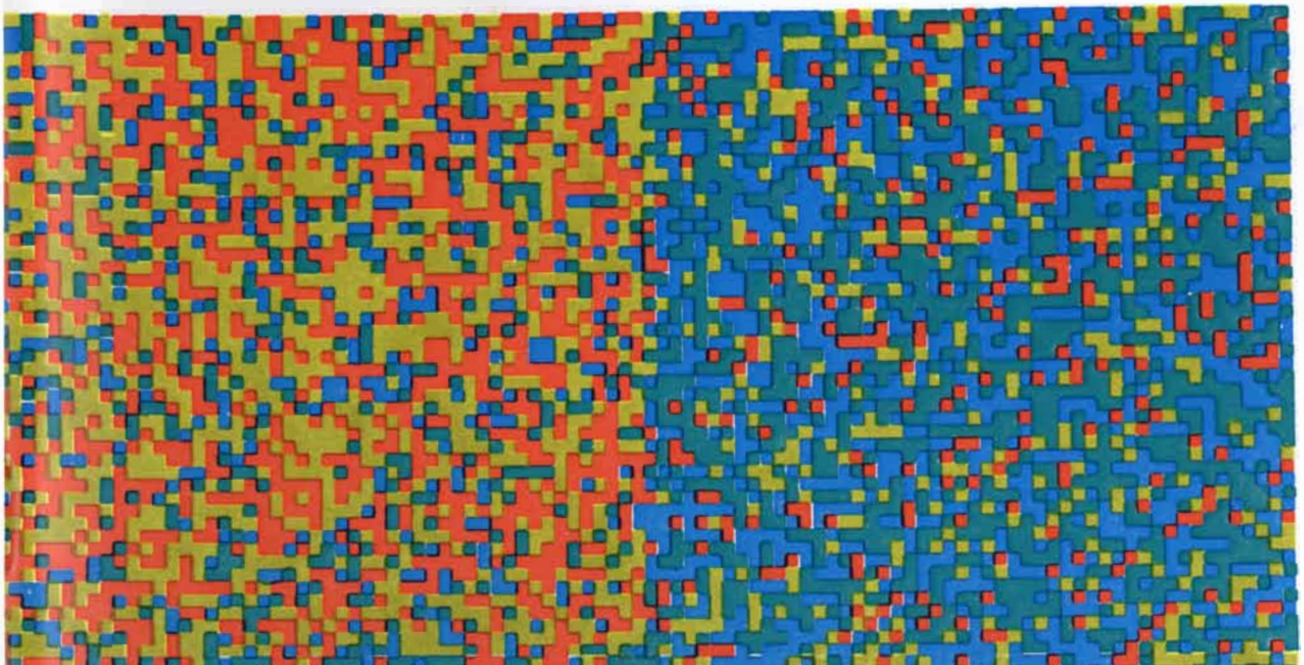
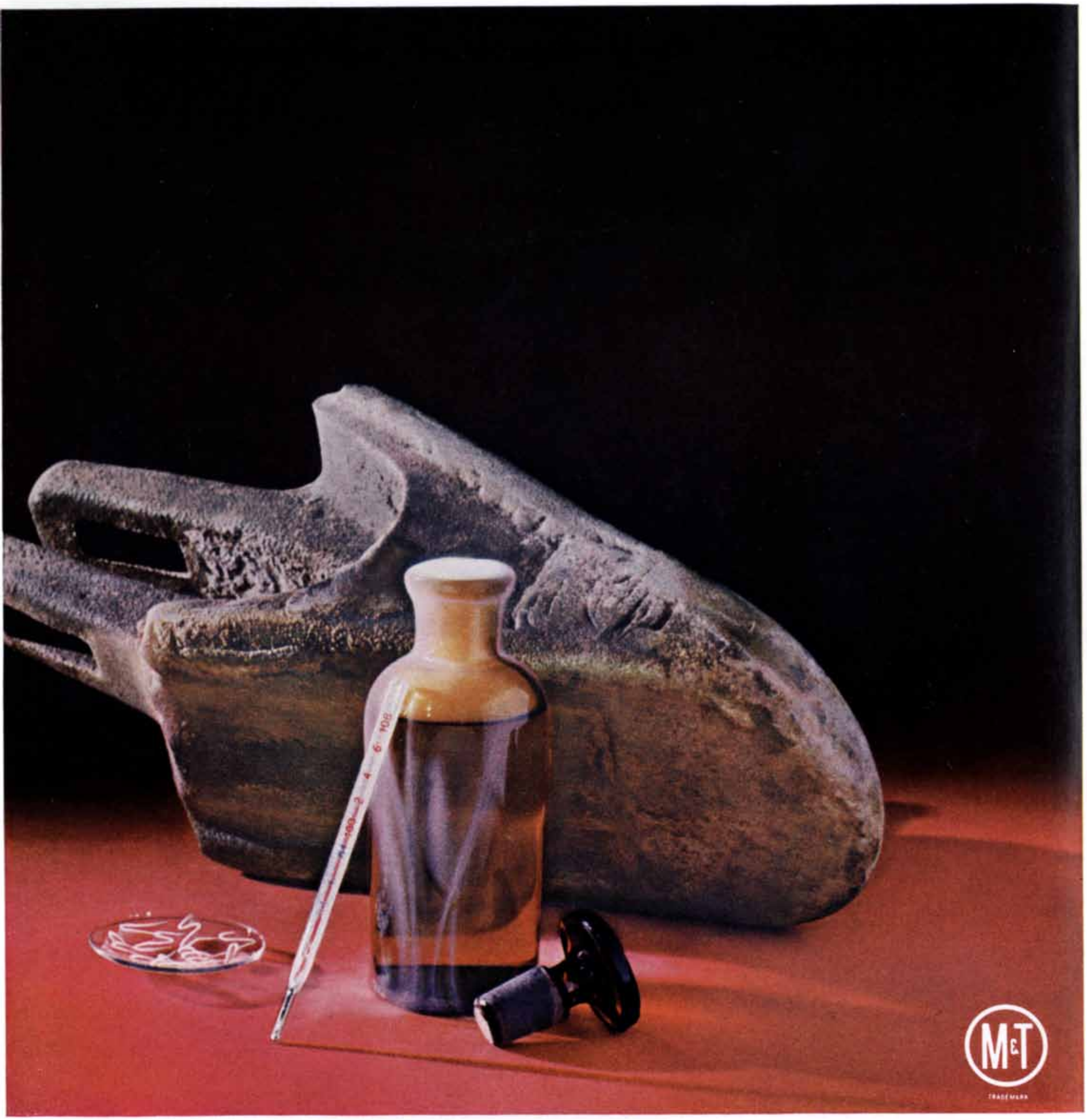
SCIENTIFIC AMERICAN



TEXTURE AND VISUAL PERCEPTION

SIXTY CENTS

February 1965



Worms, germs, corrosives, wear...old enemies meet new defenses

Modern technology enables man to set up protective measures against harmful influences. M&T contributes to these abilities through chemistry and its close relative, metallurgy.

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Disease lurks everywhere. But not on sickroom linen laundered in wash water containing bioMeT* antimicrobials; nor on hospital walls and floors protected by bioMeT products.

Parasitic worms were once a menace to poultry. And then the anthelmintic activity of M&T* organotin chemicals offered a cure.

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RECENT
findings

RESEARCH LABORATORIES

Ford

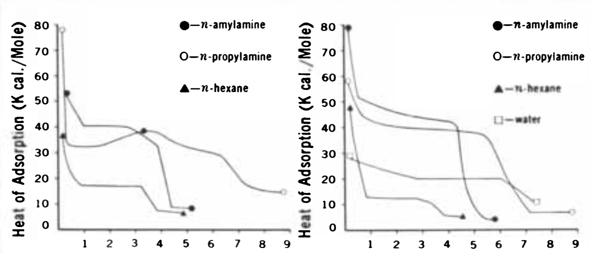
MOTOR COMPANY

ENERGETICS OF THE CHEMISORPTION PROCESS

Ford Motor Company scientists study very thin amine films to learn the reasons for their corrosion-inhibiting properties.

In a continuing program, Ford Motor Company scientists have set out to improve basic understanding of the types of bonding and stereochemistry involved in the interaction of organic molecules (and water) with surfaces.

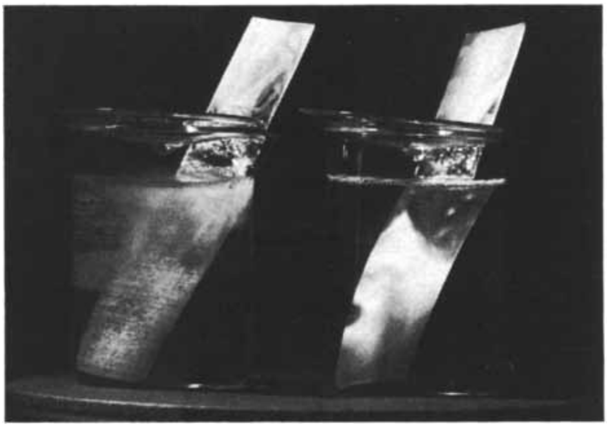
Amines are recognized as effective corrosion inhibitors because of their strong chemisorption on metal and metal oxide surfaces. To measure the energetics of the chemisorption process, heat adsorption curves were developed using an adibatic calorimeter. The results (shown below) illustrate the higher heat of surface bonding and the resulting stronger bond of amines than of hydrocarbons or water.



Typical curves for polycrystalline surfaces show higher heat adsorption of amines vs. hydrocarbons on reduced iron surface (left) and amines vs. hydrocarbons and water on iron oxide (right).

The strongly bound film formed by the amine on the metal surface is hydrophobic and thus can inhibit the electrochemical process of corrosion which requires a metal/water contact.

Considerable time has been spent in developing sophisticated crystal surfaces for use in adsorption experiments. Each of the crystal types developed has predominately one crystallographic plane for a surface. A large number of one type of crystals presents, therefore, a surface of known crystallographic orientation.



Corrosion-inhibiting properties of amines are shown in test with mild steel strips in a 5% solution of hydrochloric acid with and without amines. Flask on right contains amines in solution which have formed a film on strip. Violent reaction takes place in flask without amines. Temperature is 80° C.

This investigation of amines is only one example of as many as 50 independent research programs that may be going on in our Scientific Laboratory at a given time. Ford scientists are constantly opening new fields for original investigation—in the firm belief that a better understanding of basic science must result in new methods, better technology and an improved product. That's the Ford Motor Company way.

PROBING DEEPER TO SERVE BETTER

Ford

MOTOR COMPANY

The American Road, Dearborn, Michigan

Established 1845 **SCIENTIFIC AMERICAN** February 1965 Volume 212 Number 2

ARTICLES

DEPARTMENTS

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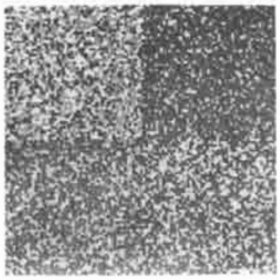

THE COVER

The pattern of colored dots on the cover was generated by a computer at the Bell Telephone Laboratories as part of a study in visual discrimination (see "Texture and Visual Perception," page 38). It reproduces a demonstration that should be performed with colored lights that have been carefully balanced to have equal subjective brightness. Since printing inks cannot be balanced in this fashion the cover does not fully reproduce the effect observed in the laboratory. Even so, as in the laboratory, the colored pattern in the top half of the cover can immediately be discriminated into left and right halves. The pattern in the bottom half is less easily discriminated, and under laboratory conditions discrimination is quite difficult. The experiment shows that the eye readily forms clusters of hues that are adjacent in the spectrum, such as red and yellow or green and blue. Such clusters appear frequently in the top half of the cover illustration. In the bottom half of the illustration the yellow and green components have been reversed and the clustering does not occur so readily.

THE ILLUSTRATIONS

Cover by Bela Julesz, Bell Telephone Laboratories

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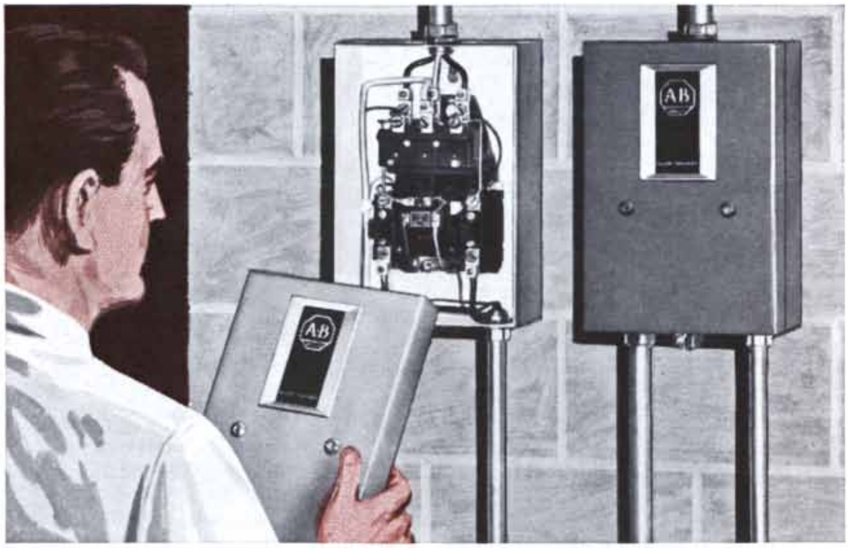
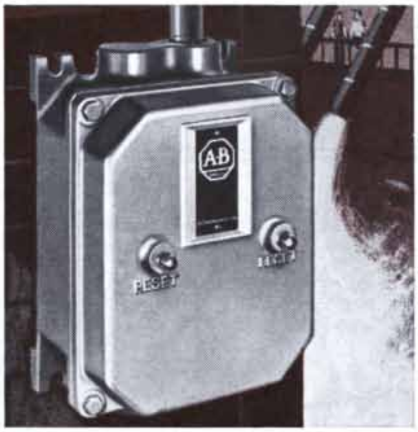
NEMA TYPE 4 stainless steel watertight and weatherproof enclosure *for indoor and outdoor installations* where moisture could be a hazard.



NEMA TYPE 1 enclosure for installations where atmospheric conditions are normal. Note white enameled interior—standard with all NEMA 1 enclosures.

NEMA TYPE 7 enclosures for installations *where hazardous gas is present.* Meets National Electrical Code requirements for Class I, Groups C and D locations.



NEMA TYPE 9 enclosures for installations *where hazardous dust is present.* Meets National Electrical Code requirements for Class II, Groups E, F, and G locations.

NEMA TYPE 12 oiltight and dust-tight enclosure. Rubber gasket seals out oil, coolants, metal chips and dirt. Commonly specified by the automotive industry.

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All 48 Series connectors assembled on one day in the same production run are stamped with an identical number. We call it a Specific Control Number, or SCN. It's your reference

to a *complete recorded history* of the part and all others made during that particular production run.

This Amphenol SCN system assures complete traceability of every component part in every stage of production. We can start with a single contact and trace up to the complete connector, or trace back from a connector to a part.

In fact, we can give you the documents the day you get the connectors . . . a ready portfolio of check-out information when you need it during design, or breadboarding, or test model inspection.

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LETTERS

Sirs:

The snobbishness and insularity of molecular biologists! On page 70 of your November 1964 issue M. F. Perutz describes the early model of the myoglobin molecule as "this rather repulsive visceral" form. On the same page he asks if the search for truth could reveal "so hideous and visceral-looking an object?" But in the next sentence but one he says: "Fortunately, like many other things in nature, myoglobin gains in beauty the closer you look at it." As a gastroenterologist, I invite Perutz, and the rest of the molecular biologists, to take a closer look at the viscera. Euclid is not alone in having looked on beauty bare.

HORACE W. DAVENPORT

Ann Arbor, Mich.

Sirs:

In reply to Professor Davenport's criticism, may I quote from one of Edmund Spenser's lyrical poems:

Tell me, ye merchants daughters,
did ye see
So fayre a creature in your towne
before;
So sweet, so lovely, and so mild
as she,
Adornd with beautyes grace and vertues
store?
Her goodly eyes lyke Saphyres shining
bright,
Her forehead yvory white,
Her cheekes lyke apples which the sun
hath rudded,
Her lips lyke cherryes charming men
to byte,
Her brest lyke to a bowle of creame
uncrudded,
Her paps lyke lyllies budded,
Her snowie necke lyke to a marble
towre;
And all her body lyke a pallace
fayre,
Ascending up, with many a stately
stayre,
To honors seat and chastities sweet
bowre.

Please note that the many parts alluded to do not include the ones commended by Professor Davenport. Yet modern art probes deeper. The inspiration for Michael Lekakis' contemporary sculpture, shown below, may have come from the same source as Professor Davenport's favorite visions.

Its similarity to myoglobin is purely coincidental, by the way, as it preceded J. C. Kendrew's discovery by several years.

M. F. PERUTZ

Laboratory of Molecular Biology
Cambridge, England

"Dancer," by Michael Lekakis

Sirs:

If D. O. Hebb's letter in your November 1964 issue were to pass unchallenged, some readers might suppose that his view is not open to question. Hebb declares that B. F. Skinner "showed an identity in certain behavior of the pigeon and human superstitious behavior." Now, we can all agree on the subtle and all-pervasive continuity between human and animal behavior. But this does not grant us license to reduce all human phenomena to animal "equivalents." Superstition, wrote Theophrastus (circa 300 B.C.) in what is still perhaps the most vivid account of the subject, is "a desponding fear of divinities.... The superstitious man, as often as he has a dream, runs to the interpreter, the soothsayer, or the augur, to inquire what god or goddess he ought to propitiate." It is hard to imagine even the most sophisticated of pigeons taking such a burden on his back.

It is, I suggest, an error to refuse to see in man any more than can be seen in the pigeon. The essence of human superstition does not consist simply in what a superstitious man *does,* however important one recognizes this to be, but also in what he believes or imagines, particularly with respect to a transcendental or supernatural world that, whether we like it or not, is closed to the best of pigeons.

JOHN COHEN

Department of Psychology
The University
Manchester, England

Sirs:

If Professor Wigner's letter ["Letters," SCIENTIFIC AMERICAN, December, 1964] is the best the establishment of the arms scientists can offer in reply to Drs. Wiesner and York, then its case rests on flimsy ground indeed. Dealing first with his point on the possibilities of further progress in arms development, he must surely realize that it is impossible to kill anybody more than once and that no breakthrough can ever alter that fact. The suboptimization of existing weapons is not a competent alternative. His own demonstration of the economy of scale of large weapons only confirms how easy it is to add further to overkill and to make impossible any defense system efficient enough to avoid the destruction of the principal assets of our society.

In this connection, Professor Wigner's defense of blast shelters is preposterous. He suggests them, of course, only for "important locations," failing to note that those in "unimportant" locations might object to being considered expendable. Moreover, it is not just a question of supporting a few troglodytes for a short time—the physical destruction of our major areas of settlement ("soft targets") would finish us forever as a significant factor in world affairs. All these points have been discussed in reams of testimony before congressional committees that have in the past wisely held civil defense expenditures to relatively small amounts. The writer once demonstrated that a blast shelter system adequate for the population would cost on the order of $200 billion and that even this would not deal with the problem of surface destruction. Professor Wigner's unawareness of this only at-

tests to the airy indifference scientists often display toward financial matters.

Dr. Wigner's most serious error, however, lies in his misunderstanding of the nature of security. Security for the U.S. rests not only on our military strength but also on our economic and political viability. Our lopsided expenditures on arms have given us the world's oldest complement of production machinery; poverty that cannot be erased in the absence of substantial investments that can only come from reduced arms spending; a misdirected effort in science and engineering that has systematically deprived our industries of innovations; an undermined currency, and a mistaken sense of national omnipotence that has expressed itself in the emergence of the largest and potentially most dangerous body of right-wing opinion in the Western world.

This is enough damage to be going on with. It is time the discussion of the arms problem emerged from its cloud-cuckoo-land of political and strategic misconceptions and concentrated on the conversion of scientific and technical effort to the real interests of our society.

JOHN E. ULLMANN

Professor and Chairman
Management, Marketing and
Business Statistics
Hofstra University
Hempstead, N.Y.

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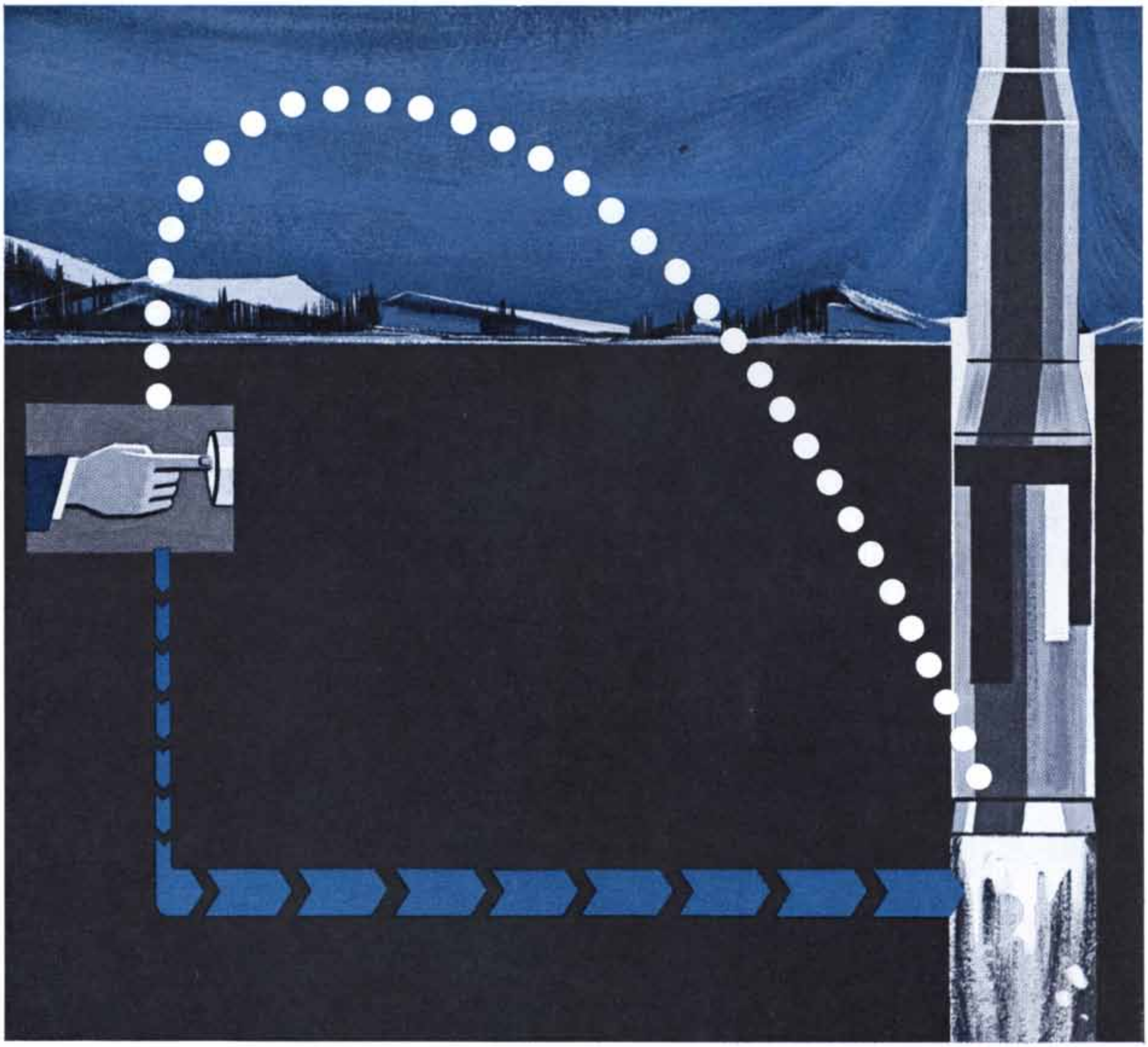
Change of address: please notify us four weeks in advance of change. If available, kindly furnish an address imprint from a recent issue. Be sure to give both old and new addresses, including postal zone numbers, if any.

URGENT: Get the message to Minuteman—for double sure!



If Minuteman is ever actually used, it *must* work. And we have to assume that our missile bases would be under severe enemy attack.

That's why our Sylvania subsidiary, in developing the improved Minuteman Ground Electronics System, isn't taking chances. A second link—radio—has been added to the hardened underground cable link between control center and missile silo. This medium-frequency link, with hardened antennas, assures that command messages will reach the missile even during and after an attack.

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Ground electronics for the improved Minuteman—another way that the vast capabilities of GT&E, directed through Sylvania Electronic Systems, are contributing to military preparedness.

Sylvania Electronic Systems, Division of Sylvania Electric Products Inc., 40 Sylvan Road, Waltham, Massachusetts 02154.

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QUIKTRAN is a variation of FORTRAN. It lets technical people instruct a computer in the language of mathematics—the language they use every day in their work. If you understand math, you can understand and use QUIKTRAN in two or three hours.

And QUIKTRAN, unlike FORTRAN, lets the computer answer you back at each step of your problem's solution. You debug a program, statement by statement, as you write it on the 1050 typewriter, instead of waiting till it's done, then hunting for an error.

```
                          NUMBER = 2+2
101. =                    NUMBER=          4
101. -READY

                          NUMBER = 12/2
101. =                    NUMBER=          6
101. -READY

                          N = SQRT(64.)
101. =                    N=            8
101. -READY

101. -READY               PROGRAM SAMPLE
102. +READY               DIMENSION ZPLOT(52), TABLE(500)
103. +READY               X=0
104. +READY               Y=1.
105. +READY               I=1
106. +READY               READ 101, DELX,CHAR,ZPLOT
107. +READY 101           FORMAT (F7.4, 53A1)
108. +READY               PRINT 102
109. +READY 102           FORMAT (5X,1HX,7X,1HY)
110. +READY   2           TABLE (I) = X
111. +READY               TABLE (I+1) =Y
112. +READY   1           PRINT 103,X,Y
113. +READY 103           FORMAT(2X,F7.4,F8.5)
114. +READY               IF (X-1.) 5,3,3
115. +READY   5           I=I+2
116. +READY               X=X+DELX
117. +READY               DELY =X*Y*DELX
118. +READY               Y=Y+DELY
119. +READY               GOAT 2
119. +ERROR           STATEMENT NOT IN LANGUAGE
119. +READY               GO TO 2
120. +READY   3           DO 4  J= 1,I,2
121. +READY               X= TABLE(J)
122. +READY               K=1. +((TABLE(J+1)-TABLE(2))/(TABLE (I+1)-TABLE (2))*50.)
123. +READY               ZPLOT(K) = CHAR
124. +READY               PRINT 101, X, ZPLOT
125. +READY   4           ZPLOT (K)=ZPLOT (K+1)
126. +READY               STOP77
127. +READY               END
```

Portion of a typical mathematical problem solved with QUIKTRAN on an IBM 7040.

What kinds of problems?

Any problem you can solve with FORTRAN (or mathematics) you can solve with QUIKTRAN.

You can develop your data processing program, debug it and solve your problem with it—all in one quick continuous flow. Answers come back in seconds instead of weeks.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1915: "Thirty-nine years ago, in his bedroom in a Boston boarding house, Alexander Graham Bell picked up a crude telephone transmitter and said: 'Mr. Watson, come here; I want you.' Thomas A. Watson, in the adjoining room, listening at the other end of the wire, heard the first sentence ever transmitted by telephone and, full of excitement, burst into the bedroom to congratulate his associate. Last month, over the same wire and with a replica of the old instrument, Dr. Bell again called up Mr. Watson. But this time Bell was in New York in the office of the president of the American Telephone and Telegraph Company, and a whole continent separated him from his former associate. To that 100-foot wire that had carried the feeble, ill-formed electrical pulsations of the first spoken message 6,800 miles of hard-drawn copper wire had been added, bringing New York and San Francisco within talking distance of each other. Thus was the first transcontinental telephone line introduced to the world."

"Work is progressing rapidly on Canada's 72-inch reflector, which will be probably for a short time only the largest telescope in the world (pending the completion of the 100-inch reflector for Mount Wilson). The disk for the great mirror started from Antwerp about a week before the war broke out. After its arrival in New York the Pennsylvania Railroad was about a week in finding a suitable car to transport it to Pittsburgh, and then there was further delay before an iron wagon could be obtained to transport it to Dr. Brashear's workshop, where it was finally placed on the grinding table. The hazardous work of boring and smoothing off the hole in the center of the mirror has been accomplished with entire success. It is expected that the mounting will be completed by October next."

"The application of the interferometer to astronomical purposes, as described by Messrs. Fabry and Buisson in *The Astrophysical Journal* for June, 1911, has since yielded interesting results, which have from time to time formed the subject of notes in the *Comptes rendus.* The latest of these records measurements of radial velocities in the portion of the Orion nebula which contains the 'trapezium.' From these it is found that the distance between the nebula and the earth is increasing at the rate of 9.8 miles a second. Although this is the average of measurements at different places in the nebula, the actual radial velocity varies from point to point; in other words, the nebula is not moving with the coherence of a solid body but is undergoing numerous local deformations, besides which in the region examined there is a movement of quasi-rotation around an axis running from southeast to northwest."

Scientific American.

FEBRUARY, 1865: "The opening of the Suez Canal to navigation throughout its entire length from the Red Sea to the Mediterranean has been officially announced to all the chambers of commerce in Europe by M. de Lesseps, president and superintendent."

"For years the enemies of the Government and of the Navy Department in particular have kept up a bitter tirade against it on account of its assumed want of care or watchfulness in blockading the Southern ports. Did a British vessel succeed in entering Charleston, vials of wrath and vituperation were poured out on everyone in the Navy, from the Secretary to the mess cook, and some papers were so unscrupulous as to assert that naval officers connived at the entrance of the blockade runners, being paid for so doing. The London *Engineer* publishes a letter from its Liverpool correspondent showing the net results—profit and loss—as regards the number of ships built, captured or now running, which presents the subject of the efficiency of the blockade in a very different light from that in which it is exhibited by our own disloyal journals. It appears that the whole number of vessels built from 1862 to 1864 was 111. Of this vast fleet of blockade-runners—far larger in fact than the steam navy of the United States before the war—one-half has been captured and nearly one-fourth destroyed, while the loss of men and money to the builders and owners has been very great. These unadorned facts are a sufficient answer to the oft-repeated statement that the blockade of the Southern coast has been defective."

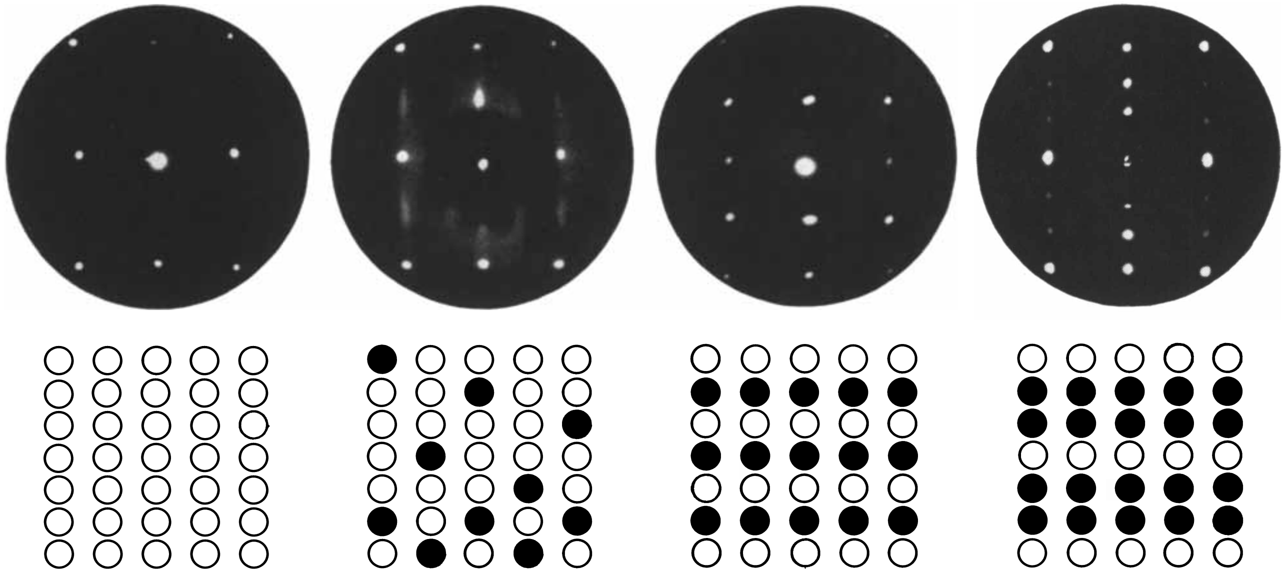
"With that remarkable estimation of the greatness of small things, which is the most valuable of his many high intellectual qualities, and with a tender appreciation of the importance of small people, Baron Liebig devotes a special article in an English scientific periodical to the description of a new diet, which he conceives to be the most fitting substitute for the natural nutrient of children robbed of their mother's milk. It is known that the cow's milk does not adequately represent the milk of a healthy woman, and when wheaten flour is added, as it commonly is, Liebig points out that, although that starch is not unfitting for the nourishment of infants, the change of it into sugar in the stomach during digestion imposes an unnecessary labor on the organization, which will be spared if the starch be changed into the more soluble forms of sugar and dextrin. This he effects by adding to the wheaten flour a certain quantity of malt. As wheaten flour and malt flour contain less alkali than woman's milk, he supplies this when preparing the soup. Liebig has himself used this soup with tea as a breakfast, and a most thoroughly nutritious meal it must be."

"The Paris correspondent of the *Chemical News* states that a curious experiment has been made by Dr. Reichenbach of Vienna. He believes in the existence of a cosmical powder or dust, which exists all through space and which sometimes becomes agglomerated so as to form large and small meteorites, whereas at other times it reaches the surface of our earth in the form of impalpable powder. We know that meteorites are mainly composed of nickel, cobalt, iron, phosphorus, etc. Dr. Reichenbach went to the top of a mountain that had never been touched by spade or pickax and collected there some dust, which he analyzed, and found it to contain nickel, cobalt, phosphorus and magnesia."

"The London *Engineer* states that Bessemer's receipts from his patent for making steel amount to $500,000 a year, making it the most profitable patent ever obtained."

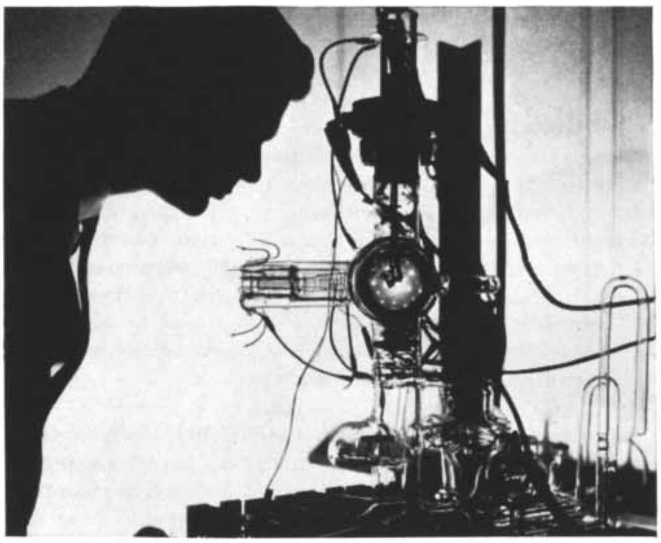
Report from

BELL LABORATORIES



Adsorption of oxygen on crystalline nickel surface produces sequence of diffraction patterns shown in upper row. These patterns can be accounted for by the surface atom arrangements in lower row (nickel as open circles, oxygen as filled circles). Clean nickel surface is represented at far left. As oxygen atom concentration increases from left to right, streaks appear (left center), implying random oxygen positions. At ½ oxygen coverage (right center), surface is ordered and streaks have coalesced into sharp spots halfway between original spots. At ⅔ oxygen coverage (right) a triply periodic pattern and atomic arrangement occur.

A closer look at the surfaces of solids



Low energy electron diffraction equipment showing spot pattern on phosphor screen at center. In this ultrahigh vacuum apparatus electrons are diffracted at the target crystal which can be seen in front of the screen. They are then accelerated to produce visible spots. Electron energy at the crystal surface is variable from near zero to several hundred electron volts.

What does a surface really look like on an atomic scale? What happens when a gas interacts with an atomically clean, crystalline surface? With recently improved apparatus (left) based on the scattering of low energy electrons into preferred directions (diffraction), it is now possible to answer such questions in considerable detail.

As an example, scientists at Bell Laboratories have recently observed the intriguing sequence of surface structures illustrated above when oxygen gas interacts with a nickel surface. Structures have been identified and transitions among them studied as functions of gas pressure and temperature on several crystallographic faces of a number of metals, semiconductors and insulators.

Other types of results concern the formation of faceted pits and pyramids at surfaces, nucleation and growth in monolayers and multilayers, and the vibrations of surface atoms. We are working toward fundamental knowledge of surfaces comparable to present knowledge of the bulk properties of crystals.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

THE AUTHORS

W. A. LITTLE ("Superconductivity at Room Temperature") is associate professor of physics at Stanford University. He was born in the Union of South Africa and lived there until he was 23. "The colorless life of a Spartan boarding school," he says, "drove me to escape in the fantasies of science fiction." From that his interest "turned slightly toward the less fictional variety of science, and that presumably is how I landed up in physics." After obtaining a B.Sc. at the University of South Africa in 1950 and a Ph.D. at Rhodes University in 1955, Little went to the University of Glasgow, from which he received another Ph.D. in 1957. While in Scotland he won the Scottish high jump championship twice. He spent two years as a postdoctoral fellow at the University of British Columbia before going to Stanford in 1958. In addition to the work reported in his article his interests are "phase transitions, liquid helium and very low temperatures."

ANTHONY KELLY ("Fiber-reinforced Metals") is a lecturer in metallurgy at the University of Cambridge. He was graduated from the University of Reading in 1949 and received a Ph.D. at Cambridge in 1953. Thereafter he spent two extended periods in the U.S.—1953 to 1955 doing postdoctoral work in physics and metallurgy at the University of Illinois and 1956 to 1959 teaching metallurgy and materials science at Northwestern University—before assuming his present post in 1959. Kelly often spends summers working in industrial and Government laboratories; he writes that "I think that is an ideal way to learn what applied science means." In his spare time he enjoys "drinking and talking about good wine."

BELA JULESZ ("Texture and Visual Perception") is head of the Sensory and Perceptual Processes Department at the Bell Telephone Laboratories. A native of Hungary, he was graduated from the Technical University of Budapest and the Hungarian Academy of Sciences. He taught and did research in communications systems in Budapest until 1956, when he joined Bell Laboratories. At Bell he was first engaged in studies of systems for reducing television bandwidth and of digital methods for processing pictorial information. Since 1959 he has devoted full time to visual research, particularly in depth perception and pattern recognition.

WILLIAM MONTAGNA ("The Skin") is director of the Oregon Regional Primate Research Center and also professor and chairman of the division of experimental biology at the University of Oregon Medical School. He is a native of Italy who came to the U.S. at the age of 14 and was graduated from Bethany College in 1936. He writes that "after abortive attempts to become first an ornithologist and then a forest ranger" he obtained a Ph.D. in zoology at Cornell University in 1944. Before assuming his present post he taught at Cornell, the Long Island College of Medicine and Brown University. In addition to the skin, about which he has written extensively, his chief interest is reproductive biology, which is one of several major research programs under way at the Oregon Regional Primate Research Center.

R. S. EDGAR and R. H. EPSTEIN ("The Genetics of a Bacterial Virus") are respectively associate professor of biology at the California Institute of Technology and an investigator at the Institute of Molecular Biology of the University of Geneva. They were graduate students together at the University of Rochester, where Epstein, who was born in Rochester, had done his undergraduate work; Edgar, a native of Canada, went to Rochester after undergraduate work at McGill University. Both obtained a Ph.D. at Rochester and then, in the late 1950's, went to the California Institute of Technology to study under Max Delbrück. Of the work reported in their article Edgar writes: "Epstein started the 'ambers' here and then went to Geneva to continue that work while I developed the temperature-sensitive system. The two systems were developed independently, with communication going on through an intermediary, an associate of Epstein's, since he is a notoriously bad letter writer (he doesn't)."

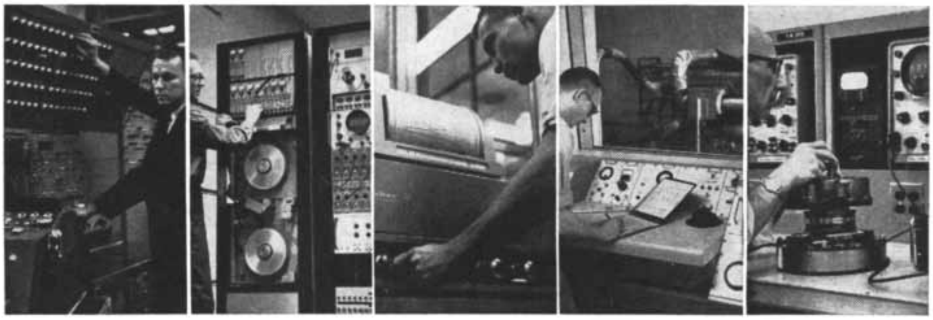
JOHN R. NICHOLS ("How Opiates Change Behavior") is associate professor of psychology and acting chairman of the department of psychology at Southeastern Louisiana College. He went there in 1956 after receiving undergraduate and graduate degrees at the University of Oklahoma, where his interest in problems of drug addiction arose. Concerning that he writes: "Opiates, which have a powerful influence on human behavior, seemed to have little or no effect on animal behavior. I worried this fascinating puzzle until it began to make sense." For several years Nichols has conducted a research project on drug addiction under grants from the U.S. Public Health Service. He has several avocational interests, including magic, photography and electronics.

PETER O. VANDERVOORT ("The Age of the Orion Nebula") is assistant professor of astronomy at the University of Chicago, where he did both undergraduate and graduate work. After obtaining a Ph.D. in physics there in 1960, he spent a summer as a research associate at the National Radio Astronomy Observatory in Green Bank, W.Va., and an academic year as a National Science Foundation postdoctoral fellow at Princeton University before taking his present post. Vandervoort describes his principal interest as "the theoretical and mathematical problems of astronomy," particularly such problems as "trying to work out a gas-dynamic theory for expanding nebulae such as Orion." He chose Orion for his investigation because "the amount of observational material was sufficient to make a comparison of observation with theory."

