paths. One pair of starting and ending squares is joined by a maximum number of different routes. Identify the two squares and give the number of different ways the checker can move from one to the other.

5. Given an initial row of n cards, in the pyramid trick described at the beginning, how can one obtain from Pascal's triangle simple formulas for calculating the value of the apex card?

The answers to last month's problems follow:

A tesseract of side x has a hypervolume of x^4. The volume of its hypersurface is $8x^3$. If the two magnitudes are



Packing a square in a cube

equal, the equation gives x a value of 8. In general an n-space "cube" with an n-volume equal to the $(n-1)$-volume of its "surface" is an n-cube of side $2n$.

The largest square that can be fitted inside a unit cube is the square shown in the illustration above. Each corner of the square is a distance of 1/4 from a corner of the cube. The square has an area of exactly 9/8 and a side that is three-fourths of the square root of 2. Readers familiar with the old problem of pushing the largest possible cube through a square hole in a smaller cube will recognize this square as the cross section of the limiting size of the square hole. In other words, a cube of side not quite three-fourths of the square root of 2 can be pushed through a square hole in a unit cube.

The illustration at the right shows the 11 different hexominoes that fold into a cube. They form a frustrating set of the 35 distinct hexominoes, because they will not fit together to make any of the rectangles that contain 66 unit squares, but perhaps there are some interesting patterns they *will* form.

So many letters are still being received on the September problem of packing squares of sides 1, 2, 3...24 into a square of side 70 that I shall postpone publishing the best solution until next month.

A large number of readers sent comments on the science puzzles of August. Several believed the impact of falling sand in the hourglass paradox might play a role in keeping a buoyant hourglass at the bottom, but this is not true. The force of impact of a falling grain is balanced by its loss of weight in free fall, with a zero net effect.

Maya and Nicolas Slater wrote from London to say that, in the boat-carriage problem, if one abandons Lewis Carroll's proviso that elliptical wheels opposite each other must have their major axes at right angles, there is a way to make the carriage pitch and roll without any wheel's leaving the ground. The wheels must be geared so that *diagonally* opposite wheels keep their major axes at right angles. Regardless of the angle between the two front wheels, all four wheels remain on the ground at all times. If the front wheels are at a 90-degree angle, the carriage rolls without pitching; if the angle is zero, it pitches without rolling. All intermediate angles combine rolling and pitching. "Our preference is for 45 degrees," the Slaters wrote. "Our only problem is keeping our coachman."

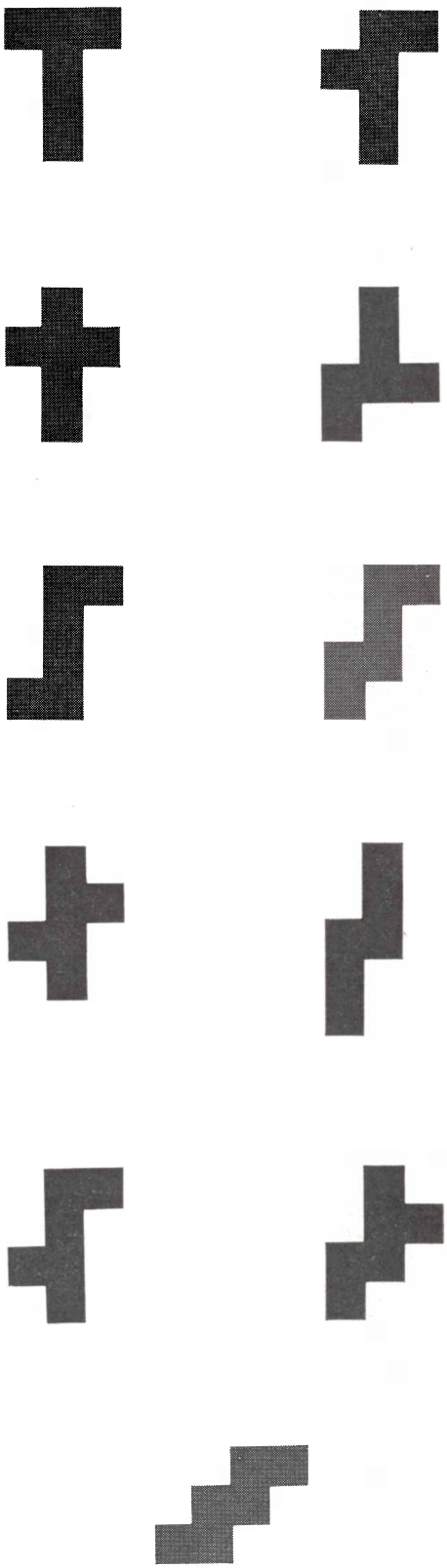
Many alternate solutions for the rope-stealing problem were received; some made use of knots that could be shaken loose from the ground, others involved cutting a rope partway through so that it would just support the thief's weight and later could be snapped by a sudden pull. Several readers doubted that the thief would get *any* rope because the bells would start ringing.

A number of readers corrected the statement that a peeled hard-boiled egg is drawn into a milk bottle by a vacuum created by the loss of oxygen when matches are burned inside. Oxygen is indeed used up, but the loss is compensated by the production of carbon dioxide and water vapor. The vacuum is created solely by the quick cooling and contracting of the air after the flames go out.

The coiled-hose paradox is more complicated than was indicated. If the funnel end of the empty hose is high enough, water poured into it will be forced over more than one winding to form a series of "heads" in each coil. The maximum height of each head is about equal to the coil's diameter. The diameter, times the number of coils, gives the approximate height the water column at the funnel end must be to force water out at the other end. (This was pointed out by John C. Bryner, Jan Lundberg and J. M. Osborne.) W. N. Goodwin, Jr., noted that for hoses with an outside diameter of 5/8 inch or less the funnel end can be as low as twice the height of the coils and water will flow all the way through a series of many coils. The reason for this is not yet clear.

Several readers thought of a second way, albeit a temporary one, to make a cork float at the center of the surface of a glass of water. Create a vortex with a spoon, then drop in the cork.

John Friedlein, who teaches mathematics at a high school in St. Charles, Ill., observed that not only does Christmas equal Halloween, as pointed out last month (Dec. 25 = Oct. 31 when the abbreviations are taken for the decimal and octal systems), but also Thanksgiving if it falls, as it sometimes does, on Novem. 27.



The 11 hexominoes that fold into cubes

A handful of people like Mary Carnwath are trying to keep our promise to the Indians. But they won't make it without you.

The Hopi Indians' village of Shipaulovi in Arizona sits on land so poor, infertile and inhospitable that so far nobody has tried to take it away from them.

Electricity has not yet reached the Hopis. Water must be hauled from three miles away. Jobs are few and far away. Only poverty and despair are close-by and in abundance.

Yet for the first time in generations, Mary Carnwath and people like her are stirring hope among the Hopis.

Mary Carnwath works and lives two thousand miles away, in Manhattan. Her own daughter is now grown-up, and through *Save the Children Federation* she is sponsoring one of the village girls, 8-year-old Grace Mahtewa.

The Mahtewas (two parents, three children, one grandmother and a sister-in-law) live tightly packed in a tiny rock and mud house. The father who knows ranch work but can't find any most of the year, isn't able to provide the family with even the bare necessities.

Grace, bright, ambitious and industrious, would possibly have had to quit school as soon as she was old enough to do a day's work. But, because of Mary Carnwath, that won't be necessary.

The $12.50 a month contributed by Mary Carnwath is providing a remarkable number of things for Grace and her family.

Grace will have a chance to continue schooling. The family has been able to make its home a little more livable. And with the money left over, together with funds from other sponsors, the village has been able to renovate a dilapidated building for use as a village center. The center now has two manual sewing machines that are the beginnings of a small income-producing business. It's only a small beginning. More money and more people like Mary Carnwath are needed. With your help, perhaps this village program will produce enough money to end the Hopi's need for help. That is what Save the Children is all about.

Although contributions are deductible, it's not a charity. The aim is not merely to buy one child a few hot meals, a warm coat and a new pair of shoes. Instead, your contribution is used to give the child, the family and the village a little boost that may be all they need to start helping themselves.

Sponsors are desperately needed for other American Indian children —who suffer the highest disease rate and who look forward to the shortest life span of any American group.

As a sponsor you will receive a photo of the child, regular reports on his progress and, if you wish, a chance to correspond with him and his family.

Mary Carnwath knows that she can't save the world for $12.50 a month. Only a small corner of it. But, maybe that is the way to save the world. If there are enough Mary Carnwaths. How about you?

Save the Children Federation is registered with the U.S. State Department Advisory Committee on Voluntary Foreign Aid, and a member of the International Union of Child Welfare. Financial statements and annual reports are available on request.

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SA-12-6

New Alcoa research paper evaluates methods of testing weldments for susceptibility to stress-corrosion cracking.

Practically all commercial aluminum alloy weldments are resistant to stress-corrosion cracking. However, the search for ever-stronger aluminum alloys, such as for armor plate, leads investigators into complex alloy systems for which the resistance to stress-corrosion cracking is a necessary consideration.

What causes stress-corrosion cracking?

Stress-corrosion cracking is cracking that is initiated by localized corrosion synergized by sustained tensile stress at the surface.

According to the theories developed by Alcoa in 1940 and 1944, stress-corrosion cracking of aluminum alloys begins at the grain boundaries of the metal. Hence, stress-corrosion cracking of aluminum alloys is characteristically intergranular. Stress-corrosion cracking can occur when three conditions are present:

Susceptible composition and metallurgical structure • High tensile stress at the surface • Specific environment

Alcoa's basic research in stress corrosion and tests of new alloys and applications have employed various methods of testing weldments. Our evaluation of these methods, as well as test results, is presented in a new 17-page paper. The investigated techniques for applying tension include the use of both constant-load and constant-deformation methods. Four types of specimen are evaluated: simple beam, U-bend, tensile specimen and residual-stress specimen. Besides evaluating test methods, the paper also includes the results of testing seven structural alloys, including three from the 7000 series, as well as five weld-filler alloys. This paper documents another addition to the thousands of man-years that Alcoa has spent on aluminum research.