CYRUS H. GORDON ("The Greeks and the Hebrews") is professor of Near Eastern studies and chairman of the department of Mediterranean studies at Brandeis University. Gordon was born in Philadelphia and obtained bachelor's, master's and doctoral degrees from the University of Pennsylvania in 1927, 1928 and 1930 respectively. For four years thereafter he was a field archaeologist in the Near East and since then, while teaching at various universities, he has conducted several archaeological explorations in the eastern Mediterranean area. Gordon's principal interest is in new discoveries bearing on the origins of Western civilization. In particular he has devoted attention to the relations between early Hebrew and Greek literatures. He has written several books and more than 200 articles in his field. This spring he plans to conduct "an archaeological study tour of the cuneiform world."

A. RUPERT HALL, who in this issue reviews *The Technological Society*, by Jacques Ellul, is professor of the history of science and technology at the Imperial College of Science and Technology of the University of London.

Our research engineers



are a bunch of meddlers

Not that we're complaining. It is their never-quite-satisfied attitude that is the foundation for a continuing engine improvement program at Caterpillar. We call it the search for uncommon quality.

At Caterpillar, the search for uncommon quality is constant and uncompromising. It includes a continuing scrutiny of every Caterpillar Engine part—its design, shape, size, weight, and material.

Just one result of this "meddling" has been the modern turbocharged-aftercooled design of today's Caterpillar engines. For the user, this concept means higher output from a more compact power package.

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EXAMPLE:

At one time, Cat fuel injectors were as large and as difficult to install as anybody else's.

No longer.

Now they are small replaceable capsules—as easy to install as a spark plug. Almost seven inches shorter and 2½ pounds lighter than previous designs, these new injectors cost $31.87 less per unit!

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At Caterpillar, the "meddlers" continue in their search for uncommon quality. This effort is dedicated to bringing you more dependable, and less costly, engine horsepower.

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One of a series briefly describing GM's research in depth

A good close look at corrosion mechanisms

Most metals corrode when given the chance.

Why? How?

To help find out, General Motors Research chemists have developed a very rapid, but accurate, method of examining corrosion reactions.

These perplexities are probed by carefully controlling an electric current that is made to flow between a metal sample and a nearby auxiliary electrode—with both immersed in a corrosive aqueous solution. This polarizing current supplements some corrosion reaction currents, opposes others. Simultaneously measuring the polarizing current and the electrochemical potential near the sample's surface provides a continuous monitor of subtle changes in instantaneous corrosion rate.

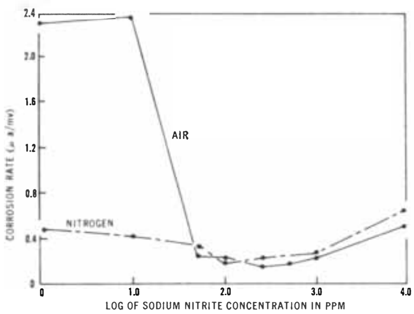
This continuous, dynamic information provides a rapid way to study the effects of a variety of corrosive ions, corrosion inhibitors, gases, and other environmental variables. It also helps in understanding the fundamental mechanisms of corrosion and protection processes.

For instance . . . results have reinforced the view that sodium nitrite inhibits the corrosion of steel, in chloride or sulfate solutions, by helping form a protective oxide film at the metal surface and maintaining it in dynamic equilibrium. They also indicate that the basic function of sodium nitrite is to help provide the current needed to form the protective oxide film.

This blending of everyday application with basic understanding is a frequent consequence of General Motors research in depth.

General Motors Research Laboratories

Warren, Michigan



Effect of gases on a mild steel sample in a corrosive solution containing inhibitor.

Established 1845 SCIENTIFIC AMERICAN February 1965 Volume 212 Number 2

Superconductivity at Room Temperature

It has not yet been achieved, but theoretical studies suggest that it is possible to synthesize organic materials that, like certain metals at low temperatures, conduct electricity without resistance

by W. A. Little

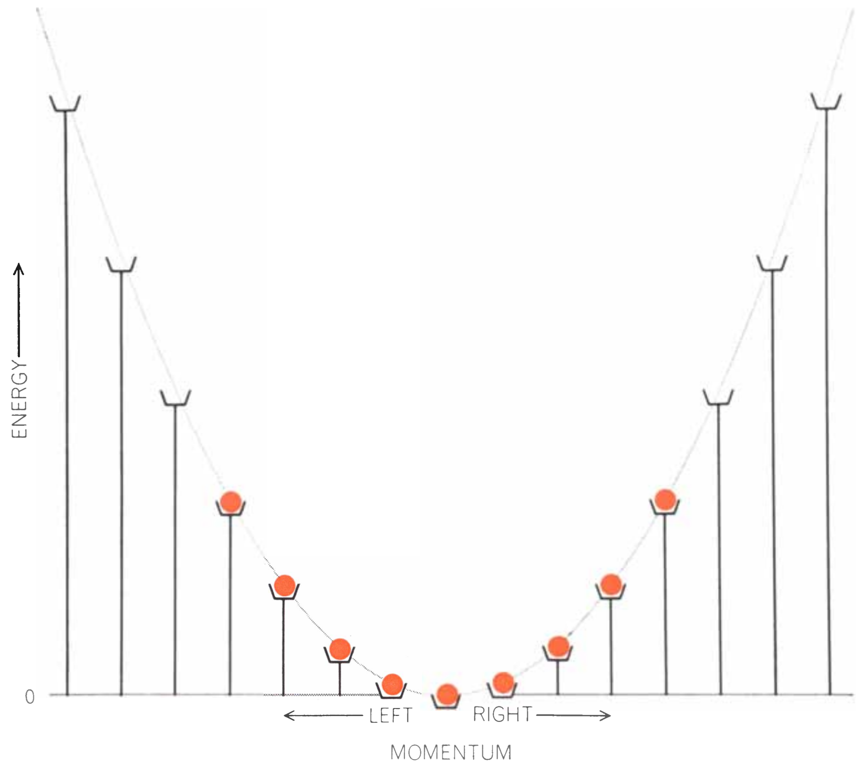
Several years ago an experiment was performed at the Massachusetts Institute of Technology that demonstrated the possibility of constructing a perpetual-motion machine. An electric current was induced to flow around a small ring of metal. The ring was then set aside. A year later the current was found to be still circulating in the material of the ring; what is more, it had not diminished by a measurable amount during this period! Although physicists object instinctively to the idea of perpetual motion and refer to such currents euphemistically as "persistent currents," they are obviously extremely persistent currents.

The secret of this extraordinary phenomenon is of course that the metal must be kept very cold—in fact, within a few degrees of absolute zero (−273 degrees centigrade). Below a characteristic "transition temperature" certain metals spontaneously enter what is known as the superconducting state, in which a stream of electrons can flow without encountering any resistance in the form of friction. Since friction is the cause of the failure of all mechanical perpetual-motion machines, its total absence in this case allows the initial current to persist indefinitely without any further input of energy, thereby violating the traditional doctrine of the impossibility of perpetual motion.

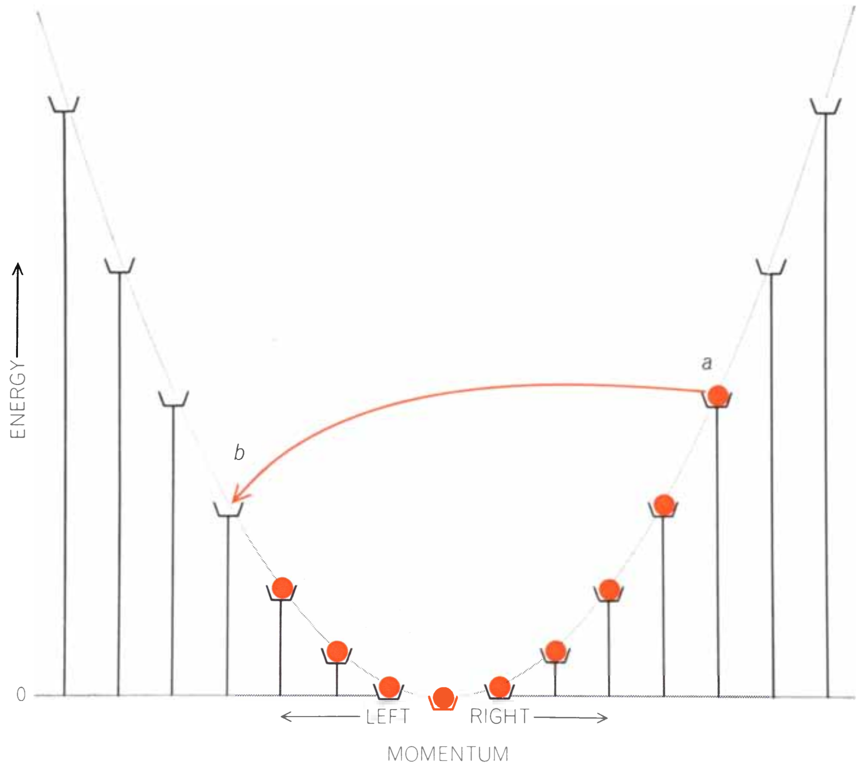
Actually the phenomenon of superconductivity is not at all rare. Since its discovery by the Dutch physicist Heike Kamerlingh Onnes more than 50 years ago many different metals and several hundred alloys composed of these metals have been identified as superconductors. As might well be expected, the technological potential of perpetual-motion machines based on the principle of superconductivity is virtually unlimited. Lossless power transmission, enormously powerful electromagnets, more efficient motors, amplifiers, particle accelerators and even computers are just a few of the serious proposals for the exploitation of superconductivity that have been put forward in the past 50 years. The main drawback of all these schemes involves the very low temperatures typically associated with superconductors; the complex and bulky refrigeration equipment required to maintain such metals in the superconducting state makes most of the proposed applications as yet economically unfeasible. The hope that the problem of refrigeration might someday be circumvented by the discovery of superconductors with higher transition temperatures has led to the investigation of a large number of alloy combinations of the known superconducting metals. Although many new superconducting alloys have been found, the outlook for high-temperature metallic superconductors is not bright. The highest transition temperature recorded so far is only 18.2 degrees Kelvin (degrees centigrade above absolute zero), which is still well below the temperature range accessible to simple refrigeration systems. Moreover, this work has yielded a considerable amount of statistical evidence that suggests that it is extremely unlikely that an alloy will ever be found with a transition temperature appreciably higher than about 20 degrees K.

What about the possibility of discovering some other substance—perhaps a nonmetallic one—that would be superconducting at higher temperatures? As a matter of fact it is an especially opportune time to investigate such a possibility in view of the great theoretical advances that have been made in recent years toward understanding the superconducting state. I have been particularly interested in the possibility of synthesizing an organic substance that would mimic the essential properties of a superconducting metal. My calculations have shown that certain organic molecules should be able to exist in the superconducting state at temperatures as high as room temperature (about 300 degrees K.) and perhaps even higher! In order to explain the line of reasoning that led to this prediction I must first discuss some of the theoretical ideas on which it is based.

An understanding of the true nature of superconductivity has proved to be one of the most difficult problems of theoretical physics in this century. A great stride forward was made in 1957 with the publication of a comprehensive microscopic theory by John Bardeen,



IN AN ORDINARY CONDUCTOR "free" electrons (*colored balls*) can roam in any way consistent with two restrictions: (1) only certain velocities, or energy states, are permitted and (2) only one electron at a time may be in any one of the allowed states. In the most stable energy arrangement all the lower energy states are filled by electrons and all the higher states are empty. No current flows because as many electrons move to left as to right.



CURRENT FLOWS in an ordinary conductor when all the allowed energy states are displaced in one direction (in this case to right); more electrons now travel to right than to left. Current decays when an electron moving rapidly to right (*a*) collides with some imperfection in the metal and is knocked backward (*colored arrow*); it can then occupy one of the vacant states corresponding to an electron moving somewhat less rapidly to left (*b*).

L. N. Cooper and J. R. Schrieffer, then at the University of Illinois. Their theory, now universally known as the BCS theory, has been successful not only in explaining practically all the experimental data that had accumulated over the past half century but also in predicting a number of new superconducting phenomena.

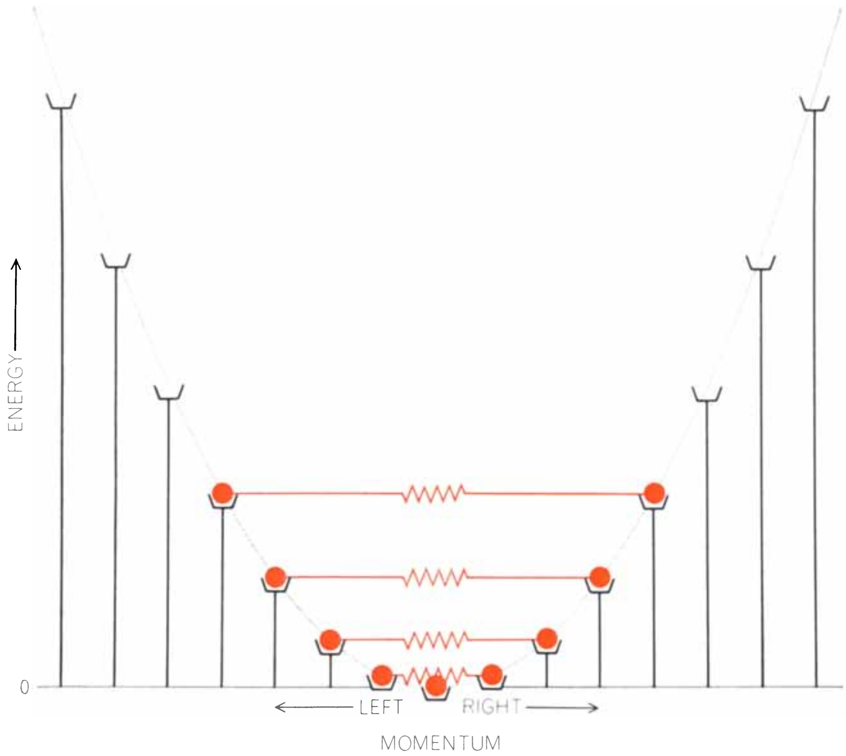
Like most scientific theories, the BCS theory did not appear out of the blue but was built on a firm theoretical foundation established by earlier investigators. In particular, some of the principal features of the BCS theory were outlined many years before by the theoretical physicist Fritz London, who developed a successful macroscopic theory of superconductivity as early as 1950. In so doing London showed an appreciation of the highly organized nature of the superconducting state and an intuitive grasp of several of the essential criteria a successful microscopic theory would have to fulfill. He recognized that each sample of a given superconductor has a unique character peculiar to itself and that in the superconducting state this character remains unaffected by heat or any other external influence. He was also impressed by the extraordinary stability of the superconducting state, a characteristic that figures prominently in the BCS theory.

It was perhaps through his perception of these rough features of a microscopic theory that London was led to suggest that the phenomenon of superconductivity might be significant in areas of science other than the specialized niche of low-temperature physics. He proposed that the existence of such a state in certain large organic molecules, such as proteins, might help to explain some of the unusual properties of these molecules. Unfortunately London died several years before the advent of the BCS theory and so was unable to develop or test his ideas further in its light. Although his other writings have influenced many workers in the field, little attention appears to have been paid to these suggestions in the decade after his death.

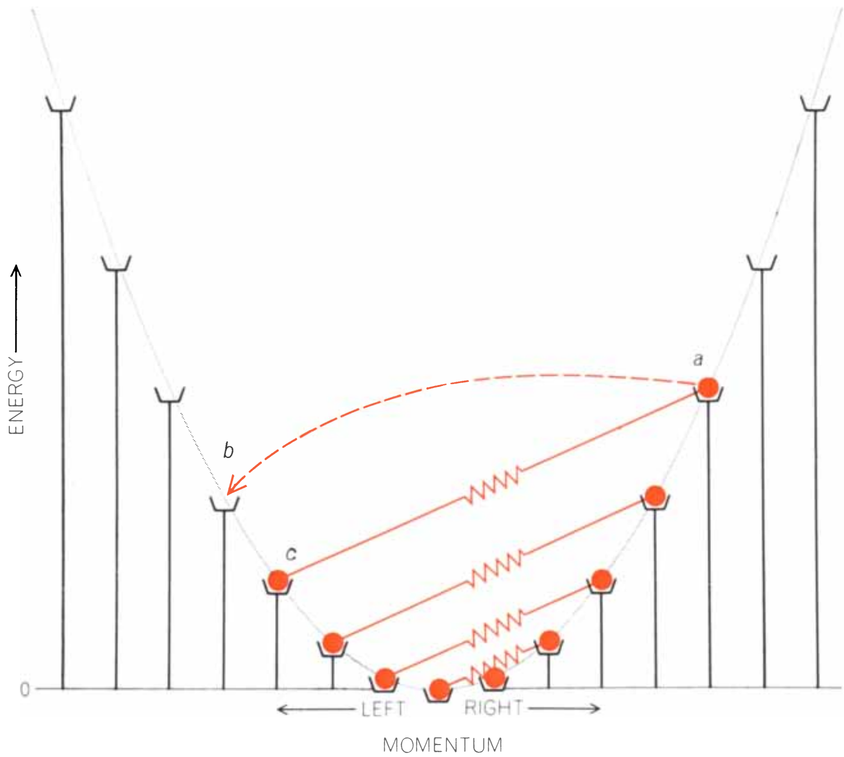
My own interest in the possibility of biological superconductivity was stimulated five years ago while I was working at Stanford University on a rather mundane problem of heat transfer to a metallic superconductor. Like London, I was struck by the great stability of the superconducting state; it occurred to me that if nature wanted to protect the information contained, say, in the genetic code of a species against the ravages of heat and other external influences, the principle of superconductivity would be well suited for the purpose. In view of nature's remarkable record of ingenuity in such matters, I thought it might be useful to determine if the superconducting state could occur in a large organic molecule built along the general lines of the genetic molecule deoxyribonucleic acid (DNA).

One molecule of this general type looked particularly promising in the light of the requirements of the BCS theory. Its structure, incidentally, is quite close to what London appears to have had in mind and suggests that he progressed further along this line of reasoning than his published work reveals. A detailed calculation of the superconducting properties of the hypothetical molecule showed that it should be superconducting at room temperature, and indeed even at temperatures well above room temperature. This bonus, although it is necessary if the phenomenon is to perform any biological function, was quite unexpected. Subsequent investigation has shown that there is a relatively straightforward explanation for this extraordinarily high transition temperature. Before describing how a superconducting current might be transmitted by such a molecule, however, it is necessary to review the mechanisms by which an electric current is transmitted in an ordinary conductor and in a metallic superconductor.

In an ordinary, nonsuperconducting metal each atom loses some of its outer, more loosely bound electrons, which are then free to roam throughout the rest of the metal. The motion of these "free" electrons is not entirely unrestricted: the requirements of quantum mechanics impose the condition that only certain energy states, or velocities, are permitted. Another restriction is imposed on the manner in which the electrons may be arranged in these states. This restriction arises out of the Pauli exclusion principle (named after its discoverer, Wolfgang Pauli), which says that only one electron at a time may be in any one of the allowed states. The electrons are free to arrange themselves in any way consistent with these two restraints. The most stable energy arrangement is one in which all the lower energy states are filled by electrons and all the higher states are empty. For every state that corresponds to an electron moving to the left there is another state of equal energy for an electron moving to the right. Thus in the lowest energy arrangement there are as many electrons moving to the left as to the



IN A SUPERCONDUCTOR an attractive interaction of "free" electrons binds them together in pairs (*see illustration on next page*). The paired electrons cannot move freely in the metal, since it turns out that in order to be bound to each other the momentum of the center of mass of each pair must be the same as that of the majority of the other pairs. When no current is flowing in the metal, the momentum of the center of mass for each pair is zero.



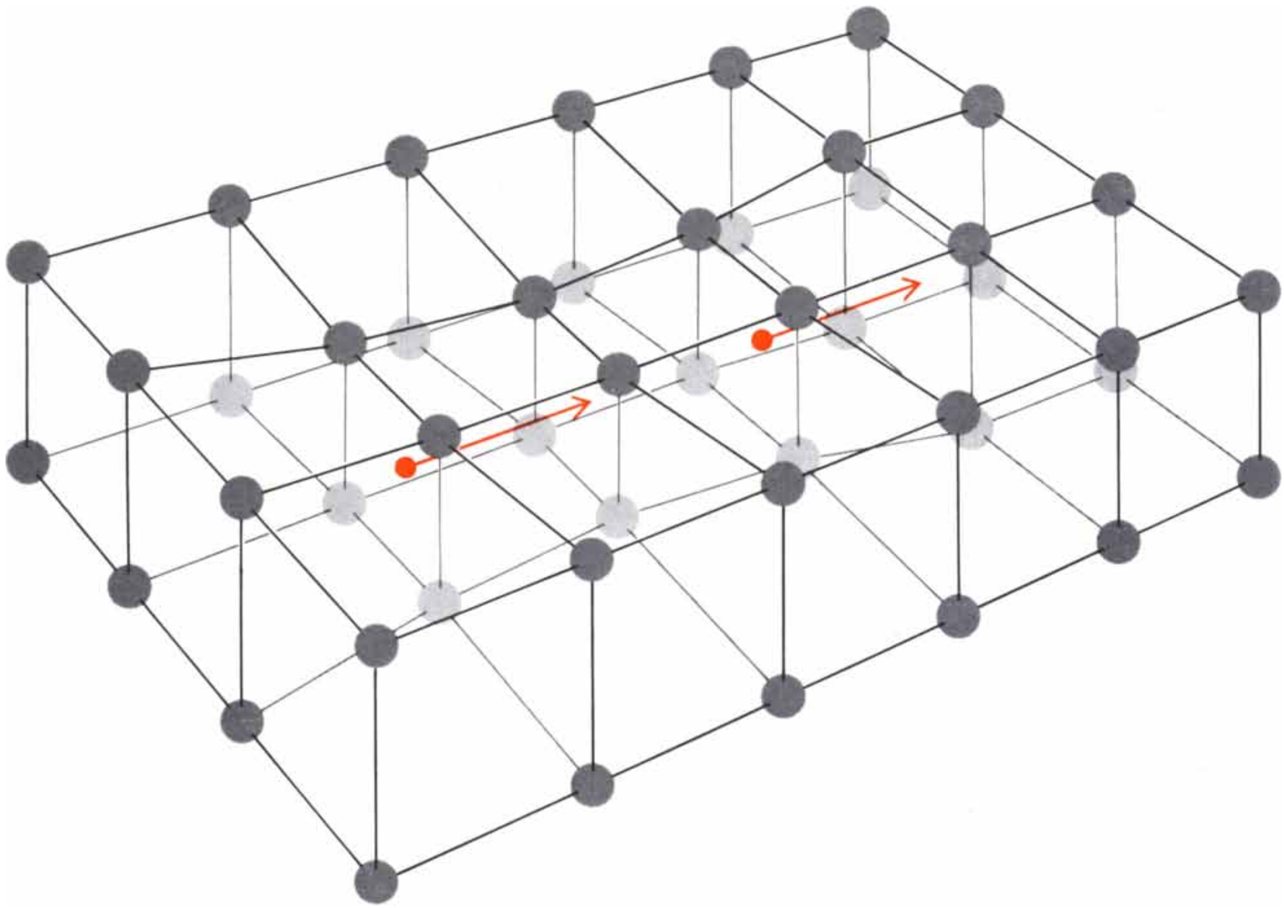
"PERSISTENT CURRENT" FLOWS in a superconductor when more electrons travel to the right than to the left. The current does not decay because if the electron at *a* were now to jump to *b*, both it and the electron at *c* would be left without mates. These two single electrons would not be able to pair up with each other because their center of mass would then have the wrong momentum. Consequently the electron pairs do not as a rule break up.

right and the entire distribution of electrons is symmetric [*see top illustration on page 22*]. In this equilibrium situation the average velocity of the electrons in any one direction is zero and consequently no current flows in the metal.

If a current is now induced in the metal, this is tantamount to saying that all the electrons are forced to move in one direction, say to the right, so to the random velocity of each electron must be added the component of this drift velocity. Electrons moving to the right would therefore have their velocities and consequently their energies increased, whereas electrons moving to the left would have their velocities and energies decreased. On the average this asymmetric distribution of the electrons would have a somewhat higher energy than the original symmetric distribution, owing to the additional kinetic energy of the drifting electrons [*see bottom illustration on page 22*]. The asymmetric distribution does not last long if left to itself in a normal metal, because if one of the electrons moving rapidly to the right should collide with some imperfection in the metal and be knocked backward, it could then occupy one of the vacant states corresponding to an electron moving less rapidly to the left. The states on the left have a somewhat lower energy because of their lower velocity and so would be preferred by the electron. In this way the asymmetric, current-carrying distribution would rapidly rearrange itself to form the lower-energy, symmetric distribution and the current would disappear.

In a superconductor this deterioration of the asymmetric electron distribution does not occur, since there is an attractive interaction of electrons that binds them together in pairs. Each electron in a superconductor has a mate with which it is paired. The paired electrons cannot move freely in the metal; it turns out that in order for them to be bound to each other the momentum of the center of mass of each pair must be the same as that of the majority of other pairs [*see top illustration on preceding page*]. Now, if the electron moving rapidly to the right collides with an imperfection and is knocked into a state corresponding to the electron moving less rapidly to the left, this electron will have no mate and its old mate will similarly be left single. These two single electrons would not be able to pair up with each other because their center of mass would then have the wrong momentum. Consequently if the cost in energy for breaking up the pair is not offset by a sizable reduction in kinetic energy resulting from the collision, the pair will not break up. The asymmetric distribution will remain and the current will persist [*see bottom illustration on preceding page*]. According to the BCS theory, this is the reason why the current in a superconducting ring can persist indefinitely.

Of course the foregoing argument only partly explains why certain substances suddenly become superconduct-



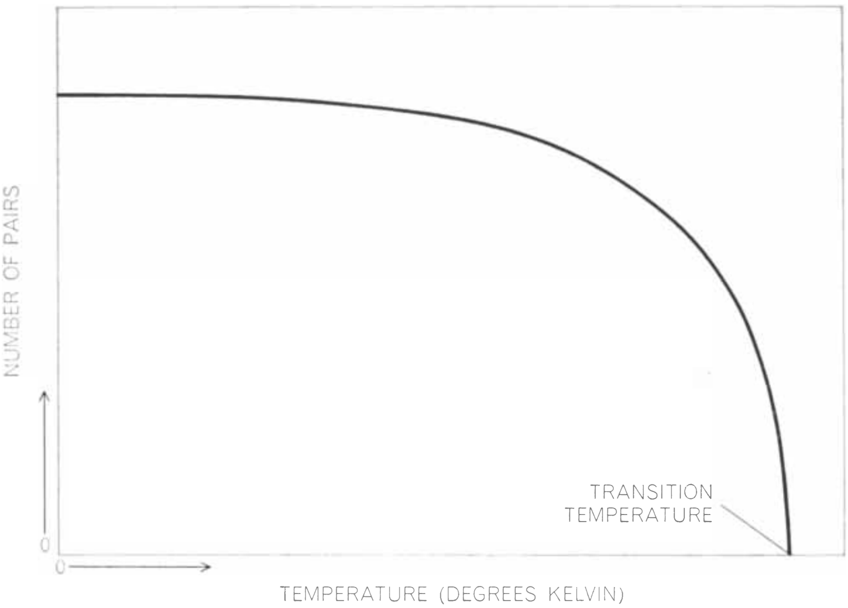
ELECTRON PAIR is formed in a superconducting metal by the attractive mechanism depicted here. As a negatively charged electron moves through a somewhat elastic lattice of positively charged ions it attracts the ions, causing the lattice to "pucker up" in its vicinity. A second electron is naturally attracted to the excess positive charge created by the higher density of ions in this puckered region of the lattice and is thereby indirectly attracted to the first electron. Since the ions move more slowly than the electrons, the puckered region trails a considerable distance behind the first electron and the second electron can follow at this safe distance.

ing at a specific temperature. Why, for example, should the electrons attract one another when we know that electrons have like charges and thus should repel one another instead? Why should the centers of mass of the pairs be correlated in any way with one another? These are subtler questions that cannot be easily answered straightforwardly, but they can be approached in a somewhat more general way with the aid of an analogy.

Imagine a thin elastic membrane stretched over the head of a drum. On top of the drumhead we put two marbles. If we tilt the drum gently from side to side, how do the marbles move? Obviously the weight of each marble depresses the elastic membrane so that when the two marbles come close to each other, one rolls down into the depression made by the other; to all appearances the two are attracted to each other. If we now tilt the drum to one side, the marbles move about on the surface together as a pair—each moving in the depression made by the other. If the tilting is done more vigorously, however, the agitation can eventually become so violent that the two marbles separate and begin to move about more or less independently of each other.

What has this to do with superconductivity? In a metal the positively charged ions, which remain after the atoms are shorn of their outer electrons, are not rigidly fixed at their sites in the crystal lattice but are able to move elastically about these sites. If one of the "free" electrons moves among the positively charged ions, the ions will be attracted to the negatively charged electron as it passes. This distorts the lattice and causes it to "pucker up" in the vicinity of the electron [*see illustration on opposite page*]. A second electron is naturally attracted to the excess positive charge created by the higher density of ions in the puckered region of the lattice and is thereby indirectly attracted to the first electron. The situation is closely analogous to the second marble being attracted to the first by the depression in the elastic drumhead; the puckered lattice and the depression in the drumhead play equivalent roles in the two cases.

In a metal the attractive force produced by this mechanism can be such that two electrons can become firmly bound to each other. The binding will only occur, however, if the temperature is sufficiently low, since at higher temperatures the thermal agitation of the electrons will tend to break up the electron pairs in much the same way as the violent tilting of the drumhead can separate a pair of marbles.

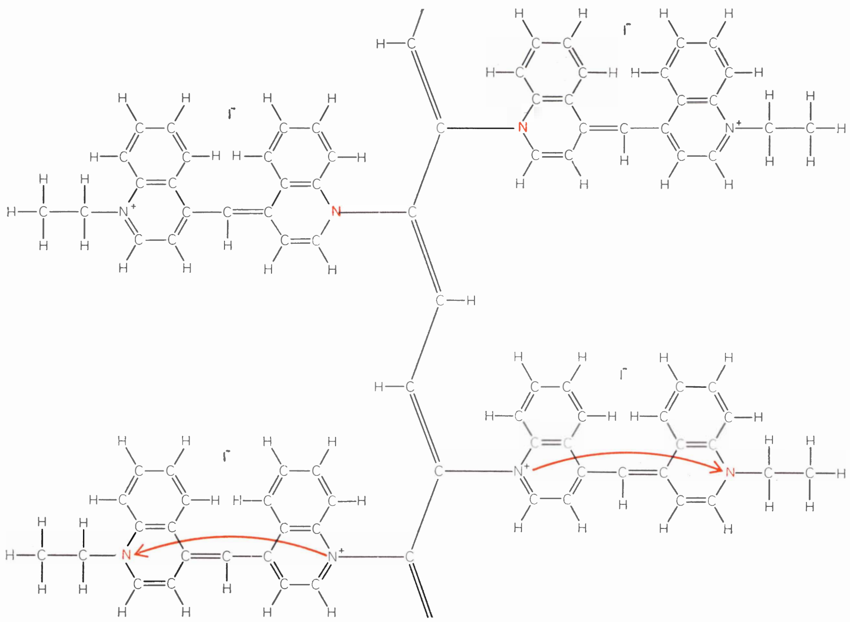


CATASTROPHIC BREAKUP of electron pairs in a superconductor occurs as the superconducting transition temperature is approached from a lower temperature. Although the pairs begin to break up slowly, the unattached electrons resulting from the just broken pairs interfere with the remaining pairs, causing them to break up and accelerating the entire breakup process rapidly. No electron pairs can exist above the transition temperature.

It is useful to look more closely at the details of this process. Suppose the first electron is moving down a corridor of positive ions. The range of the electron-ion interaction is quite short; accordingly the electron will give each ion a short, sharp pull as it passes. This impulse starts the ion moving toward the position of the electron, but since the ions move rather more slowly than the electrons, the electron responsible for the motion will be a considerable distance away by the time the ion has moved as far as it can against the elastic restraints of its neighbors. As a result the puckered region of the lattice trails some distance behind the first electron, and the second electron can follow at this safe distance.

Between the two electrons there is enough space for many other electrons to move. What effect do these electrons have on our theoretical model? If their motion is quite chaotic and completely uncorrelated with that of the first electron, they will interfere seriously with the orderly procedure described above. They too would pucker the lattice in their neighborhood and stretch it elsewhere. If the lattice is stretched where it should be puckered and puckered where it should be stretched by this host of uncorrelated electrons, there will be little left of the puckered region produced by the first electron for the second electron to follow. The scent, so to speak, will rapidly be lost and the pair broken. On the other hand, if the motion of all the other electrons is correlated so that each electron dodges the others and maneuvers in precisely the right way, then each electron can enjoy fully the attraction of its mate and a large number of pairs can coexist with one another.

It turns out that the prerequisite for all the pairs being in harmony with one another in this way is that their centers of mass must all have the same momentum. At low enough temperatures this highly coordinated state of the electrons occurs spontaneously, because the gain in the energy of each pair more than offsets the disadvantages involved in the loss of freedom of the individuals. If the temperature is raised, however, the thermal agitation eventually becomes sufficient for some pairs to break up. The resulting uncorrelated, unattached electrons now become a disruptive nuisance to the electron couples. They interfere with the attractive mechanism and thereby weaken the binding force of the remaining pairs. This in turn causes more pairs to break up. As the temperature is raised still further, the breakup of pairs becomes catastrophic; above a well-defined temperature no pairs can



HYPOTHETICAL SUPERCONDUCTING MOLECULE is built around a "spine" of carbon atoms connected by alternating single and double bonds. Periodically along the spine a side chain consisting of the common dye diethyl-cyanine iodide extends outward. These side-chain molecules are highly polarizable; that is, an electron can move freely from a nitrogen site close to one end of the molecule to another nitrogen site close to the other end. A colored *N* designates the nitrogen atom that contains the resonating electron in the two possible conditions of polarization. Electrons can also move freely along the spine itself.

exist at all [*see illustration on preceding page*].

The superconducting state is obviously distinguished by a high degree of internal organization. It can exist only below the temperature at which the breakup of the electron pairs becomes catastrophic. The temperature at which this occurs is the superconducting transition temperature.

It is not difficult to deduce from the preceding argument the criteria that would have to be fulfilled for an organic molecule to exist in the superconducting state. The molecule would have to be provided with roughly the same essential ingredients that are found in the superconducting metal. A medium is required in which the electrons can move, and a somewhat elastic charged structure is needed to play the role of the ion lattice.

Imagine a long molecule built of a chain of carbon atoms that form what I shall call a "spine." On each side of the spine molecular side chains extend outward rather like the ribs of the human rib cage. As I have mentioned, this structure was suggested by the genetic molecule DNA, the carbon atoms of the spine replacing the sugar-phosphate sequence of DNA and the side chains replacing the bases. If the carbon chain is conjugated, that is, if it has alternating single and double bonds along the chain, it will behave much like a metal, with the electrons moving freely from one end of the spine to the other. For the side chains a molecule such as diethyl-cyanine iodide, a dye commonly used to sensitize photographic emulsions, would appear to be suitable. This is a highly polarizable molecule in which an electron can move freely from a site close to one end of the molecule to a site close to the other end [*see illustration above*]. In an electric field the charge readily shifts from one end to the other and the molecule thus becomes polarized in the field.

Consider now an electron moving along the spine of such a molecule. As the electron passes each side chain its electric field polarizes the side-chain molecule and induces a positive charge at the end nearer the spine. Because of the high speed of the electron in the spine the region of maximum induced positive charge in the side chains trails some distance behind this electron. A second electron is attracted to the region of positive charge and is thereby indirectly attracted to the first electron. This is exactly the same argument we used in describing the superconducting metal and naturally leads to the same phenomenon. When the detailed calculations of the BCS theory are carried out for the organic molecule, however, one finds that the theoretical transition temperature is enormously high—typically around 2,000 degrees K.! This figure is of course much higher than that of any known superconductor and, if it is to be trusted, must be based on some good physical reason. It turns out that it is.

Let us return to the description of the attractive mechanism between free electrons in a conventional superconductor. As an electron passes the ion it gives it a short, sharp impulse and then is gone. The impulse transfers to each ion a certain amount of kinetic energy, which starts the ion moving. The ion continues to move until the elastic restraints of its neighbors stop it. At this point the kinetic energy of the ion is completely converted into potential energy. It is elementary to show that the maximum distance the ion can be displaced is inversely proportional to the square root of the mass of the ion. If the ions are heavy, the displacement is small; if the ions are light, the displacement is large. The larger the displacement is, the larger is the distortion of the lattice and consequently the larger the magnitude of the excess positive charge in the puckered region. Since the second electron is attracted to this region and is thereby bound to the first electron, we should expect the strength of this binding also to depend on the mass of the ions of the lattice. By the same token, the transition temperature, which is determined by the binding energy, should be inversely proportional to the square root of the ionic mass. This is in fact the case. Experiments carried out on samples composed of different isotopes of a given superconducting element have shown that in most cases the transition temperature does depend on the isotopic mass in just this way. This correspondence is known as the isotope effect; its discovery early in 1950 provided an important clue to the understanding of superconductivity.

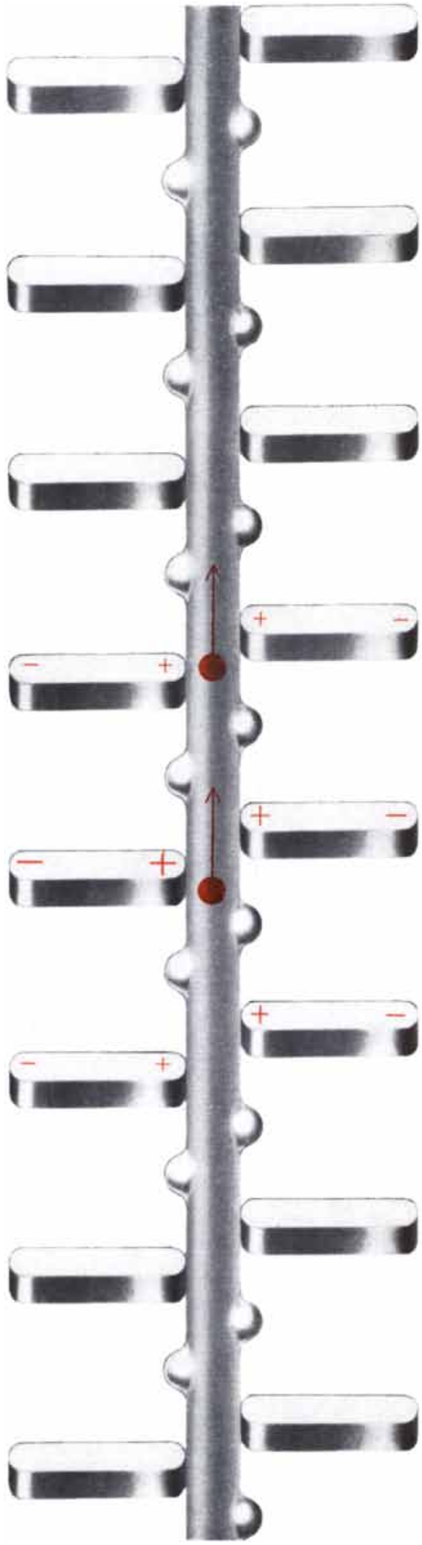
The isotope effect also plays an important role in explaining the tremendously high transition temperatures of our hypothetical superconducting molecules. In these molecules we have replaced the ions of a metal with polarizable side-chain molecules. Under the influence of the electric field of the electron in the spine, the side chains themselves do not move, but a single electron *within* each side chain does move and this produces the polarization. Instead of being an ion, as in the case of the metal, the moving entity is now an electron with a mass only a hundred-thousandth of a typical ionic mass. According to the requirements of the isotope effect, the transition temperature should be on the order of the square root of 100,000 times larger than that for the average metallic superconductor (that is, 316 times 6 degrees K., or roughly 2,000 degrees K.). This figure is almost exactly the same as the one arrived at by our earlier, independent calculation. Obviously the high transition temperature is a result of an attractive interaction that is mediated by an extremely light particle—an electron rather than an ion.

In order for the motion of the ions and the electrons to be in any way analogous it also seems necessary from the theoretical point of view for the electrons to move in a chainlike spine. This is probably the reason why no metal falls into this category of superconductor and why no high-temperature superconductors have been found as yet.

Once we accept the possibility that superconductivity could occur at room temperature in a molecule of this type, a whole new world of science and technology opens before us. Indeed, speculation as to the uses to which such a superconductor could be put reads more like science fiction than any serious scientific proposal. Of course, the chemical problems and eventually, perhaps, the technological problems in the synthesis and production of such materials are immense. After all, we are asking for the synthesis of a molecule to precise, almost engineering specifications, a task that has never before been demanded of organic chemistry. Nevertheless, many chemists feel that this can be done and that given a reasonable amount of time some such molecules undoubtedly will be synthesized. It is to be hoped that when that day comes, our extension of the BCS theory will pass the acid test.

Suppose for the sake of argument we are presented with a plastic material that is superconducting at room temperature. How could we use it? The obvious applications mentioned at the beginning of this article immediately spring to mind, but even more exciting prospects arise from a superconductor's diamagnetism, or impermeability to a magnetic field. Because of the highly coordinated motion of the electrons a magnetic field cannot penetrate the interior of a superconductor. This property can be demonstrated by placing a bar magnet above a sheet of superconducting metal. The magnet floats freely above the sheet, supported entirely by its magnetic field. The field is unable to penetrate the superconductor and so provides a cushion on which the magnet rests. It is easy to imagine hovercraft of the future utilizing this principle to carry passengers and cargo above roadways of superconducting sheet, moving like flying carpets without friction and without material wear or tear. We can even imagine riding on magnetic skis down superconducting slopes and ski jumps—many fantastic things would become possible.