When you want authoritative answers about aluminum, come to Alcoa. Would you like to learn more about testing weldments for stress corrosion? Write Aluminum Company of America, 904-M Alcoa Building, Pittsburgh, Pa. 15219. Ask for the paper *Evaluation of Various Techniques for Stress-Corrosion Testing Welded Aluminum Alloys* by M. B. Shumaker, R. A. Kelsey, D. O. Sprowls and J. G. Williamson.

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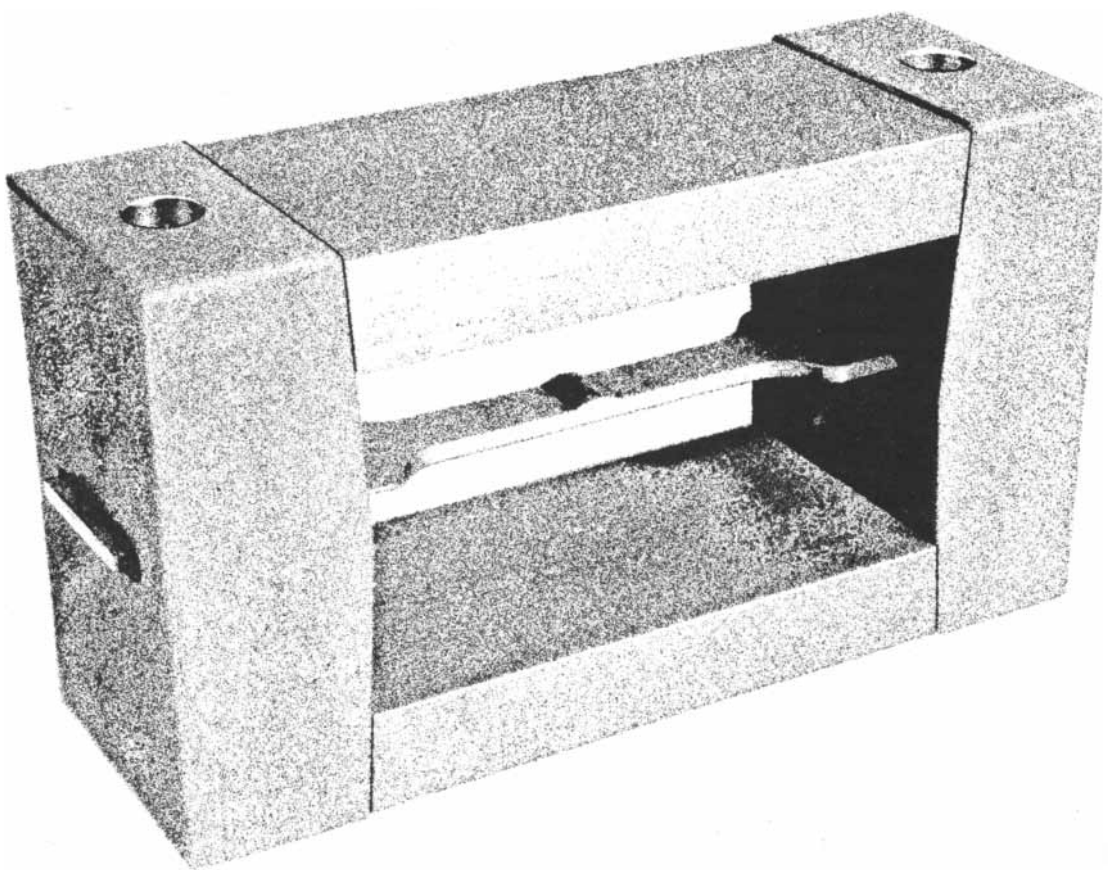


THE AMATEUR SCIENTIST

An amateur's experiment in animal behavior and a study of the salty rain of Venezuela

Conducted by C. L. Stong

Among the various kinds of experiment undertaken by amateurs, experiments in animal behavior are fairly rare. The reason may be that the potential experimenter, being himself a member of the animal kingdom, realizes that animals are complex systems and rather unpredictable. The fact remains that experiments in animal behavior can be profitably performed by the amateur, provided he is modest and realizes that his results may not be as conclusive as, say, an elementary experiment in physics.

A case in point is an experiment in the behavior of chicks performed last year as a science-fair project by Elizabeth Neville of Calgary, Alberta. At the time Miss Neville was only 13! In describing her experiment it will be helpful to consider first two similar kinds of experiment in the literature of animal behavior.

A traditional question about animal psychology concerns whether or not animals perceive colors the way human beings do. In one classic experiment Karl von Frisch of Austria demonstrated that honeybees can distinguish between blue and white. The insects were first trained to feed on sirup that had been placed against a blue background. Sirup was then applied to a blue square set in a checkered design of gray squares that ranged in tone from near-white to near-black. Frisch reasoned that the intensity of light reflected by a particular gray square of the series would match the intensity of the blue square. Unless the bees were endowed with a color sense they would be unable to distinguish the blue square from the matching gray square. When the insects were released, the majority flew directly to the colored square, a positive response indicating that honeybees do perceive blue. In subsequent experiments other investigators substituted translucent windows of various colors for Frisch's opaque squares. These experiments indicated that bees are blind to deep red but sensitive to bands of color in the yellow-green, blue-green and blue regions of the spectrum, and to ultraviolet radiation that is not perceived by the human eye.

Similar questions can be asked about how animals perceive form. Robert L. Fantz of Western Reserve University has described an experiment for determining the preference of newly hatched chicks for food particles of certain shapes, principally with the objective of discovering if such preferences are partly innate [see "The Origin of Form Perception," by Robert L. Fantz; SCIENTIFIC AMERICAN, May, 1961]. He first made up synthetic particles about the size of seeds in various two-dimensional and three-dimensional shapes. The two-dimensional particles ranged in form from circles to triangles and the three-dimensional ones from spheres to pyramids. To eliminate the influence of such factors as touch, taste and smell he enclosed each particle in a transparent capsule of plastic. The capsules were attached to sensitive switches in an electrical counting apparatus and arranged along one wall of a box within easy pecking reach of the chicks. The chicks were hatched in total darkness and tested before they encountered any food. More than 1,000 birds served as subjects. They pecked 10 times oftener at the sphere than at the pyramid. Objects about an eighth of an inch in diameter were preferred to other sizes. Among the flat forms circles were preferred to triangles. These results demonstrate that the chick is endowed with an inborn ability to discriminate shape and with the tendency to peck at those shapes that resemble the shape of its natural food.

Miss Neville's experiment took up the perception of both color and form. Do chicks have an innate preference for color as they do for form? If so, does the preference for color take precedence over preference for shape? As subjects for the experiment she selected 12 chicks about 20 hours old that had never eaten before. Her apparatus consisted of a box 24 inches long, 15 inches wide and six inches high. The food particles used in the experiment were made of moistened white bread pressed to a thickness of about one millimeter, dyed with food coloring and cut or molded into spheres, disks and equilateral triangles three millimeters in diameter. Another group consisted of triangles 1.5 millimeters thick but with the same diameter. She dyed 120 particles of each shape brown and 60 particles red.

Before running the first test Miss Neville checked the materials and procedure by offering the food particles to a group of chicks that was not used in the subsequent experiment. The check revealed that isolated birds refused to eat and that the particles were somewhat too large. The particle size was reduced to two millimeters. The experimental birds were then put into the text box in groups of six along with 120 dry brown food particles equally divided among spheres, disks and thin and thick triangles. The various shapes were mixed and distributed uniformly on the floor of the box. The birds refused to eat the food. They were removed after 15 minutes and the food was moistened. On being returned to the box the chicks began to eat and were allowed to do so for five minutes. During this interval they consumed 11 spheres, nine thin triangles, three thick triangles and two disks. Because of the strong preference shown for spheres and thin triangles the box was then stocked with 30 each of these two shapes in red and brown. The remaining six chicks were placed in the box for five minutes. The consumption was nine brown triangles, eight brown spheres, one red triangle and no red spheres. Statistically there is less than one chance in 100 that random pecking could account for this score.

Both experiments were repeated 24 hours later. Meanwhile the chicks had been given normal "starter" feed for 20 hours. The preference for brown spheres and brown thin triangles per-

sisted, as in the first experiment. A second group of birds was then placed in the box along with 15 particles each of all shapes and both colors. The chicks ate with such vigor that they had to be removed at the end of two minutes. The score: 15 brown spheres, 12 brown disks, 12 brown thin triangles, 13 brown thick triangles, 11 red spheres, 11 red disks, seven red thick triangles and four red thin triangles.

"From these results," writes Miss Neville, "it appears that, when form is held constant, chicks show a significant preference for brown over red, which may be explained by an inborn preference for the natural color of seeds. The preference for brown over red was displayed even more prominently during the second experiment than the data suggest, because the birds pecked at the brown shapes first and did not start on the red ones until the brown became scarce. In the matter of preference for form the results do not agree with Fantz's observation that chicks prefer spheres to pyramids. This disagreement might be explained by the fact that spheres tended to roll out of the beaks of my newly hatched chicks, although they pecked at them frequently. The results of my second experiment are more closely in accord with Fantz's. By then the birds had developed some skill in eating. The experiments suggest that newly hatched chicks have an inborn preference for color and that their preference for color is stronger than it is for form. I should like to recheck these conclusions by an experiment based on a different concept but so far I have not succeeded in designing one."

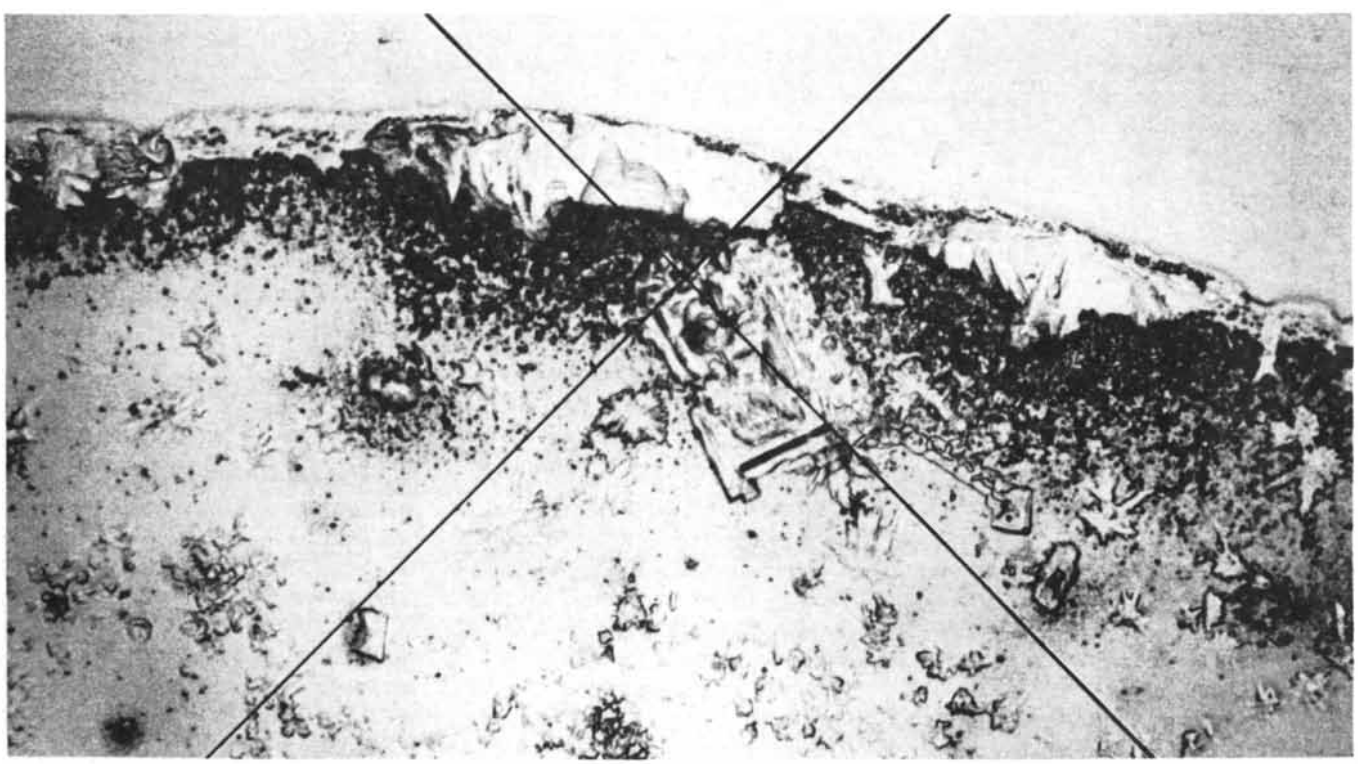
A few years ago Guillermo Zuloaga, a geologist who lives in Caracas, Venezuela, took time off from his professional work to make a study of the thick haze known as the *calina* that annually reduces visibility to almost zero along the northern coast of South America (see "The Amateur Scientist," SCIENTIFIC AMERICAN, October, 1961). Zuloaga has now made a similar study of another aspect of the Venezuelan climate: the periodic wind called the *alisio* that blows the *calina* away.

"This story," he writes, "is about the surprising content of marine salts I found in the water of the first rains that fall after the long dry season in Venezuela, and the relation of these salts to the trade wind known in Spanish as the *alisio*.

"All along the coast of Venezuela, which stretches more than 1,000 kilometers at the southern edge of the Caribbean Sea, the *alisio* blows steadily from the northeast most of the year. The influence of this wind on our climate is enormous. Because of it we have a very mild climate. Were it not for the *alisio* Venezuela would be as hot and humid as countries in Africa and Asia at the same latitude. The name *alisio* comes from the Greek *aliso,* which means 'salting.' Possibly some erudite conquistador in the distant past gave this fitting name to our wind. It is about its 'salting' characteristic that I wish to comment.

"The *calina* forms when airborne droplets of water from the sea partially evaporate and leave microdrops of brine suspended in the lower atmosphere. The presence of the *calina* does not increase the relative humidity as measured by either the hair hygrometer or the wet-and-dry-bulb thermometer, but it creates the impression of high humidity; the air feels 'thick,' yet the relative humidity may measure less than 50 percent.

"Now we come to the study with which I have been lately amusing myself. On the afternoon of April 14 this year the air in Caracas was stifling. The temperature in my house reached 90 degrees Fahrenheit, almost a record for the city. The relative humidity was 50 percent. As I was driving downtown two or three drops of rain fell on the windshield of my car; I noticed that they dried almost immediately, leaving white spots. This sparked my curiosity. I hurried back home, attached a number of clean microscope slides to a little board and attached the board to the car so that the slides would be exposed to the air as I drove. For two hours I drove

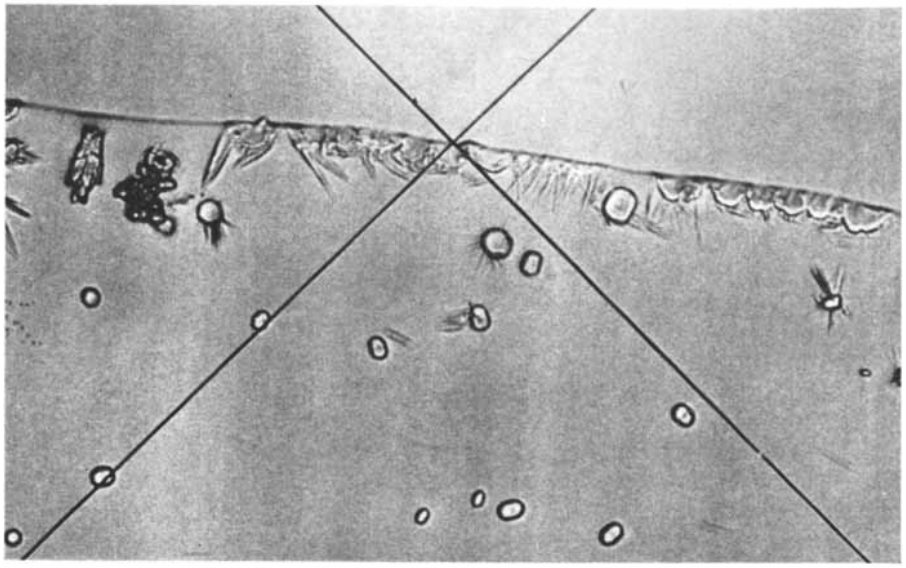


Progressive crystallization of sodium chloride and gypsum in a drop of salty rain

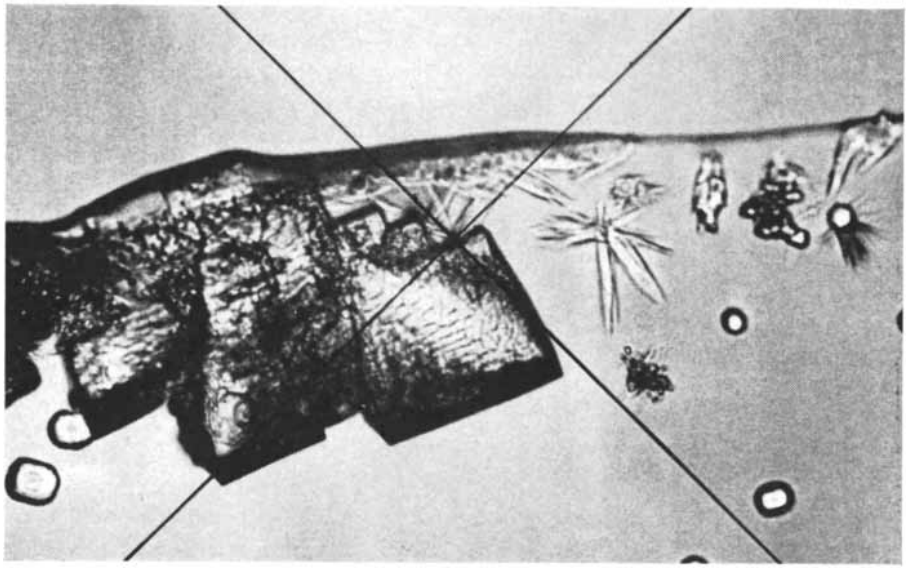
back and forth, but not another drop of rain fell. Fortunately our wet season was due, and on the afternoon of April 19 we had our first rain. It was not abundant, but I was ready for it and collected 250 milliliters of rainwater in trays and many drops on microscope slides. Some friends who were spending the day at the beach knew of my interest and collected additional specimens in clean ashtrays.

"The drops that fell on the microscope slides left patches of white when they dried, and I hurried to examine the patches under the microscope. In addition to a little ash and dust there were abundant crystals of common salt together with other crystals that took me some time to identify. These crystals turned out to be hydrated calcium sulfate, more commonly known as gypsum [*see illustration on opposite page*]. The collected water was filtered and boiled down to about a third of its volume. I sent some to a friend for spectroscopic examination; with the remainder I made drops and let them dry. In every case I obtained abundant salt crystals. The smaller crystals were gypsum, and there were still smaller ones I could not positively identify.