Have we anything of interest to expect from the biological point of view? If it proves possible to synthesize an artificial superconducting molecule, it seems to me that nature would surely have discovered the fact ages ago. Thus we would expect to find molecules of this type playing some unique role in nature, but we can only speculate as to what this role may be. The highly coordinated motion of the electrons within our hypothetical molecule couples the different parts of the molecule together in an extremely intimate way. As a result reactions in one part of the molecule can influence the reactivity of other groups in any part of the entire molecule, however remote. Could this long-range influence explain some of the intricacies of biological molecules? In our molecule the particular value of the common momentum of the centers of mass of the pairs has a very interesting property: it endows the molecule with a unique, preferred three-dimensional folded structure. Associated with each possible value of this momentum there is a unique, intricate shape for the molecule as a whole. Could these structural requirements have anything to do with the large-scale organization of living systems? We cannot be sure at this stage, but the implications of the idea are intriguing. According to our model there is a highly specific attraction between two molecules whose electron pairs have the same momentum but no such attraction between molecules with different momenta for the pairs. Has this anything to do with the extraordinary selectivity and specificity of certain biochemical reactions? Again we do not know, but the idea is suggestive. When one reflects on all these possibilities, the age-old dream of the perpetual motion of mere mechanical devices appears drab and colorless in comparison.



ELECTRON PAIRS are conducted along the spine of a hypothetical superconducting molecule by an attractive mechanism similar to that in a superconducting metal. As an electron passes each side chain its electric field polarizes the side-chain molecule and induces a positive charge at the end nearer the spine. A second electron is attracted to this region of positive charge and is thereby indirectly attracted to the first electron.

FIBER-REINFORCED METALS

Modern knowledge of defects in solids opens a way to increase the strength of materials. A promising technique combines strong fibers such as crystal "whiskers" and a matrix of metal

by Anthony Kelly

Engineers who design structures constantly seek new materials that are stronger and stiffer than existing ones. The advent of such technologies as supersonic flight and rocketry has intensified the search by generating a demand for materials that combine strength and stiffness with lightness and resistance to elevated temperatures. At the same time metallurgists and other materials specialists seek ways to improve the quality of existing materials, which seldom realize the full potential of their molecular structure.

Over the past 20 years knowledge of crystals and their imperfections has reached a state in which it is possible to predict accurately how strong materials such as metals can be. It has also been recognized that the best principle for creating strong materials is to embed strong fibers in a comparatively weak matrix. The matrix is typically a metal; the fibers can be a metal, another crystalline substance or a glass. Several high-strength materials have been developed on this principle, but they are very expensive. The problem remains of discovering combinations that can be fabricated easily in structurally useful dimensions.

By embedding fibers of silica (silicon dioxide) in aluminum metallurgists at Rolls-Royce Limited in Britain have produced a material with a strength twice as great as the strongest conventional aluminum aircraft alloy without any increase in weight. The material can be fabricated in any size, although it has the limitation of not being very stiff. Its use in structures awaits only the extensive testing necessary to ensure that it will stand up under operating conditions. Several other materials, including some developed in the U.S., show considerable promise. This article will discuss the principles involved in designing materials of this type and the development situation as it now stands.

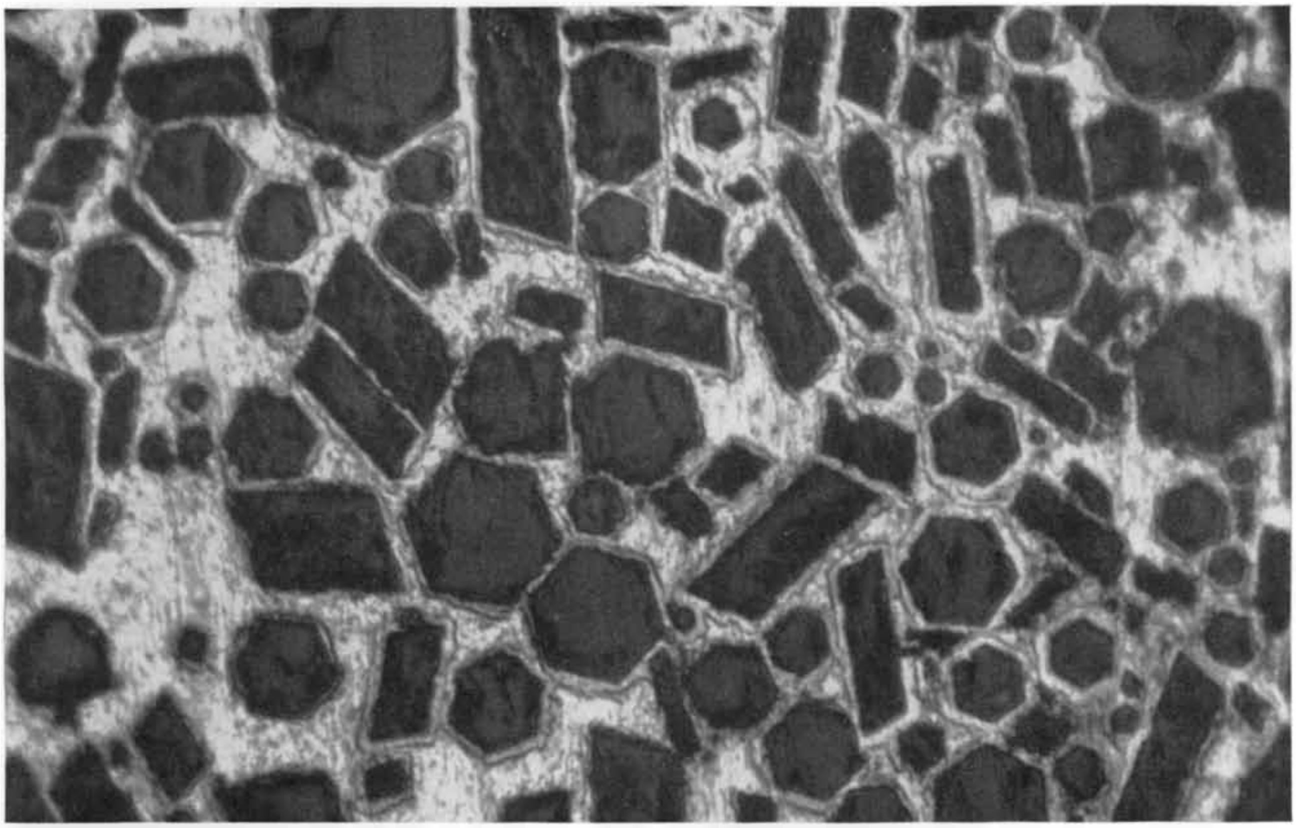
The marked contrast between the theoretical and actual strength of a material was demonstrated in 1923 by the Swiss physicist Fritz Zwicky, now professor of astrophysics at the California Institute of Technology. Zwicky calculated how strong a crystal of ordinary table salt should be; the calculation indicated that a force of 300,000 pounds per square inch should be required to break such a crystal. If a salt crystal is large enough for one to get a grip on it, however, one can snap it with one's fingers; the force required is only a few hundred pounds per square inch. Zwicky chose the salt crystal for his calculation because at that time it was one of the few crystals in which the forces binding the constituent atoms of the crystal—in this case sodium and chlorine—were known. A similarly large discrepancy between observed and calculated strength exists for many other crystalline materials, including steel. The discrepancy is so striking that it has become known as the "crystal paradox."

The paradox is due to the fact that crystals have many defects that drastically reduce their strength. This was not recognized when Zwicky made his calculation, but today the defects have been classified and in a number of cases are well understood. As a result the task faced by metallurgists and other materials specialists has been to ascertain how close to the theoretical limit they can design usable materials by controlling the behavior of the defects. The story of the mastery of these defects is an exciting one, but it must be said that there have been retreats as well as advances. For example, an eminent theoretical physicist predicted 20 years ago that steel could not be made stronger than 200,000 pounds per square inch, which was less than the strength of the steels available at the time.

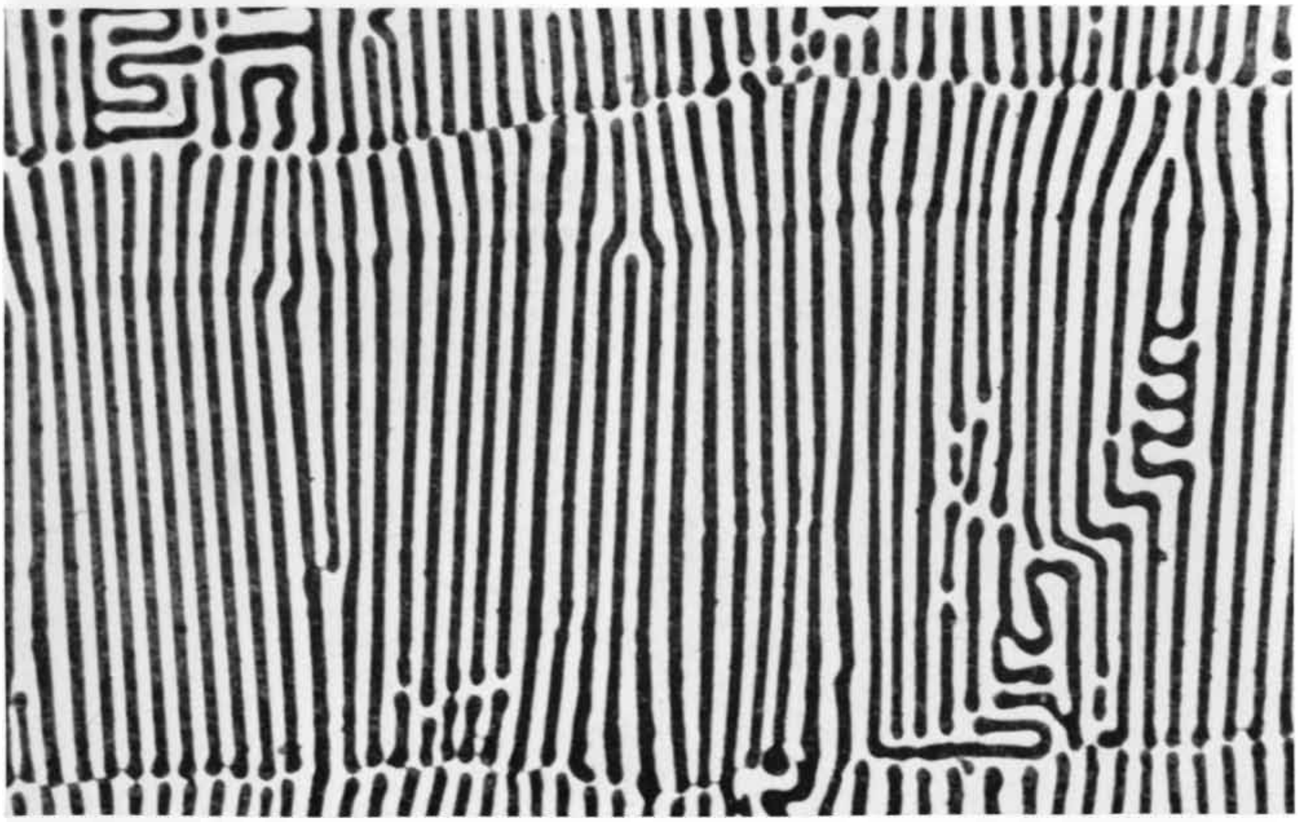
There are tough materials other than crystalline ones, examples being rubber and the synthetic organic fibers such as nylon. The strongest materials, however, are all crystalline. The reason is that the regular arrangement of atoms in a crystal gives it both strength and stiffness. The theoretical and actual strengths of several crystalline materials are presented in the top illustration on page 31; the variations in the upper limits arise from the different binding forces between the atoms of the substances.

If crystals always performed at their theoretical limit, it would be possible to make materials up to about 10 times the strength of the recently developed "strong steels," which is about 425,000 pounds per square inch [see "The Strength of Steel," by Victor F. Zackay; SCIENTIFIC AMERICAN, August, 1963]. The production of such materials and of steel that realizes even more of its theoretical strength would solve a wide variety of structural problems, not only in advanced technologies such as supersonic flight and rocketry but also in the design of pressure vessels and overhead cable systems.

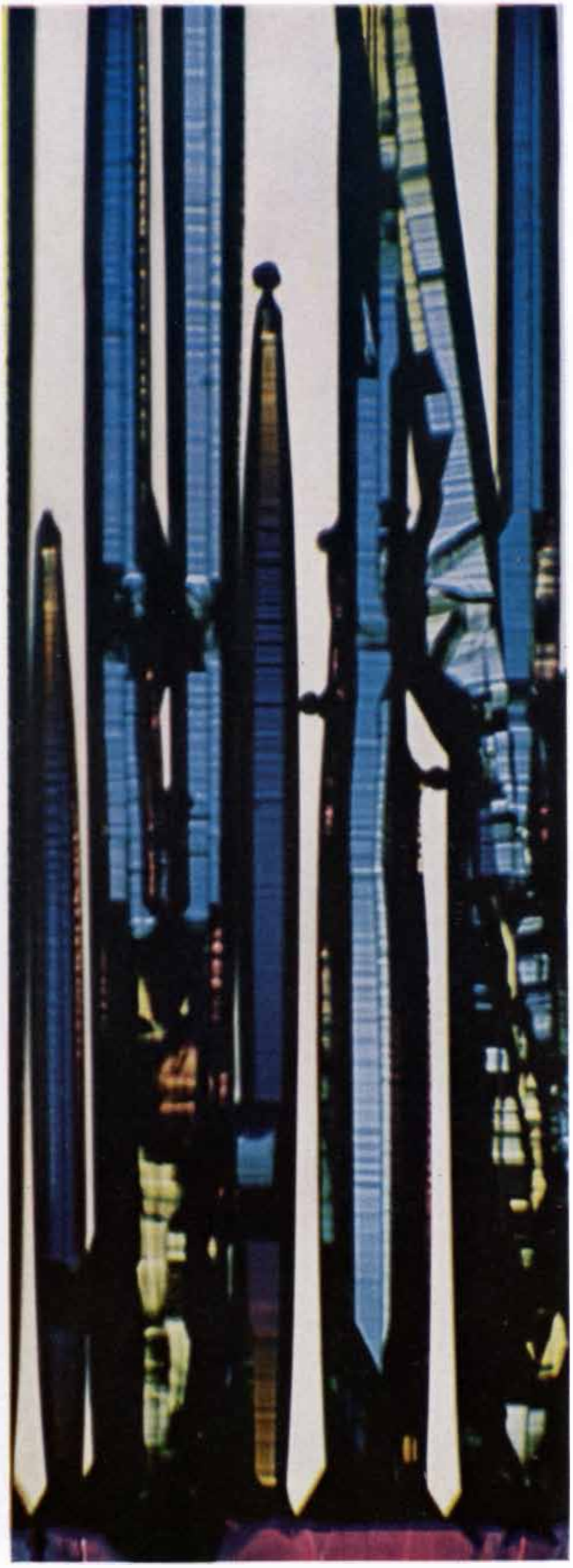
Some of the crystalline substances that have the greatest theoretical strength are nonmetals such as graphite, boron and alumina (aluminum oxide). These substances have the added virtue of being comparatively light, so that their strength for a given weight might be as much as four times that of the strongest steel. Moreover, such materials are quite stiff, which is at least as important as their being strong. A rod of



HIGH-STRENGTH MATERIAL made at the General Electric Space Sciences Laboratory consists of sapphire whiskers in a silver matrix. In this cross-section view the enlargement is 1,200 diameters. Tests indicate that the material can withstand high temperatures.



ALTERNATIVE TECHNIQUE, developed at the United Aircraft Research Laboratories, grows whiskers in a matrix by controlled solidification of an alloy. This magnesium-tin alloy, shown in cross section enlarged 850 diameters, has whiskers of platelike shape.



SAPPHIRE WHISKERS grown at the General Electric Space Sciences Laboratory are shown in two magnifications, 60 diameters at left and 180 diameters at right. Whisker growth occurs as molten aluminum vaporizes and oxidizes. Tensile strength of these relatively large whiskers is about 500,000 pounds per square inch; far smaller whiskers may achieve as much as six times that strength.

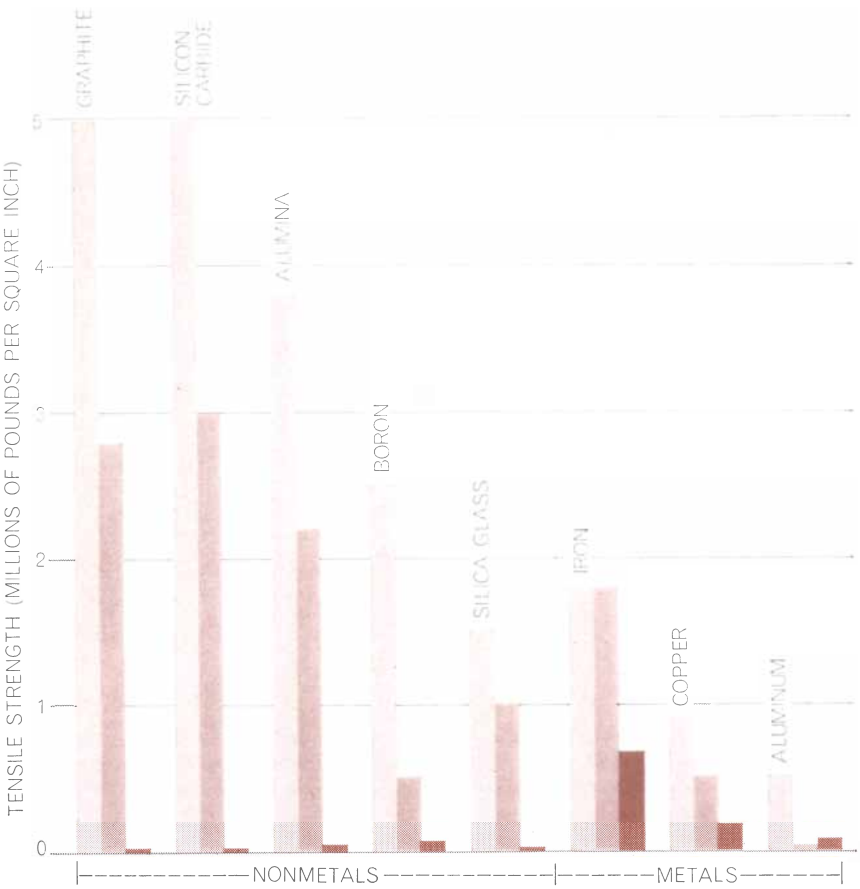
graphite should be stronger and stiffer than a rod of steel; the fact that it is not in normal circumstances arises from the different way in which the atoms are bound together in graphite and in steel. Because of this difference the defects in the two crystals have a quite different character.

Metal crystals typically consist of atoms arranged in a highly symmetrical lattice [*see bottom illustration at right*]. The atoms are bound together by sharing their outer electrons, and some of these electrons are able to move freely through the crystal; a good model of such a crystal is a set of ball bearings in sticky syrup. Important features of the mechanical properties of metals follow from this model. For the purposes of the present discussion the significant feature is that a metal crystal strongly resists any attempt to change its volume but yields easily to forces that tend to make the atoms slip over one another.

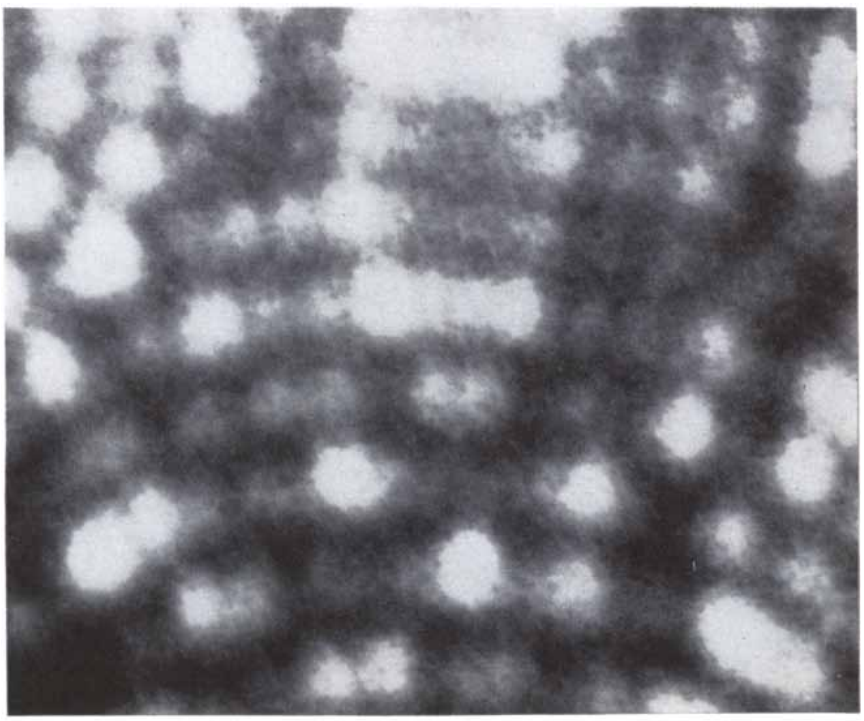
The slippage of atoms inside a metal crystal occurs because of the defects called dislocations [*see top illustration on next page*]. A dislocation is essentially a line of disorder running through the crystal lattice. In one sense it is like a wrinkle in a rug: as it moves through a crystal, part of the crystal is displaced with respect to the rest, just as a wrinkle can be made to move across a rug when the rug on one side of the wrinkle is moved with respect to the floor. In another sense it is different: it is able to multiply as it moves through the crystal, so that the total length of the dislocation is increased.

Dislocations abound in a metal crystal, but they do not greatly disturb the arrangement of atoms in it. They move easily through the crystal and are readily introduced into it at the surface. This is why metals can be drawn, beaten and rolled so effectively. In other words, metals are ductile because their abundant dislocations move so easily. If a metal is very pure, so that nothing can interfere with the motion of its dislocations, it will change shape easily under small forces. In such a situation it is said to undergo plastic flow. This property of metals bears on the development of strong materials in two important ways. The first is obvious: One way to make a metal strong is to eliminate dislocations or impede their movement. The second is that because of plastic flow it is usually difficult for a metal to develop cracks. The significance of the second point will be apparent after a brief discussion of the first.

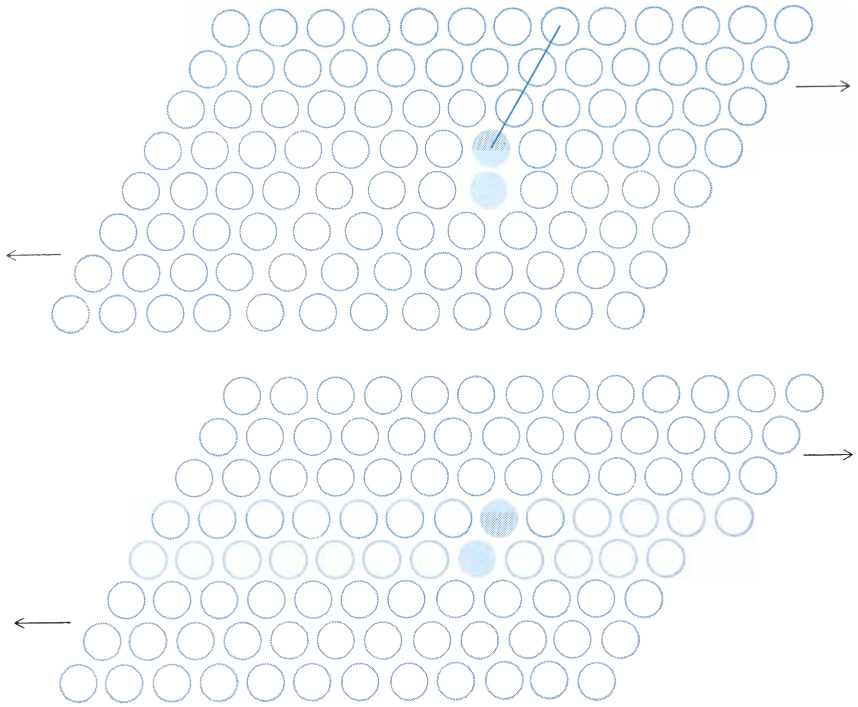
There are several ways to impede the



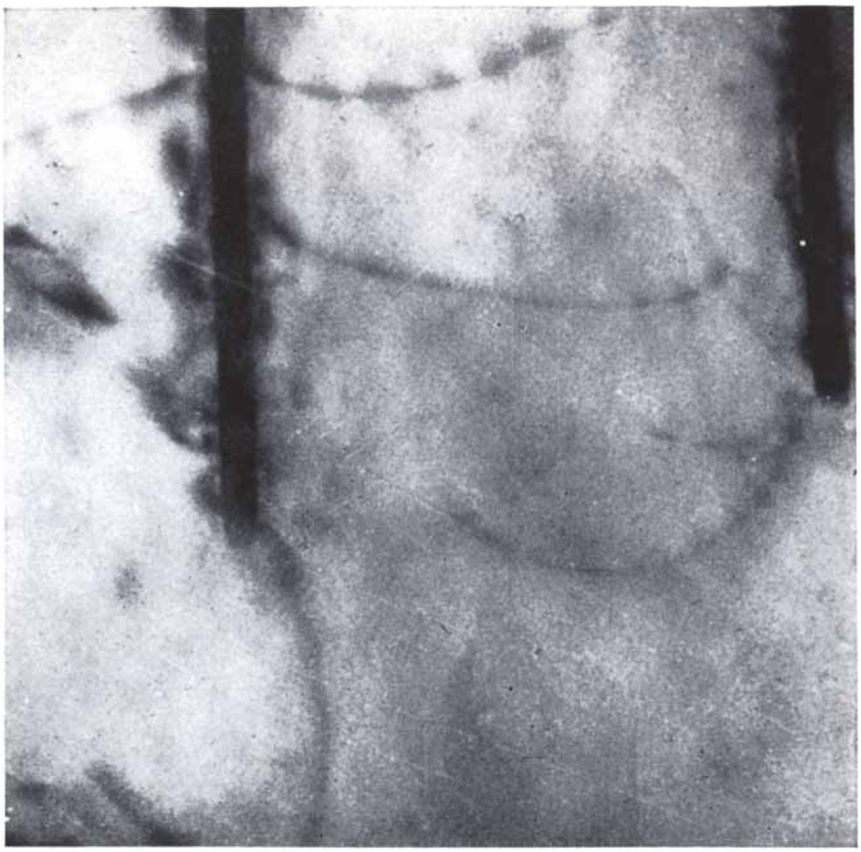
THEORY AND PERFORMANCE of materials are contrasted. Each set of bars shows, from left to right, the theoretical strength of the material, the strength achieved experimentally with fibers and the highest observed strength of large pieces of the material. In the case of aluminum the middle bar refers to the strength achieved with aluminum wire.



REGULAR ARRANGEMENT of atoms in a metal crystal appears in this field-ion micrograph of a tungsten crystal enlarged 12 million diameters. Atoms are the white spots.



DISLOCATION in a metal crystal is depicted schematically. A dislocation occurs at the end of an extra plane of atoms. Such a plane is indicated at top by the colored line. Under the application of force a dislocation can move; then atoms are shifted with respect to one another, as suggested by a comparison of the colored circles in the two illustrations.



IMPEDIMENT TO MOVEMENT of dislocations can be provided by obstacles. In this aluminum alloy, enlarged 250,000 diameters, the obstacles are provided by plates of a copper-aluminum compound. Dislocations (*faint lines*) can be seen bending between obstacles.

movement of dislocations. Among the ways that can be applied to all metals are adding foreign atoms; reducing the size of the grains, or individual crystals, in the metal, and increasing the number of dislocations so that they interfere mutually with one another's motion. Any of these methods is moderately effective, provided that the metal does not have to serve at elevated temperatures.

Still more effective, particularly at high temperatures, is the introduction of comparatively large obstacles to dislocations. The obstacles act as a kind of roadblock: because the dislocations must be forced between them, more stress is required before the dislocations will move. Such obstacles are provided by crystals in which dislocations cannot move—typically such nonmetals as alumina, beryllia (beryllium oxide) and some two-metal compounds such as titanium-aluminum.

The best obstacles to the motion of dislocations are ceramic crystals. A typical ceramic crystal has the same structure as that of diamond [*see top illustration on opposite page*]. The atoms are much farther apart than they are in a metal, and the electrons binding them together are not free to move through the crystal. The electrons are localized in the bonds, which means that the bonds are stronger and the angles between them much more important. In such a situation a dislocation is unusual because it produces a much more violent disruption of the crystal structure than a dislocation in a metal does.

Dislocations do exist in ceramic crystals, but it is more difficult to introduce them in ceramics than in metals. Moreover, they are very difficult to move except at extremely high temperatures. At ordinary temperatures dislocations in substances such as diamond and alumina do not move at all, even when they are present in large numbers. Whereas diamond resists the motion of dislocations because its bonds are strong, alumina does so because its crystal structure is complicated. Indeed, there are solids in which the arrangement of atoms is so irregular that dislocations cannot occur in them at all. These are the glasses, which are not crystalline but can be regarded as supercooled liquids.

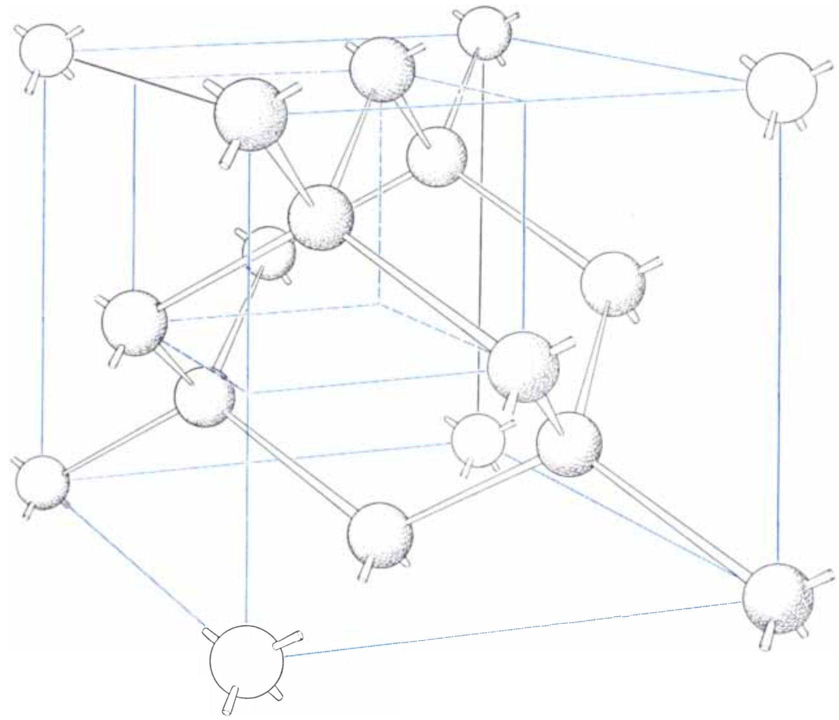
Ceramics and glasses, then, either contain no dislocations or their dislocations cannot move, at least at ordinary temperatures. In other words, they are not subject to plastic flow. One would think, therefore, that such materials should quite easily attain their maximum theoretical strength. The fact remains that normally they fail to do so.

The explanation of this phenomenon returns us to the subject of cracks. When the motion of dislocations is eliminated as a cause of weakness, imperfections such as cracks, surface steps and notches have a special significance. A crack or a notch in a body subjected to a force is shown in the top illustration on the next page. It is evident from the illustration that large stresses are produced at the bottom of the crack. How large these stresses are depends on how sharp the crack is at its bottom and how deep it is.

In a metal sharp cracks cannot develop because of plastic flow. Slippage at the bottom of the crack, resulting from the motion of dislocations, will always eliminate its sharp leading edge [*see bottom illustration on next page*]. As a result the stress at the bottom of the crack never becomes large enough to split the material apart and enable the crack to grow. Although this description is highly simplified, it serves to explain the fact that most pure metals are said to be "notch-insensitive" at ordinary and high temperatures. The working strength of such metals is not acutely affected by the presence of notches and cracks. The way the metals break and the force required to break them depend on the motion of dislocations.

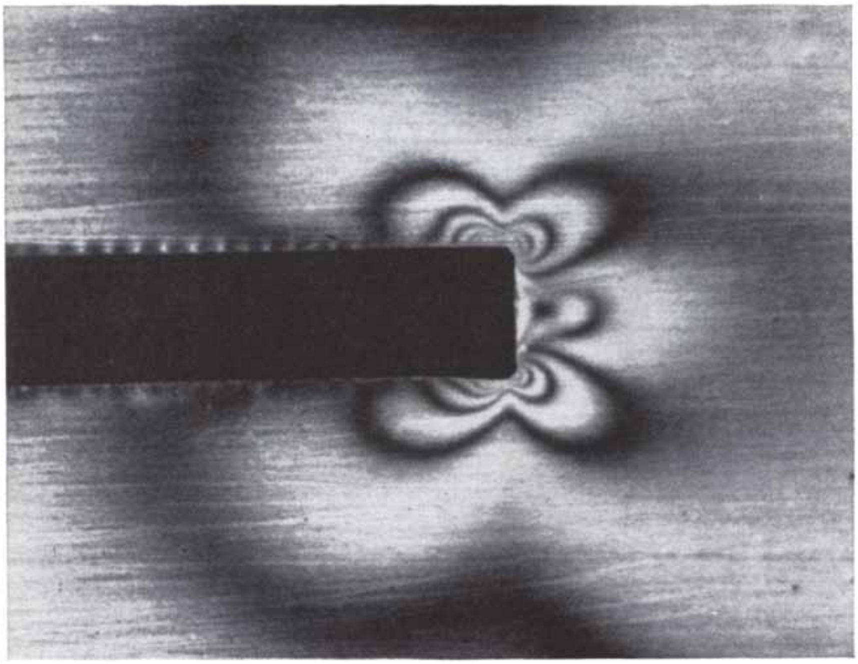
The contrast between ceramic and metallic substances with respect to cracks is illustrated by glass and copper. Drop a glass vase on the floor and it shatters; a copper bowl is merely dented. A piece of glass will scratch copper, but copper will not scratch glass. Glass is in fact the stronger solid, but it can be rendered a useless, brittle thing by a small, sharp crack. It is vulnerable because the stress at the bottom of the crack cannot be eliminated by plastic flow.

Like glass, crystals of diamond, silicon, silicon carbide and beryllia are quite brittle. If the smooth surface of such a crystal is marred by cracks or surface steps, its strength is greatly reduced, in many cases almost to nothing. If cracks and surface steps are eliminated, the crystals are extremely strong, approaching the theoretical strengths shown in the top illustration on page 31. At one time it was thought that specimens of these substances were strong because they were small. It is true that small specimens are usually stronger than large ones, but this is because they are likely to have fewer cracks or steps.

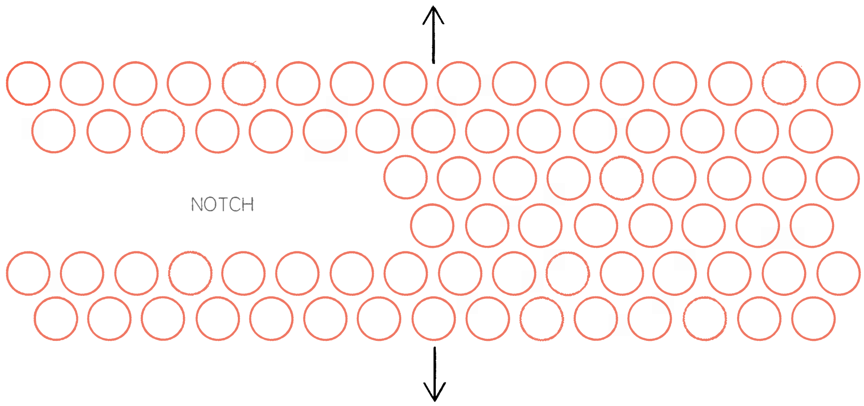


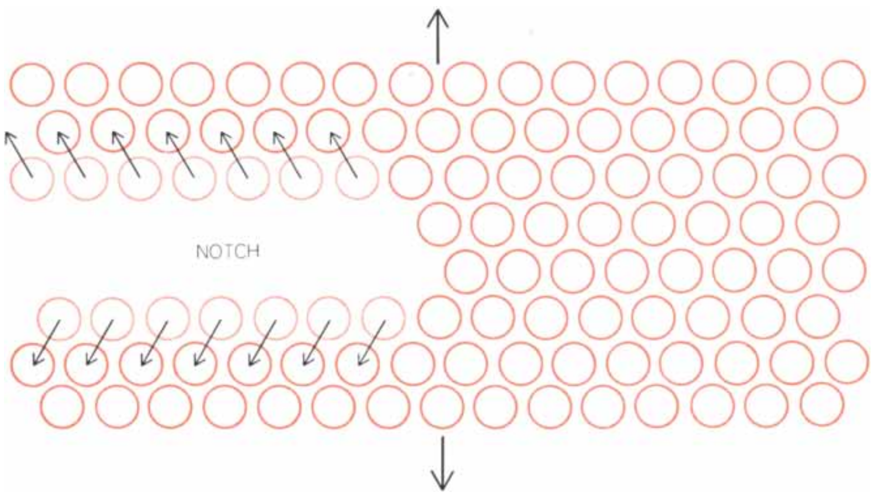
DIAMOND CRYSTAL has atoms farther apart than those in a metal crystal. In addition the electrons binding the atoms are always localized in the bonds, so that the angles between bonds are significant. This structure makes it difficult for a dislocation to move.

ENTANGLED DISLOCATIONS are shown in a crystal of iron, enlarged about 100,000 diameters. Entanglement is another structure that impedes motion of individual dislocations.



STRESSES IN A NOTCH concentrate at the bottom of the notch, as shown by the dark lines in this view by photoelastic techniques of a metal under stress. Significance of this concentration for the propagation of a crack in metal is depicted in the illustration below.





BLUNTING OF CRACK in a metal crystal occurs because of the tendency of atoms to slip over one another when the crystal is placed under stress. This resistance to cracking is a useful property when metal is used as a binder for fibers of a high-strength material.

Recent work with silicon, alumina and glass has shown that a large specimen can be just as strong as a small one if its surface is smooth.

Strength of this kind can be exhibited by a piece of well-made glass, which will withstand a stress on the order of 800,000 pounds per square inch. The glass would break explosively if its surface were scratched while the glass was under tension. It is for this reason that if such a substance is to be used in a high-strength structural material, its surface must be protected. Moreover, since the surface of a small piece of the substance is more likely to be free of cracks and steps than a large one, a strong material must contain many small pieces.

The argument is now almost complete. From what I have said so far it will be evident that the avenue to the strongest materials lies in the use of single crystals of substances such as alumina, graphite and tungsten carbide or of single fibers of glass, either of conventional silica glass or of boron glass. The strongest materials of the future, with strengths approaching the theoretical values, will consist of large numbers of crystals or fibers. The crystals or fibers will have very smooth surfaces, which will be well protected against cracks or other damage.

Two problems remain to be considered: how to bind the crystals or fibers together and how to arrange them geometrically within the matrix of the binder. If materials for use at room temperature are the objective and it is not required that they be particularly stiff, then fibers of conventional silica glass bound in a resin make an attractive material [see "Two-Phase Materials," by Games Slayter; SCIENTIFIC AMERICAN, January, 1962]. Indeed, this "fiberglass" has already found wide application. The material is not stiff because silica glass lacks stiffness; in technical terms, silica glass has quite a low Young's modulus. Even more important, resins cannot withstand certain chemical environments and cannot withstand high temperatures at all.

Clearly in many circumstances one must look elsewhere for binders. This is where metals enter on the scene. They make good binders for crystals and fibers, particularly at high temperatures. A principal reason for the usefulness of metals as binders is that alloy compositions able to resist corrosive environments and high temperatures have already been developed.

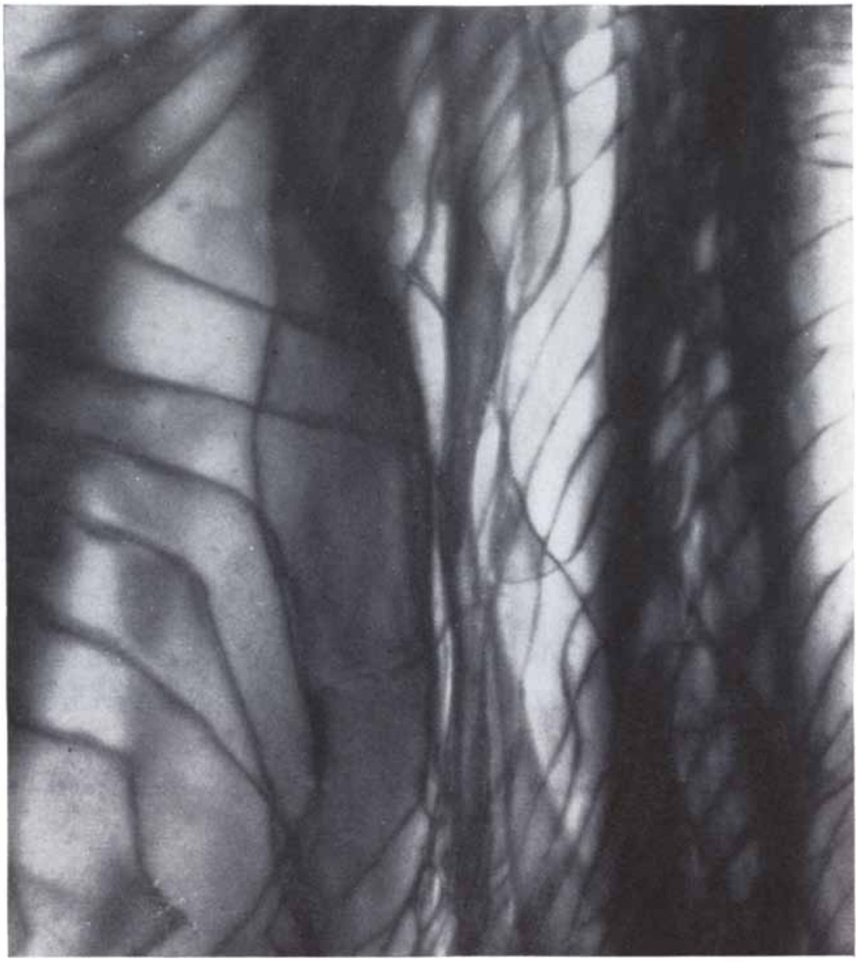
Another reason for choosing a metal

matrix is the capacity of metals for plastic flow. This capacity has a bearing on the geometric arrangement of the crystals or fibers in a strong composite material. The functions of the matrix are to hold the pieces of the material's strong component together, to protect their surfaces and to separate adjacent pieces so as to prevent cracks from spreading directly from one piece to another. The binder must also permit the application of force to the composite material, and any force applied must be distributed evenly among all the pieces of the strong component.