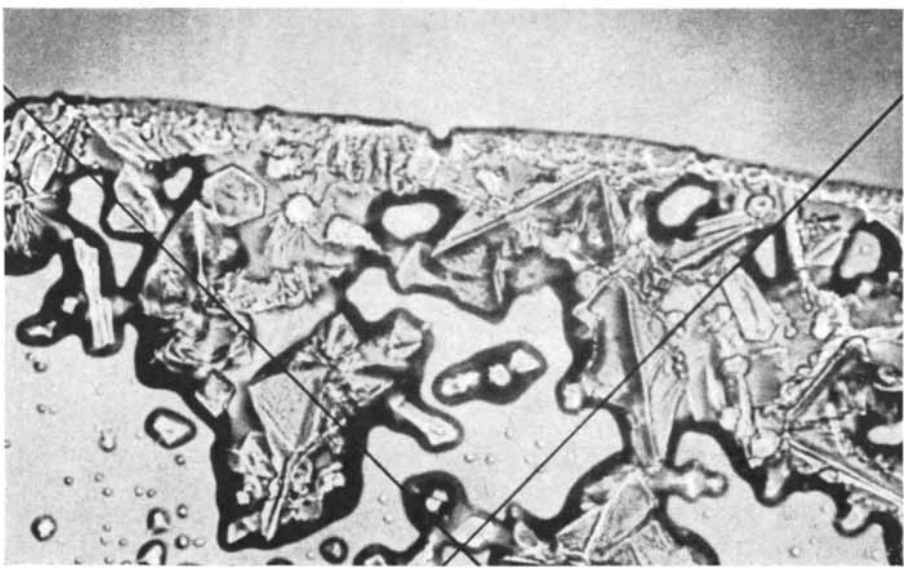
"The presence of gypsum came as something of a surprise. I had not identified it in the *calina*. Following the lead that the *calina* originates in the sea, I drove down to the beach and collected a specimen of seawater. The drops crystallized on the microscope slide as I watched—a fascinating phenomenon to observe. Crystallization proceeds not in the order of the abundance of the different salts but in the order of their decreasing solubility. To identify the respective substances I had to refresh my memory on the chemical composition of seawater and the solubility of its contents. When about 80 percent of seawater has evaporated, gypsum begins to crystallize out of it. Gypsum makes up only about 2.5 percent of the solids in solution. Common salt, or sodium chloride, appears when the volume of the water has been reduced about 90 percent. Actually I found a considerable overlap in the crystallization process. The retreating edge of the drops, as seen in the microscope, had a rapidly growing band of both common salt and gypsum, the salt in cubes and the gypsum in thin plates. Both large cubes of common salt and the branching crystals called dendrites were forming in the center of the drop at the same time as the gypsum. Quantitative analysis of the rainwater indicated a sodium con-



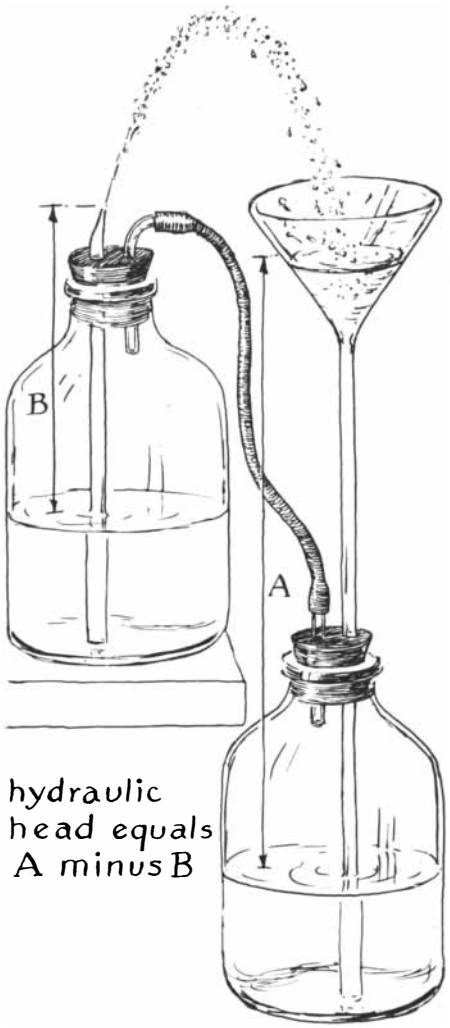
First stage of progressive crystallization in a drop of seawater



Second stage of crystallization in a drop of seawater



Third stage of crystallization



The fountain of Hero in modern form

centration of 17 parts per million; this concentration, added to the concentration of chlorine, would make a solution about 1,000 times more dilute than seawater. Other elements present in the rainwater were calcium, magnesium, zinc, silicon, boron, iron, aluminum and other metals found in seawater.

"For the last experiment in the series I picked up a few drops of morning dew from the grass in my garden. On letting these dry I was amazed to find a high concentration of salts, and particularly to observe how deliquescent they were. I had to put the slides on a hot plate for two hours before even partial crystallization occurred. Evidently our dew contains a higher proportion of magnesium chloride to sodium chloride than rainwater does.

"As the *alisio* developed and more rains came I collected drops from a series of rains. It would seem that the *alisio* does not simply blow the *calina* away; the rains that come with the *alisio* wash the *calina* out of the air. The *calina* is not entirely washed out by a few short rains. When the *alisio* diminished and the weather cleared for a few days, the concentration of salt in the atmosphere built up. The last traces did not disappear until the rainy season was in full swing.

"One is tempted to speculate on what effect the salty rains of the *alisio* have on the vegetation in this part of the world. One might at first assume that the effect would be uniformly adverse. That this assumption may be wrong is suggested by two recent conversations I have had with botanists. Plants do, after all, require not only water but also small quantities of mineral nutrients. One botanist remarked that the salt content of the *alisio* rains might at last explain why Venezuela has such thriving epiphytes: plants that grow not in the soil but aloft on trees or even on telephone wires. The mineral nutrients needed by the epiphytes may be airborne in the *alisio* rains. The other botanist simply mentioned a saying of the local farmers: 'A good rain after the dry season is better than a thousand waterings.' "

An amusing device that appears to defy gravity can be assembled in a few minutes from a pair of stoppered bottles, a funnel, a pair of glass tubes and a short length of rubber hose. First two holes are made in each stopper. The funnel is thrust through a hole in one stopper so that the spout comes close to the bottom of the bottle. A length of glass tubing is heated at one end and stretched to form a nozzle about a millimeter in diameter. The open end of the tube is pushed through the second stopper so that it comes close to the bottom of that bottle. The remaining holes in the stoppers are used for interconnecting the air spaces in the two bottles through glass nipples and the rubber tubing, as shown in the illustration on this page. All the connections must be airtight. The bottle that contains the nozzle is filled with water and supported so that it is about a foot higher than the empty bottle.

Now for the action. Prime the apparatus by pouring an ounce or two of water into the funnel. A slender stream will promptly spout from the nozzle and rise several inches higher than any part of the apparatus. If the stream is directed into the open mouth of the funnel, the level of the water in the funnel will thereafter remain constant, apparently circulating endlessly through the apparatus. Can this be perpetual motion? The explanation will soon become evident to those who perform the experiment. The inventor of this ingenious fountain, Hero the Elder of Alexandria, enjoyed puzzling friends with it some 2,000 years ago. The effect can be made more pleasing by directing the nozzle straight up from the center of the funnel. The jet then functions as a classical fountain. This modification requires a longer glass tube for the nozzle, and two bends. If you do not happen to have a funnel of the type shown on this page, just extend the spout of an ordinary funnel by coupling a glass tube to it through a short length of rubber hose.

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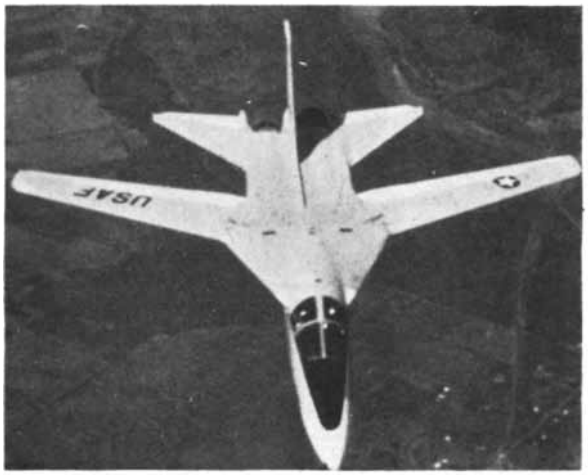

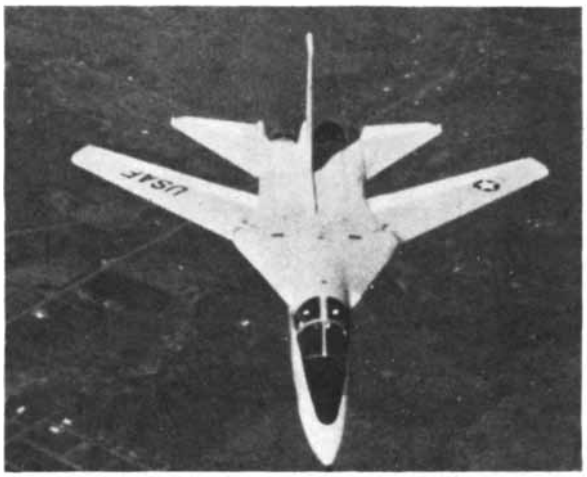

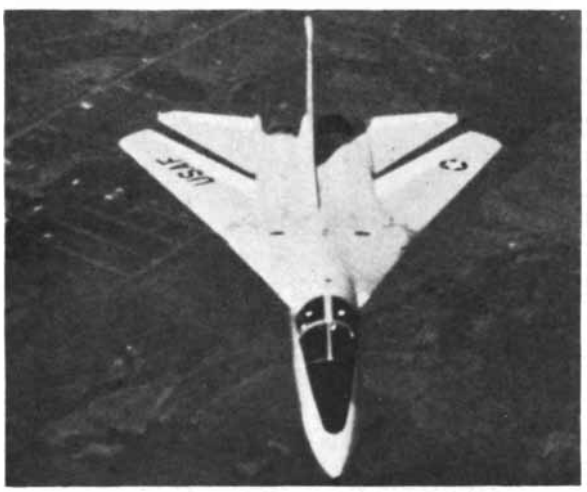

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BOOKS

A Christmas survey of new books about science for younger readers

by Philip and Phylis Morrison

James R. Newman's annual survey of children's books about science in the December issue of *Scientific American* has for many years been a valued guide to teachers, parents and all other friends of children. Here we continue his work. As Newman often remarked, it is not possible for any such collection of reviews to be all-inclusive. We have reviewed about one book out of six actually received, and out of many more known to us by claim or title. For each book we mention we omitted one we judged to be nearly as good. Still, the books we do mention are to our taste the best.

There is one general comment to be made. We were struck by the fact that some of the books we received were excellent in choice of topic, admirable in appearance but misleading or even mistaken in content. These books regularly turned out to be the product of authors who did not have a background in the subject. It would appear that such books originate with the uninformed hopes of the publisher rather than with any knowledge and enthusiasm on the part of the author, and perhaps they are not worth publishing. Of course there are exceptions. We know excellent children's books about science written by gifted nonexperts who love the subject and have taken the trouble to steep themselves in it, and we have seen bad books written by professional masters of the subject.

Happily there are so many admirable books that we need dwell no further on the unsuccessful ones.

Physical Sciences

THE FIRST BOOK OF MARS, by David C. Knight. Franklin Watts, Inc. ($2.65). REPORT FROM MARS: MARINER IV 1964–1965, by the Jet Propulsion Laboratory of the California Institute of Technology. U.S. Government Printing Office (50 cents). MARINER IV TO MARS, by Willy Ley. New American Library, Inc. (60 cents). Knight's book—brief, handsome, with a ground-based color photograph of the planet—is meant for readers from 12 up. It is the only one of the three to show all 21 of the *Mariner IV* photographs. He tells the stories well: the Orson Welles radio program, the misnamed "canals," the strange little moons, the polar caps (with a long sequence of photographs). The book fulfills its title splendidly.

The Jet Propulsion Laboratory has produced a booklet of which the Government Printing Office can be proud. Good color photographs of *Mariner IV* in the making and at launch complement a text centered, quite properly, around the hardware, the design and the fortunate events of the voyage. For readers of high school age and older.

Willy Ley has written another of his rich accounts, dwelling on the history of our knowledge and error about Mars. Among the fresh and fascinating sources quoted are a recent eyewitness to what may have been a meteorite impact on Mars and early European novels about Mars. The book is a best buy; it deserves a more lasting format than this newsstand paperback. Also for readers of high school age and up.

THE MATHEMATICS OF SPACE EXPLORATION, by Myrl H. Ahrendt. Holt, Rinehart & Winston, Inc. ($2.95). THE PHYSICS OF SPACE, by Richard M. Sutton. Holt, Rinehart & Winston, Inc. ($2.95). Aimed at high school students seriously interested in space, these two books are outstanding members of a series sponsored by the National Aeronautics and Space Administration. Ahrendt presents clear, brief chapters built around the main algebraic formulas involved in understanding space flight. For example, he gives formulas for free fall, distance to the horizon, the atmospheric pressure-height relation, rocket velocity as a function of mass ratio, and elliptical orbits. He gives the needed data and then a list of problems, chiefly numerical. The answers are given in the back of the book. A group of students who worked at this book would learn solidly. For high school students and enthusiasts of the seventh and eighth grades.

The Sutton book is a series of supple and attractive chapters based mainly on small experiments and demonstrations. This is not a problem-book like the first; it has complete guidance for a series of demanding but practicable projects related to space, to the earth and to the physics of space flight. The same kind of readers will be well served. Grown people who are *not* space experts will find both books of value, although Ahrendt is rather too difficult if you do not like to calculate.

THE CHRISTMAS SKY, by Franklyn M. Branley. Thomas Y. Crowell Company ($3.75). The Star of Bethlehem is here sought by reason. Page by page in this clear and gentle book the possibilities are explored. It was not a meteor, because it endured; it was not a comet, because it was welcome; it was not a nova. The birth of Jesus is carefully and convincingly dated from the circumstances of history. It is assigned to the spring (the flocks are not in the fields at the winter solstice), probably of the year 6 B.C. In that very season there was a rare close triple conjunction of Mars, Jupiter and Saturn in the constellation Pisces, where a similar event had traditionally heralded the birth of Moses. Magi, comets, blazing suns and intricate planetary configurations, city walls and bearded kings lead up to a "Holy Family Receiving Gifts," set forth in a glow of colored block prints by Blair Lent in an artful, up-to-date version of a simple, reverent and antique style.

THE CHEMISTRY OF A LEMON, by A. Harris Stone. Prentice-Hall, Inc. ($3.50). Bound between lemon yellow covers, with lemon yellow endpapers and many pen-and-ink drawings each bearing somewhere its telltale yellow mark, this novel and charming books deals, as almost no others of its kind do, with reality. Here reality is a lemon. There are two

dozen genuine experiments to be done with the fabric and the acid and the oil a lemon provides, all of them described in the right way—by questions. There are things simple enough for a beginner of eight or nine, yet it is not likely that anyone but a professional will be able to carry out all the investigations implied. A pioneer work, a success, a beauty. Its editors have not understood it, and have somewhat marred its clarity by errors of layout, but this book is strong enough to dissolve such minor stains.

GEOLOGY ILLUSTRATED, by John S. Shelton. W. H. Freeman and Company ($10). The proud title of this eye-filling book is justified. Four hundred photographs, mostly stunning aerial views taken by the author himself in the West, with accompanying drawings by his cartographer brother, present the basis of physical geography in the field. With a rare skill at explanation and a delicate sense of evidence, Shelton argues for the work of thrust and uplift, ice and water, and unites the processes in a dozen type localities crowned by the Grand Canyon. Here is physical geology remade as fresh as it was a century ago, into a triumph of direct observation and clear thought, not a set of conventional assertions with formal names. An outstanding book for self-study or for a college text. It is also suitable for interested readers in high school or in the home.

EARTHQUAKE COUNTRY, by Robert Iacopi. Lane Magazine and Book Company ($5.95). All about the earthquakes of California, this magazine-style account, lithographed with plenty of maps and photographs, is an exploration of the great fault systems of the most populous state. The San Andreas Fault is the star, and it is surveyed from the Salton Sea north to Point Arena. Its past is recounted, its physics sketched, its shaky future prophesied in part. Also treated are how earthquakes cause damage, how to measure quakes, how to build against them. The slip across the square lattice of an Imperial Valley orange grove is one unforgettable picture. The book is on a wholly popular level, but its concreteness and thoroughness lift it above many rivals. For any touring California family with an interest in the earth and its motions.

WHAT IS RELATIVITY?, by L. D. Landau and G. B. Rumer. Fawcett Publications, Inc. (60 cents). Disdaining the pretense that only algebra makes meaning clear, two Russian physicists write in completely nonmathematical prose a brief, witty and never superficial introduction to the topic. This paperback reprint of a successful book has a fine new introductory essay by R. S. Cohen.

WHAT'S THE BIGGEST?, by Barbara R. Fogel, illustrated by Barbara Wolff. Random House ($3.50). This is a joy of a prephysics text, for children or for reading aloud. From stars to craters, from sports stadium to tall human being, you learn the biggest—both the quantitative facts and a start at understanding the reasons for them. There are formal works on the philosophy of physics less pertinent than this book. Excellent drawings.

Biological Sciences

THE MAMMALS: A GUIDE TO THE LIVING SPECIES, by Desmond Morris. Harper & Row, Publishers ($12.95). There are about 4,000 extant species of mammals. They are all listed here, and a photograph plus a page of description are supplied for 300 representatives. From the only freshwater seal to the smelly naked bat of Borneo the animals are fascinating. The work is complete, and technical enough for specialists; it is a treasury for children who like animals.

HOME IS THE SEA: FOR WHALES, by Sarah R. Riedman and Elton T. Gustafson. Rand McNally & Company ($4.50). Dolphins as acrobats and pilots, the capture of killer whales, the beat of the great cetacean heart, the whale fetus and its delivery—this book is a well-informed account of the entire order. It is serious, compact, well illustrated. The California gray whales were called "devil fish" because of their "savage defense of their young" against whalers! The authors are not firm enough on the urgency of protection for whales. A model of exposition, second in depth only to the standard references and more up-to-date than they are. For youngsters of junior high school age and up; fine for adults.

THE WORLD OF THE PORCUPINE, by David F. Costello. J. B. Lippincott Company ($4.95). An eloquent defense of this maligned woods creature by a man who rears them, pats them and notices that they unexpectedly require more light to photograph well because of that remarkable quilly texture. The book is deeply knowing, with a genuine scientific bibliography of research papers. It is profusely illustrated with the author's first-class photographs.

FOXES LIVE HERE, by Irmengarde Eberle. Doubleday & Company, Inc. ($3.25). A direct and simple narrative of a pair of red foxes and their pups over the cycle of a year. Fine full-page photographs on nearly every other page. For reading to young children.

ROBINS, by Edwin A. Mason. Follett Publishing Company ($1). A primary reader, with the faults of its simplicity. The depth of its way of looking at the very familiar, however, sets it apart from its usually dreary genre.

SEA HORSES: STORY AND PHOTOGRAPHS, by Lilo Hess. Charles Scribner's Sons ($3.25). Large closeup photographs of these heraldic creatures, full-grown and tiny replicas alike, studding an informal text aimed at those who would keep a sea stable.

THE GULL'S WAY, by Louis Darling. William Morrow and Company, Inc. ($6.50). In the unity of his color photographs, free pencil drawings and poetic text Darling has created a true work of art. With a scientist's eyesight and a poet's vision he has joined the two cultures in this beautiful slender book, rich and yet humble. A six-week watch on a Maine coastal islet provided the data for the book; a full heart has written it, out of a sense of the continuity of all life. It will probably become a classic.