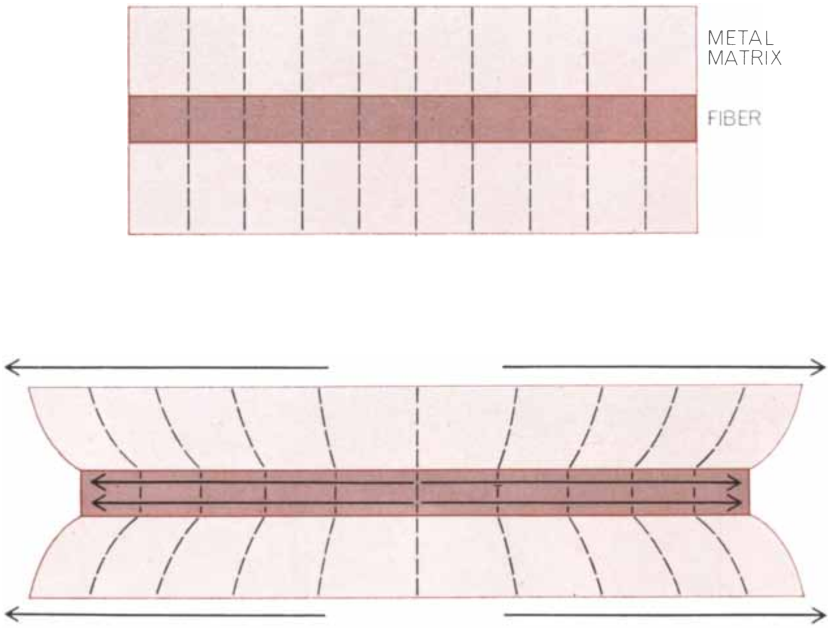
Since metals yield and flow under small forces, in a composite material it is necessary for the strong component to bear the stress. Here is the key to the geometry of the strong component within its matrix. The pieces of the strong component must have one long dimension. Then, as the metal flows past them under the action of applied forces, the strong pieces take the load. This action is best understood by considering the flow of the metal around a single rod or fiber [*see bottom illustration at right*]: the stress in the rod builds up from the ends. Thus in order to realize its maximum strength the strong component of the composite material should be in the form of rods, fibers or long, thin plates. Obviously it is not difficult to fabricate glass in these forms, but crystals are a different matter. Fortunately in recent years it has become possible—although far from easy—to grow single crystals in the form of thin "whiskers."

The fibrous geometry necessary for high strength has other advantages. Long, thin, cylindrical fibers can be so densely packed that they fill 90 percent of a given space. Therefore a composite material consisting of strong fibers in a plastic matrix can realize 90 percent of the strength of the strong component. A further advantage is that fibers of a strong substance such as glass are produced by being drawn through a die, which eliminates surface defects.

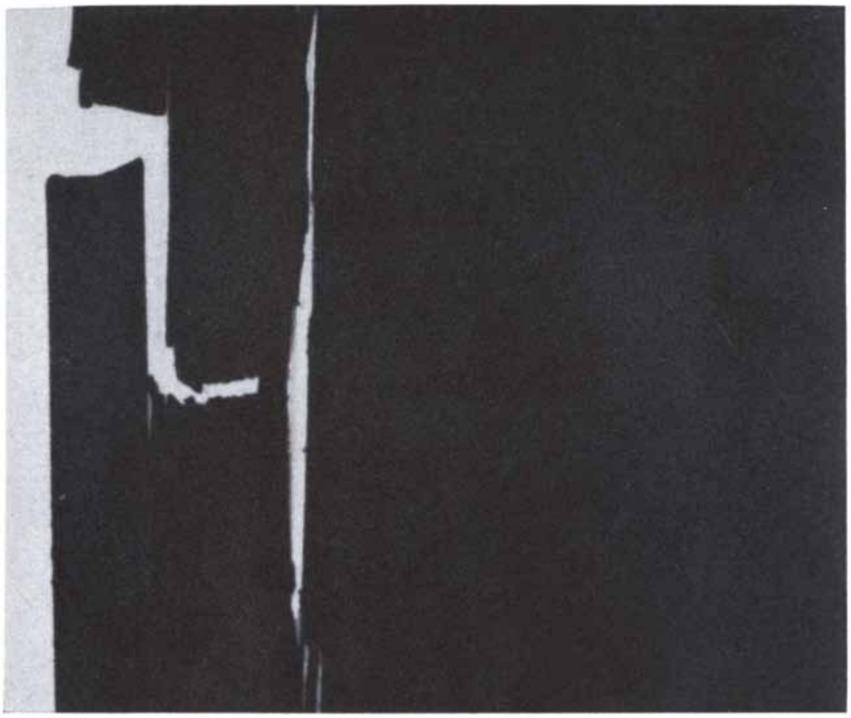
A more significant advantage is the fact that a fiber-matrix composite material not only is strong but also can be made very tough; it need not be at all brittle even when it consists largely of a brittle material. The obvious way to achieve this property is not to bind the fibers together too strongly. Then, although the material will be weak in a direction at right angles to the fibers, a crack in one fiber is not propagated to the next. Moreover, if the crack moves at right angles, it will pull the material



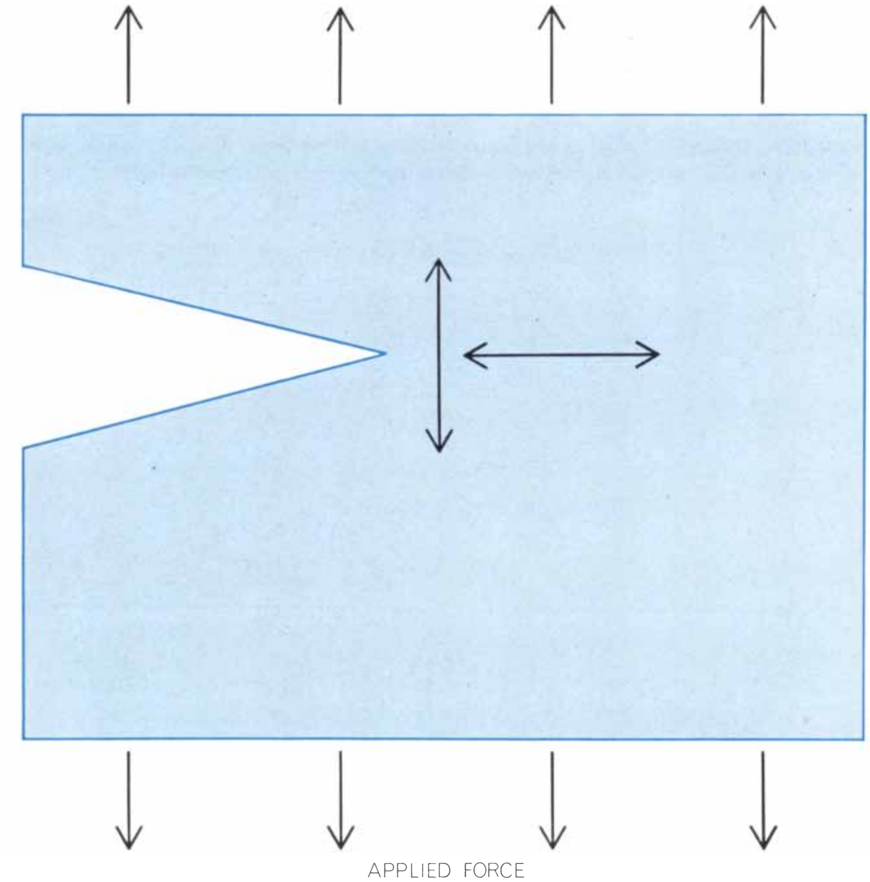
CERAMIC DISLOCATIONS, which move less readily than those in metal, appear in this view of a tungsten carbide crystal by electron microscope; enlargement is 88,000 diameters.



FUNCTION OF MATRIX is depicted in this schematic representation of a single fiber or whisker in a metal binder. At top the material is shown with no load. Under force (*bottom*) the metal flows plastically; friction transfers the load to the fiber. Strain in fiber is greatest at middle and smallest at ends, as indicated by spacing of vertical lines.



EFFECT OF CRACK in a material given high strength by fibers in a metal matrix is shown for silica fibers in copper. Forces at work are depicted in the illustration below.



UNDER LOAD a material such as that in the photograph at top has concentrated stresses both parallel and at right angles to the applied load, as shown by the double-headed arrows. Right-angled load pulls material apart parallel to the fibers and arrests the crack.

apart parallel to the fibers. No harm is done by that since the material is weakly bonded anyway; the action therefore renders the crack blunt and ineffective as a concentrator of stress [*see illustrations on this page*].

There are subtler ways to provide toughness, by which I mean resistance to crack propagation, in fibrous metal composites. One that has been demonstrated is to arrange matters so that if some fibers break, the others do not follow suit but instead pull gently through the matrix. Principles similar to these have always been used by nature as a means of providing resistance to fracture in materials such as tooth, bone and wood. Man has only recently started to use such principles consciously, but he is already employing them at much higher levels of stress than are encountered in natural materials.

The argument is now complete. The highest strength in structural materials will be obtained from a composite of a very strong substance, in the form of fibers or whiskers, and a softer metal matrix in which the fibers or whiskers are dispersed. This is the recipe that was used in the silica-aluminum material developed at Rolls-Royce.

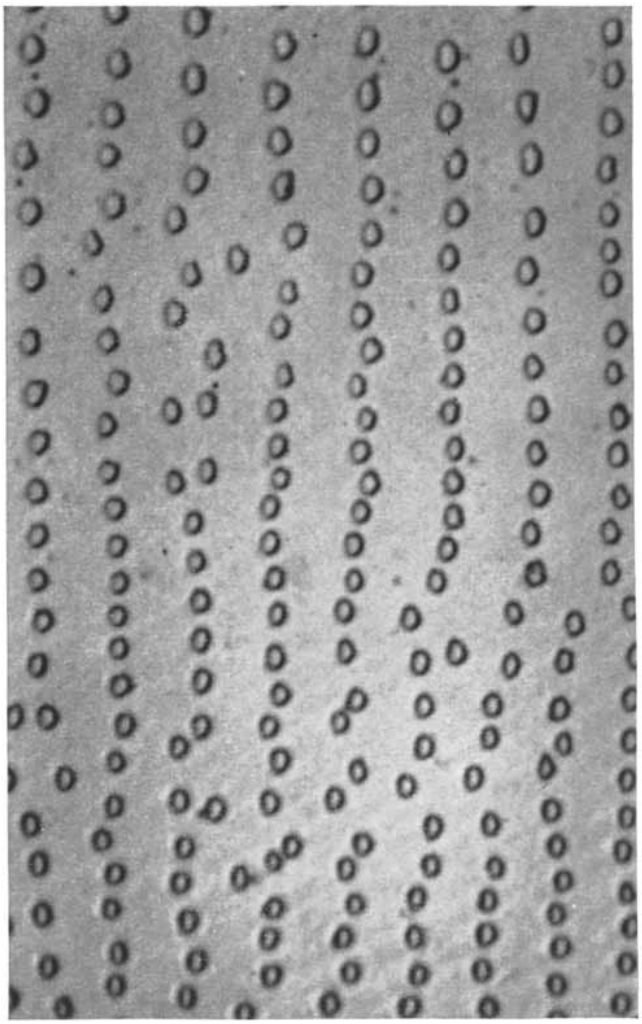
Using a similar technique, W. H. Sutton and his colleagues at the General Electric Space Sciences Laboratory have created a material with a higher strength at 850 degrees centigrade than conventional steel has at room temperature. Their material incorporates whiskers of alumina or sapphire in a matrix of silver [*see top illustration on page 29*]. So far they have fabricated only small pieces of the material. Its cost is also high, so for the time being its use is limited to situations in which no other material will serve as well.

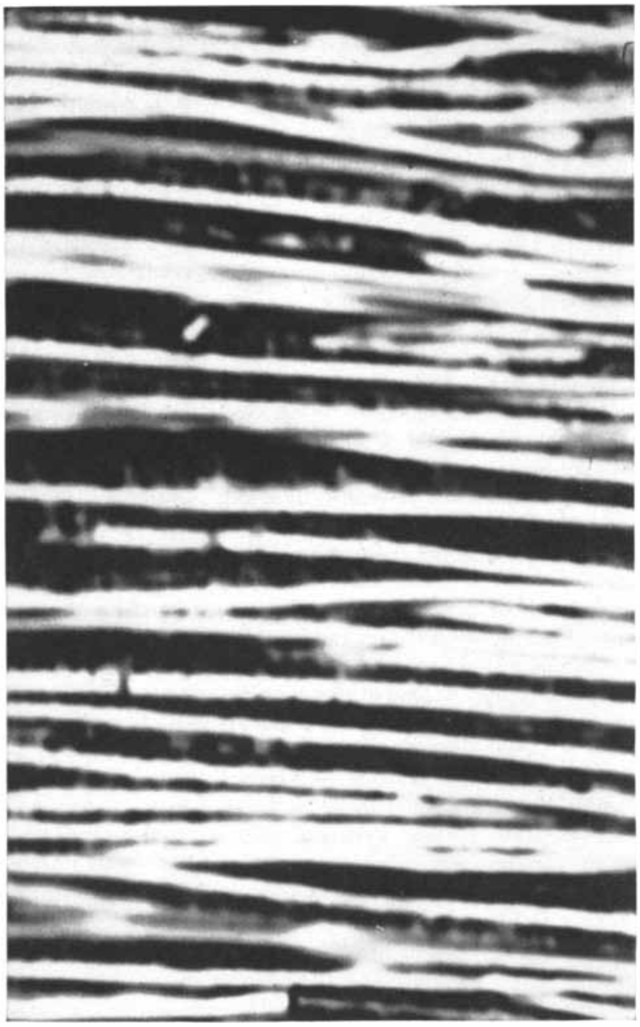
The technique has also been used to increase the strength of conventional metals, which have the advantage of being currently available and hence cheap. Aircraft alloys of aluminum are being reinforced by steel wires. Only about 2 percent of the volume of the structure needs to consist of steel wire to achieve a large reduction in the rate of crack propagation under fatigue conditions, meaning when the metal is subject to a large number of stress reversals. Tungsten wire has also been incorporated into cobalt alloys so as to provide creep resistance, meaning resistance to fracture at high temperatures. To industry perhaps the most stimulating immediate prospect comes from the realization that strong steels, which currently fail in service because their strength is achieved only at the cost of a marked tendency to brittleness, can have their toughness increased without loss of strength by the application of the principles I have described.

Even though the principles of designing a strong material by combining fibers or whiskers in a metal matrix are clear, much technological work remains in producing such materials. In the case of fibers, which can easily be made of substances such as silica glass and boron glass, the main task is the development of a fully suitable matrix. Particularly when the composite material is to be used at high temperatures, the difficulty is preventing the matrix from attacking the fibers chemically.

Other substances, such as graphite and silicon nitride, have thus far been made strong only in the form of whiskers. The problem of harvesting, sorting, cleaning and aligning whiskers is formidable, but progress is being made. One quite new approach is to try to bypass these difficulties by growing the whiskers *in situ*, that is, within the metal matrix. This has not yet been done with the substances of the highest strength, although it may be possible with graphite. Striking success has been achieved, however, with aluminum and copper. Roy Fanti and his colleagues at the United Aircraft Research Laboratories have grown beautifully aligned microstructures by carefully controlling the way in which a nickel-aluminum melt solidifies. They are also working with such combinations as nickel and beryllium, nickel and boron and tantalum and carbon. In each case the composition of a particular alloy determines which component becomes the whisker and which the matrix [*see illustration below*].

All these new materials, when put into service, will necessitate changes in conventional engineering design. For example, although pieces of some fiber-reinforced composite materials have been welded together, joining them may not generally be possible; the entire finished article may have to be made in one piece. Another consideration is that the markedly directional properties of fiber-matrix composites will have to be mitigated in many applications by building laminated structures similar to plywood. Finally, superstrong materials with a breaking strength of around a million pounds per square inch can only develop that strength by undergoing elastic deflections of 2 percent or so. Those are large deflections for conventional engineering practice; as a result new criteria for the stability of structures will have to be developed where such materials are employed.





WHISKERS GROWN IN MATRIX are shown in cross section (*left*) and longitudinal section (*right*) at enlargements of 2,000 diameters. The material is a copper-chromium alloy developed at the United Aircraft Research Laboratories by unidirectional solidification of a melt. In the longitudinal section some of the copper has been dissolved to show the chromium whiskers more clearly.

Texture and Visual Perception

Random-dot patterns generated by computer show that the recognition of familiar shapes is not needed for the discrimination of textures or even, as had been thought, for the binocular perception of depth

by Bela Julesz

Because we are surrounded every waking minute by objects of different sizes, shapes, colors and textures we are scarcely surprised that we can tell them apart. There are so many visual clues to the distinctiveness of objects that we hardly ever make the mistake of believing that two different objects are one object unless we have been deliberately tricked.

Four years ago I became interested in studying the extent to which one can perceive differences in visual patterns when all familiar cues are removed. In this way I hoped to dissociate the primitive mechanisms of perception from the more complex ones that depend on lifelong learned habits of recognition. To obtain suitable patterns for this investigation a computer was used to generate displays that had subtly controlled statistical, topological or other properties but entirely lacked familiar features.

This method is basically different from those employed earlier by workers interested in visual perception. One method that has been widely used is to impoverish or degrade the images presented to the subject. This can be done by adding visual "noise," by presenting the stimuli for a limited time or by otherwise impairing the normal conditions of viewing. Another approach is to study human subjects whose perceptual mechanisms are known to be deficient (for example people who are colorblind) or animals whose perceptual mechanisms have been altered by surgical operations. I hoped that my approach of "familiarity deprivation" might be a useful addition to these other methods.

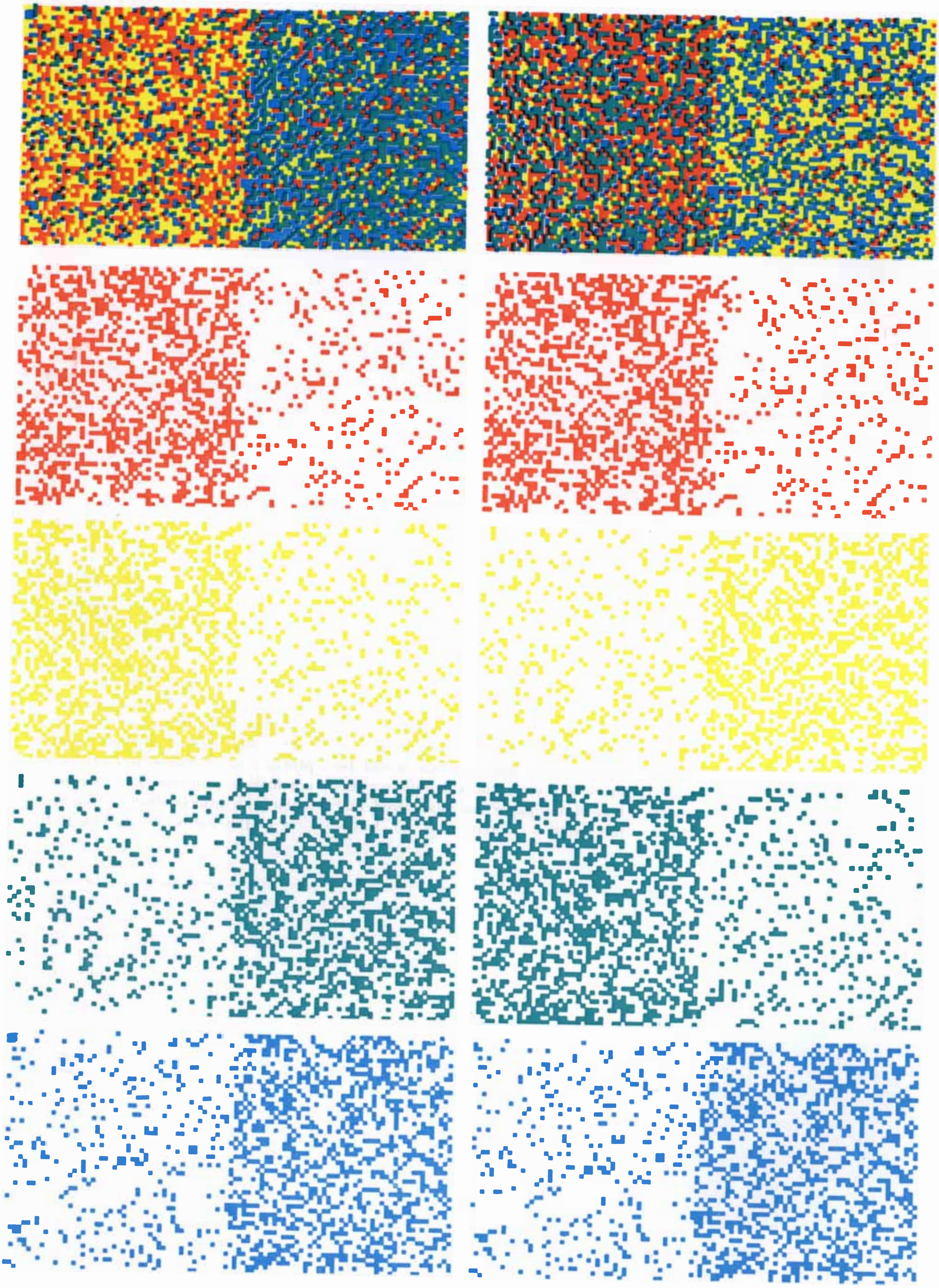
In a broad sense I was interested in the same kind of problem that has long concerned psychologists of the *Gestalt* school. One such problem has been to explain why it is that under certain conditions an outline drawing is seen as a unified whole—as a *Gestalt*—and under other conditions is seen as having two or more parts. I undertook to reduce this problem to how one discriminated between the parts (or did not discriminate between them). In my investigations, which have been conducted at the Bell Telephone Laboratories, I have been concerned with two specific questions. First, can two unfamiliar objects connected in space be discriminated solely by differences in their surface texture? Second, can two unfamiliar objects with identical surface texture be discriminated solely on the basis of their separation in space?

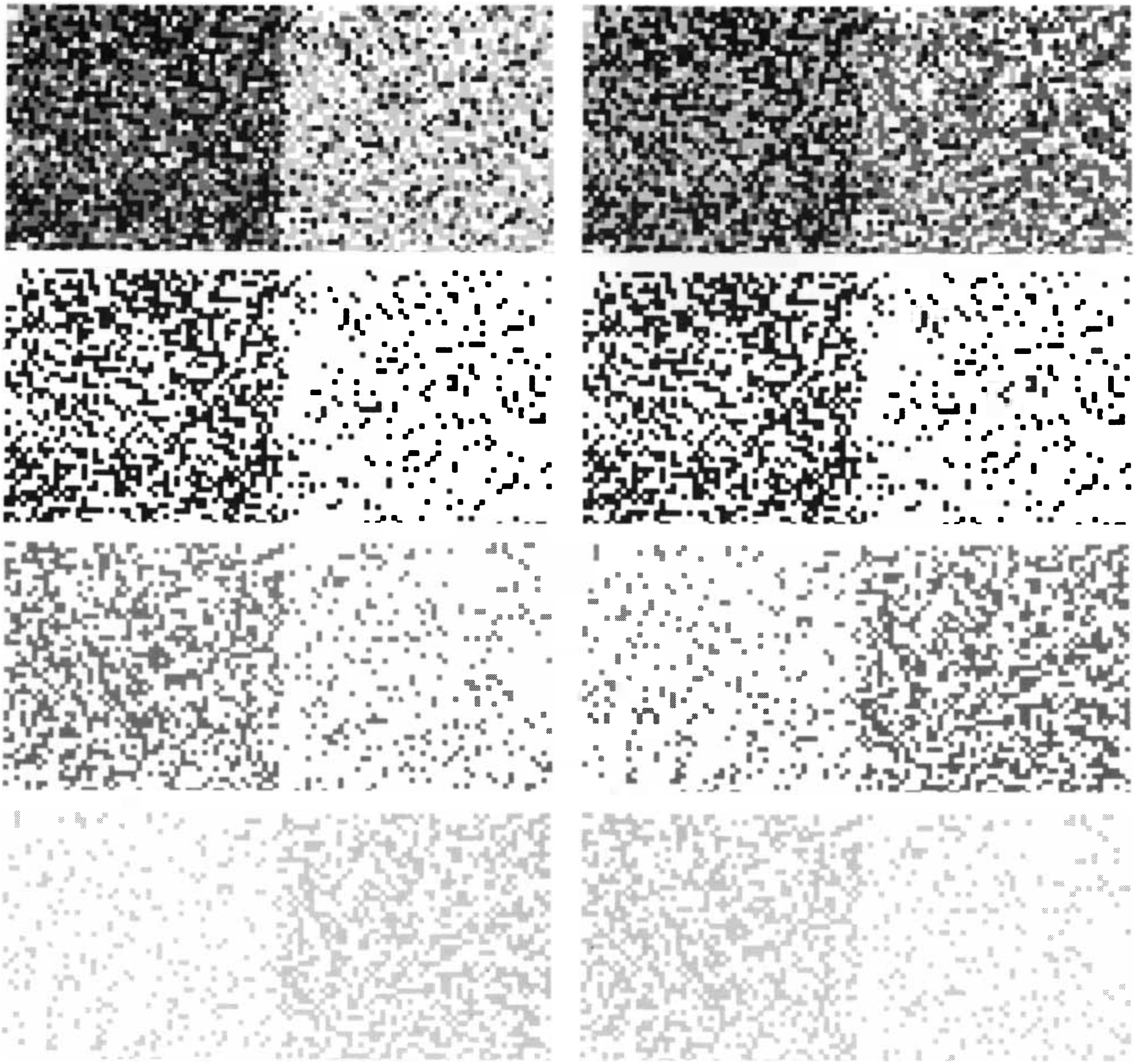
To make these questions less abstract let me give examples that could arise in real life. The first question would be involved if you wanted to replace a section of wallpaper and discovered that the original pattern was no longer available. If the pattern happened to be nonrepresentational and irregular, you might be able to find a new pattern that could not easily be discriminated from the old one when the two were placed side by side. Yet if you studied the two patterns closely, you might find that they differed substantially in detail. You would conclude that the matching must be attributable to the similarity of certain critical features in the two patterns.

The second question has its counterpart in aerial reconnaissance to detect objects that have been camouflaged. Flying at a height of several thousand feet, an observer can easily be deceived by the camouflage because normal binocular depth perception is inoperative beyond 100 feet or so. But if he photographs the ground from two points several hundred feet apart and views the resulting pictures stereoscopically, he will usually discover that even a camouflaged object will stand out vividly in three dimensions.

Of course neither of these examples provides an adequate test of the discrimination problems I hoped to examine with artificial displays. The weakness in the wallpaper analogy is that most wallpaper patterns, including irregular ones, have repetitive features and even forms that suggest familiar objects. The aerial reconnaissance example has the important defect that most camouflaged objects have contours that can be recognized monocularly as

TEXTURE DISCRIMINATION in random fields of colored dots is highly dependent on the way the component colors are paired. The two patterns at the top of the opposite page are basically the same as those shown one above the other on the cover of this issue. Neither version adequately reproduces the author's laboratory demonstration, in which the patterns are created by colored lights of equal subjective brightness. To simulate this condition the yellow picture elements on the cover have been reduced in brightness by a fine-mesh overlay of black dots. They have the drawback, however, of making the yellow areas look greenish. In the version on the opposite page the black-dot overlay has been omitted, with the result that the yellow elements are much too bright. On the whole the cover comes closer to achieving the desired effect, which is to show that a texture composed chiefly of red and yellow dots is readily discriminated from a texture composed chiefly of blue and green dots (*top half of cover*), whereas a texture composed chiefly of red and green dots is not so readily discriminated from one composed chiefly of blue and yellow dots (*bottom half of cover*). These paired textures—one easily discriminable, the other less so—are respectively repeated at top left and right on the opposite page. The makeup of each top panel is shown in the four panels below it. The only difference is in the transposition of yellow and green.





EASE OF DISCRIMINATION in random patterns of various brightness levels seems to depend on whether or not adjacent dots of different values form clusters. The pattern at top left forms two easily discriminated areas because the half field on the left contains mostly black and dark gray dots, which form dark clusters, whereas the half field on the right contains mostly light gray and white dots, which form light clusters. When the dark gray and light gray components are reversed (*top right*), the clustering does not take place and the half fields are not so readily discriminated. The composition of each top pattern is shown in the three panels below it.

SPONTANEOUS DISCRIMINATION occurs even though the smaller field has the same average tonal quality as the larger field because the granularity of the two fields is different. At a distance the granularity is less noticeable and discrimination more difficult.

SCIENCE SPECIFY PRECISE SUBJECT MERCURY GOVERNS ECNEICS YFICEPS ESICERP TCEJBUS YRUCREM SNREVOG
METHODS RECORDS OXIDIZE COLUMNS CERTAIN QUICKLY SDOHTEM SDROCER EZIDIXO SNMULOC NIATREC YLKCIUQ
DEPICTS ENGLISH CERTAIN RECORDS EXAMPLE SCIENCE STCIPED HSILGNE NIATREC SDROCER ELPMAXE ECNEICS
SUBJECT PUNCHED GOVERNS MERCURY SPECIFY PRECISE TCEJBUS DEHCNUP SNREVOG YRUCREM YFICEPS ESICERP
EXAMPLE QUICKLY SPECIFY METHODS COLUMNS MERCURY ELPMAXE YLKCIUQ YFICEPS SDOHTEM SNMULOC YRUCREM
SCIENCE PRECISE EXAMPLE CERTAIN DEPICTS ENGLISH ECNEICS ESICERP ELPMAXE NIATREC STCIPED HSILGNE
SPECIFY MERCURY PUNCHED QUICKLY METHODS EXAMPLE YFICEPS YRUCREM DEHCNUP YLKCIUQ SDOHTEM ELPMAXE
EXAMPLE GOVERNS OXIDIZE ENGLISH SUBJECT RECORDS ELPMAXE SNREVOG EZIDIXO HSILGNE TCEJBUS SDROCER
COLUMNS SUBJECT PRECISE MERCURY PUNCHED CERTAIN SNMULOC TCEJBUS ESICERP YRUCREM DEHCNUP NIATREC
ENGLISH RECORDS EXAMPLE SUBJECT OXIDIZE GOVERNS HSILGNE SDROCER ELPMAXE TCEJBUS EZIDIXO SNREVOG
CERTAIN PRECISE PUNCHED METHODS ENGLISH COLUMNS NIATREC ESICERP DEHCNUP SDOHTEM HSILGNE SNMULOC
OXIDIZE QUICKLY SCIENCE DEPICTS SPECIFY PRECISE EZIDIXO YLKCIUQ ECNEICS STCIPED YFICEPS ESICERP
DEPICTS EXAMPLE ENGLISH CERTAIN RECORDS SCIENCE STCIPED ELPMAXE HSILGNE NIATREC SDROCER ECNEICS
SPECIFY MERCURY GOVERNS PRECISE QUICKLY METHODS YFICEPS YRUCREM SNREVOG ESICERP YLKCIUQ SKOHTEM

NONSPONTANEOUS DISCRIMINATION is represented by two half fields that have the same apparent texture and granularity. The left half field, however, contains familiar English words, whereas the right half field contains only random sequences of seven letters.

shapes of some sort; they are not, in other words, random patterns.

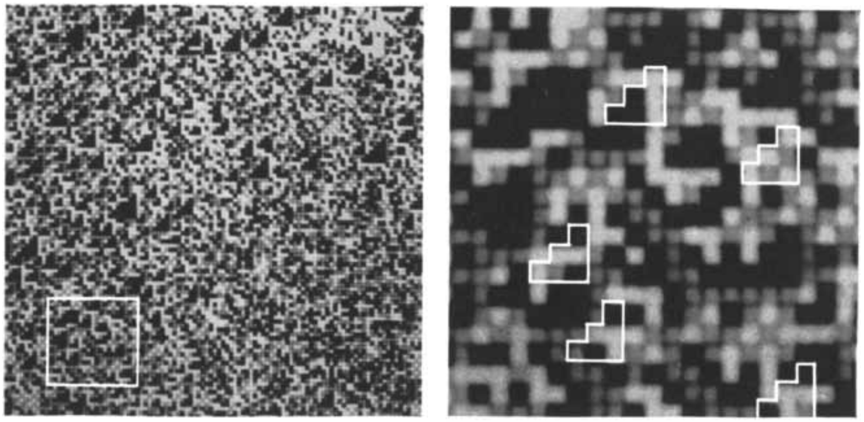
These and other difficulties are quite easily circumvented by using a computer to generate random-dot patterns in which all familiar cues and other unwanted factors are eliminated. For the purpose of studying the first problem—the role of texture in discrimination—random-dot patterns with different properties were generated side by side. The objective was to determine those pattern properties that make it possible to discriminate between the adjacent visual displays. I was concerned primarily with the discrimination that can be achieved immediately. Such discrimination can be regarded as a spontaneous process and thus can be ascribed to a primitive perceptual mechanism.

An example of spontaneous discrimination is given by the illustration at bottom left on the opposite page. Both fields of the pattern contain black, gray and white dots with equal first-order, or overall, probability; therefore if the pattern is viewed from a distance, both fields appear uniformly gray. When the two fields are viewed at close range, however, they exhibit a different second-order, or detailed, probability. This shows up immediately as a difference in granularity.

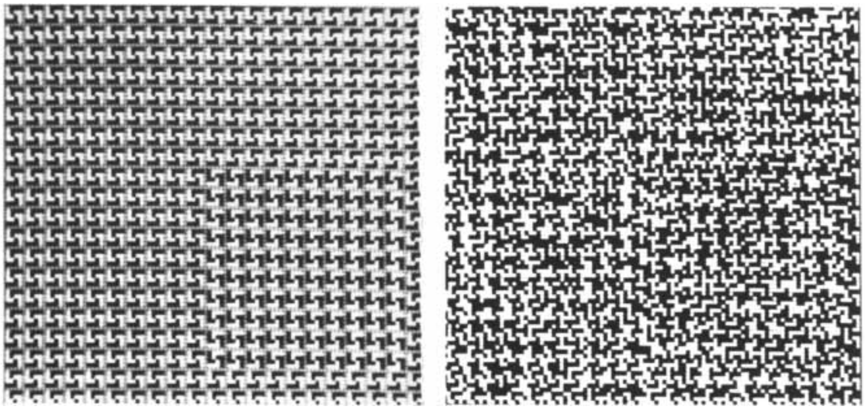
The illustration at bottom right on the opposite page represents a case in which there can be no spontaneous discrimination between two fields. In this case discrimination can be achieved only by someone who knows the difference between English words and random sequences of letters. Here discrimination requires a sophisticated kind of pattern recognition. This article is concerned only with discrimination of the spontaneous type.

In the case of random-dot patterns one might expect that discrimination of visual texture is fundamentally governed by variations in the statistical properties of the patterns. That is true in the most general sense, because any two different patterns must differ in some such property. It turns out, however, that simple statistical measurements of brightness distribution are not adequate to describe perceptual performance.

This is demonstrated in the illustration at upper left on this page, which consists of two patterns made up of black, gray and white dots. In one quadrant the dots are distributed with equal probability and completely at random. The surrounding area matches the quadrant in overall brightness, but it also contains small triangular units composed of black, white and gray dots in various arrangements. Although these triangular units occur with equal probability, the only ones observed are those made up entirely of black dots; the others pass unnoticed.



CLUSTER IDENTIFICATION in the pattern at left extends only to triangular shapes made up entirely of black dots. Other equally probable triangles containing dots of mixed brightness do not form clusters. These are marked in the enlargement at right.

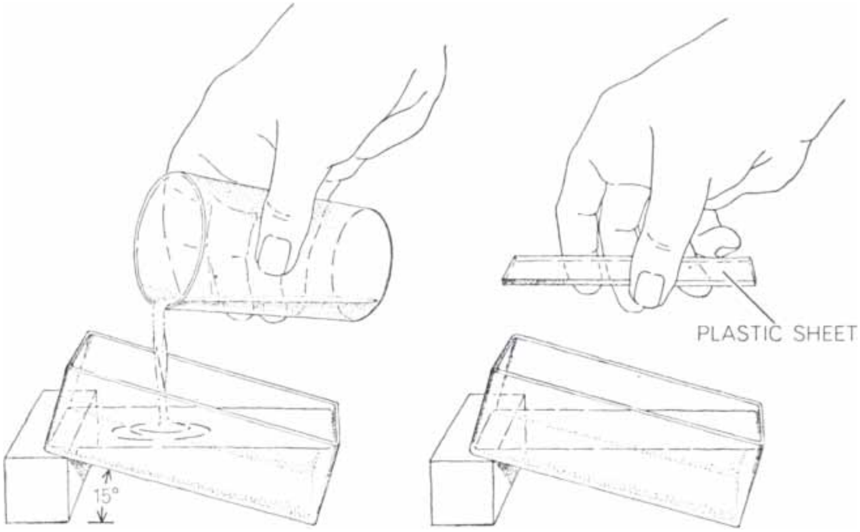


EFFECT OF "NOISE" is demonstrated in these two patterns. In the pattern at left the two subpatterns containing either black or white "S" shapes are easily discriminated. Moreover, every fifth horizontal and vertical row is gray. The pattern at right is identical except that the dots in the gray rows have been made black or white at random. By breaking up the connectivity of the pattern in this way the subpatterns are almost obliterated.

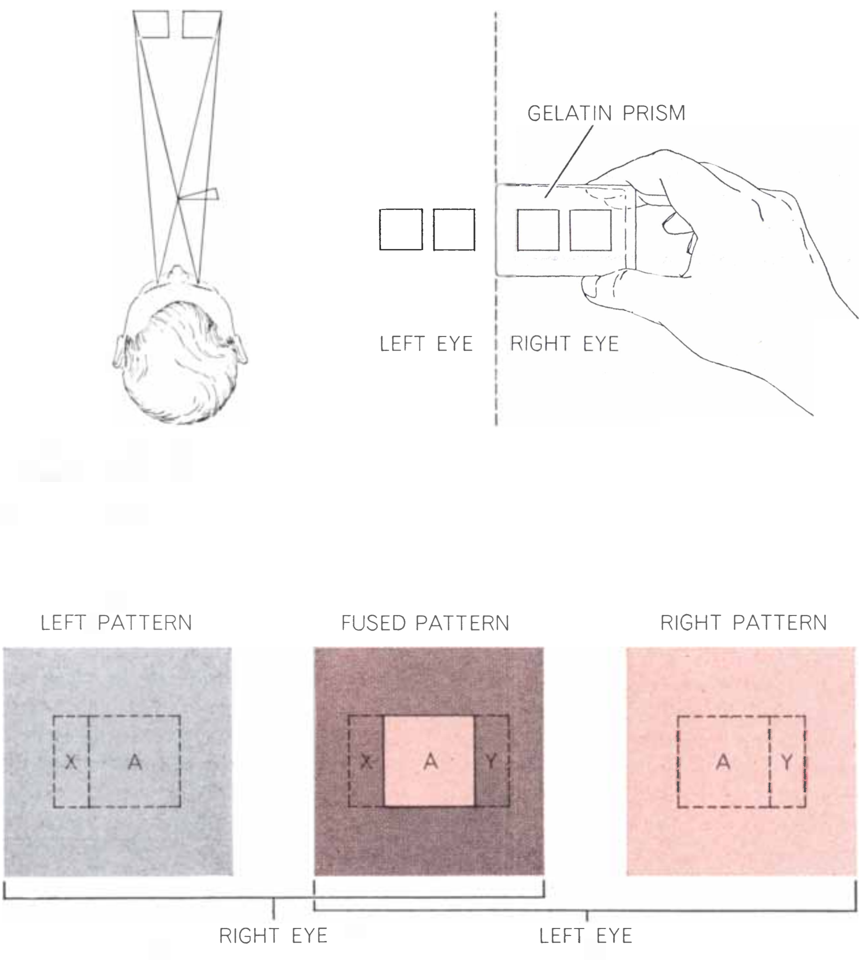
This indicates that discrimination of visual texture is not based on complex statistical analysis of brightness distribution but involves a kind of preprocessing. Evidently the preprocessing extracts neighboring points that have similar brightness values, which are perceived as forming clusters or lines. This process, which should not be confused with the actual spatial connection of objects, might be called connectivity detection. It is on the relatively simple statistics of these clusters and some simple description of them, such as spatial extent, that texture discrimination is really based.

The lower pair of illustrations above shows this connectivity detection even more clearly. In the left member of the pair two textures are easily discriminated; in the right member discrimination is difficult, if not impossible. In the pattern at the left every fifth horizontal and vertical row is gray; in the pattern at the right, which is otherwise identical, every fifth row is randomly peppered black and white. The "noise" added to the pattern at the right has only a minor effect on the statistics of the two subpatterns to be discriminated, yet it breaks up the connectivity of the subpatterns enough for them to merge into one field. The black and white "S" shapes that appear so clearly in the pattern at the left are completely destroyed in the pattern at the right. If the disrupted pattern is viewed at a sharp angle, however, the line clusters reappear and discrimination is facilitated.

The importance of proximity and similarity was emphasized early in the work of the *Gestalt* psychologists, par-



GELATIN PRISM provides a simple stereoscopic viewer. A clear plastic box for holding the gelatin can be obtained at a five-and-ten-cent store. Use five parts of very hot water to one part of household gelatin and mix thoroughly. Tilt the box about 15 degrees and pour in the gelatin solution. In about 30 minutes, when the solution has gelled, dampen the surface and press a rectangular sheet of clear plastic (or glass) against it. The prism will ordinarily work without this top sheet, but images may appear fuzzy.