ABOUT EGGS, AND CREATURES THAT HATCH THEM, by Melvin John Uhl, illustrations by Madeline Otteson. Melmont Publishers, Inc. ($2.50). EGGS—AND WHAT HAPPENS INSIDE THEM, by Margaret Cosgrove. Dodd, Mead & Company, Inc. ($3.25). Two embryologies for children. The first, for the youngest readers, is a rather sketchy view. The second, for somewhat older ones, pictures and describes the unborn chick and child and much else.

INSECTS, by Ross E. Hutchins. Prentice-Hall, Inc. ($6.95). CADDIS INSECTS, by Ross E. Hutchins. Dodd, Mead & Company, Inc. ($3.25). THE TRAVELS OF MONARCH X, by Ross E. Hutchins, illustrated by Jerome P. Connolly. Rand McNally & Company ($3.08). Hutchins is an entomologist, a splendid photographer (particularly of small scenes) and a writer of clarity and directness. These three excellent books are diverse. The first is a handsome general book of insects meant for adult readers or interested high school students. The second is a small special study, with fascinating photographs, of the Western near-moths whose aquatic larvae spin seine nets and build dwellings of stone, logs and shin-

gles. These structures are of course on a tiny scale and quite stereotyped, yet they are remarkable examples of tool-using. Ten- to 12-year-olds could read the simple text. Hutchins' third book, whose pages are awash with color, is a true tale of the migration of one fragile tagged monarch butterfly from Canada to Mexico. It is an exciting story that can be read to young children or by somewhat older ones. It has an index and a helpful invitation to would-be butterfly-taggers.

MOTHS AND BUTTERFLIES AND HOW THEY LIVE, by Robert M. McClung. William Morrow and Company, Inc. ($2.95). SALLY'S CATERPILLAR, by Anne and Harlow Rockwell. Parents' Magazine Press ($2.95). Two good books. The first is a general account, with notes on collecting. The second, prettily illustrated in a Continental style, is a tale of a girl who brings her pet from its home on Martha's Vineyard to New York.

DID A BEAR JUST WALK THERE?, by Ann Rand, illustrated by A. Birnbaum. Harcourt, Brace & World, Inc. ($3.75). A book with a few lines on each brightly painted page, celebrating the heart of science: asking questions.

HOW TO BE A NATURE DETECTIVE, by Millicent E. Selsam, pictures by Ezra Jack Keats. Harper & Row, Publishers ($2.95). This ingenious book, for children in the early grades, asks questions and answers them logically from the tracks of animals. A problem walks out across the last page.

STRAIGHT HAIR, CURLY HAIR, by Augusta Goldin, illustrated by Ed Emberley. Thomas Y. Crowell Company ($3.25). This original and merry little book tells about the cross-sectional shape of hair and about its follicles. It presents genuine experiments youngsters can do. You need your own hair, Scotch tape, keys and some curiosity. Delightful.

HOW ANIMALS COMMUNICATE, by Bil Gilbert, illustrated by Chet Reneson. Pantheon Books ($3.95). A set of personal and instructive essays on bee and dolphin, ape and dog and their languages. It is a particularly handsome book, with beautiful and apt drawings. For junior high and high school biologists.

TRIUMPHS OF BIOLOGY, by Philip Goldstein. Doubleday & Company, Inc. ($4.95). Here a hard problem is extremely well solved: six great themes in biology from Abraham Trembley and John Dalton to Linus Pauling and Arthur Kornberg are described in long citations from original papers. The arrangement, drawings and annotations are so well done that the result is readable, human, exciting and richly instructive. A first-rate book for high school students.

RAISING LABORATORY ANIMALS: A HANDBOOK FOR BIOLOGICAL AND BEHAVIORAL RESEARCH, by James Silvan. The Natural History Press ($4.95). The husbandry of two dozen species, from the amoeba to the hamster and the opossum, is here described in working detail. The author plainly has the requisite wet, grassy or furry thumb. More than that, he has a sympathetic but unsentimental fondness for his creatures. He throws in many questions, problems and conjectures for experiment, and a list of sources of animals and supplies. Amateurs and high schools can hardly do without this sound and attractive book. A paperback edition is available for $1.45.

THE ATLANTIC SHORE: HUMAN AND NATURAL HISTORY FROM LONG ISLAND TO LABRADOR, by John Hay and Peter Farb. Harper & Row, Publishers ($6). The chapters of this book discuss the several ecologies of the coast and dilate on birds. A list of 50 places along the coast worth a visit is included. An excellent family book for Easterners who know, or want to know, the shore.

NATURE AS DESIGNER: A BOTANICAL ART STUDY, by Bertel Bager. Reinhold Publishing Corporation ($12.50). Beautiful photographs of the sculpture of pods and fruits and stems, enlarged some fivefold. The book lies on that frontier of art closest to science—or is it the other way around?

DINOSAUR HUNT, by George O. Whitaker and Joan Meyers. Harcourt, Brace & World, Inc. ($3.50). This thin book is both fascinating and beautiful. Its authors are a museum collector and preparator—who first worked in his present laboratory as a young, unpaid volunteer —and a poet, the daughter of a famous paleontologist. The text is a luminous narrative of a real expedition to Ghost Ranch on the high New Mexico plateau, where in 1947 Whitaker found the intact skeletons of primitive little dinosaurs. The story is always concrete, specific, intimate. Jeep, air hammer, scalpel and shellac are used before your eyes in that mixture of surgery and quarrying which brings us the evidence of the remote past. The maps, photographs and loving line drawings so well complement the words that the book draws the reader into the triumph of the happy, hard-working field party. Detailed enough for the professional, the account can be read by sixth-graders. It should guide more than a few careers.

FAMOUS FOSSIL FINDS, by Raymond Holden. Dodd, Mead & Company ($3.50). Here we do not follow a single party day by day through its work but instead find a small story on each of a dozen of the great finds in which paleontology takes pride. We have the La Brea tar pits, the coelacanth, the giant sloth, the frozen mammoth, the dinosaur eggs, the "dragon's teeth" of the Hong Kong apothecaries, and more. The tales are smoothly told and illustrated with nice pencil sketches. This is a generalized bird's-eye view, made for dipping into by young readers. The stories are well worth telling and their results are sensibly appraised.

TALES TOLD BY FOSSILS, by Carroll Lane Fenton. Doubleday & Company, Inc. ($4.95). Here the story is not of finding evidence but of telling what the evidence reveals. Fenton himself has drawn some 200 attractive and admirably detailed pictures to accompany his text, which is a simplified systematic paleontology from Precambrian algae to *Homo sapiens* and his early art. For each epoch and surrounding Fenton describes in 10 pages the best-known forms, their way of living, their evolutionary story. The account is warm, with allusions to the men and events behind the data, but it is always centered on the plants and animals of geological history. There is a book list of outstanding usefulness, and a couple of pages directing readers to where the real thing can be seen in museums throughout the U.S. and Canada. Deftly and expertly done for reading and for long-time reference.

SCIENCE AND THE SECRET OF MAN'S PAST, by Franklin Folsom. Harvey House, Inc. ($5). In an unusual book, written very simply and well illustrated with pencil drawings, a single theme is followed through a set of short and loosely connected chapters. The theme is dating the past, on the scale of the last couple of million years. Stratigraphy and the classification of artifacts are described with care. The physical methods, from fluorine to radiocarbon and even the recent fission-track scheme, are explained understandably if sketchily. Pollen census, clay varves, tree rings and the rest are not forgotten. The text is for any reader older than a sixth-grader who will

accept a style featuring short paragraphs and quick transitions. The book is reliable throughout.

Social Sciences

HUMAN BEGINNINGS, by Olivia Vlahos. The Viking Press, Inc. ($5.95). Written with what must be called unerring informality and charm, this loving and serious account of physical and cultural anthropology divides into two distinct parts. In the first part evolution and its time scale are outlined in a clear and brief way, ending with a more extensive account of the past million years. There is an up-to-date account of Olduvai findings—*Homo habilis, Homo erectus* and the rest—that does not overstate the case. The second part is a similarly attractive summary, telling about the growth of culture from its beginnings with tools, fire and kinship up to the invention of writing and the rise of cities. Across the text, in the margins and around the paragraphs spread the strong pen-and-ink drawings of Kyuzo Tsugami, showing everything from the tree shrew to *Zinjanthropus,* from a Neanderthal bear-cult shrine to a steel furnace of the Sudan. A book that will be cherished by readers 12 and up.

RAVEN'S CRY, by Christie Harris. Atheneum Publishers ($3.95). Here is a novel, suitable for young readers, perhaps from 10 up. The story is so thoroughly immersed in the life of the Haida, the remarkable industrial Indians of British Columbia (they built and traded great cedar canoes along 1,000 miles of coast), that the book is first-rate ethnography. The generations of a great Haida family are followed from the first visit of the Iron Men, come from Boston in their great flying white-winged canoe, until today. The story is poignant: firearms, Bible, gold, whiskey and smallpox play their traditional roles. But the Haida are so like us in their determination to excel—in skill, in trade, in wealth, in status—that the story is much richer than the pastoral tragedy of so many tribes. Nor is Haida culture wholly broken: its art, powerful and unified, lives. It can be seen in this beautiful book in the block prints of Bill Reid, a modern and innovative Canadian artist, working consciously to enlarge the tradition of his own Haida heritage.

INTRODUCTION TO ARCHAEOLOGY, by Shirley Gorenstein. Basic Books, Inc., Publishers ($4.50). An archaeologist who has dug in Mexico and the U.S. Southwest writes a connected narrative outlining the way she and her expert colleagues do their work. She tells what they look for, how to find a place to dig, how to keep records, how to analyze the data and finally, as the crown of the work, how to reconstruct a culture. She has written a smooth book—serious, helpful and teacherly. Diagrams from the professional literature are among the illustrations.

THE ARCHAEOLOGY OF SAN FRANCISCO, by Robert C. Suggs. Thomas Y. Crowell Company ($3.50). THE ARCHAEOLOGY OF NEW YORK, by Robert C. Suggs. Thomas Y. Crowell Company ($3.50). On the shoreline at LaGuardia Airport and near the flats of Emoryville on the East Bay diggers have found and studied the signs of those who lived in Queens and Oakland long before Columbus set sail. In these two similar books a dozen sites in each metropolitan area are described, with the story of how they were excavated. The ways of life of the old West Coast shell-collectors and the Algonkians of New York are reconstructed in a freely imagined but controlled way. The people and their artifacts are drawn in a striking scratchboard technique by Leonard Everett Fisher. Fine books, which left a faint disappointment in the lack of pinpoint locations of the sites themselves so that city folk could see the very places of the old way.

AFRICAN KINGDOMS, by Basil Davidson and the Editors of Time-Life Books. Time Incorporated ($3.95). The freshness, timeliness and sympathy of this expert story of the ancient cultures of the once-dark continent distinguish it among the many books of this Time-Life series. Half a dozen sets of photographs, largely in color, display among other things the stunning rock paintings of the Sahara and the great bronze sculpture of Benin.

Mathematics

A NEW LOOK AT GEOMETRY, by Irving Adler. The John Day Company ($7.95). With a decent respect for history, and a sense of search for enjoyment, the experienced author has here produced a substantial book traveling deep into modern mathematics. There is no more accessible and understanding study of what spaces are, and of the relation between physical and mathematical space. It contains a quick and compact look—but not a breathless one, and there are good problems set for the reader—at the old geometry of Euclid and before, at analytic, vector, group-theoretic and projective geometry. Newton and Ein-

stein are examined by way of Euclidean and non-Euclidean spaces, and the book closes with topological spaces and a small flourish of axiomatics. Not for the dilettante or the expert, the book is aimed right at high school mathematics teachers, practicing or prospective, and their best students.

MATHEMATICS OF CHOICE, OR HOW TO COUNT WITHOUT COUNTING, by Ivan Niven. Random House ($1.95). FROM PYTHAGORAS TO EINSTEIN, by K. O. Friedrichs. Random House ($1.95). Niven writes an informal, clear algebra of combinatorics for high school students and mathematical amateurs. It is by no means elementary by the end of the book, with generating functions, induction and nonassociative products. All the usual formulas are here and well derived. The Friedrichs book is much less problem-centered; it is a set of lectures on the theme of the famous theorem. He causes the theorem to flow easily from the idea of vectors $[(a + b)^2]$ after presenting the more geometrical proofs. Then he goes on to show the rise of four-vectors at the heart of the theory of special relativity. These are two recent paperbacks of a generally excellent series sponsored by the School Mathematics Study Group.

CHIPS FROM THE MATHEMATICAL LOG, edited by Josephine P. Andree. Mu Alpha Theta, University of Oklahoma ($1). A paperback anthology of problems and commentary from the journal of the national high school and junior college mathematics clubs. First-rate problems at a penny a page.

ARE YOU SQUARE?, by Ethel and Leonard Kessler. Doubleday & Company, Inc. ($3.50). A gay and witty book whose rich night sky may well contain a square moon and square stars. Did you ever ride in a round train all the way to Bangor, Maine? These authors are not square, and their book is a true pregeometry for small children on the way to first grade.

WHAT SHAPE IS IT?, by Charles Hatcher. Duell, Sloan & Pearce ($2.95). A crowded, swift book for children in the grades who might want to use a paperclip plumb line or spin a cardboard triangle into a whirling cone. Somehow it is about the physics of geometry.

THE MYSTERIOUS FLEXAGONS, by Madeline Jones. Crown Publishers, Inc. ($1.95). A cutout book with clear, simple directions for making flexagons—very handsome ones in strong, colorful designs. Three hexahexaflexagons crown the work. If anyone of any age in your family likes papery puzzles, or if you know about the flexagon, the book is waiting for you.

Technology

WONDERS OF THE MODERN WORLD, by Joseph Gies. Thomas Y. Crowell Company ($5.95). The Japanese Bullet Train, the Chicago sewage system, the Dutch plan to reclaim the Rhine delta from the sea, and 10 more projects are described in nontechnical language with plenty of facts and figures. Photographs of each and an appendix listing, among other things, the biggest dams, bridges and tunnels complete the book, which is much too interesting to put down. For readers of 14 and up, but some 12-year-olds will read it excitedly.

THE FIRST BOOK OF BRIDGES, by Creighton Peel. Franklin Watts, Inc. ($2.65). BRIDGES, by Robert Silverburg. Macrae Smith Company ($4.50). BRIDGES, written and illustrated by Henry Billings. The Viking Press, Inc. ($3.56). Three excellent books, all up-to-date, listed in order of increasing depth. The first two have splendid photographs, the last no less splendid drawings. The Billings book, first published a decade ago and now revised, has the strongest discussion both of the social environment of a bridge and of the analysis of stress.

ROMAN ROADS, by Victor W. Von Hagen. The World Publishing Company ($4.95). Maps, line drawings and fine photographs abound in this lightly written and thorough history of the great network of 53,000 miles of road with which was woven an empire over Europe and North Africa. There is even a Roman poet's account: "First comes the task of preparing the ditches..." until finally "...others go ahead to drain the pools, bridging those thirsty streams that lie ahead." What Latin scholar over 12 would not welcome this book?

BUILDING THE SUEZ CANAL, by the Editors of *Horizon*. American Heritage Publishing Co., Inc. ($4.95). Between the marvelous contemporary endpaper drawings, the text and 100-odd pictures carry the reader through Ferdinand de-Lessep's struggle past dizzy pickaxes and steam dredges to a brief account of the campaign of the Franco-British forces in 1956 and a final stunning Gemini photograph in color. Here is a century

in cartoon, exposition, engineers' drawings and personal anecdote. The illustrations outdo the readable text.

ELECTRONIC BRAINS, by Rolf Lohberg and Theo Lutz. Sterling Publishing Co., Inc. ($4.95). Two German authors ("a mathematician with journalistic interests and a journalist with technical ones") published this book in Stuttgart in 1963. It is a breezy and cheerful work, aimed at people who have little patience with technical language, and having no literary pretensions. The book's first sentence quite reasonably asserts that there are no such things as electronic brains. This vein of common sense runs throughout. The book is filled with happy metaphors (music boxes for programs, lamp cords with multiple switches for the logic circuitry) and clear explanation. It gets down to cases with surprising detail, including full-page flow sheets for specific payroll computations. All of this is reached by easy steps. For the reader over 12, or indeed for anyone of a practical turn of mind who is not much at reading but is fascinated by computers, this book is thoroughly appropriate. There are good photographs and freehand drawings, although the volume is not handsome.

WE BUILT OUR OWN COMPUTERS, edited by A. B. Bolt. Cambridge University Press ($3.95). Five sixth-formers from the Exeter School in England explain and describe half a dozen computers they have in fact built for themselves. The computers range from arrays of matchboxes with buttons—which can "learn"—to a general-purpose analogue computer and a digital arithmetic machine. Ticktacktoe and nim machines are here. No machine called for a budget of more than $40 (although there was much scrounging) except for the analogue machine, which cost some $200. The details of the British milieu require some translation, but it is not very difficult. For Tottenham Court Road read Canal Street.

A HISTORY OF KNIVES, by Harold L. Peterson. Charles Scribner's Sons ($3.50). A knowing and enthusiastic monograph for 10-year-old boys and their elders, the book tells of knives from the days of the flint hand axe through the bowie knife, the machete and the Gurkha *kukri* to an elegant design made for astronauts. There are excellent pencil drawings of many knives and of some of their users. Two pages of reasonable caution on the care and handling of knives close the book, with the engaging remark that these are "the same rules, in all particulars, that a Roman citizen would have given his son two thousand years ago."

GO ON WHEELS, by Julius Schwartz, pictures by Arnold Roth. McGraw-Hill Book Company ($2.50). They may have cows and grass and the like in the country, but city kids have wheels. They have roller skates, bicycles, cars and 10-wheel trailers roaring by. They can make their own wheels of paper plates and try them out. In an easily read metrical style, with genuine enjoyment amid cheerfully rough pictures, there are suggestions for things small children can do for themselves: silly wheels, mismatched wheels, square wheels. A piece of real prescience by an author of insight. For readers of age four to eight.

EARLY BICYCLES, by Philip Sumner, illustrated by Alan Osbahr. Stephen Greene Press ($10). A dozen large prints —about 11 by 16 inches—of lovingly rendered bicycles, functional or bizarre. A brief text describes each one.

THE LOOK OF CARS, by Henry B. Lent. E. P. Dutton & Co., Inc. ($4.95). It was the Ford Model-A that gave us our first look at the work of Detroit stylists. This book tells how they model cars full size in clay and "paint" them by applying a thin plastic film, what cars looked like in the past, what ideas the stylists play with for the future, even how to train for the profession. A list of schools of design is included. The book does not blink at obvious failure: it describes the rise of tail fins, a form suggested by the P-38 fighter, and the fall of the Edsel. Lent is a retired advertising executive; this book is clearly from the Establishment side. The public taste is seen as the cause and the arbiter. Maybe it is. Written for readers of 12 and up, it is good reading for all who stare at cars. Not much about what is inside.