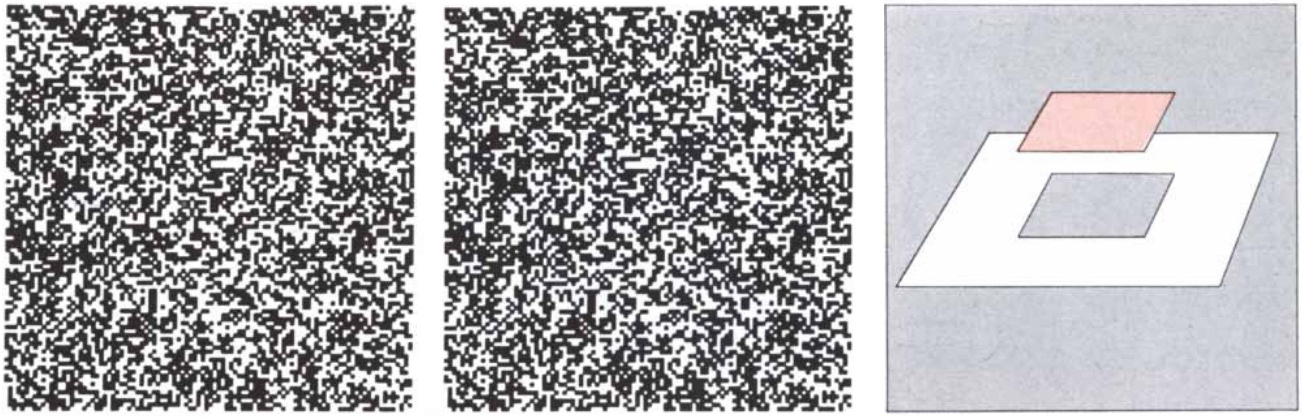
TO USE PRISM hold it about six inches in front of the right eye, thin edge toward the nose. Adjust the prism so that both stereoscopic images can be seen through it. Both images should also be visible to the left eye, as shown in the upper two diagrams. With little difficulty the images should rearrange themselves so that there appear to be only three images, of which the center one is the fused stereoscopic image. Once binocular fusion has occurred the image can be made sharper by moving the prism closer to the right eye.

ticularly that of Kurt Koffka and Max Wertheimer. Now, with the help of the random-dot-pattern technique one can give a more precise meaning to these notions. For example, the last experiment, in which the disrupted pattern is viewed at an angle, shows that neighboring points need not touch each other to appear connected. This notion comes as no surprise. On the other hand, when one observes that neighboring points of similar brightness are perceived as clusters, the meaning of "similar brightness" requires further clarification. How dissimilar in brightness can adjacent points be and still be perceived as clusters? In order to examine this question two computer patterns were generated.

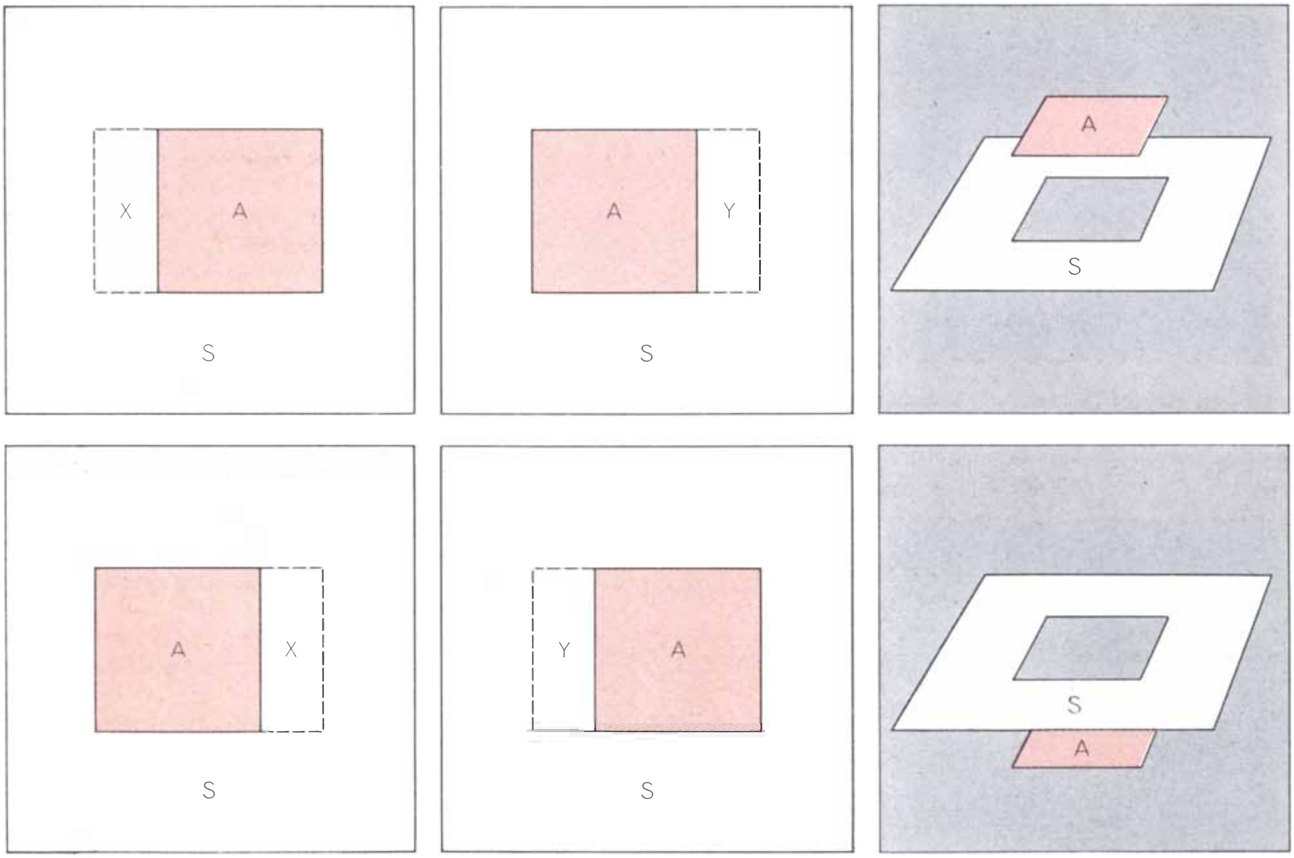
In one pattern, shown at top left on page 40, the field at the left is composed chiefly of black and dark gray random dots; the field at the right contains mostly white and light gray dots. As a result the field at the left forms a large dark cluster and the field at the right forms a light cluster, with a fairly sharp boundary between them. In the adjacent pattern the light gray and dark gray dots are transposed so that the field at the left contains chiefly black and light gray dots and the field at the right contains chiefly white and dark gray dots. Here discrimination between the two fields is more difficult. These and similar results suggest that the visual system incorporates a slicer mechanism that separates adjacent brightness levels into two broad categories: dark and light. The level of slicing can be adjusted up and down, but it is impossible to form clusters by shifting our attention to dots that are not adjacent in brightness.

One might argue that the eye could hardly respond otherwise when brightness levels are involved. It can be shown, however, that the same connectivity rules hold for patterns composed of dots of different colors adjusted to have the same subjective brightness. This is the demonstration shown on the cover of this issue of *Scientific American* and also on page 39. Since these patterns are made up of colored inks that do not reflect light with equal intensity, they do not fully simulate the laboratory demonstration, in which the dots are projected on a screen in such a way that their subjective brightness can be carefully balanced. Nonetheless, the printed demonstration, particularly the one on the cover, is reasonably effective. In the pattern on the cover what one observes is that the top half of the pattern is immediately discriminated into a red-yellow field on the left and a blue-green field on the right, whereas the bottom half of the pattern seems more or less uniform in texture across its entire width. This uniformity in texture is achieved simply by transposing the yellow and green random elements so that the field at the left is composed mostly of red and green dots and the field at the right is composed mostly of blue and yellow dots. The first demonstration shows that red and yellow dots form clusters that are easily discriminated from the clusters formed by blue and green dots. The second demonstration shows that dots of nonadjacent hue, such as red and green or blue and yellow, do not form clusters.

Evidently this clustering, whether it is of adjacent brightness levels or of adjacent hues, represents a preprocessing mechanism of great importance in the visual system. Instead of performing complex statistical analyses when presented with complex patterns, the visual system wherever possible detects clusters and evaluates only a few of their relatively simple properties. One now

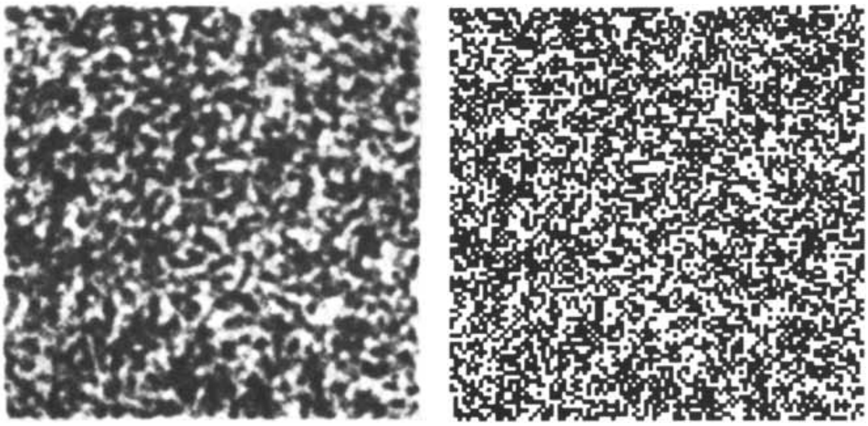


STEREOSCOPIC IMAGES investigated by the author consist of random-dot patterns generated by a computer. When these two images are viewed with a stereoscope or with a prism held in front of one eye, a center panel should be seen floating above the background, as illustrated at the far right. The principle employed in making such stereoscopic images is explained below.

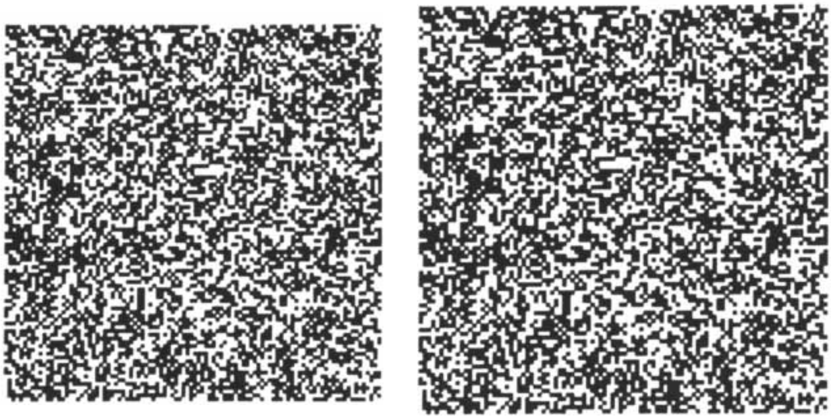


STEREOSCOPIC PRINCIPLE is simply that identical areas that appear in both fields must be shifted horizontally with respect to each other. Because these areas are themselves random-dot patterns they cannot be seen monocularly against a random-dot surround. In these diagrams *A* identifies the area common to both fields. In the upper pair of fields *A* is shifted inward, leaving two areas, *X* and *Y*, that are filled in with different random-dot patterns. When viewed stereoscopically, *A* seems to float above the surround. When *A* is shifted outward as shown in the two lower fields, *A* seems to lie behind the surround.

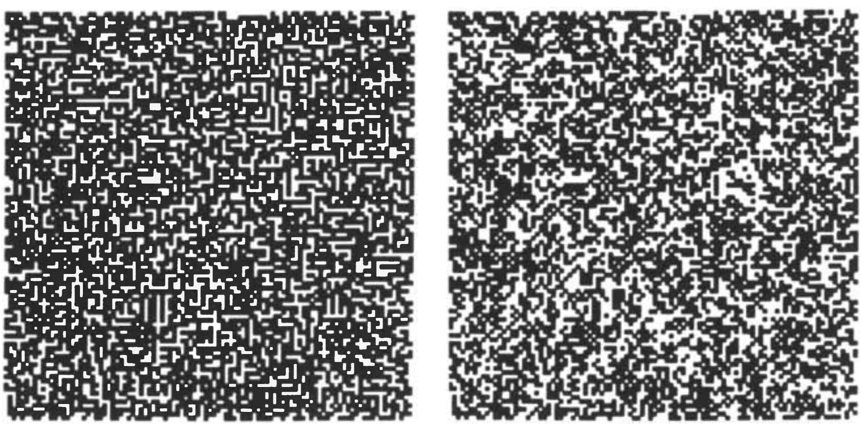
has a formula for matching wallpaper patterns. As long as the brightness value, the spatial extent, the orientation and the density of clusters are kept similar in two patterns, they will be perceived as one. Even for familiar patterns with recognizable and different forms discrimination can be made very difficult or impossible if the simple rules that govern clustering are observed. Thus a wallpaper pattern made up of seven-letter English words arranged in columns, as in the illustration at bottom right on page 40, would appear to be matched by a similar pattern containing nonsense sequences. The seven-letter nonwords would form clusters that could not be discriminated spontaneously from English words.



BLURRED IMAGE was produced by defocusing the field at left in the random-dot stereoscopic patterns on the preceding page. The field at right is unchanged. In spite of the blurring the two fields will fuse into a stereoscopic image; moreover, the image looks sharp.



REDUCED IMAGE also does not interfere seriously with the ability to obtain a good stereoscopic image. The two random-dot patterns are again those shown on the preceding page. The stereoscopic field at left, however, has been reduced about 10 percent in size.

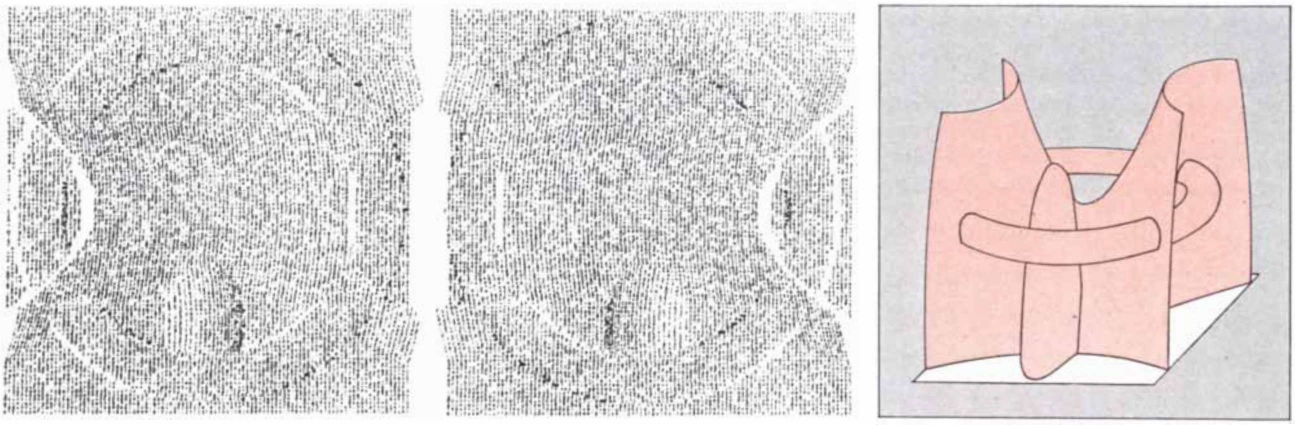


NOISY IMAGE (*left*) is produced by breaking up triplets of black dots along one diagonal and white triplets along the other diagonal wherever they occur in the left field on the preceding page. Nevertheless, the two fields will still fuse stereoscopically.

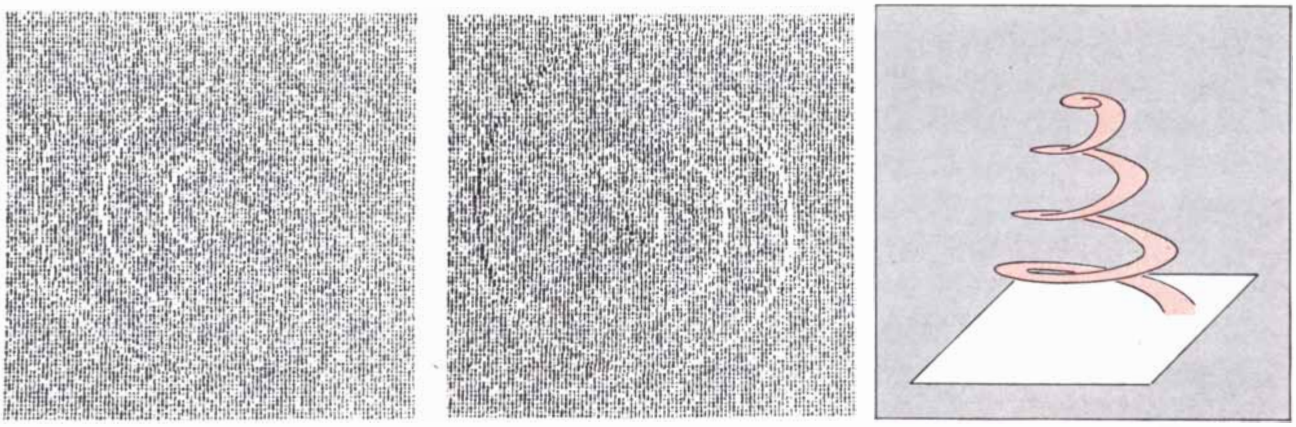
These findings answer in the affirmative the first question raised at the beginning. Objects can indeed be discriminated by differences in their surface texture alone even if they are spatially connected and cannot be recognized. The basis of this texture discrimination depends on simple properties of clusters, which are detected according to simple rules. Cluster detection seems to be a quite primitive and general process. Recent neurophysiological studies of frogs and cats have disclosed that their visual systems extract certain basic features of a scene prior to more complex processing [see "Vision in Frogs," by W. R. A. Muntz, SCIENTIFIC AMERICAN, March, 1964, and "The Visual Cortex of the Brain," by David H. Hubel, SCIENTIFIC AMERICAN, November, 1963]. The "bug" detector in the frog's visual system and the slit detector in the cat's visual system are special cases of connectivity detection. It will be interesting to see if neurophysiologists can find evidence for cluster detectors of the type suggested by these perception experiments.

We are now ready to consider the second question: Can two unfamiliar objects of identical texture be discriminated solely on the basis of their spatial separation? To study this question it was necessary to create patterns that were unfamiliar, that had the same surface texture and that could be perceived in depth. Again the problem was solved with the help of random-dot patterns generated by a computer. This time the computer was used to generate pairs of patterns that were identical except for a central area that was displaced in various ways. I had hoped that one would obtain a sensation of depth when the two patterns were viewed stereoscopically, and I was delighted when that turned out to be the case. This proved that one can perceive a camouflaged object in depth even when the camouflage is perfect and the hidden object cannot be discerned monocularly. In short, the answer to the second question is also yes.

A pair of these random-dot stereoscopic patterns is shown in the upper illustration on the preceding page. The two patterns are identical except for a center square that is shifted horizontally to the left by six dots in the pattern at the right. By virtue of this shift the



SADDLE-SHAPED FIGURE (*far right*) **was transformed into left and right stereoscopic fields by a computer program devised by the author. The picture elements consist of 64 standard characters randomly selected but paired in the left and right fields.**



SPIRAL "STAIRCASE" is another example of a computer-generated three-dimensional figure. The white gaps visible in the monocular fields of this figure and the one above could be reduced by programming the computer to produce a texture of finer grain.

square seems to float above the background when it is viewed stereoscopically. If the reader does not have an old-fashioned stereoscopic viewer at hand, by following the instructions on page 42 he can easily make a prism of gelatin that will serve the same purpose.

The phenomenon demonstrated by the binocular fusion of such random-dot patterns has a number of surprising implications. First of all, as the original statement of the problem requires, the stereoscopic picture is completely devoid of all familiarity and depth cues. Although the area selected for stereoscopic displacement in the first example is a simple square, it could be of any shape and it could also give the illusion of having more than one level [*see illustrations above*]. The fact that the center square and its surround are horizontally shifted by different amounts in the fields at left and right corresponds to the different depth levels that are perceived. Thus spatial disconnectivity alone is enough for the center square and its surround to be perceived as two distinct objects.

The demonstration also demolishes a long-standing hypothesis of stereopsis, or binocular depth perception, in which it is assumed that the slightly different images that are simultaneously projected on the retinas of the two eyes are first monocularly recognized and then matched. The process was thought to be somewhat analogous to the operation of an optical range finder, in which the corresponding separate images are first recognized and then brought into alignment. This last step corresponds to measuring the amount of displacement between patterns and determining the amount of depth by simple trigonometry (which the range finder performs automatically).

Research in stereopsis has traditionally been devoted to the problem of relating the displacement, or disparity, of images and the perception of depth. It has become increasingly apparent that depth perception involves many cues and cannot be described by trigonometry alone. Little or no attention was paid to the more fundamental problem of how the visual system is able to identify the same object in the separate two-dimensional images formed on each retina. The studies with random-dot patterns have now shown that monocular recognition of shapes is unnecessary for depth perception.

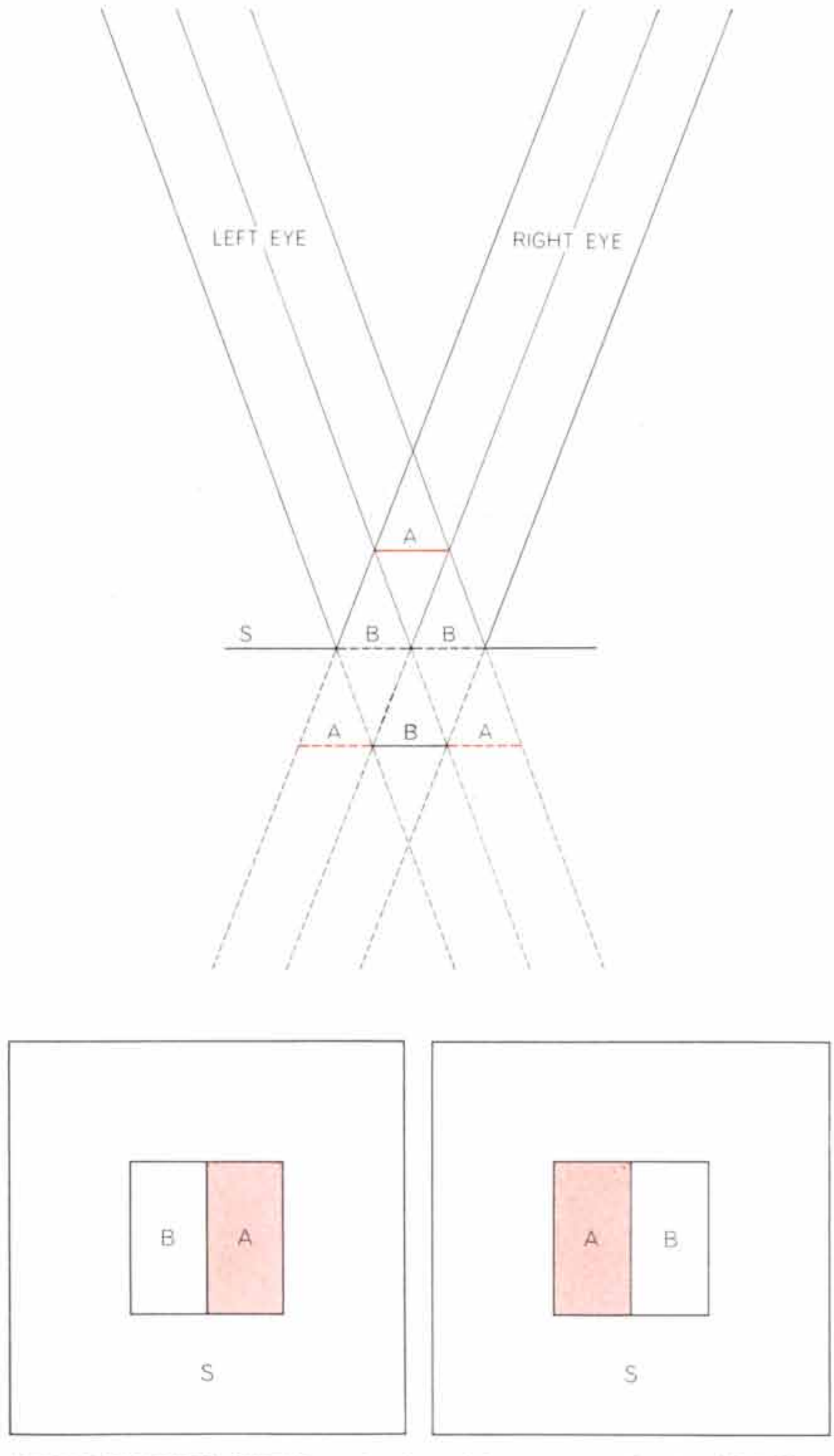
The method of producing random-dot stereoscopic images is shown in the lower illustration on page 43. The surround (*S*) is composed of randomly selected but identical dot patterns in the fields at left and right. The center panel (*A*) is also identical in the two fields but is shifted in one field with respect to the other as if it were a solid sheet. If the shift is inward (toward the nose of the observer), the center panel seems to float in front of the surround. If the shift is in the opposite direction, the panel seems to lie behind the surround. The greater the parallax shift, the greater the perceived depth.

If one simply cut a panel out of a random-dot pattern and shifted it, say, to the left, an empty space would be exposed along the right edge of the panel. The empty region (labeled *Y* in the middle diagram on page 43) is simply filled in with more random dots. A similar region (labeled X) must be filled when the panel is shifted to the right. Each region is projected onto only one retina (X onto the left retina and Y onto the right) and therefore exhibits no displacement. It is curious that these regions are always perceived as being the continuation of the adjacent area that seems to be farthest away.

By further manipulation of the random-dot patterns, it is possible to produce panels whose apparent location in space is ambiguous. If the X and Y regions described above are filled in with the same random-dot pattern, which we will label B, then when the two fields are viewed stereoscopically the center panel A may seem to be raised above the surround or area B may seem to lie below the surround. The diagram on this page illustrates the reason for this ambiguity. If the center panel is to be wider than the parallax shift (that is, wider than B), it must contain repeating vertical stripes of $ABAB$ and so on in one field and stripes of $BABA$ and so on in the other. An ambiguous panel created in this way is shown in the lower pair of stereoscopic images on the opposite page.

All these depth phenomena can be perceived in a very short interval, provided that the two fields are presented to the observer in reasonable alignment. The presentation time is so short (a few milliseconds) that there is no time for the eye to move and thus no time for a range-finder mechanism to operate. One must therefore conclude that depth perception occurs at some point in the central nervous system after the images projected onto the left and right retinas have been fed into a common neural pathway. This was actually demonstrated as long ago as 1841 by Heinrich Wilhelm Dove of Germany, who used brief electric sparks to illuminate stereoscopic images only three years after Charles Wheatstone of England had first shown how the young art of photography could be used to produce them. Evidently the convergence movements of the eye serve mainly to bring the images on the left and right retinas into approximate register. This does not mean, however, that convergence motions do not influence the perception of depth when the presentation time is of long duration.

The processing in the nervous system that gives rise to depth perception is now more of a mystery than ever. The German physiologist Ewald Hering believed that this processing involves the crossing or uncrossing of images that are initially perceived as double because they lie either in front of or behind the eyes' point of convergence. The extent to which this cue is utilized could not previously be determined because double images were inherent in stereoscopic presentation. The random-dot stereoscopic images, on the other hand, do not contain recognizable images prior to their actual perception in depth; thus it is impossible to perceive double images either before or after fusion.



AMBIGUOUS DEPTH EFFECT can be obtained by transposing the A and B fields in the random-dot patterns. When viewed stereoscopically (*top diagram*), area A may seem to be raised above the surround or area B may seem to lie below it. In either case the nonfused area seems to be a continuation of the field that looks farthest away.

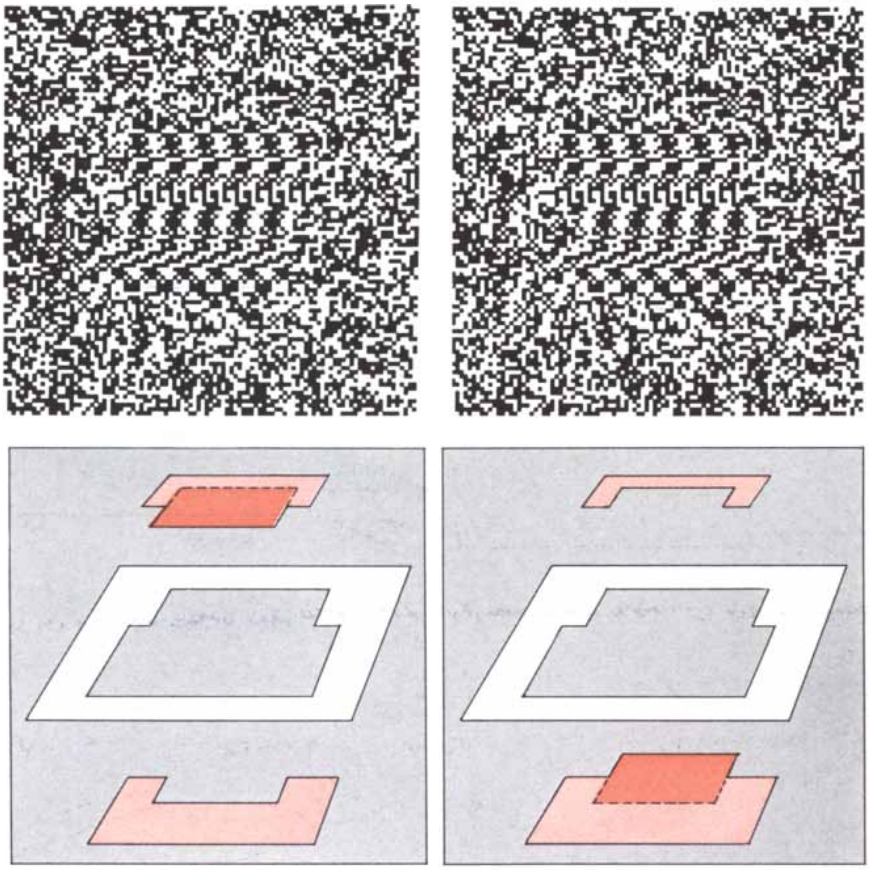
It could still be argued that although random-dot stereoscopic pairs do not contain recognizable shapes, some similar patterns can be perceived in the two fields and these might serve as the basis for fusion. This possibility can be tested in several ways. In the top stereoscopic pair on page 44 the field at the left has been blurred by being printed out of focus. Even when the patterns are almost obliterated in this way, stereopsis is easily obtained. What is more surprising is that the perceived image resembles the sharp one. The blurred image serves only to convey the required disparity information and is then suppressed.

The bottom stereoscopic pair on page 44 carries the disruption of patterns still further. This is achieved by breaking the diagonal connectivity in the field at the left. Along one diagonal whenever three adjacent dots were black, the middle dot was changed to white, and along the other diagonal whenever three adjacent dots were white, the middle one was changed to black. In the field at the right diagonally adjacent groups of three black or white dots were left unchanged. This procedure changes 20 percent of the picture elements in the field at the left and so removes them from the fusion process. The fact that the two fields look so different when viewed monocularly and yet can be perceived in depth when viewed stereoscopically provides additional evidence that no monocular pattern recognition is necessary and that the ultimate three-dimensional pattern emerges only after fusion has taken place.

Although the random-dot stereoscopic images lack monocular depth cues, which normally augment depth perception, they are actually easier to perceive in depth than stereoscopic images of real objects. The explanation is that each black or white dot in a random pattern contributes depth information, whereas in actual objects there are large homogeneous areas that carry no depth information. Thus random-dot stereoscope fields that differ in size by 10 percent or more can easily be perceived in depth [*see middle illustration on page 44*].

It is probably obvious that these findings have important implications for *Gestalt* psychology. According to this school stereoptic perception is not a result of disparity in the images projected on the two retinas; rather each eye works up its complex of stimuli into a *Gestalt* and it is the difference between the two *Gestalten* that gives rise to the impression of depth. The fact that stereopsis can be obtained in random-dot images without any monocular cues decisively settles this question, since no *Gestalten* can be worked up.

It might still be argued that *Gestalt* factors may operate after the binocular fusion of the two fields. In this connection it is interesting to look closely at the vertical boundaries of the raised panel formed by the top stereoscopic pair on page 43. The boundaries are fuzzy. The reason is that the black-and-white picture elements along the boundary have an equal probability of being perceived as belonging either to the raised panel or to the surround. Because a square has a "good *Gestalt*" one might expect to perceive these points as forming a straight line. That they do not suggests that perception is governed by simple considerations of probability.

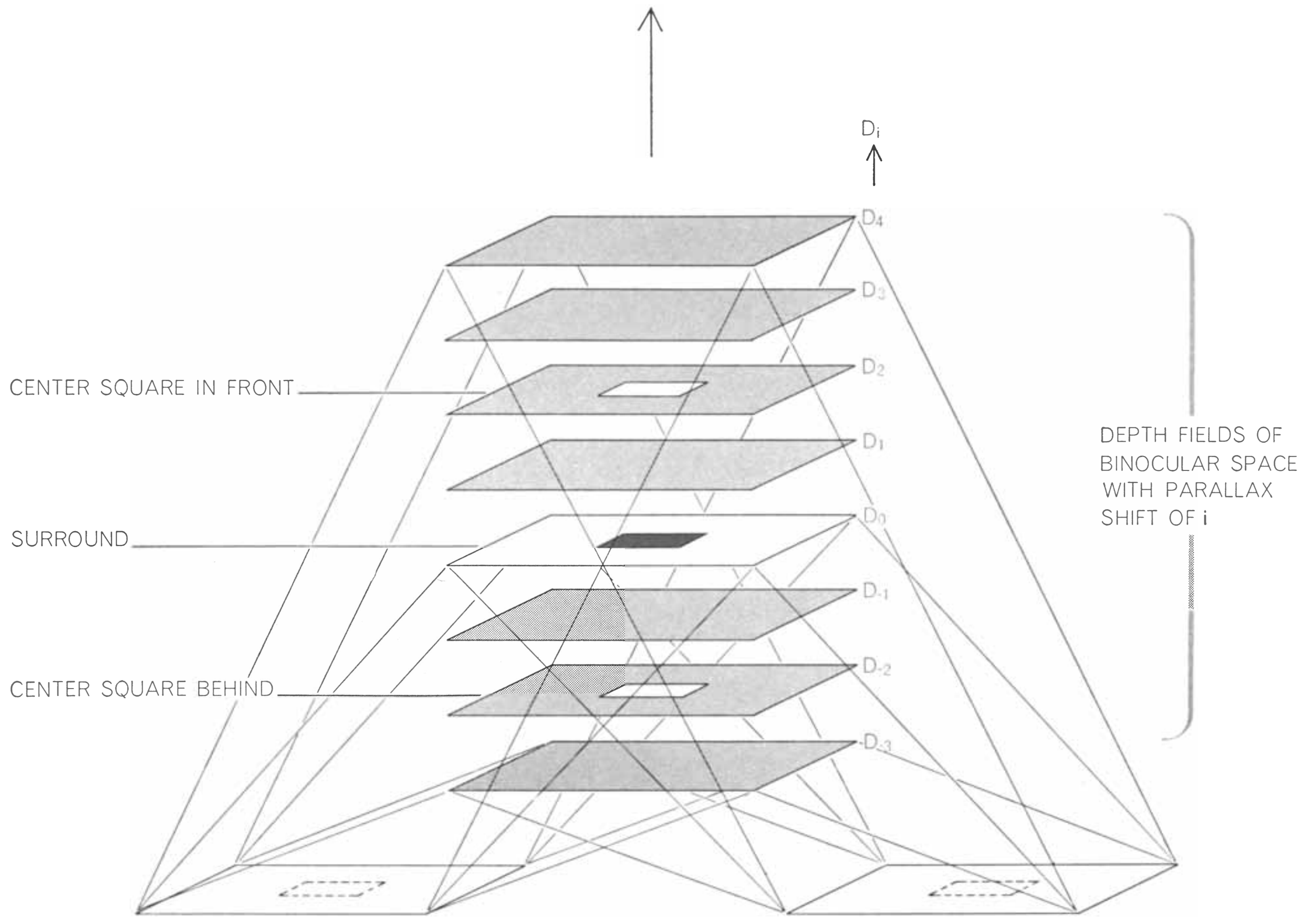


AREA OF AMBIGUOUS DEPTH appears in the middle of this periodically striped stereoscopic pattern. Sometimes it will seem to be a continuation of an elevated panel (*lower left*); at other times it will seem to be part of a depressed panel (*lower right*).

In presenting random-dot stereoscopic pairs for very brief intervals I have found evidence for a restricted but unmistakable kind of subliminal perception. This term refers, of course, to the idea that an individual can be influenced by a stimulus he does not consciously perceive. Efforts to demonstrate this phenomenon by other techniques have been inconclusive and controversial.

The finding was made while I was trying to measure the minimum time needed to perceive stereopsis in random-dot images. The time cannot be measured simply by presenting the images for briefer and briefer periods, for the reason that an afterimage remains on the retina for an indeterminate time. I found that it was possible to "erase" these afterimages by a new technique in which a second stereoscopic pair of random-dot images is flashed onto a screen almost immediately after the first pair.

In these short-interval experiments the first stereoscopic pair flashed onto a screen has a panel that is unmistakably either in front of the surround or behind it. This pair is followed quickly by another in which the location of the panel is ambiguous; under more leisurely viewing conditions it will seem to lie either in front of or behind the surround. Not only were the subjects unaware that the second pair was ambiguous but if the interval between the two presentations was made short enough



AUTOMAP-1 is a computer program that compiles a three-dimensional contour map from two-dimensional stereoscopic images. The program compares left and right fields point by point and subtracts the brightness of each point from its counterpart. Where the two fields match, the difference is zero, shown above as a white area. Thus the surround (D_0) is white except where there is a shifted center panel. The program repeats the point-by-point comparison after shifting one field horizontally (both left and right) by one unit, two units and so on. This provides an ordered set of depth planes (D_i). When a shift such as D_2 or D_{-2} brings a shifted panel into alignment, the points in the panel cancel and show up as zero (white). Form recognition is not needed.

they were also unaware that they were seeing anything but the second pair. The second pair erased all conscious knowledge of the first. The real presentation time of the first pair could therefore be established because it was governed by the time allowed to elapse before presentation of the second pair.

The main result was that the first stereoscopic pair, although not consciously perceived, can influence the way in which the second pair—the ambiguous pair—is perceived. When the presentation time of the first pair was long enough, the ambiguous panel in the second pair consistently seemed to be at the same depth as the panel in the first pair. A presentation time adequate to produce this result was about 40 milliseconds; it can be regarded as the "minimum perception time" for stereopsis. When the first pair is presented for a shorter time, or when the second pair is delayed by more than a certain interval, which I have called the "attention time," the second pair is removed from the subliminal influence of the first and is perceived ambiguously. These experiments suggest that the first pair serves as a "depth marker" and determines which of the two possible depth organizations in the second pair should be favored. All this processing must take place in the central nervous system because the times are too short for any eye motion to be initiated.

The various studies described in this article indicate that visual texture discrimination and binocular depth perception operate under simpler conditions than has been thought, since they do not require the recognition of form. This finding makes it attractive to try to design a machine that will automatically produce contour maps according to information contained in aerial stereoscopic photographs. As long as it seemed that such a task could only be done by a machine that could recognize complex and virtually unpredictable shapes, the job seemed all but hopeless. On the basis of the new findings I have helped to devise a computer program (called Automap-1) that can be used to compile a three-dimensional contour map from high-resolution stereoscopic images [*see illustration above*]. This computer program not only should be useful for reducing the tedium of producing such maps but since it is based on psychologically observed phenomena it is also a crude model of part of the visual system.

This article has described methods for studying visual texture discrimination and depth perception in their purest form. The methods have shown that connectivity detection is basic to both visual tasks and that it is a more primitive process than form recognition. It remains to be seen if on the psychological level a simpler "explanation" can be given. I hope that the next findings in this area will come from neurophysiologists.

Kodak reports on:

making prints under tension . . . mapping, past and future . . . a virtuoso tracer . . . a richer potion for the coppersmiths

1 paper, 7 contrasts, no waiting

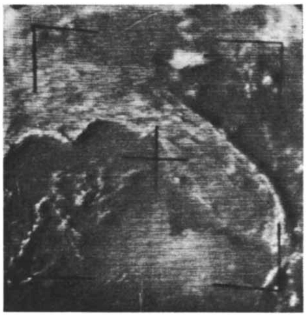
The lucky man who finds peaceful self-expression in classic black-and-white printmaking from his proud collection of negatives will take no joy in KODAK EKTAMATIC SC Paper. This new enlarging paper would defeat the purpose of his happy evening in the darkroom. Fun is out. Great enterprises are assumed to await pictures tensely, hobbyists told to play at home.

The negative is handed to the operator with cropping instructions. A glance tells him which of the seven KODAK POLYCONTRAST Filters this degree of contrast requires him to slip into the enlarger. A sheet of the new paper goes down on the easel (quaint relic, that word). It has the right speed, the right surface texture, the right, white, bright base tint, the right weight, the right image tone. (In these circumstances there is no time and no need to search through a great matrix of boxes for the best esthetic choice. Therefore, we provide no choice.) The instant the printing light flicks off, the operator grasps the sheet and inserts it into a slot in a machine that has been humming near the printer. Seventeen seconds later the sheet comes back out bearing the sparkling-bright picture, almost dry to the touch. Waiting hands seize it, and with a loud roar the focus of tension shifts elsewhere.

Need for long-term preservation of the print, though remarkably unlikely, can be met by conventional fixing and washing after the urgency has passed. The paper can even be conventionally processed in KODAK DEKTOL Developer in the absence of urgency. Our accomplishment, however, lies in the whiteness of the whites that KODAK EKTAMATIC SC Paper delivers when there *is* urgency, provided it is processed in the machine and chemicals we recommend.

If you need such a recommendation because rapidity of access to high-quality prints does happen to concern you, an inquiry about the KODAK EKTAMATIC *System should be addressed to Eastman Kodak Company, Professional Photographic Division, Rochester, N. Y. 14650.*

Color saves shoe leather



TIROS or NIMBUS transmits a picture of the Florida peninsula and lo, Florida turns out to have exactly the same shape that the Spanish navigators of the 16th century said it had. That men could map as well as they did before they learned to fly grows in wonder. Mapping without aerial photography now seems like building the Pyramids by muscle.

Despite the enormous reduction in map-making footwork from olden times, some observations still have to be made by men on the ground. With the Pharaohs' knack for low unit labor costs now a lost art, field-completion work runs big on a mapping budget.

The higher information content of color photography should permit a thinner network of ground-control points. Color in mapping has become practical. Shortly it will be necessary to judge where black-and-white remains economically defensible.

What has happened is that we have put on the market 1) an aerial color film on dimensionally stable ESTAR Base and of a speed that no longer restricts its use to an intolerably narrow range of solar altitudes but can be *adjusted* in processing to exposure conditions; and 2) glass plates that can carry the color image into the stereo plotting equipment.

For no better reason than to be well informed, you should know that this is happening. Maps are basic to civilization. The small coterie who need specific details about the film and the plates can get the information from Eastman Kodak Company, Special Sensitized Products Division, Rochester, N. Y. 14650.