Biography

JULES VERNE: PORTRAIT OF A PROPHET, by Russell Freedman. Holiday House ($3.95). Sent to study law in Paris, Verne read Poe instead. He was befriended at the lavish house called Monte Cristo by its owner, the prince of successful authors, Alexandre Dumas. The literary life had won young Jules, and he soon saw actors perform his first work, a domestic farce. The law behind him, he wrote a Poe-influenced adventure story around the then very topical subject of ballooning. Its success led to his deter-

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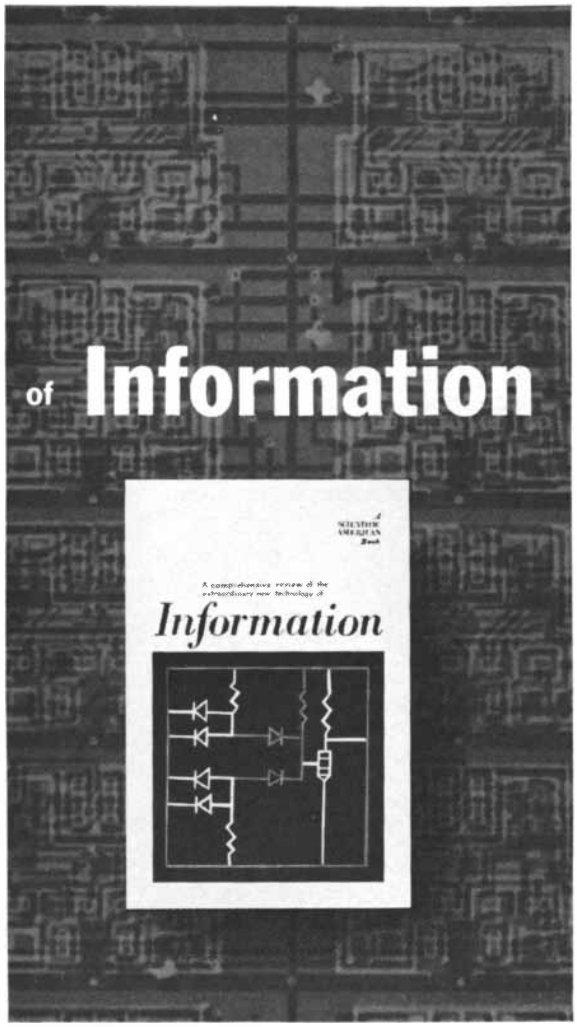

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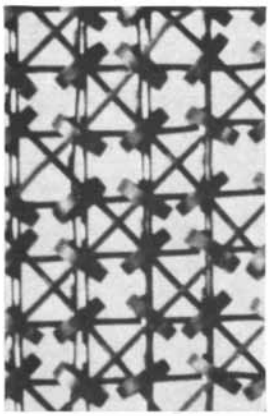

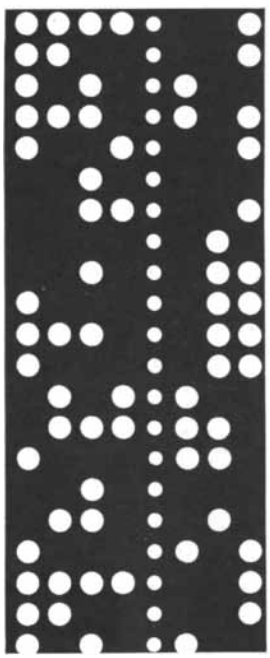

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mination to write of the new world of science and technology to come. He wrote his father that he would no longer "linger on well-trodden paths, when science is performing miracles."

Fifty years of wonderful tales, based on thorough (if not unerring) research, followed. *Around the World in 80 Days* was an 1874 play in Paris, a wildly successful extravaganza complete with an elephant. During its first serial publication steamship firms privately sought to entice the hero Phileas Fogg to travel his last transatlantic lap on their ships; Verne instead had him buy a small steamer of his own.

In this entertaining biography one can also read of Verne's darker side; not all was progress and delight. War, weaponry, secrets, pollution were in his later books. Men had then, as they still have, to choose between life and death. There are adult biographies of Verne; this brief one is good reading for anyone from 12 up. It is only a little fictional in form. There are several good photographs and many endearing period engravings taken from the books.

SEEKER OF SEAWAYS: A LIFE OF MATTHEW FONTAINE MAURY, PIONEER OCEANOGRAPHER, by Janice J. Beaty. Pantheon Books ($3.95). A landbound naval officer, Maury learned the winds and currents so well that the first sailing captain to follow his charts cut the four-month round trip from Baltimore to Rio de Janeiro by five weeks. A Virginian, Maury resigned his commission after Fort Sumter and died a broken but honorable rebel. A well-written, fresh and timely biography for readers of 12 and older.

Various

SCIENCE BENEATH THE SEA: THE STORY OF OCEANOGRAPHY, by William M. Stephens. G. P. Putnam's Sons ($3.29). A survey of a whole science from the *Challenger* to Commander Scott Carpenter, submarine astronaut, this book is unfailing in taste and temper. Waves as big as a Coast Guard cutter, diatoms under the microscope, horrid and marvelous anglerfish, and the buoy-vessel *Flip* that can float on end are all splendidly presented in word and picture. Most such stews are indigestible mixtures; this is a grand *paella*. We learn, complete with citation, that cherry Lifesavers are the best slow-dissolving release for a certain deep-sea instrument, and the more fundamental facts are no less interesting and unexpected. For readers of 12 and up, all the way up. Other books "like" it abound, but one should accept no substitute!

SURF'S UP! AN ANTHOLOGY OF SURFING, edited by H. Arthur Klein and M. C. Klein. The Bobbs-Merrill Company, Inc. ($5). This book assembles a couple of dozen pieces on this dazzling sport, brought to California in Theodore Roosevelt's time from its home in Hawaii. Cartoon columns from California papers make argot such as *ho-dad* and *cowabunga* clear to the uninitiate. Slick magazine pieces are here side by side with Byron, Mark Twain, Jack London (who really tells a great deal about the sport) and Snoopy. Sticking mostly to history and the subculture, the book includes some physics of waves, boards and surfers. The celebrated print of Hokusai is echoed here by a great wave photographed from surfboard by Don James; the photographs are perhaps the best thing in this exciting volume.

BETWEEN HEAVEN AND EARTH, by Gaston Rebuffat, photographs by Pierre Tairraz. Oxford University Press ($12.50). As surfing is all dynamics, sudden decision, timing and bravura, so mountaineering is all statics, patience, deliberate skill and exaltation after long endurance. Based on the famous film of 1961 about the work of an Alpine guide, the book recounts the story of film making in the peaks, presents the poetic script of that documentary and gives what amount to step-by-step narratives of great Alpine climbs: Matterhorn, Mont Blanc, Aiguille du Midi, Aiguille de Drus. There are 100 photographs, reproduced in a beautiful rotogravure, and half a dozen handsome color plates. Men on pinnacles, vistas of frozen magnificence and rainbow glories are all here. For mountaineers of any literate age.

THE STORY OF THE BLUE NILE, by Alan Moorehead. An abridgment by Lucy Moorehead. Harper & Row, Publishers ($3.95). Even in this smooth abridgment for literate junior high school students, Moorehead's prose sparkles and flows across a century. He tells as well as anyone can ever tell the tale of the Scots explorer James Bruce, who found the Nile's source in the Ethiopian plateau, of Napoleon's expedition against Egypt and her Mameluke cavalry, and of the British campaign against the Emperor of Ethiopia three generations before Mussolini. A garish jacket and cover grate on the eye, but the writing is proof against false embellishment. The illustrations inside the book are splendid; French scientists are shown in

an engraving climbing all over the still-buried and mysterious Sphinx to measure her outcropped head.

THE RIO GRANDE, by Alexander L. Crosby. Garrard Publishing Company ($2.19). Bringing life to the desert, the Rio Grande is the most romantic of American rivers. The ancient Pueblo peoples, the knights of Coronado, the Mexican army, the Texas gunfighters—all knew these banks. This simple book, written by a man who has traveled the river and read its marvelous literature, relates the history and a little of the present of the Rio Grande. The photographs by Laura Gilpin, whose book on the river a generation ago broke the path, are here in quantity. Here also is Elfegio Baca, a two-gun teen-age lawman who outmatched an armed mob and lived to keep the peace in Socorro for a long lifetime. Physically this is a durable, plain school book; it is nonetheless a first-class example, and it is easily read.

ROAD RACE ROUND THE WORLD: NEW YORK TO PARIS, 1908, by Robert B. Jackson. Henry Z. Walck, Inc. ($3.25). Traveling across the U.S. from Times Square, by ship to Asia and then on wheels all the way to Paris, three out of six automobiles made it. This is a brief narrative of their hardships and triumphs. The Thomas Flyer—the moral if not the actual winner—made it in 170 days. She is preserved today in gleaming dignity in a Reno collection. For readers of nine and older.

NORTH, SOUTH, EAST, AND WEST, by Franklyn M. Branley, illustrated by Robert Galster. Thomas Y. Crowell Company ($3.25). The simple text and cheery, strong drawings of this book on navigation show how to tell the cardinal points by using your own shadow. For readers old enough to know right from left and under nine.

BRAIN BOOSTERS: A BOOK OF EXASPERATING NATURE AND SCIENCE PUZZLES, by David Webster. The Natural History Press ($3.50). Three hundred of them, from ice cube structure to flashlight circuitry. Answers are given, which limits the exasperation.

WONDERFUL TIME, by Phyllis McGinley, illustrated by John Alcorn. J. B. Lippincott Company ($3.50). More metaphysics than physics, the verses each have a full-page line drawing in a cheerfully grotesque style to confront them with their own metaphors. For readers under eight but not for every taste.

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A View From The Bridge

Research Physicist Darragh Nagle enjoys this view as he crosses the Los Alamos bridge en route to work in the Meson Physics Division. Dr. Nagle conducts research leading toward final design of the Los Alamos Meson Physics Facility (LAMPF), the world's first proton linear accelerator in the 800 MeV energy range. The 2,600-foot-long accelerator will produce an average beam current of 1 milliampere, manifestly higher than other machines of comparable output energy. If you would like to join Dr. Nagle and other LASL scientists and engineers in exciting new ventures, send your resume to:

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