Dyed chicken finds rabbit in rat

Read *Physical Techniques in Biological Research* (New York, Academic Press, 1956) III, p. 136. Learn of a piggyback operation where fluorescent chicken antiserum to rabbit globulin was made to seek out rabbit antiserum specifically localized in rat tissue to permit quantitative analysis by microdensitometry of the fluorescence photomicrographs. This is a virtuoso example of the fluorescent antibody tracer method.

Note remarks to the effect that along with the successes of this technique, there have also been disappointments due to organic synthesis difficulties, among others. Note statement that *Chemical and Engineering News* carries advertisements of companies that undertake organic synthesis on order and could be approached to make fluorescein isocyanate as the fluorescent dye. This could mean us.

Not that Distillation Products Industries (Division of Eastman Kodak Company, Rochester, N. Y. 14603) wants to stanch the gratifying flow of inquiries for custom synthesis in quantity. Nevertheless it feels obligated to point out that 5-Dimethylamino-1-naphthalenesulfonyl Chloride, *which it can now furnish off the shelf as* EASTMAN *P9090, is favorably reported on as a fluorescent dye for the fluorescent antibody technique in* Proc. Soc. Exptl. Biol. & Med. 98, *120 (1958). Always be sure you are up to date on what's available in* EASTMAN *Organic Chemicals. Latest catalog is No. 43. Watch above-named* C. & E. News *for additions.*

Resist change or change resists

We have raised the solids content and changed the solvent combination in KODAK Photo Resist. We are calling the new stuff KPR Type 2 and shall continue to supply the old formula for as long as enough customers resist change.

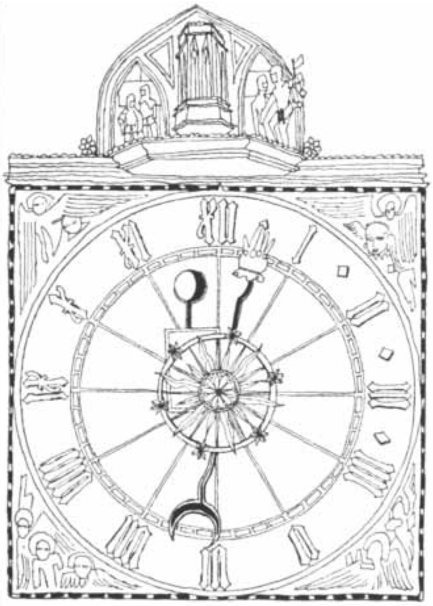
KODAK Photo Resist has had its effect on electronic design. In retrospect it seems inevitable that an effect had to be felt from a product that sort of coalesced design and fabrication, causing the actual manufacture to commence way back on the drawing board. At any rate, one needn't look very hard at a 1954 circuit to recognize it for the antique it is, and now even consumer electronics has to turn to photographic techniques to produce its tiny, tighter-toleranced printed circuits.

A single dip or spray of KPR2 should give these manufacturers (and any other customers to whom the difference between two dips and one dip is important) about 0.0003″ of coating to expose to light under the negative of the circuit drawing. This thickness of resist remaining after development suffices for a stopoff in the electroplating. It defines the plating area better, untrammeled by humidity complications, because our new solvent system contains no water-miscible ingredients.

Anybody who has tried working copper with the old KPR *and wanted better results might now make a fresh approach. Order a quart of* KPR2 *from a Kodak Graphic Arts Dealer. Our suggested price is the same as for the old formula with the lower content of magic photopolymer. If added active ingredient in the bottle cuts the labor cost, it's a wonderful buy, particularly if it's free. We have to help our electronics friends. The new circuitry is no longer new, and competition is fierce.*

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

SCIENCE AND



The Integrity of Science

The scientific community is under increasing political, military and commercial pressure, a committee of the American Association for the Advancement of Science has warned. The result is that society has been bringing into play the powerful tools of science without adequate understanding of their potential effects, and has been making essentially scientific decisions on the basis of nonscientific considerations. In its report at the December meeting of the A.A.A.S. in Montreal the Committee on Science in the Promotion of Human Welfare indicated that in some cases the behavior of individual scientists as objective investigators had been compromised.

The report, entitled "The Integrity of Science," was specifically critical of failures to evaluate ahead of time the broad effects of scientific experiments or technological innovations. On these grounds it cited the widespread use of pesticides and detergents without preliminary tests of their effects on environmental pollution. Two major American military projects came in for similar criticism: Project Starfish, a high-altitude nuclear explosion above the Pacific Ocean, and Project West Ford, an attempt to orbit millions of tiny copper needles as a reflecting layer for military communications. "Science has developed powers of unprecedented intensity and world scale," the committee wrote. "The entire planet can now serve as a scientific laboratory."

The committee also charged that the Apollo program for putting American astronauts on the moon by 1970 had been adopted for the wrong reasons. The man-on-the-moon project will have a large effect on the direction of basic research in this country, the report maintained, and it was adopted without an opportunity for "a conscious choice" by the scientific community or by the American people.

The committee, headed by Barry Commoner of Washington University, concluded that "the principles of disciplined investigation" may be neglected "if, because of secrecy, the experiments are not open to the full scrutiny of the scientific community." The report called for as much relaxation as possible in military and commercial secrecy. And it insisted that scientists, Government agencies and politicians should document statements about science so that the public can decide whether a given decision in scientific policy is motivated by scientific considerations or by nonscientific ones.

Academy of Engineers

The National Academy of Sciences has brought into being a sister organization: the National Academy of Engineering. The two academies plan to coordinate their operations, with the Academy of Engineering autonomously studying the technological needs of the U.S., advising the Federal Government on technological questions and promoting national and international technological programs.

The National Academy of Sciences was incorporated by Congress in 1863 as a private body that would further the application of science to the general welfare. In recent years many academy members (there are almost 700, elected on the basis of distinguished achievement in scientific investigation) have been called on to advise the Government in various areas of science and engineering. It became apparent that the advisory functions performed by scientists and engineers were sufficiently distinct to warrant separation. The Academy of Sciences, making use of a clause in its act of incorporation that empowers it to create organizations with related aims, established a committee of 25 engineers, businessmen and educators to recommend a staff and charter for a prospective Academy of Engineering.

In December, 1964, the committee suggested and the Academy of Sciences approved a set of formal goals for the new academy, bylaws for its operation, officers to lead it and criteria for electing members. The members of the committee have become charter members of the academy. They have elected as first president of the academy Augustus B. Kinzel, vice-president in charge of research for the Union Carbide Corporation. The election of future members will be based on "important contributions to engineering theory and practice, including significant contributions to the literature of engineering; and demonstration of unusual accomplishments in the pioneering of new and developing fields of technology."

Double Forces

An experiment that counted photons at the rate of 15 billion a day for several months has provided evidence that the proton and neutron, which interact through the "strong" force that holds the atomic nucleus together, also interact to a slight extent through another of the four recognized forces of nature: the "weak" force. This force has only a trillionth (10^{-12}) of the strength of the electromagnetic force that binds electrons to protons and only a hundred-trillionth (10^{-14}) of the strength of the nuclear force; it is, however, 10^{25} times stronger than the gravitational force. Heretofore the only particles definitely known to participate in weak interactions were neutrinos, electrons and several of the mesons.

That protons and neutrons should also "feel" the weak force had been predicted several years ago by Richard P. Feynman and Murray Gell-Mann of the California Institute of Technology. A preliminary report on the experiment that appears to confirm the prediction was made by Felix H. Boehm and Egbert Kankeleit of Cal Tech at the December meeting of the American Physical Society in Berkeley, Calif.

Boehm and Kankeleit designed an experiment that would examine the direction of spin of gamma ray photons released in the decay of the radioactive isotope hafnium 181. This particular isotope was selected because the protons and neutrons in its nucleus were expected to produce the clearest evidence of a weak interaction, if one existed, for protons and neutrons. If there were no influence from a weak interaction, exactly half of the photons produced in the radioactive decay should emerge with a right-handed spin and exactly half with a left-handed spin. Evidence for the weak force would be found if the numbers were not quite equal; this would indicate a violation of parity, which is permitted to nuclear events associated with the weak force.

The gamma rays emerging from hafnium 181 were sent through a strong electromagnet, which controlled the direction of spin of the electrons in its own iron atoms. Every 10 seconds the polarity of the magnetic field was reversed, thereby reversing the direction of spin of the iron's outer electrons. This meant that the photons from hafnium 181 encountered electrons of alternating polarity. When photon and electron had opposite spin, the photon would usually be deflected out of the beam and would not reach a scintillation counter. If the spins were the same, deflection was less likely and the photon would be counted.

The experiment determined for a large sample of photons whether or not the polarity of the electromagnet had any effect on the number of photons reaching the counter. It showed that on the average left-hand and right-hand spins did not balance out for three out of every 10,000 photons. This was evidence that parity was not fully conserved and that the weak force was operative to a corresponding degree.

Site of Short-Term Memory

A University of Chicago neurologist has obtained direct experimental evidence as to the site in the brain of "short-term memory": the capacity, unique in primates, to absorb information that has temporary value, retain it briefly, use it and then forget it. Sidney Schulman found that by destroying the two dorsomedial nuclei in the thalamus of monkeys he could severely impair the animals' performance in a delayed-response test involving their ability to recall what they had just seen. He concludes, in a paper published in *Archives of Neurology*, that in monkeys the nucleus is probably an essential component of the mechanism by which "novel and transient events" are retained in the brain "for relatively brief periods of time."

Schulman began by training rhesus monkeys in a simple shell game in which the animal watches as the experimenter puts a slice of banana under one of two inverted cups. A screen is lowered; when it is raised, the animal lifts a cup to get its reward. The monkeys learned to pick the correct cup more than 80 percent of the time after delays ranging up to 50 seconds. Schulman also trained the monkeys in another test involving visual discrimination. Then he implanted in the dorsomedial nuclei of each monkey a "seed" of yttrium 90, a weak source of beta radiation calculated to destroy the nuclei with minimal damage to the surrounding tissue. The extent to which the nuclei were destroyed (established by autopsy at the end of the experiment) ranged from 100 percent to about 50 percent.

When Schulman repeated his tests after the yttrium implantation, three monkeys with complete or virtually complete destruction of the dorsomedial nuclei did much worse than before in the shell game; one of them, with 100 percent destruction, could not reach the 80 percent criterion even when the screen was not lowered at all. Of the other nine animals, some showed less impairment and some showed none. There was no consistent relation between the extent of the destruction and performance; apparently a small remnant of the nucleus can provide normal performance. As evidence that it was the retention of recently acquired information that was primarily impaired and not other mental abilities, Schulman cites the fact that the animals could be trained to understand and work at the game postoperatively and that the impairment in their performance generally became more conspicuous as the delay interval was increased. Moreover, all the animals were able in time to match their preoperative scores in the visual discrimination test, which indicates that other fairly sophisticated abilities were only temporarily affected by the damage to the dorsomedial nucleus.

Neutrino Trap

A new astronomical observatory, consisting of a 100,000-gallon tank of cleaning fluid, is nearing completion at the 4,500-foot level at a mine in Idaho. The observatory's function is to detect neutrinos, and its first task will be to analyze the blizzard of these particles that is generated by thermonuclear processes in the core of the sun. John N. Bahcall, a physicist at the California Institute of Technology, presented the details of the project at the recent meeting of the Second Texas Symposium on Relativistic Astrophysics at the University of Texas.

The new observatory is located underground in order to screen out cosmic rays. Neutrinos have no electric charge or rest mass and consequently are able to travel at the speed of light through hot, cold, dense or tenuous matter almost as easily as through empty space. Of the 10 billion or so neutrinos that pass through every square centimeter of the earth's surface every second only about one is absorbed by the earth. As a convenient neutrino-absorber Bahcall and his colleagues employ a huge covered tank containing the common cleaning fluid tetrachloroethylene, the molecule of which consists of two carbon atoms and four chlorine atoms. On the comparatively rare occasions when a neutrino is absorbed by the nucleus of an atom of chlorine, the chlorine atom will be converted into an atom of argon 37. Since argon 37 is radioactive, a decaying atom of it can readily be detected by an array of Geiger counters. If current theories of how stars generate energy are correct, one would expect from three to nine counts a day from the sun alone.

Bahcall points out that the production of neutrinos "...is extremely sensitive to temperature. The higher the temperature, the greater the neutrino production and the greater their energy. Different kinds of absorbing material are sensitive to different kinds of neutrinos. This should make it possible to selectively record different kinds of neutrinos and thus develop a neutrino spectrum, analogous to the light spectrum that produces information about astronomical objects." Since neutrinos are the only subatomic particles that penetrate the earth's atmosphere from outer space, they should yield much valuable information about the temperature inside the sun, the density of matter there and the relative abundances of the lighter elements.

Bahcall adds: "We also hope to learn something about what goes on in the vast explosions in the universe—supernovae, radio galaxies and quasi-stellar radio sources." If the absorber succeeds in detecting neutrinos from the sun, it may then be "aimed" to record neutrinos from other objects in the sky.

Paleolithic Funeral

The grave of a Paleolithic mammoth-hunter recently discovered in permanently frozen soil 130 miles northeast of Moscow contains a skeleton and funerary goods in such an excellent state of preservation that Soviet archaeologists have been able to reconstruct in considerable detail a funeral rite of at least 33,000 years ago. Such opportunities are rare; not until more than 25,000 years later, following the rise of Neolithic communities, were formal burials abundant.

A 55-year-old male of Cro-Magnon physical type, between five feet seven inches and five feet nine inches tall, the interred individual had lived when the surrounding region was cold steppe dotted with patches of pine and birch. He and his fellows killed reindeer, bison, moose, horse, hare, Arctic fox and mammoth. At the time of his death (no cause was apparent) or subsequently he was dressed in tailored trousers and pullover shirt, both made of fur. These garments had been decorated by sewing on them many rows of beads carved from mammoth ivory. He wore on each wrist a dozen thin platelike bracelets, also of mammoth ivory; strands of Arctic-fox teeth completed his personal adornment.

The original excavation was in the form of a narrow, oval basin, which was then strewn with live coals from a wood fire and a layer of the red iron pigment hematite. The body was placed on its back atop these layers, its legs extended and its hands resting together at the waist. Thereafter a second layer of red pigment was strewn on the body. A flint knife, a massive scraper and a pierced stone pendant were included in the grave. Otto Bader and Mikhail Gerasimov, who opened the grave, consider it to be the richest Paleolithic burial yet discovered in Europe.

One Man's Meat

An entomologist at Cornell University has found that catnip, a strong-scented mint extract best known for its ability to excite cats, is repellent to many insects. Writing in *Science,* Thomas Eisner suggests that the true adaptive function of the terpene nepetalactone, the active ingredient in catnip, may be to protect the catnip plant against certain plant-eating insects.

In recent years many defensive compounds chemically allied to catnip have been isolated from insects. In order to investigate the possibility that nepetalactone might also have a defensive role, Eisner conducted a series of simple experiments. One of the experiments consisted in observing the response of a variety of insects to the vapors emanating from the tip of a fine capillary tube filled with pure liquid nepetalactone and pointed toward their bodies from a few millimeters away. The insects were a mixed assortment that had come to rest at night on an illuminated surface. According to Eisner, "the caddis-flies flew away. The alleculid beetles fell to the ground (as do many beetles when disturbed). The remainder simply turned away from the capillary and walked off. As they escaped, complete control could be exercised over the course of their locomotion by maintaining the capillary at close range, pointed at them from various directions; their every move was in distinct avoidance of the vapors. Capillaries filled with water had no comparable effect."

Insects that responded to the vapors of nepetalactone also reacted characteristically to direct contact with the liquid. Eisner describes one such experiment: "An ant (*Solenopsis germinata*) that was carrying a small live curculionid beetle dropped its prey instantly when a droplet of nepetalactone was applied to the beetle, and began intensive cleansing activities. Other workers that made casual contact with this ant were themselves induced to cleanse."

The response of cats to catnip is still mystifying. As Eisner points out: "Surely a mint plant derives no benefit from an ability to stimulate cats!" He adds: "Whether the Felidae actually produce such terpenes themselves, employing them perhaps as pheromones for the regulation of some of their behavior, is a possibility worth exploring. Terpenes are intriguing compounds, widely distributed, and have functions that are yet to be explained in many species. In plants and insects similar terpenes appear to have evolved in fulfillment of similar defensive needs. It is certainly conceivable that the same compounds might be present in yet a third group of organisms (perhaps in cats), but for entirely different adaptive purposes."

The Sun as a Radar Target

Radar observations have now been added to the various techniques employed on a routine basis for studying the erratic behavior of the solar atmosphere. Since April, 1961, a powerful radar beam from a transmitter at El Campo, Tex., has been aimed at the sun for 17 minutes approximately every other day. The 17-minute transmission period is set by the time required for the radar signals to make a round trip. At the end of 17 minutes the antenna, which consists of a nonsteerable array of 1,016 dipoles, is switched from transmitting to receiving.

A report covering nearly 600 radar observations of the sun from El Campo has recently been published in *IEEE Transactions on Military Electronics* by Jesse C. James of the Lincoln Laboratory of the Massachusetts Institute of Technology, which operates the radar installation. The El Campo studies began only two years after the first radar contact with the sun was made by workers at Stanford University.

Unlike the moon and nearby planets, which have become familiar radar targets, the sun does not present a simple reflecting surface. The 7.84-meter waves of the radar beam used at El Campo do not reach the sun's photosphere—the visible disk that is the source of almost all the sun's light energy—but are reflected from the solar corona. This is the outermost region of the solar atmosphere, which consists of highly ionized gas at a temperature of about a million degrees centigrade.

About 5 to 10 percent of the time the radar echo is so immersed in noise that it cannot be detected at all. Under the best conditions the noise, consisting of solar and cosmic noise in about equal parts, is 100 to 1,000 times stronger than the signal being sought. It is possible to extract the faint echo, however, because the outgoing signal is coded, usually by shifting the frequency up and down between two levels. If the echo plus noise is integrated for a suitable length of time (1,000 seconds), the coded component manifests itself.

The integrated strength of the echo can be used to calculate a "solar radar cross section": the apparent size of the sun regarded as a radar target. Over the three-year period of observation the cross section varied from zero (no echo) to 16 times the area of the photosphere. Even the year-to-year variations were striking. The weighted average cross sections for the three successive years (April to April in each case) were 2.2, 1.1 and .6. No correlation could be found between these variations and other regularly observed solar phenomena such as sunspot number and the flux of radio waves emitted by the sun at a frequency of 2,800 megacycles.

The radar observations have corroborated one theoretical prediction: the existence of a strong solar wind in the coronal region. Because of the wind the coronal reflecting surface appears to be moving outward at a velocity of about 16 kilometers per second.

THE SKIN

The human body's largest organ, this protective envelope not only stabilizes temperature and blood pressure but also gives rise to the hair patches, odors and shades of color characteristic of man

by William Montagna

As a naked animal who is apparently becoming progressively more hairless as his evolution advances, man is extraordinarily dependent on the properties of his skin. Skin is a remarkable organ—the largest and by far the most versatile of the body. It is an effective shield against many forms of physical and chemical attack. It holds in the body's fluids and maintains its integrity by keeping out foreign substances and microorganisms. It acts to ward off the harsh ultraviolet rays of the sun. It incorporates mechanisms that cool the body when it is warm and retard the loss of heat when it is cold. It plays a major role in regulating blood pressure and directing the flow of blood. It embodies the sense of touch. It is the principal organ of sexual attraction. It identifies each individual, by shaping the facial and bodily contours as well as by distinctive markings such as fingerprints. The skin crowns all these properties with the ability to regenerate itself and thereby heal wounds. As A. E. Needham of the University of Oxford has remarked, scratches and other minor wounds are so common (probably, at a conservative estimate, averaging one a week per person) that few human beings would survive very long if it were not for the skin's property of self-repair.

We shall survey in this article the highlights of what has been learned about man's skin: its anatomical properties, functions and evolution. The subject has many aspects, because skin is a complex tissue that forms a great variety of structures. In mammals the same tissue that produces the epidermis also differentiates into hair, spines, nails, claws, hooves, scales and horns; in birds it produces feathers, the beak, scales and claws; in reptiles it gives rise to scales, spines and claws. In man the glands of the skin deserve particular attention, because they perform several vital roles.

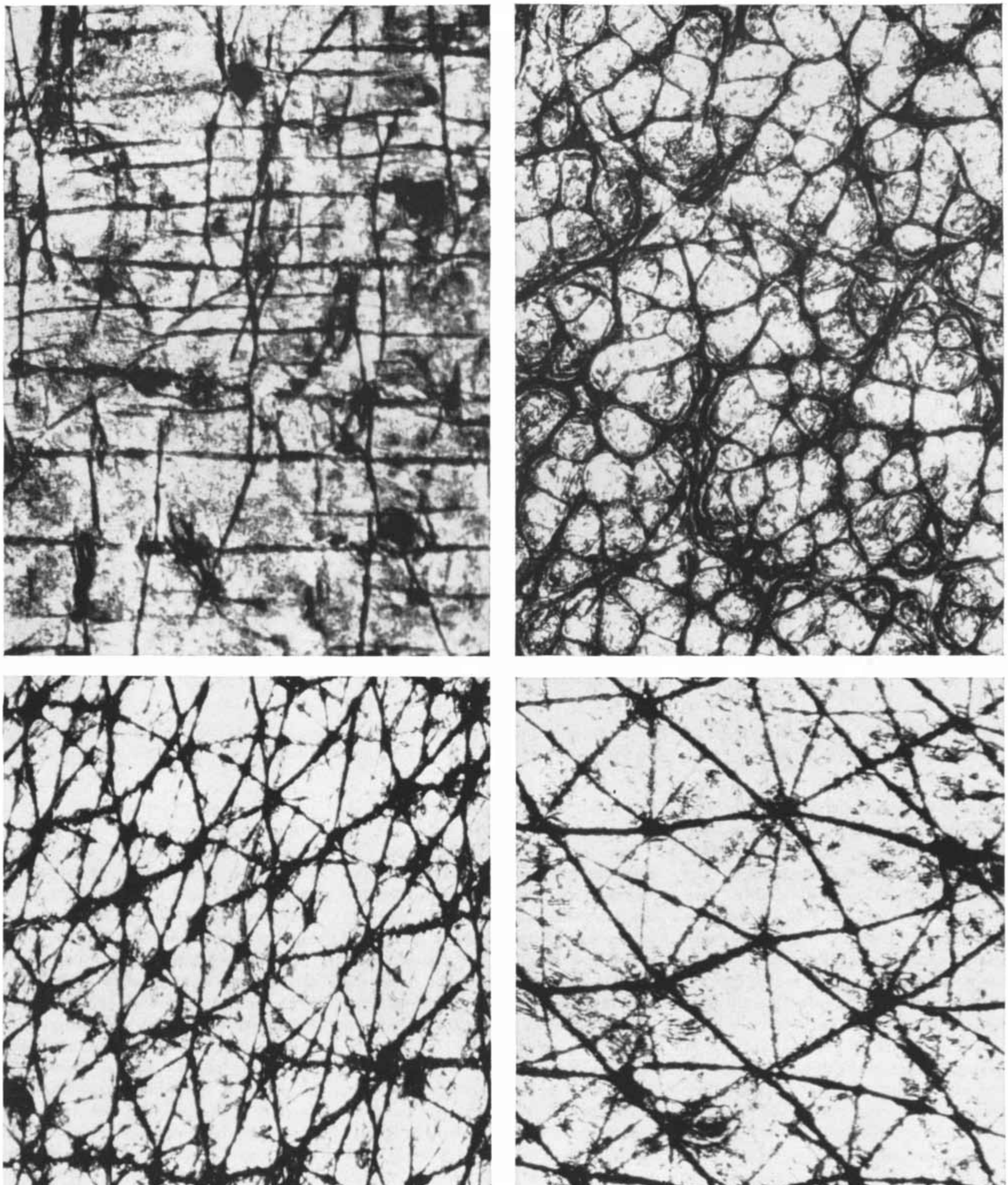
The skin is composed of two principal layers: (1) the underlying dermis, a thick, fibrous tissue that forms its main bulk, and (2) the epidermis, the thin surface coat, which consists of four or five sheets of cells veneered on one another. The top layer of the epidermis is made up of flattened, dead cells—necessarily dead, because living cells cannot survive exposure to air or water. It is this mantle of dead tissue, called the horny layer, that serves as the principal shield of the body. Thin, flexible and transparent, it is nevertheless a sturdy structure, with its cells held together by "attachment plaques." In protected areas of the body this layer is smooth and very supple; on surfaces that get a good deal of wear, such as the palms of the hands, it is thicker and more rugged.

If you scratch your skin with your fingernails, you will scrape off tiny flakes of the dead surface tissue. The skin of the whole body is continually exfoliated by the wear and tear of rubbing and exposure to the environment. The deeper layers of the epidermis steadily replenish the horny layer, however, by moving up more cells. As the cells ascend toward the surface, they die by degrees as they produce keratin, the fibrous protein that constitutes the bulk of the dead surface structures, not only of the skin proper but also of the hair, nails and other skin growths. Death is the goal of every epidermal cell, and it is achieved in an orderly manner. Like the leaves of autumn, the epidermal cells, having lived for their season, eventually dry out and peel off.

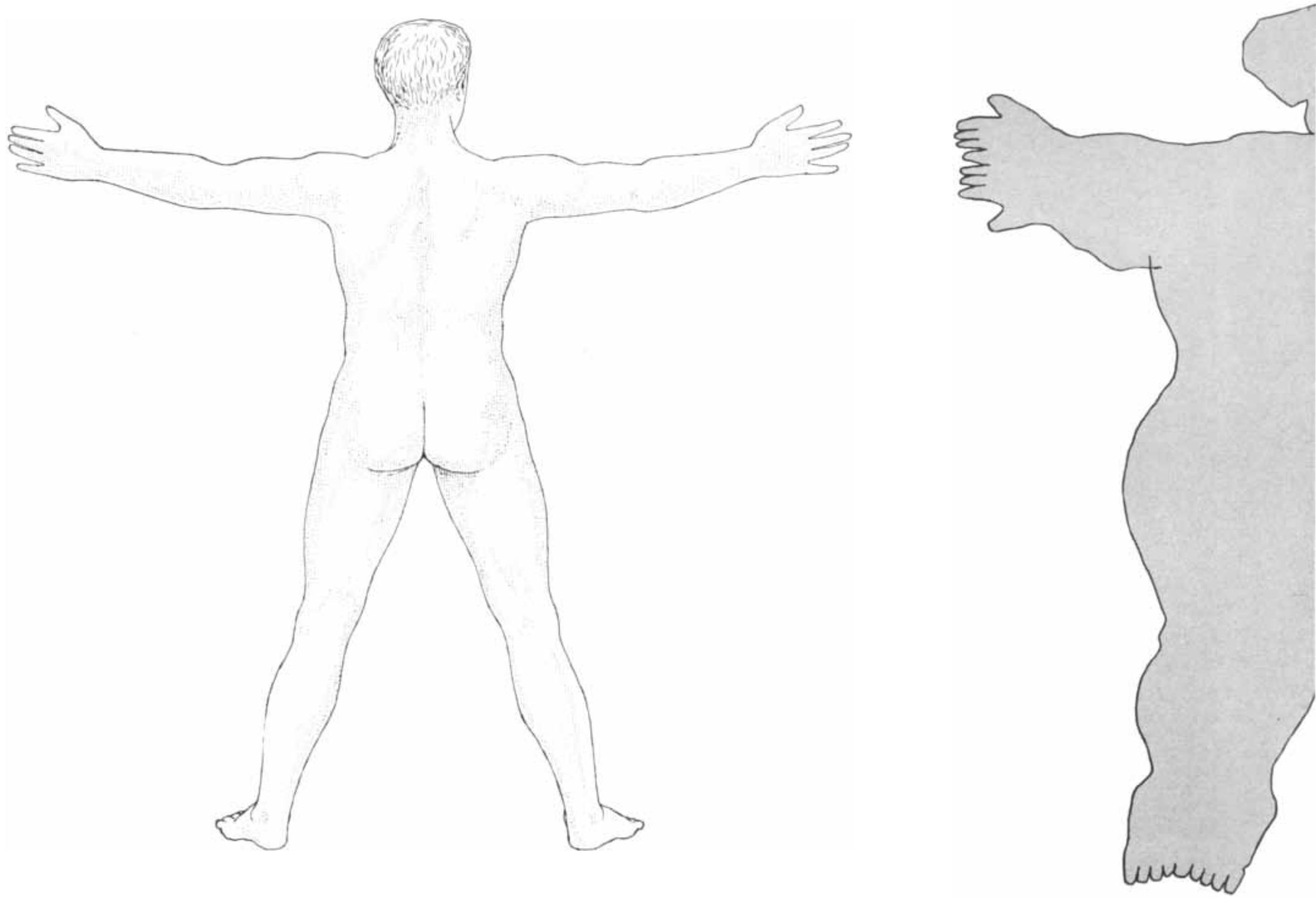
The horny layer they form is a relatively effective barrier against the entry of most foreign substances, but its effectiveness is not complete. Among some of the noxious substances it fails to keep out are metallic nickel and the oleoresins of poison ivy. The skin is so sensitive to nickel that even the comparatively few molecules that are rubbed off on contact may produce a violent reaction with the living tissues if the nickel penetrates the epidermis. The skin's sensitivity to an encounter with the leaves of poison ivy, or even the smoke from its burning leaves, is well known. A thicker horny layer might have made man impervious to all invasions, as it has the elephant, but man would then have had to pay the price of a loss of suppleness and agility. The human skin, all things considered, has achieved a remarkably effective compromise.

To continue with our examination of the skin's surface, we observe that, like a very detailed map, it is heavily marked with topographical features: furrows, ridges, pores, hair follicles, pebbled areas and so on. Each area of the body has its own characteristic topography. Some of the markings have obvious general usefulness. The hands and feet need rough surfaces; if they were perfectly smooth, they could not get a good grip. Some features are clearly the result of long habit in the exercise of certain muscles that pull on the skin; among these are the wrinkles formed by smiling and by knitting the brow. By and large, however, most of the patterns in the skin are strictly genetic. Largely determined by the orientation of the fibers in the dermis and by other anatomical factors, they are peculiar to each individual and therefore serve as a means of personal identification.

Look at the skin of your palm or a finger under a magnifying lens. Its ridges, forming whorls, loops and arch-



SKIN TEXTURE varies from place to place on the human body, as is evidenced by varying patterns of lines and pores. From left to right, the four illustrations show impressions in plastic of forehead and elbow skin (*top*) and of chest and back skin (*bottom*). The work of H. D. Chim and R. L. Dobson at the University of Oregon Medical School, the impressions are here enlarged 75 diameters.



TOTAL SURFACE AREA of the skin, which seems surprisingly large in contrast to the outline of a human figure (*left*), is calculated by adding the areas of a series of cylinders constructed from an average of leg, arm and torso circumferences. A man six feet

es, make up specific pattern designs, called dermatoglyphics. No two individuals, not even identical twins, have exactly the same dermatoglyphics. The patterns are formed before birth; they are laid down in the fetus during the third and fourth months of development. Their congenital origin shows itself in certain graphic ways. For example, women's fingerprints are distinctly different from men's: women have fewer whorls and more arches. In an individual the dermatoglyphics of the right hand show major differences from those of the left, which suggests that handedness may be established during the third or fourth month of fetal life. There are even indications that unusual skin markings may be associated with congenital brain abnormalities, such as mental deficiency and epilepsy [*see bottom illustration on page 62*]. Dermatoglyphic peculiarities have shown up consistently in such individuals; this implies that the factors responsible for the brain abnormalities may have operated during the third and fourth fetal months, when the skin patterns were being formed.

The development of skin begins very early in the human embryo. The epidermal cells soon differentiate further into the skin's suborgans: hair follicles, nails, sebaceous glands and sweat glands. At about three months, for example, hair follicles start to form on the head, the part of the body that develops first, and as the fetus grows the trunk and limbs also acquire hair follicles. By the time the infant is born it has as many hairs or rudiments of hairs on its body as it will ever have. The common notion that hair does not begin to form on some parts of the body until one matures (for instance, that a boy's cheeks are hairless until he approaches the age of shaving) is incorrect. The hairs are there all the time, although they may not grow noticeably before puberty. Moreover, there is no substantial difference between men and women with respect to the number of hair follicles: a woman has about as many hairs on her body as a man, but many of them are so small and colorless that they escape notice. Indeed, the same observation holds for the comparison between man and his furrier relatives—the gorilla, the orangutan and the chimpanzee. Man has about the same number of hair follicles as these animals; the difference is simply that most of his are obsolescent and fail to grow much.

Man's skin follows a characteristic life cycle. In infancy and early childhood it is dry, soft, velvety, clear and apparently almost hairless. Because it is so free of blemishes and presumably because it suggests the clear, soft skin of a sexually attractive young woman, baby skin has come to be regarded as the epitome of skin beauty. With adolescence comes an enlargement of the hair follicles and a more active growth of the hair. The sweat glands and sebaceous glands (which produce a fatty secretion) go from a nearly dormant state to full activity. Physiologically speaking, the skin arrives at full bloom with puberty. Its ensuing history, however, is not completely happy, partly

tall and of average weight and body build has about 15,000 square inches of skin area.

because its owner proceeds to subject it to daily abuses.

In the effort to enhance its attractiveness, men and women submit their skin to systematic stretching, scraping, gouging, soaking and burning. In our fastidious society the skin is treated with daily baths, which remove its natural emollients and essential substances. It is doused with powders, poultices, oils and other chemical and physical treatments that may cause varying degrees of irritation. To give it a "healthy" tan, the skin is ritualistically exposed to excessive and injurious doses of sunlight and wind.

That the skin survives these daily torments is a remarkable tribute to its toughness. But age and decades of indignities do, of course, take their toll. Man's most obvious sign of age is the dry, wrinkled, flaccid skin that marks his late years. It is then a tired organ—a relic of what it was in its youth.

From place to place on the body the skin is a study in contrasts. On the eyebrows it is thick, coarse and hairy; on the eyelids, thin and hairless. On the red border of the lips it is completely hairless; on the upper lip, chin and jowl of a man, so hairy that bristles are visible within a few hours after shaving. On the nose, the cheeks and the forehead the skin is oily; on the jowls, dry and greaseless. The rest of the body shows contrasts as striking as those on the face. The skin areas of the chest, the pubic region, the scalp, the abdomen and the soles of the feet are as different from one another, structurally and functionally, as if they belonged to different animals.

A brief examination of a few specific properties of the skin will serve to illustrate how exquisitely it is adapted to its functions. As a wrapping that must accommodate itself to changes in the shape and size of the body, the skin is highly elastic. Pull the skin and it will snap back. Cut out a piece and the detached piece will contract, whereas the skin around the wound will widen the cut by elastically pulling away from it. During pregnancy the skin of the lower trunk of a woman is highly stretched. Afterward, when her body returns to its normal size, the skin makes heroic efforts to regain its former area, but the stretching may leave permanent scars—the light streaks in the skin that commonly appear on the abdomen of a woman who has borne children. Similar streaks appear on the body of a person who has gone through repeated bouts of gaining weight and reducing. Such bouts sometimes leave the fatigued skin sagging in pendulous folds that refuse to shrink back.

Another conspicuous property of the skin is its pigmentation. Evenly scattered deep in the epidermis are the melanocytes, cells that produce the dark pigment melanin. Spider-shaped, with long tentacle-like processes, these cells inject granules of melanin into the surrounding epidermal cells, where the pigment forms a protective awning over each cell nucleus on the side toward the skin surface. The prime function of the pigment is to shield the cells by absorbing the ultraviolet rays of the sun. All human beings, regardless of race, have about the same number of melanocytes; the darker races are distinguished from the lighter ones only by the fact that their melanocytes manufacture more pigment. This protective capacity has evolved in the tropical peoples of the world as an asset with high survival value.

Dense webs of blood vessels course through the skin all over the body. They transport through the skin a great deal more blood than is needed to nourish the skin itself; this immense circulation performs two important functions for the entire body. First, it acts as a cooling system. The skin's sweat glands pour water onto the skin's surface, and the evaporation of the water cools the blood circulating through the skin. When the outside environment is warm or the body is engaged in strenuous exercise, the blood vessels assist the cooling process by relaxing and allowing a maximum flow of blood through the skin, which accounts for the flushed appearance of the skin at such times. On the other hand, when the environment is cold, the vessels contract rapidly and greatly reduce the blood flow in the skin, thus conserving the internal body heat.

Second, the skin's circulation serves to help regulate the blood pressure. The blood vessels in the skin have sphincter-like passages that can shut off the flow through the capillaries and thereby cause the blood to bypass them so that it flows directly from the small arteries into the veins. This mechanism for speeding the flow acts like a safety valve when the blood pressure rises to a dangerous level.

The skin's extraordinary network of blood vessels is matched by an equally massive network of nerves. Much of this nervous system is concerned with controlling the glands, blood vessels and other organs in the skin. There is also a vast complex of sensory nerve endings. These are particularly prominent in the most naked surfaces of the body: the fingers, palms, soles, lips and even the cornea of the eye, which has no blood vessels. These specialized nerves are sensitive to tactile and thermal stimuli. Without them the human body would be almost as out of touch with the outside world as it would be if it lacked the major sense organs.

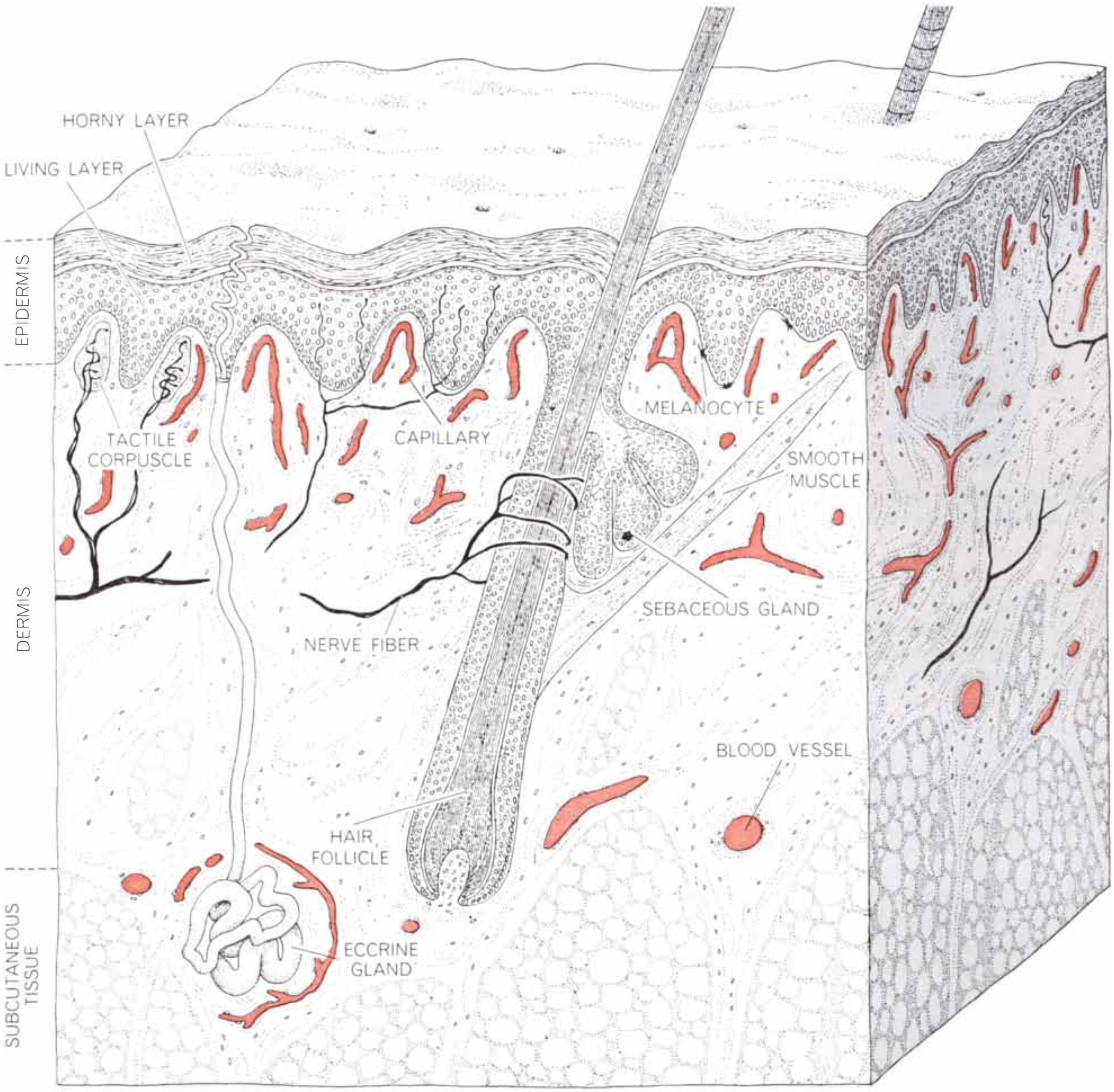
The Hair

Hairs are products of the skin that man shares with all the rest of the mammalian order. In many ways hair is a paradoxical growth. For other mammals it serves a wide variety of useful functions, but man is able to dispense with most of them. In fact, in man hair has become largely an ornamental appendage; it seems to survive mainly as a means of sexual attraction.

The most obvious function of a heavy coat of hair for mammals in the natural state is protective insulation against the weather and other hazards of the environment. This is as true in a warm climate as in a cold one: the fur-covered animals of the Tropics are insulated by their hair against the strong sun and heat. Hair, however, is only one of the devices that have evolved among mammals for this purpose. The whale, a completely naked mammal, is adapted to living in polar waters by a thick layer of insulating blubber, capped by a heavy skin with a thick, horny layer. Man's nakedness and his thin skin plainly indicate that he originated in a tropical or temperate environment. His spread into the colder regions of the earth was made possible only by his development of artificial clothing and shelter.

A few special protective functions of hair remain important to the human body. The hairs inside the nostrils slow incoming air currents, trap dust particles, keep out insects and prevent the nasal mucus from pouring down over the lips. The hairs in the outer ear and around the anogenital orifices act as barriers against the entry of foreign matter and small invaders such as insects. The bushy eyebrows and the eyelashes help to shield the vulnerable eyeballs.

Man also retains some use of the sensory function of hair. Most hair follicles in a mammal's skin have a collar of sensory nerves around them, and the animal therefore senses any slight movement of the hair due to contact with an object. The nerve supply is par-



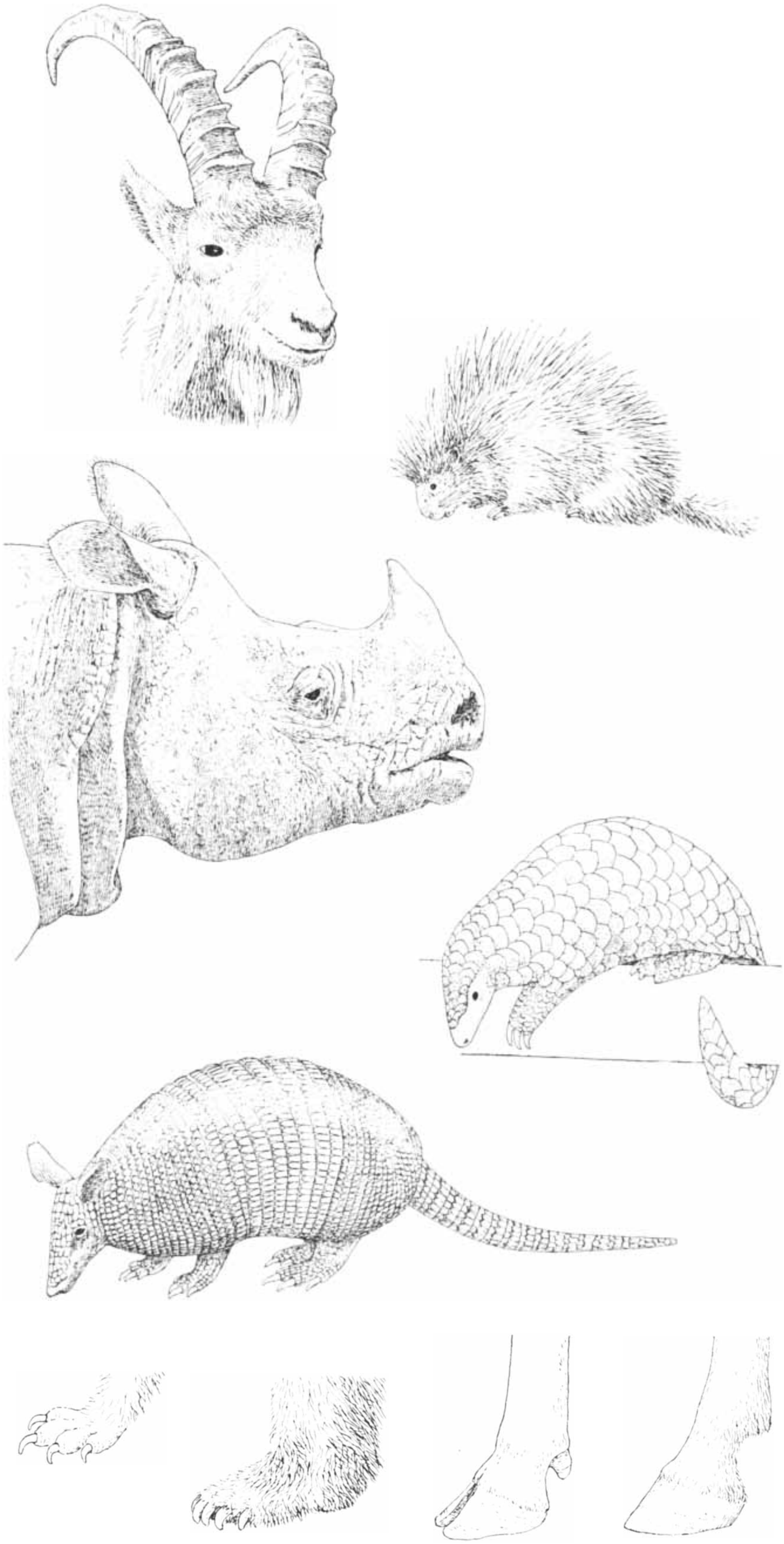
ZONES OF THE SKIN are displayed in an idealized section. The underlying dermis, the thickest part of the organ, is supported by a fat-rich subcutaneous stratum. Intermingled with the cells of the dermis are fine blood vessels (*color*), tactile and other nerves, the smooth muscles that raise the hair when contracted, and a variety of specialized glands. Above the dermis are the twin levels of the epidermis: a lower zone of living cells capped by a horny layer of dead cells filled with the fibrous protein keratin. Melanocytes, the pigment organs that produce the granules responsible for varying skin colors, lie at the base of the epidermis.

ticularly rich around hair follicles in certain sensitive regions of the body, among them the face, the anogenital areas and certain special areas that are important to a given animal's activities. A squirrel, for instance, is sensitized in this way on the surface of the abdomen, so that it feels its way with its abdominal hairs as it runs along the bark of a tree. Lemurs, which use their hands to move about in trees, have patches of sensory hairs on the inner surface of their wrists. Nearly all mammals have long, sensitive vibrissae, or whiskers, around the muzzle; these hairs communicate their motion directly to nerves and indirectly through pressure on blood-filled sacs around the follicles. The whiskers are particularly well developed in nocturnal animals, and they attain large size in seals and walruses. Man, although he lacks the blood-filled sacs around the follicles, possesses nerve endings around many of his hair follicles, particularly those that surround the mouth.

Obviously, aside from a few special functions such as the screening of external passages, hair is not really essential to man. It is not so easy to see, however, what positive advantages may have been responsible for his evolution toward nakedness, as compared with other primates. It has been suggested that lack of a heavy fur may have had some adaptive value for running and hunting in the open savannas, but this is conjectural. At all events, there is no doubt that, although man still has as many hair follicles as his primate cousins, his hair growth is gradually declining, and one of the most obvious indications of this is the increasing prevalence of baldness.

Hair Growth

The follicle that produces a hair is a tube that extends all the way through the skin and widens into a bulb—the hair root—at its deep end. When the hair has attained its characteristic length, it stops growing (except on the scalp, where the hair may grow very long if it is not cut). Having reached its limit, the hair forms a clublike base and puts out rootlets that anchor it to the surrounding follicle. The follicle shrinks and goes into a resting period. After a time it forms the germ of a new hair, which then works its way toward the surface, loosening the old hair and causing it to be shed. Thus hair growth is a matter of alternate growing and resting periods, with new hairs arising period-



THE VERSATILE SKIN gives rise to a wide variety of superficial structures; among the mammals these include, from top to bottom, the bold horns of the ibex, the quills of the porcupine, the hairy "horn" of the rhinoceros, the scales of the pangolin and the armadillo, and various claws and hooves. Like all of these, man's hair and nails are special skin structures.

INDIVIDUALITY OF FINGERPRINTS is one of the best-known characteristics of the skin. These thumbprints can be readily told apart, although they are those of identical twins. The same individual quality exists on any skin surface, but the strong pattern of ridges and grooves found on the ventral surfaces of hands and feet are the most easily identified.

GENETIC BASIS of skin patterns is shown by the existence of similar patterns among unrelated individuals with similar chromosomal abnormalities. None of the patterns outlined (*color*) on this palm print of a mongoloid imbecile is abnormal, yet the simultaneous presence of these configurations is a very rare event among normal people. These patterns are ulnar loops on the digits (*a*), the simian crease (*b*) and an off-center axial triradius (*c*). The palm print was made by Irene A. Uchida of the Children's Hospital in Winnipeg, Canada.

ically to displace the old. In many animals this is a seasonal process; the animal sheds nearly all its hair at one time, starting a completely new crop.

The pelt of such an animal makes a good fur piece only if it is taken during the resting period, when the clubbed hairs are firmly attached to the follicles and will remain so after the skin is tanned. In man and some other mammals the pattern of growth and shedding is different: in any given area there are always some follicles growing and some resting, so that normally there is no wholesale shedding and the total hair growth remains constant in all seasons of the year.

Human hair grows at the rate of about a third of a millimeter per day. The follicle is at an angle to the skin surface, hence the emerging hair lies over on the skin except when certain muscle fibers attached to the follicle pull on it and cause the hair to stand erect. The same muscle action also forms the mounds known as goose pimples. Thus proverbial references to goose pimples and hair standing on end in moments of fright have a real basis; it will happen when the hormones released by the emotion activate the muscles of the hair follicles.

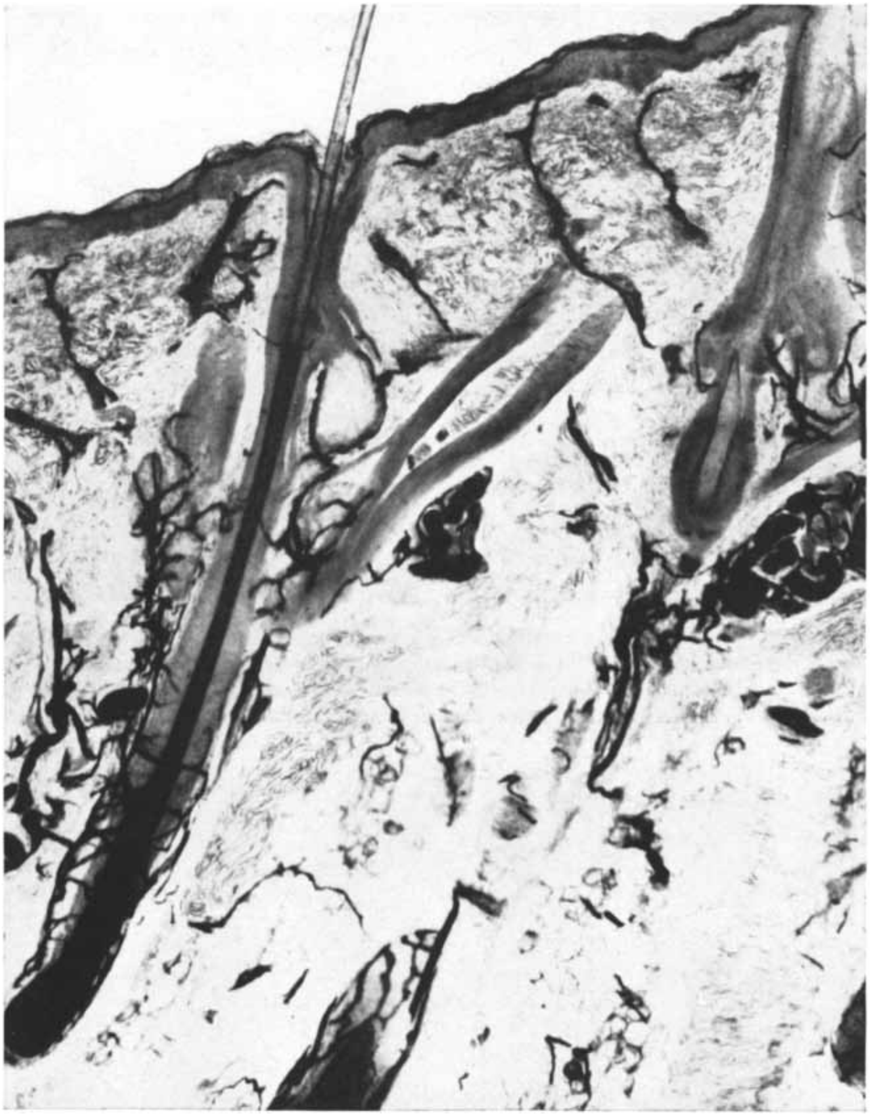
The individual hairs of man may be round (which causes the hair to be straight), alternately round and oval (which makes the hair wavy) or ribbon-shaped (which makes it kinky). The color of the hair depends on the amount and distribution of melanin in it and on the hair's surface structure, which affects the reflection of light. A study of how hair grows helps to explain some of the superstitions about it. One of these is the notion that a traumatic experience may turn the hair gray or white overnight. The idea is incorrect, but it has this much basis: a shock may cause some shedding of fine, normally pigmented hairs, thereby exposing to greater prominence the coarser graying hairs, which were already present and are more resistant to stress.

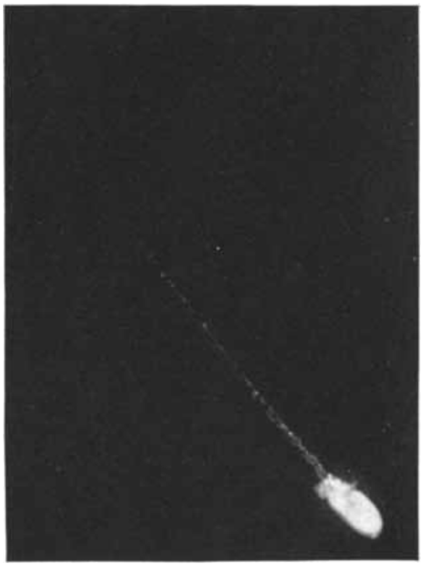
Another common misconception is the one that shaving causes the hair to grow increasingly coarse. It is true that the stubble after shaving feels rough, but the reason is simply that the soft, tapered ends of the hairs have been cut off; the new hairs that will succeed them later will still have soft, tapered ends. Then there are the startling stories about corpses that have been observed to grow a beard in the days after death. This phenomenon too has a simple explanation: after the skin of a dead person dries and shrinks it may expose a millimeter or two of hair that was below the surface before death.

From the evolutionary point of view the most interesting aspect of man's hair is the baldness that develops on the top of his head. This baldness is actually an extension of a natural process that occurs in all human beings and begins before birth. In the young fetus the entire head is covered with hairs—the forehead as well as the scalp. After the fifth month the hair follicles on the forehead gradually become involuted and diminish in size. At birth the infant often still has some visible hair on its brow, but the forehead continues to become increasingly naked, and by late childhood it establishes a high, well-defined hairline. (There are, however, freakish cases in which an individual retains a bushy growth of hair on his forehead like that on his scalp.) The same balding process that occurs on the forehead also takes place elsewhere on the body; babies are often visibly hairier at birth than they are later. Thus man's nakedness is the result of a progressive involution of his hair follicles. Although he has as many follicles as other primates, most of them are so small that the hairs they produce are not visible on the surface.

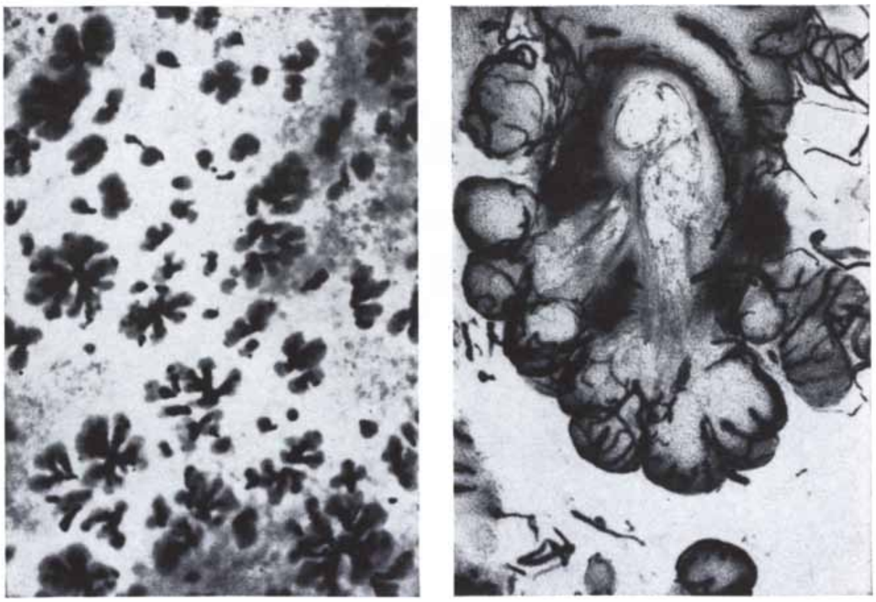
Exactly the same process of involution of follicles is responsible for balding of the scalp, which may begin in young men as early as the twenties. It is curious that this dramatic loss of hair should take place on the scalp, which, unlike other parts of the body, will normally grow hair to almost unlimited length (as much as 12 feet) if the hair is not cut. The explanation lies in the action of androgenic (male) hormones, which paradoxically are responsible not only for the growth of all hair but also, under certain circumstances, for the reduction of the scalp hair. Eunuchs, having a deficiency of androgenic hormones, rarely become bald on top—a fact that was noted by Aristotle, who himself was bald. I should emphasize at this point that once involution of the scalp follicles has taken place no agency will avail to grow a new crop of hair.

Significantly, man is not the only primate that develops baldness. The stump-tailed macaque and the orangutan become virtually bald on the forehead when they mature. The ouakari monkey of South America, starting with a full head of hair in its youth, loses all the hair on its scalp and forehead by the time it reaches adulthood. We hope to learn a great deal about baldness by studying these animals. Whether

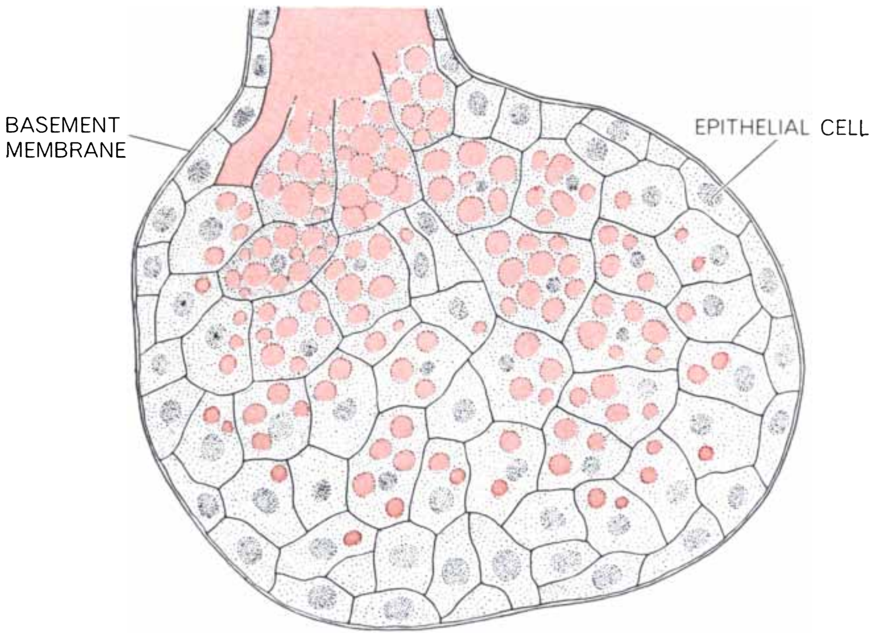




HAIR GROWTH alternates between active and dormant phases. The human hair at the left in the upper photograph is growing; the follicle that produces it is surrounded by many blood vessels. In contrast, the hair at the right is not growing; its follicle is quiescent and shriveled and the base of the hair is clubbed. The lower pair of photographs contrasts an active hair (*left*) with a dormant one (*right*). Each hair has been plucked from its follicle.



SEBACEOUS GLANDS are not always associated with hair follicles; these photographs show the numerous nests of these glands situated on the inside of the human cheek (*left*) and the abundance of fine blood vessels surrounding one such cheek gland (*right*). Wherever located, the cells of these glands synthesize and accumulate globules of fat (*see below*).



PRODUCTION OF SEBUM, a mixture of fatty acids, triglycerides, waxes and cholesterol, occurs as the sebaceous gland cells become choked with accumulated fat globules (*color*), die and disintegrate. As the sebum accumulates in the gland's duct, capillary traction and the pressure from skin movements bring the semiliquid material to the surface of the skin.

we like it or not, it seems clear that in the long run we shall have to accept the fact that man is becoming increasingly bald and must reconcile himself to the ornamental value of nakedness.

Most of the members of the animal kingdom possess skin glands of one sort or another, which produce a remarkable variety of secretions. Fishes and amphibians secrete slime; toads produce poisons that make them unpalatable to most predators; the duckbill platypus secretes toxic substances from rosettes of glands on its hind legs; most birds have a pair of preen glands over the tail (in chickens and turkeys vulgarly known as "the pope's nose") that secretes a preening ointment that contains precursors of vitamin D. The many varieties of mammalian skin secretions, some odorless and some extraordinarily malodorous, some fatty and some watery, some colorless and some strikingly pigmented, perform a wide range of functions, prominent among which is sexual attraction. The skin of man has two main kinds of secretory gland: the sebaceous glands and the sweat glands.

The former produce an odd material called sebum, which is a semiliquid mixture of fatty acids, triglycerides, waxes, cholesterol and cellular debris. The production of sebum is somewhat like the production of the horny layer by the epidermis. The cells of the sebaceous glands synthesize globules of fat, gradually become bloated with the accumulation of these globules and eventually break up. This mélange of dead and decaying cell fragments is the sebum.

Investigators who have studied sebum are at a loss to imagine what useful purpose it may serve. The secretion does not emulsify readily, it is toxic to living tissues, produces skin blemishes and in general seems to do more harm than good. The sebaceous glands themselves offer no clear clues, only a confusion of inconsistencies. Most of them are attached to hair follicles and deposit their sebum on the hairs inside the follicles, but in some areas of the skin the glands are not connected with follicles; there the sebum oozes out on the skin through ducts. The glands are particularly prominent around the nose and mouth, on the inside of the cheeks, on the hairless border of the upper lip, on the forehead, over the cheekbones, on the inside edge of the eyelids (where they are so large that one can easily see them with the naked eye by turning up a lid before a mirror), on parts of the neck and upper torso and on the genital organs. All this suggests that the sebum may play useful roles, although it is hard to see what they are. It does not seem likely that sebum is only a lubricant.

The human body often appears to contain senseless appendages and even to make outright mistakes, but the sebaceous glands are too numerous and active to be dismissed as trivial. Nor do they seem to be mere survivals from earlier stages of evolution in which they were more important to the body; man has a greater number of and more active sebaceous glands than most other mammals and has them in places where they do not appear in other animals.

In spite of a considerable amount of research, very little has been learned about the cause or treatment of acne, for which the sebaceous glands are in some way responsible. Why do these lesions occur particularly in young adolescents? Why do they break out on the face, neck and upper torso but not on the scalp or the anogenital areas, where the sebaceous glands are also large and numerous? The only facts about acne that seem definitely established are that there is a hereditary disposition to it and that it is connected in some way with diet and with the activity of the androgenic hormones. These hormones have a great deal to do with the development and functioning of the sebaceous glands. The glands are large in a newborn infant, become dormant during childhood, begin to enlarge again in early puberty and grow to full bloom in adults. They show a definite relation to the level of androgenic hormones in the individual. The glands are larger and more active in men than in women; they are only poorly developed in eunuchs, and they increase in size and number when a eunuch is treated with androgens.

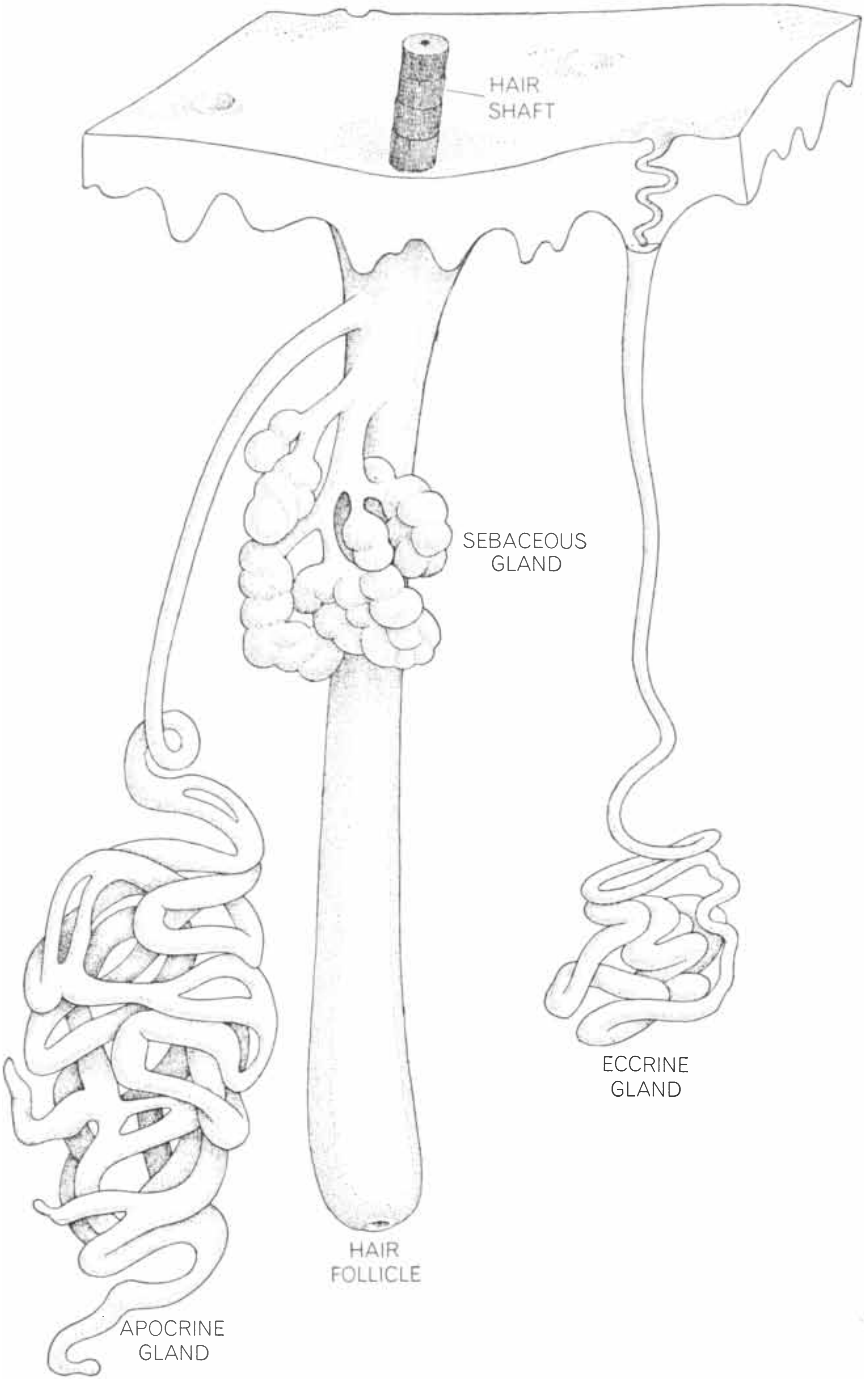
The Two Kinds of Sweat Gland

In the usage of physiologists the term "sweat glands" lumps together many different organs, most of which have nothing to do with sweating. Some produce scent or musk, others mucoid substances, still others colored secretions. What all the so-called sweat glands have in common is that they are tubular in form and are found only among the mammals.

The glands that actually produce sweat are of two general kinds: the apocrine glands, which are usually associated with hair follicles, and the eccrine glands, which are not. The two types have different origins, structures and functions. Because the eccrine glands predominate in the more advanced primates, some evolutionists have supposed that this type evolved more recently and that the apocrine type is more primitive; actually one of the most primitive of all mammals, the duckbill platypus, has well-developed eccrine glands, and man not only is richer in eccrine glands than any other primate but also has more and better-developed apocrine glands in certain parts of his body. It is not possible to say definitely that either type is more ancient or more primitive than the other.

The apocrine glands secrete the odorous component of sweat. They are primarily scent glands, and they produce their secretions in response to stress or sexual stimulation. Before the deodorant and perfume industries usurped their function of creating a person's body odor, the apocrine glands no doubt played an important role in human society. Aside from their odor-generating property, these glands are quite unnecessary to man. There are clear signs that man's apocrine glands, like his hair, are much less luxuriant than they were in his ancestors.

A human fetus in its fifth month produces rudiments of apocrine sweat glands over almost its entire body. Within a few weeks, however, most of these rudiments disappear, and the human body eventually has well-developed apocrine glands only in the armpits, the navel, the anogenital areas, the nipples and the ears. This seems to be a clear case of ontogeny mirroring phylogeny—the fetus recapitulating



SWEAT GLANDS comprise two major categories: apocrine glands, which secrete a milky, odorous fluid (*left*), and eccrine glands, which secrete water (*right*). The former, together with the sebaceous glands, produce the body's odors; the latter help to regulate body heat.

man's evolutionary history. Oddly, although man no longer has apocrine glands all over his body, in his armpits these glands are larger and more numerous than in all other animals. Man is distinguished from all other mammals by a highly developed axillary organ in his armpits, made up of very large apocrine glands with eccrine glands interspersed among them.

The apocrine secretion is a milky, sticky fluid of varying color—pale gray, whitish, yellow or reddish. Although the glands are large, the amount of their secretion is very small; most of the fluid in the copious sweat of the armpits is supplied by the eccrine glands, which provide the vehicle for the spread of the odorous apocrine substances. The freshly secreted apocrine sweat is actually rather odorless, but it becomes malodorous when its substances are decomposed by the action of bacteria on the skin's surface.

The eccrine glands, the source of most of man's sweat, secrete water, which has two main functions: (1) cooling the body by evaporation and (2) moistening the friction surfaces, such as those of the palms and the soles, which prevents flaking of the horny layer, improves the grip and assists the tactile sensitivity. The glands responsible for the two functions show clear-cut differences, both in their response to stimuli and in their embryonic development. Eccrine glands of the first category produce sweat in response to heat; those in the second category, sweat in response to psychic stimuli. As for development, the eccrine glands on the palms and soles appear in the fetus at the age of three and a half months, whereas those in the rest of the body do not develop until the fifth month and are the last structures to form. This suggests that the secretions for gripping arrived early in evolution and the cooling secretions may be a recent development.

Cats, dogs and rodents have eccrine glands only in the pads of their paws. Some South American monkeys have a hairless surface on the lower side of the prehensile tail, and this surface is copiously supplied with eccrine glands. So are the knuckles of the gorilla's and the chimpanzee's hands, which they use in walking. In the monkeys and the apes the hairy skin of the body also has a considerable sprinkling of eccrine glands, but it is significant that these are not nearly so active as man's. The skin of a monkey remains dry even on the hottest days. Obviously profuse sweating would be a liability to a furry animal: if its hair were soaked with sweat, the animal would continually be wrapped in a wet and chilling blanket.

For naked man, on the other hand, the array of active sweat glands all over the body skin is a highly useful adaptation. It endows him with an essential cooling system that compensates for his lack of an insulating pelage. Man has millions of eccrine glands on his body, the number varying with individuals and ranging from two million to five million, or an average of about 150 to 340 per square centimeter of skin surface. Some of the individual differences may depend on differences in body size. Some people sweat much more profusely than others, but this is not strictly related to the individual's total number of sweat glands; the difference lies, rather, in the relative activity of the glands.

The human sweating response has been investigated by means of such experiments as the administration of drugs, spices and other treatments. The results are not very enlightening. Sweating can be evoked by different drugs of apparently opposite chemical properties; individuals often respond differently to a given drug; the drug may produce inconsistent responses even in the same individual. Moreover, sweating is an enigma that amounts to a major biological blunder: it depletes the body not only of water but also of sodium and other essential electrolytes that are carried off with the water.

Perhaps the eccrine glands are still an experiment of nature—demonstrably useful to man but not yet fully refined by the evolutionary process. In view of its indispensability to the human body, sweating is likely to survive, in spite of the determined efforts of antiperspirant technologists.

To sum up, the outstanding features of man's skin are its nakedness and its ability to sweat profusely. His hair is largely ornamental, the only luxuriant growths of his body having no practical value for protecting him from the environment. One of the important mechanisms man has developed as an adaptation to his increasing nakedness is the body-temperature control system regulated by the eccrine sweat glands, which adjust their output of cooling water both to changes in the outside temperature and to the internal heat generated in the body by exercise. All in all, the seemingly delicate skin of man is a remarkably complex and adaptable organ, serving not only as armor against the outside world but also as an important contributor to the body's internal husbandry.

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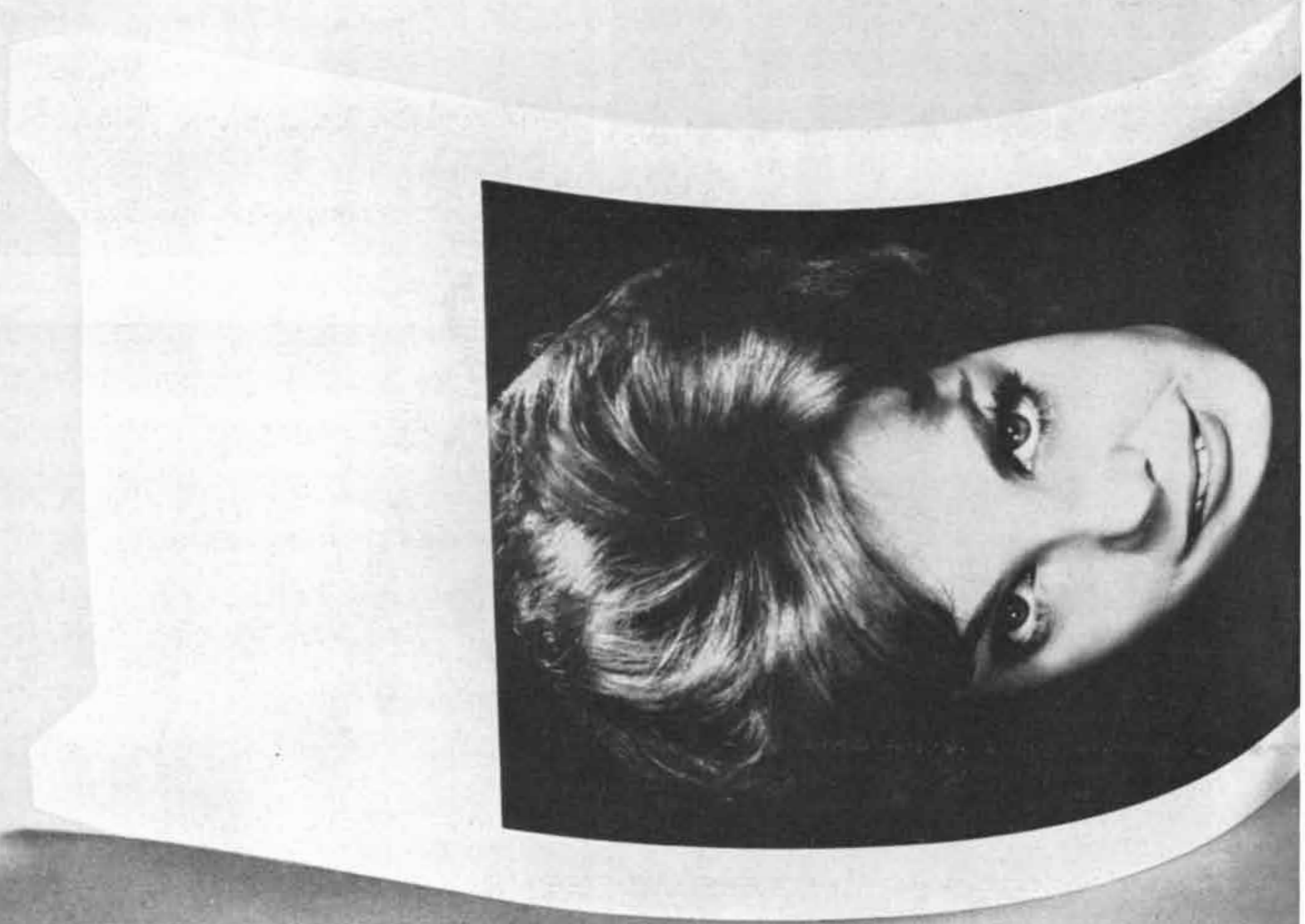

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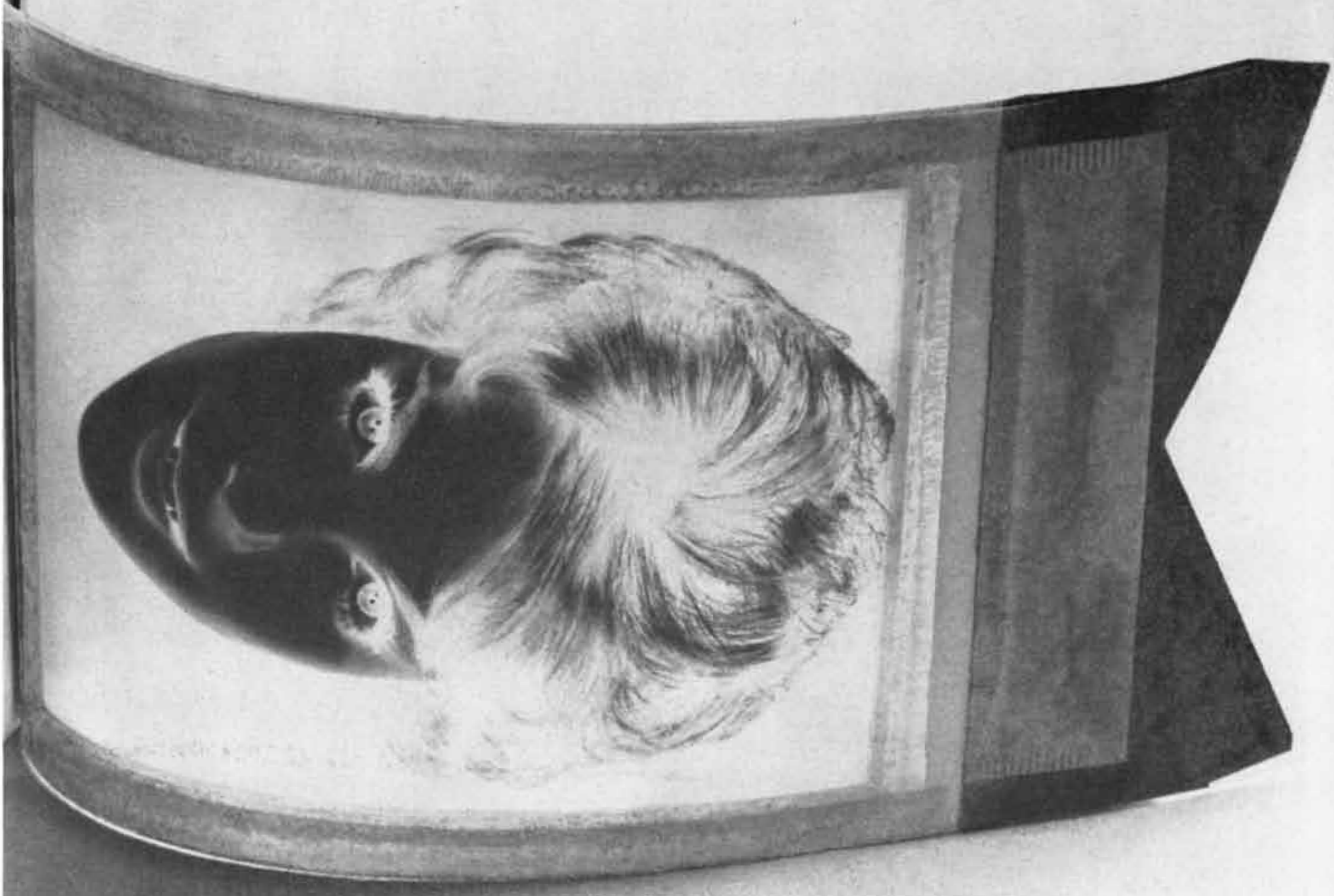

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ROLE OF INDIVIDUAL GENES of the T4 bacterial virus was investigated by the authors. This electron micrograph made by E. Boy de la Tour of the University of Geneva shows a complete virus particle with its hexagonal head and springlike tail assembly (*upper center*) and a number of "polyheads": cylindrical tubes of hexagonally arranged protein subunits that were not assembled into virus heads. The failure in assembly is due to a mutation in gene No. 20. The enlargement is about 270,000 diameters.

The Genetics of a Bacterial Virus

The T4 virus is a simple form of life with a precise architecture dictated by genes in its DNA molecule. By mapping the genes and learning their function one learns how the virus is put together

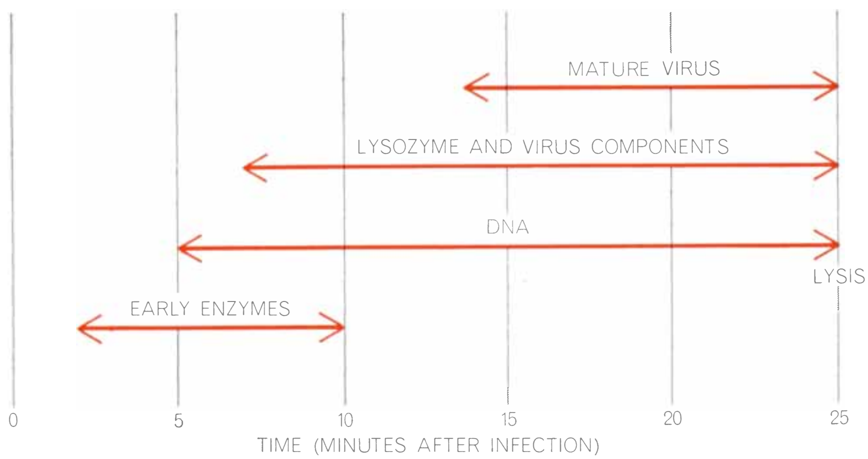
by R. S. Edgar and R. H. Epstein

Viruses, the simplest living things known to man, have two fundamental attributes in common with higher forms of life: a definite architecture and the ability to replicate that architecture according to the genetic instructions encoded in molecules of nucleic acid. Yet in viruses life is trimmed to its bare essentials. A virus particle consists of one large molecule of nucleic acid wrapped in a protective coat of protein. The virus particle can do nothing for itself; it is able to reproduce only by parasitizing, or infecting, a living host cell that can supply the machinery and materials for translating the viral genetic message into the substance and structure of new virus particles. Since a virus is an isolated packet of genetic information unencumbered by the complex supporting systems characteristic of living cells, it is a peculiarly suitable subject for genetic investigation. One can study the molecular basis of life by identifying the individual genes in viral nucleic acid and learning what part each plays in the formation of virus progeny. That is what we have been doing for the past four years, working with the T4 bacteriophage, a virus that infects the colon bacterium *Escherichia coli.*

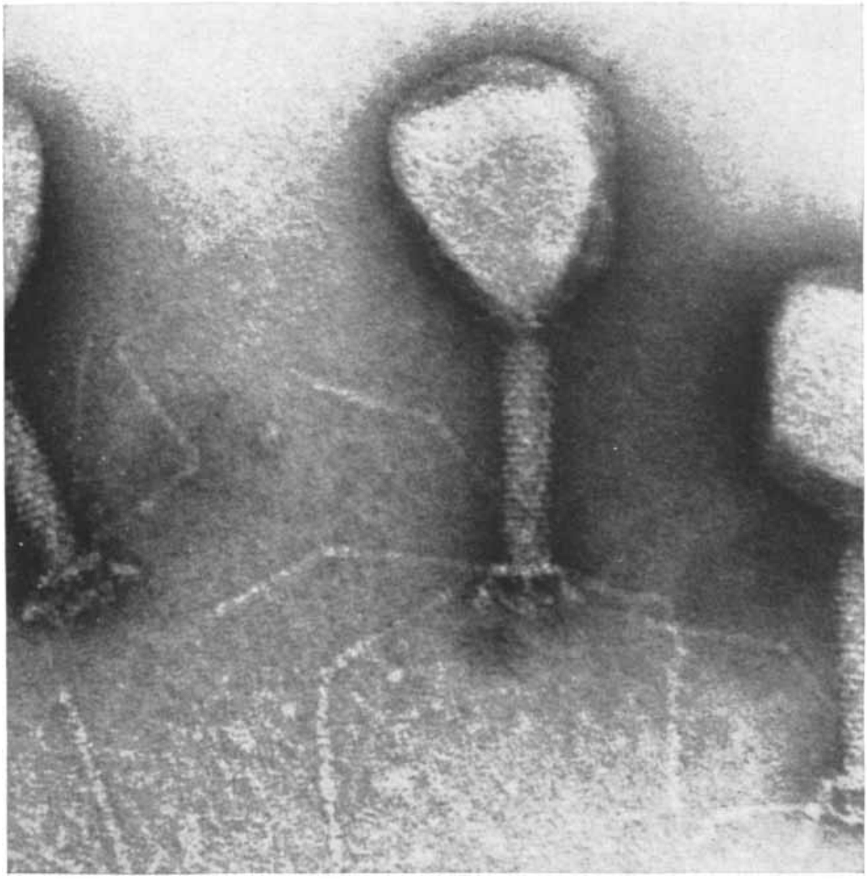
The T4 virus is one of the most complex viral structures. About .0002 millimeter long, the T4 particle consists of a head in the shape of a bipyramidal hexagonal prism and a tail assembly with several components. The head is a protein membrane stuffed with a long, tightly coiled molecule of deoxyribonucleic acid (DNA). The protein tail plays a role in attaching the virus to the host bacterial cell and injecting the viral DNA through the cell wall. Six tail fibers resembling tentacles bring the virus to the surface of the cell; a flat end plate fitted with prongs anchors the virus there as the muscle-like sheath of the tail contracts to extrude the viral DNA through a hollow core into the cell.

Within a few minutes after the DNA enters the bacterium the metabolism of the infected bacterial cell undergoes a profound change. The cell's own DNA is degraded and its normal business —the synthesis of bacterial protein— ceases; synthetic activity has come under the control of the viral DNA, which takes over the synthesizing apparatus of the cell to direct the synthesis of new types of protein required for the production of new virus particles. The first proteins to appear include enzymes needed for the replication of the viral DNA, which has components not present in bacterial DNA and for the synthesis of which there are therefore no bacterial enzymes. Once these "early enzymes" are available the replication of viral DNA begins. Soon thereafter a new class of proteins appears in the cell: the proteins that will be required for the head membrane and tail parts. About 15 minutes after the viral DNA was first injected new viral DNA begins to condense in the form of heads; protein components assemble around these condensates and soon whole virus particles are completed. For perhaps 10 minutes the synthesis and assembly of DNA and protein components continue and mature virus particles accumulate. The lysis, or dissolution, of the infected cell brings this process to an abrupt halt. Some 200 new virus particles are liberated to find new host cells to infect and so repeat the cycle of reproduction.

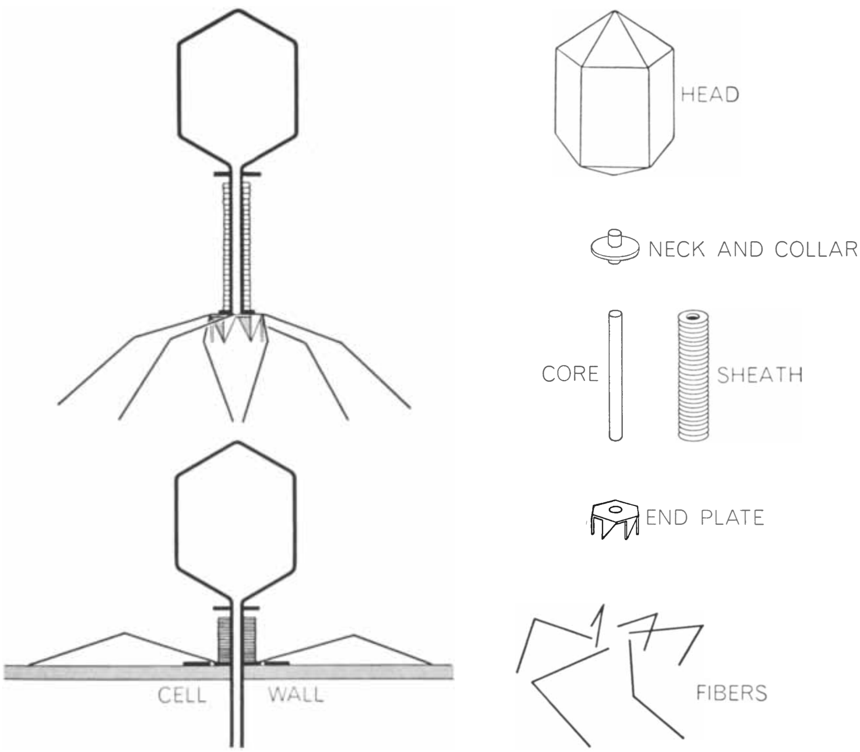
The remarkable sequence of synthesis, assembly and lysis is directed by the message borne by the genes of the viral DNA. Each gene is a segment of the DNA molecule, a twisted molecular ladder in which the rungs are pairs of nitrogenous bases: either adenine paired with thymine or guanine paired with cytosine. (In T4 DNA the cytosine is hydroxymethyl cytosine.) The sequence of base pairs in the DNA molecule, like



VIRUS INFECTION of a colon bacterium (at 37 degrees centigrade) proceeds on schedule, with the sequence of syntheses leading up to the lysis, or dissolution, of the host cell.



T4 BACTERIOPHAGE is enlarged about 300,000 diameters in an electron micrograph made by Michael Moody of the California Institute of Technology. The preparation was negatively stained with electron-dense uranyl acetate, which makes the background dark.



T4 COMPONENTS are diagrammed. A complete virus particle is shown at top left. Below it is a particle attached to a bacterial cell wall, with its sheath contracted and its hollow core penetrating the cell wall. The various components are shown separately at the right.

the sequence of letters in a word, spells out the information for the assembly of amino acids into protein molecules; a gene is defined as a segment of DNA sufficient to encode a single protein molecule. Since the average protein molecule consists of about 200 amino acid units and the code of DNA requires three base pairs per amino acid, the average length of a gene should be about 600 base pairs. Since there are about 200,000 base pairs in a molecule of T4 DNA, we began by assuming that the molecule contains several hundred genes and initiates the production of several hundred proteins in the host cell. Our task was first to map the location in the T4 DNA molecule of as many genes as possible and then to associate these genes with specific functions.

In order to identify a gene, map its location and learn its function one must find a gene that has undergone mutation: a molecular mistake that occurs like a typographical error in the sequence of base pairs and results either in genetic nonsense, meaning the inability to form protein, or in "missense," meaning the formation of faulty protein. Once a mutation occurs it is copied in successive replications of the DNA and reveals itself by its malfunction in protein synthesis. A mutation therefore serves as a marker for a gene. Moreover, by comparing the growth of a mutant strain of an organism with the growth of a "wild type," or normal, strain one can often infer the normal function of the gene under examination.

The trouble is that most mutations important enough to be recognized and studied are lethal; that is, they result in offspring that cannot survive, or at least cannot reproduce. How, then, can one study lethal mutations? In advanced plants and animals there are two copies of every gene, and it is possible to study "recessive" mutations that are lethal only when they happen to occur in both copies. Less advanced forms of life such as molds, bacteria and viruses, however, have only one copy of each gene, so some other method of studying lethal mutations must be found.

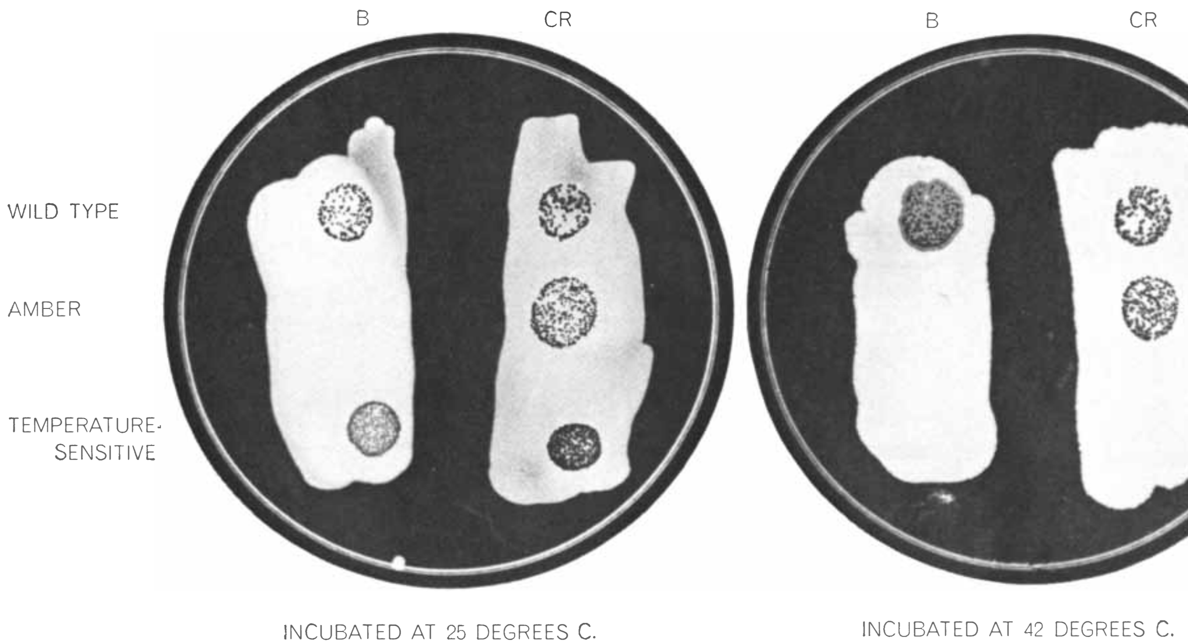
One such method was developed by George W. Beadle and Edward L. Tatum for the study of mutations in the genes of molds and bacteria. The genes that can be investigated by this method are those that direct the synthesis of enzymes required for the formation of nutrients, such as amino acids and vitamins, that are essential to the mold or bacterial cell. In these cases a mutation, although inherently lethal, will not prevent cell growth if the missing nutrient is supplied by the experimenter: it is a "conditional" lethal mutation. Such mutations are restricted to genes whose function can be supplanted by the experimenter. Our aim is to study mutations that affect the synthesis and assembly of virus components, and we had no way of supplying proteins or pieces of virus to infected cells. We needed other kinds of conditional lethal mutations.

One of us (Edgar), working at the California Institute of Technology, has dealt primarily with a class of mutations that are temperature-sensitive: they render the gene inactive at one temperature but not at temperatures a few degrees lower. An example of such a gene in a higher animal is the gene that controls the hair pigment in Siamese cats. The gene is inactive at body temperature, with the result that most of the cat's coat is white. On the cooler parts of the body—the paws, the tip of the tail, the nose and the ears—the gene becomes functional and the hair is pigmented. Of course, this defect is not lethal to the cat, but similar mutations in genes with functions essential to an organism are conditional lethal mutations if one can control the temperature. A strain of T4 bacteriophage with a temperature-sensitive lethal mutation, for example, grows perfectly well if it is incubated on bacteria at 25 degrees centigrade but not if it is incubated at 42 degrees. Temperature-sensitive mutations can occur in many different genes, since what they do is simply render a protein—regardless of its particular function—more readily inactivated by heat. They apparently do so by substituting one amino acid for another at some sensitive point in the structure of the protein molecule; in other words, they are "missense" mutations.

Epstein has worked with another class of conditional lethal mutations: the "amber" mutations, which he developed at Cal Tech and has studied primarily in the laboratory of Edouard Kellenberger at the University of Geneva. (We call them the amber mutations because they were discovered with the help of a graduate student named Bernstein, and *bernstein* is the German word for "amber"; it is often safer to give a new discovery a silly name than a speculatively descriptive one!) In these mutations the conditional property is not temperature-sensitivity but the ability of a virus to grow in certain host cells. Whereas the wild-type T4 virus grows equally well in colon bacteria of strains *B* and *CR*, amber mutants grow only in *CR*. Apparently only *CR* bacteria are able to translate the mutant message into protein properly; in strain *B* the mutant gene is translated into protein only up to the point of mutation and the resulting protein fragment is inactive. In other words, amber mutations are translated as "nonsense" in strain *B* but as "sense," or at worst as "missense," in strain *CR*. Again we could expect the amber mutations to occur in many different genes, since these mutations affect the overall translatability of any affected gene rather than the ability of specific genes to direct the synthesis of specific proteins.

Mutations arise at random in the normal course of virus infection and reproduction; we amplify the process by treating virus particles with one of a variety of chemical mutagens. We then plate the virus on cultures of colon bacteria. Any amber or temperature-sensitive mutant reveals itself by its failure to grow under "restrictive" conditions, that is, on strain *B* in the case of an amber mutation or at 42 degrees in the case of a temperature-sensitive mutation. In this manner we have isolated more than 1,000 amber and temperature-sensitive mutant strains. The mutations, however, occur at random at various sites in the many genes of the viral DNA. Since we are trying to identify genes, not merely mutations, we need to determine which mutant strains contain mutations affecting the same gene.

We do this by performing complementation tests [*see illustration on next two pages*]. The test consists in infecting bacteria simultaneously with two mutant viruses under restrictive conditions in which each mutant alone would be unable to grow in the bacterial cells.

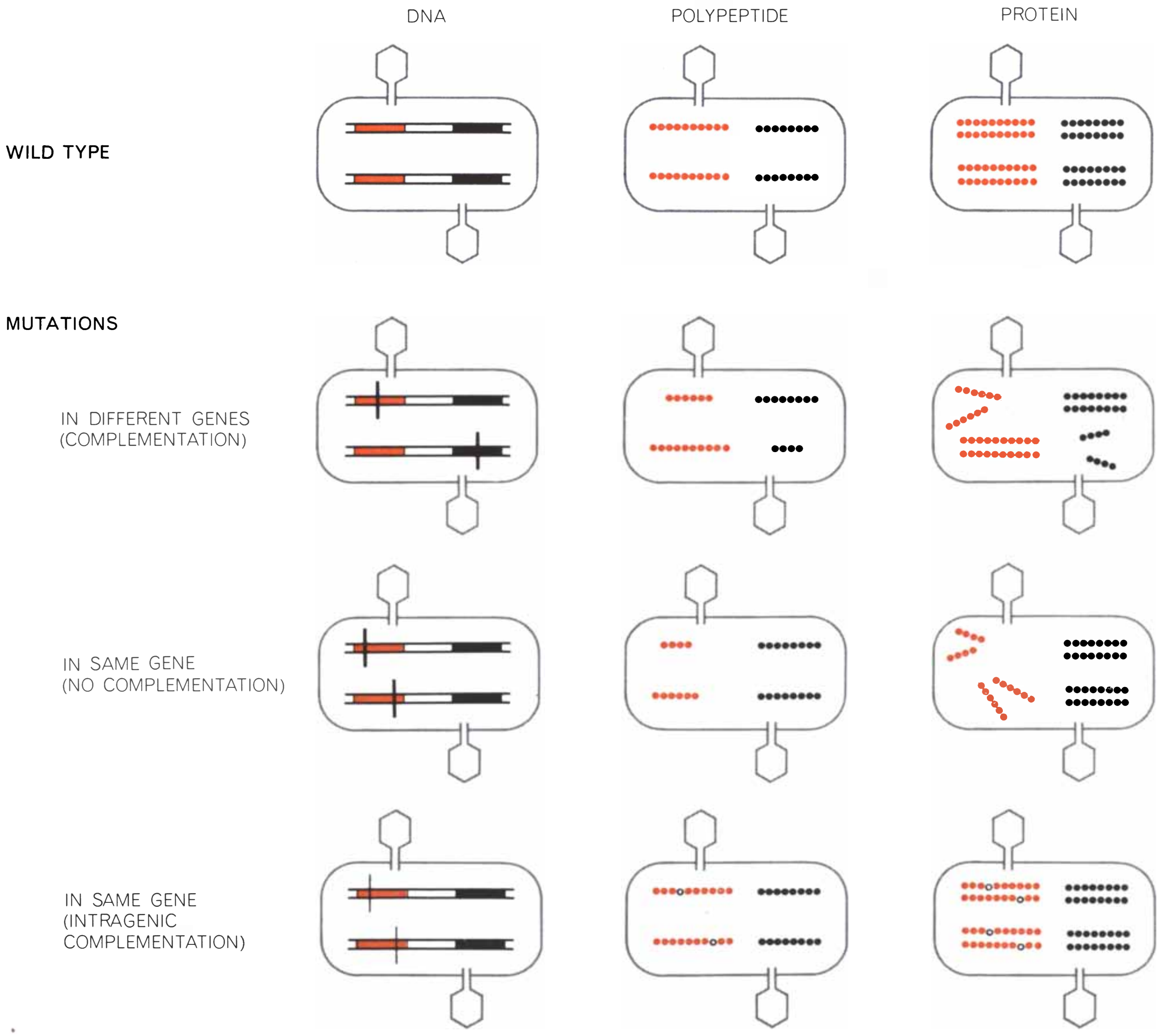


GROWTH CHARACTERISTICS of "wild type" virus and "amber" and temperature-sensitive mutants are compared. The photographic prints were made by exposing actual Petri dishes in an enlarger. On each dish bacterial strains *B* and *CR* had been streaked, with drops of virus suspensions placed on each streak, and the plates had been incubated at two temperatures, as shown. The amber mutants grew only on strain *CR*, the temperature-sensitive mutants grew only at 25 degrees C. and the wild-type virus grew under all conditions.

Infection of strain *B* bacteria at high temperature is restrictive for both amber and temperature-sensitive mutants. If, under these restrictive conditions, a yield of progeny virus is produced from cells infected by two mutants, the mutations must be complementary defects. Each mutant can perform the function the other mutant is unable to perform, and we can conclude that the two mutations are in different genes. If, on the other hand, the doubly infected bacteria produce no progeny virus, the two mutant strains must be unable to complement each other. Their mutations must affect a common function, and we conclude that they are in the same gene.

When complementation tests are applied to amber mutants, the results are clear-cut. These mutants, when tested against one another, fall into mutually exclusive classes: mutations in different genes result in full complementation no matter how they are paired, whereas mutations within the same gene fail to complement each other no matter how they are paired. In the case of temperature-sensitive mutants, however, the results are equivocal: some of the mutants display "intragenic" complementation and yield virus progeny even under restrictive conditions. Apparently two different "missense" mutations can give rise to "hybrid" proteins that, although altered, are nevertheless complete and functional. The amber mutants, as we have mentioned, involve "nonsense" mutations and therefore would not be expected to show intragenic complementation. Since both amber and temperature-sensitive mutations occur in many genes, the ambers provide a check on the equivocal temperature-sensitive results.

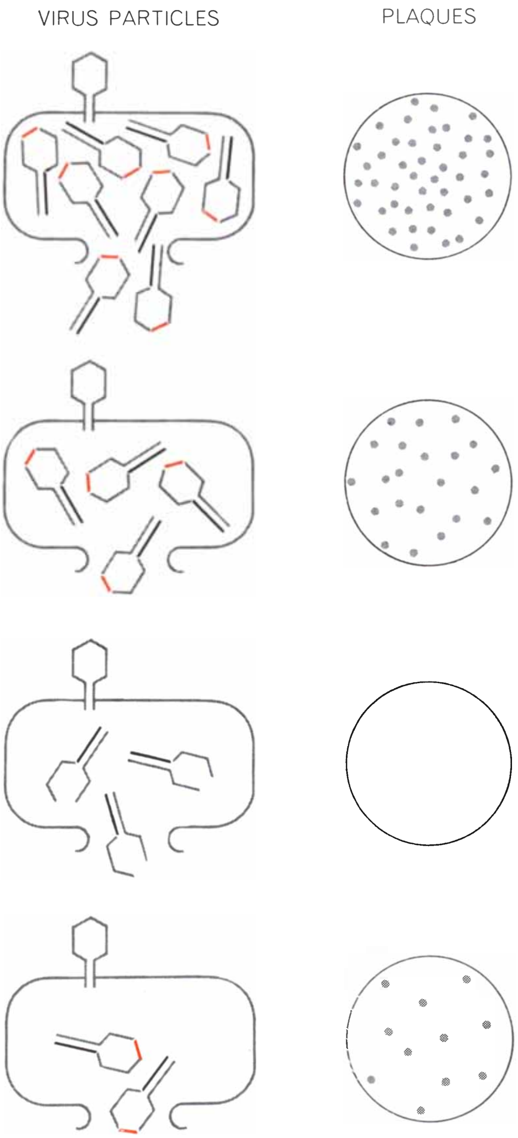
By means of complementation tests we subdivided our many hundreds of amber and temperature-sensitive mutants into separate groups, each of which identifies one gene of the virus; our mutations turned out to be located in 56 different genes. The next step was



COMPLEMENTATION TEST identifies individual genes. The top row shows how, in wild-type virus, two genes of the deoxyribonucleic acid (DNA) molecule (*color and black*) might direct the synthesis of two polypeptide chains that form proteins and end up as virus components. An infection with wild-type virus results in a large number of plaques on a bacterial culture (*right*). If two mutations being tested occur in different genes, one gene makes the protein the other cannot make; they complement each other and virus particles are produced (*second row*). Two mutations in the same gene will ordinarily not complement each other, as

to locate those genes, and four that had been identified earlier by other investigators, on a genetic map—a representation of the position of the genes in relation to one another.

Such a map is constructed on the basis of recombination, the process by which the genetic material from two parents is mixed in the progeny. In viruses recombination can occur when viruses of two different strains infect the same cell. The mechanism of recombination is still poorly understood, but it probably involves the breakage of DNA molecules and the reassociation of pieces derived from both strains to form a new "hybrid" DNA molecule. Recombination between two different mutants can result in some virus progeny that carry both mutations and in some wild-type viruses with no mutations. The wild-type recombinations can be recognized by their ability to multiply under restrictive conditions. The closer together two genes are on the DNA molecule, the less likely it is that breaks and reunions will occur between them, so the frequency of recombination is a measure of the distance between the two genes. We infect a bacterial culture with two strains that are mutant, say, in genes *a* and *x* respectively, and incubate it under "permissive" conditions in which both mutants can grow. Among millions of virus progeny of such a cross there will be some wild-type recombinants. By plating measured amounts of the progeny under permissive and under restrictive conditions we can determine what fraction of the progeny are wild-type. From this we calculate the frequency of recombination between genes *a* and *x* and thus the distance between them.



seen in the third row. In some cases involving the temperature-sensitive mutants, however, "intragenic complementation" occurs: some virus is produced in spite of errors in polypeptide synthesis (*bottom row*).

By plotting the results of hundreds of crosses we constructed a genetic map of the T4 DNA molecule [*see illustration on next page*]. A remarkable feature of the map is that it has no "ends" and must be drawn as a linear array that closes on itself—a circle. This is rather surprising, since it has been established by electron microscopy and other means that the actual form of the T4 DNA molecule is that of a strand with two ends. (Just to confuse matters, some other viruses do have circular molecules!) Why the map should be circular is not yet known with certainty. It is probably because different viral DNA molecules have different sequences of genes, all of them circular permutations of the same basic sequence. In alphabetical terms, it is as if one DNA were *a, b . . . y, z* while another were *n, o . . . z, a . . . l, m*. In the second case *z* and *a* would be "closely linked" and would map close together.

Recombination occurs between mutation sites within genes as well as between genes, so we have been able to make a number of "intragenic" maps. These show that the genes are not uniform in size. Although most of them are quite small, each accounting for about half of 1 percent of the length of the map, gene No. 34 is about 20 times larger, and genes No. 35 and No. 43 are also outsized. Average gene size is therefore not a precise indicator of the number of genes in the virus. It looks as if the mutations discovered to date cover about half of the map, so we conclude that roughly half of the genes remain to be discovered. Unfortunately a kind of law of diminishing returns seems to be taking effect: for every 100 new mutants we isolate and test we are lucky to discover one new gene. Apparently amber and temperature-sensitive mutations are rare in the genes that are as yet undiscovered. We are devising new techniques with which to seek them out, but there will probably be a number of genes that are simply not susceptible to the conditional-lethal procedure. This could be because neither amber nor temperature-sensitive mutations occur in them or because, if they do occur, the loss of gene function is not lethal and the mutation therefore goes unnoticed.

While attempting to uncover the remaining genes, we have begun to determine the functions performed by the genes already identified. The mutants were originally detected because of their inability to produce progeny virus under restrictive conditions. In order to investigate the nature of the abortive infections more closely in an attempt to find out just what step in the growth cycle goes awry, we have employed a large number of mutants involving several different defects in each of the 60 genes. We chose just a few aspects of bacteriophage growth to examine, largely because they are easy to observe or measure and because they provide information on the major events of the cycle.

1. Can the infecting mutant virus accomplish the disruption of the bacterial DNA molecule? With the phase microscope one can observe whether or not the bacterial nucleoid, or DNA-containing body, disintegrates. So far every mutant we have tested has been able to disrupt the host DNA, so it is clear that in every case the infective process is at least initiated.

2. Does DNA synthesis occur in the infected cell? After the disruption of the bacterial nucleoid all host functions cease. Any new DNA that is revealed in chemical tests is viral DNA and an indication that the genes responsible for DNA synthesis are operative.

3. Do the infected cells lyse at the normal time? During the last half of the growth cycle an enzyme, lysozyme, is synthesized that is responsible for disrupting the cell wall. Normal lysis indicates that this enzyme is synthesized and does its work.

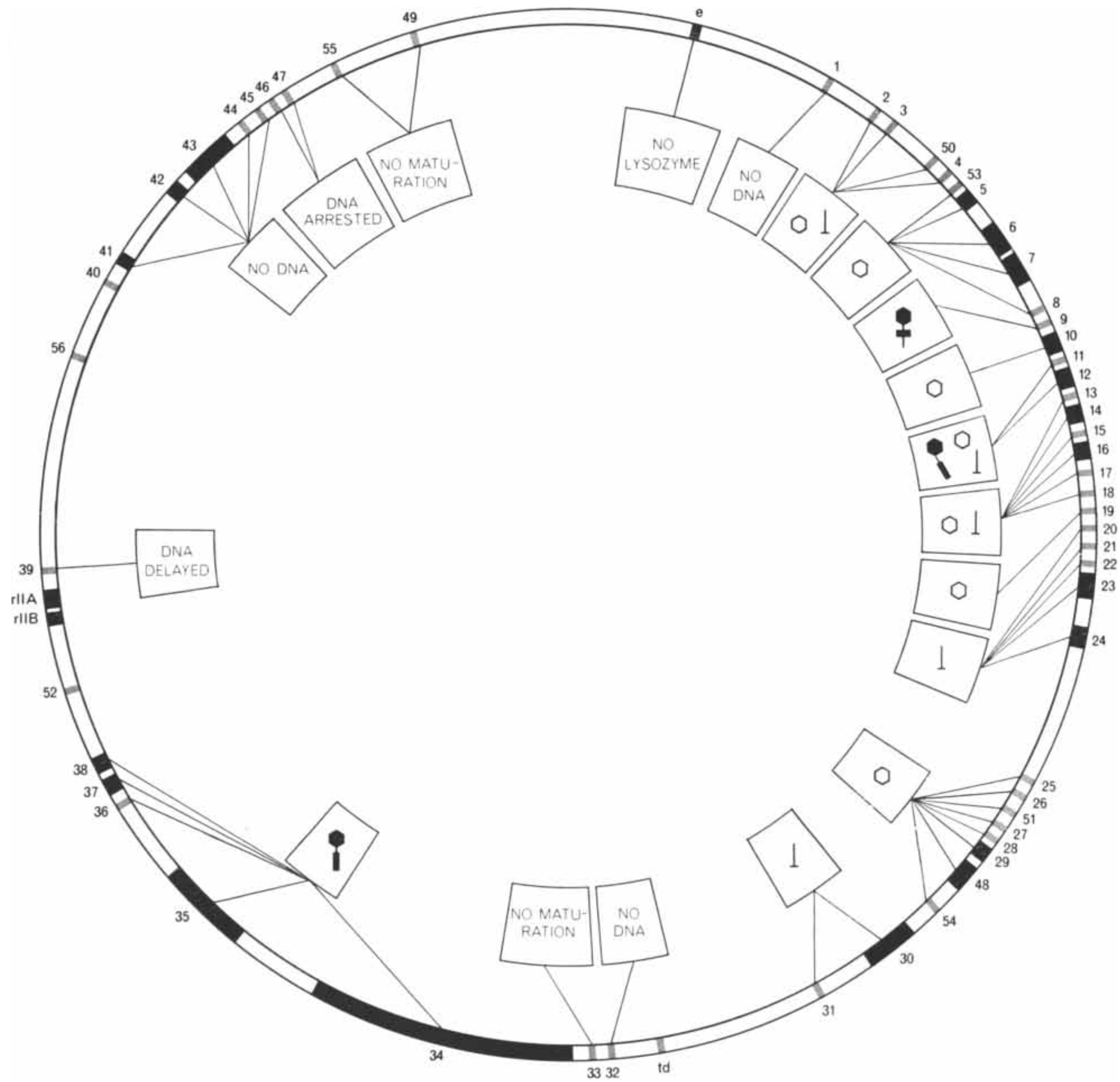
4. Are complete virus particles or components such as heads and tails produced in the infected cells? Electron

microscopy tells us the extent to which protein virus components have been synthesized and assembled in an infected cell.

Our data indicate that the various genes can be assigned to two groups. There are genes that appear to govern early steps in the infective process, as indicated by the fact that they affect DNA synthesis, and genes that appear to govern later steps, as indicated by their role in the maturation of new phage particles.

The major class of "early" genes includes those that are essential if any DNA synthesis is to occur. Mutations in these genes must cause the loss of some enzyme function necessary for DNA synthesis. Seven genes of this type have been identified, the precise function of one of which has been determined: John M. Buchanan and his co-workers at the Massachusetts Institute of Technology have found that gene No. 42 controls the synthesis of an enzyme necessary for the manufacture of hydroxymethyl cytosine, one of the four bases in the T4 DNA molecule.

The "no DNA" mutants reveal an interesting regulatory feature of gene action. Not only is there no DNA synthesis in cells infected by these mutants, but also the cells do not lyse and no virus components are made. It appears that the decoding of the late-functioning genes depends somehow on the prior synthesis of viral DNA. Buchanan's group has found, moreover, that in these cells any of the early enzymes that are



GENE MAP OF T4 shows the relative positions of the 60 genes identified to date and the major physiological properties of mutants defective in various genes. Minimum length is shown for some of the genes (*black segments*) but is not yet known for others (*gray*). The boxes indicate deficiencies in synthesis associated with mutations in some genes or, in the case of other genes, the components that are present in defective lysates of corresponding mutants. There may be no DNA synthesis or it may be delayed or arrested. There may be no virus maturation at all. Synthesis and lysis may proceed normally but, as shown by the symbols, incomplete viruses may be produced, ranging from heads or tails only to complete particles lacking tail fibers (*genes No. 34 through No. 38*).

not eliminated by the particular mutation continue to be synthesized well beyond the normal shutoff time of 10 minutes. It appears, then, that in the absence of normal DNA synthesis some timing mechanism for switching early genes off and turning late ones on fails to function.

Among the early genes some others have been found that appear to delay or modify DNA synthesis or to block the activity of late genes without disturbing DNA synthesis, but the manner in which they function is still obscure.

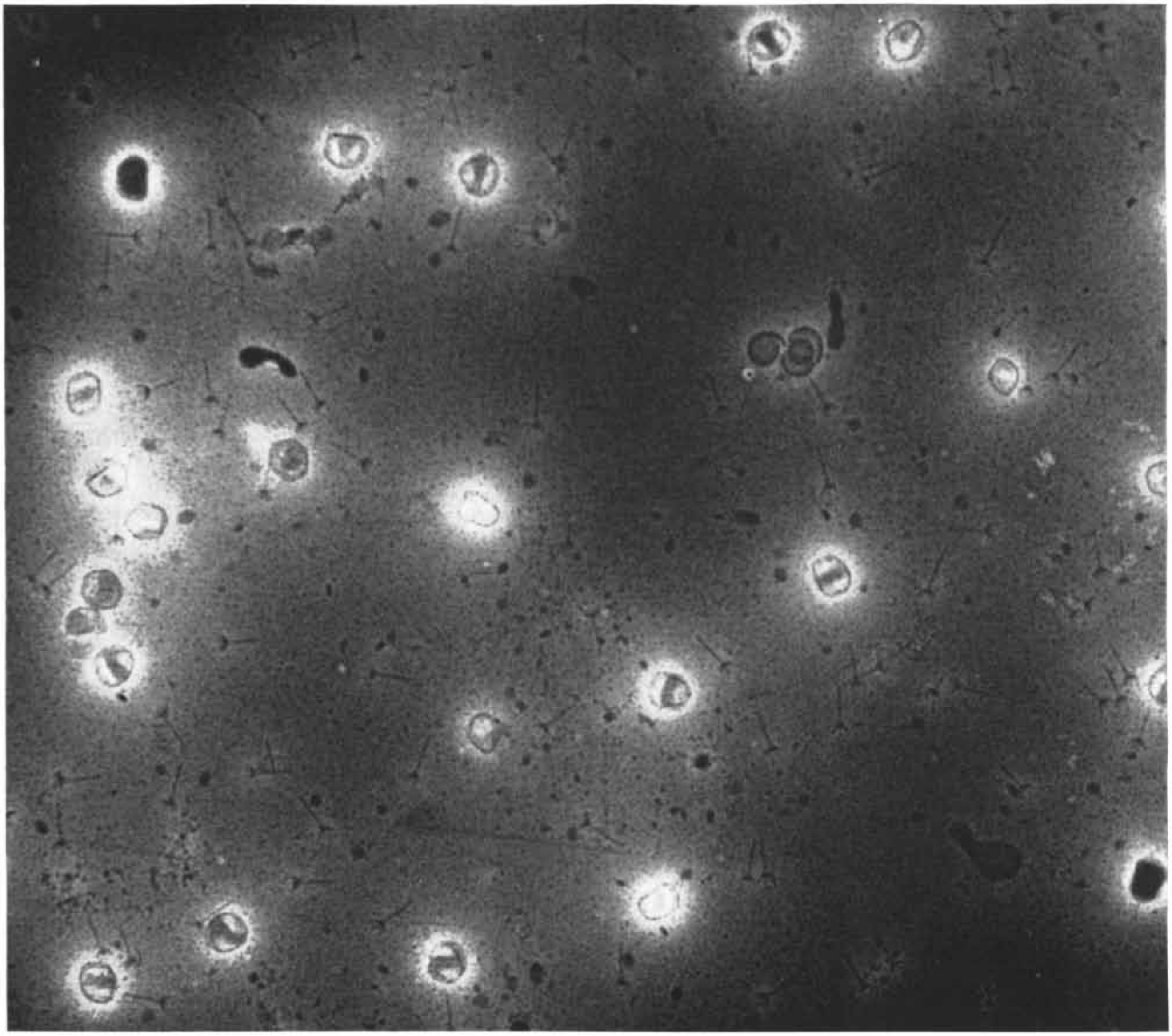
Most of the genes—about 40 of those we have identified so far—clearly play roles in forming and assembling the virus components. Mutations in these morphogenetic genes seem not to affect the synthesis of DNA or the lysis of the cell. What happens is that no infective progeny virus particles are produced, only bits and pieces of virus. For example, mutations in genes No. 20 through No. 24 result in the production of normal numbers of virus tails but no heads; mutations in the segment from gene No. 25 through No. 54 produce heads but no tails; mutations in genes No. 34 through No. 38 produce particles that are complete except for the tail fibers. Presumably the defective gene in each case is concerned with synthesis or assembly of the missing component.

A glance at the map [*opposite page*] shows that the arrangement of the genes in the DNA molecule is far from random: genes with like functions tend to fall into clusters. Similar clusters of certain genes in bacteria are called "operons," and all the genes within an operon function together as a unit under the control of separate regulatory genes. There is no indication that the clusters in viral DNA act as operons; the available evidence suggests, indeed, that each gene acts independently. Still, it is difficult to believe the clustering does not reflect in some meaningful way a high degree of coordination in the activities of the genes.

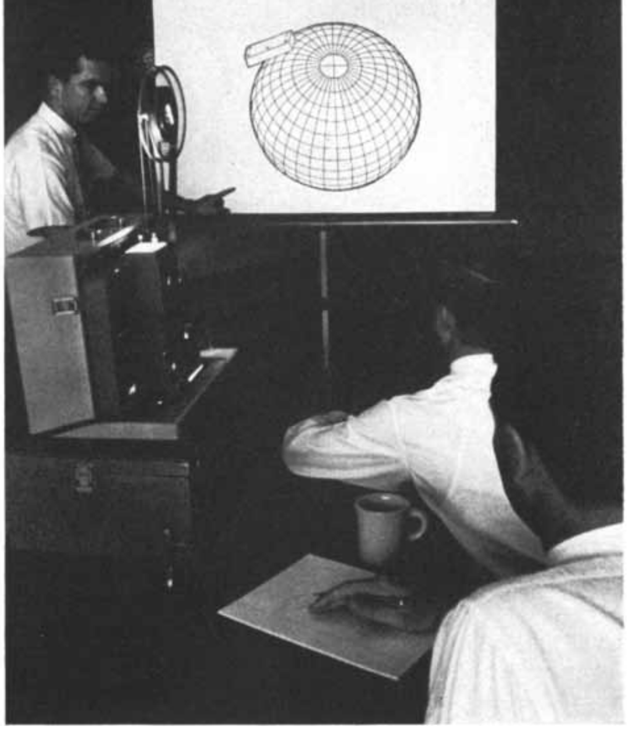
The large number of genes associated with morphogenesis is of particular interest. What do all these genes do? There is evidence that only a few of them are concerned with the actual synthesis of protein components. For example, the head of the virus particle is made up of about 300 identical protein subunits aggregated in a precise pattern; if there are any other protein molecules in the head membrane, they must be present in very small amounts. Yet at least seven genes and probably more are involved in the production of virus heads. Sydney Brenner and his associates at the University of Cambridge have found that just one of these genes, No. 23, is responsible for the actual synthesis of the protein subunits; cells infected with mutants defective in any other genes contain normal numbers of the subunits. The other genes must therefore be concerned with the assembly of the units rather than with their synthesis. When gene No. 20 is defective, for instance, the subunits assemble in the form of long cylindrical tubes instead of forming hexagonal heads [*see illustration on page 70*].

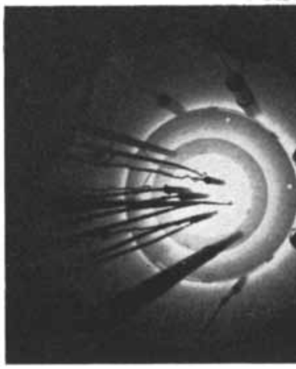
At this time we can only speculate as to the precise roles of the many morphogenetic genes. One possibility is that the proteins made by all of them are incorporated into the virus but in minor amounts that have escaped detection. Such minor components might be necessary to serve as the hinges, joints, nuts and bolts of the virus. Another possibility is that the proteins made by some of these late genes do not appear in the completed virus at all but instead play accessory roles in the assembly process —perhaps "gluing" subunits together in the specific configurations necessary for the proper construction of the virus. This notion of accessory morphogenetic genes is somewhat novel to many students of virus structure, who have generally believed that the assembly of viruses comes about through a spontaneous "crystallization" of subunits. In other words, it has been assumed that the form of a virus is inherent in its structural components. Although this may be true of viruses with simple spherical or cylindrical forms, it may not be true of viruses with more complex forms. The study of the effects of mutations on the assembly of viruses should serve as a powerful tool with which to explore this problem.

The relation between genes and form should be of general interest. Life is characterized by the complexity of its architecture. This complexity is manifested at all levels of organization, from molecules to the assemblages of specialized cells that make up higher animals and plants. The building blocks of all living things are, like virus particles, intricate molecular aggregations. Knowing how a bacteriophage such as T4 is put together may help us to understand the origins of form in all living systems.



DEFECTIVE LYSATE of a temperature-sensitive strain mutant in gene No. 18 is enlarged about 60,000 diameters in this electron micrograph made by Edgar. Heads and tails have been formed but not assembled, and most of the heads are empty of DNA. The lysate was negatively stained with phosphotungstic acid, which filled the empty virus heads, and the exposed plate was printed as a negative.



How Opiates Change Behavior

In which rats that administer morphine to themselves become addicted whereas animals that receive the drug passively do not. This result suggests that human addiction depends on the circumstances of intake

by John R. Nichols

"Who could be so heartless as to practice medicine without opium?" asked the medieval physician Paracelsus (who carried some in the hilt of his sword for suitable emergencies). For thousands of years physicians have used the dried juice of the poppy to relieve suffering, even at the risk of instilling an almost ineradicable craving for it. Today morphine, a bitter white crystalline alkaloid of opium, has replaced opium itself, but the risk of addiction has not diminished. No one knows exactly how many morphine addicts there are in the U.S., but estimates range upward from 40,000.

Physicians contribute far more than their reasonable share to the population of addicts. Their rate of addiction is estimated to be about one per 100. In contrast, the many hospital patients who receive morphine have the usual physiological reactions to the drug but rarely develop the persistent behavioral change characterized by active efforts to obtain it. Can the difference in the conditions under which patients and physicians are introduced to morphine account for their subsequently different behavior toward it?

In 1952 I began to study the conditions under which addiction occurs. The first problem turned out to be the term "addiction" itself. The word is used in such an arbitrary and loose manner, even by investigators, that it has little real meaning. It is better to use the more descriptive term "sustained opiate-directed behavior," which focuses attention on the important part of the problem: the change in behavior that is brought about by opiates.

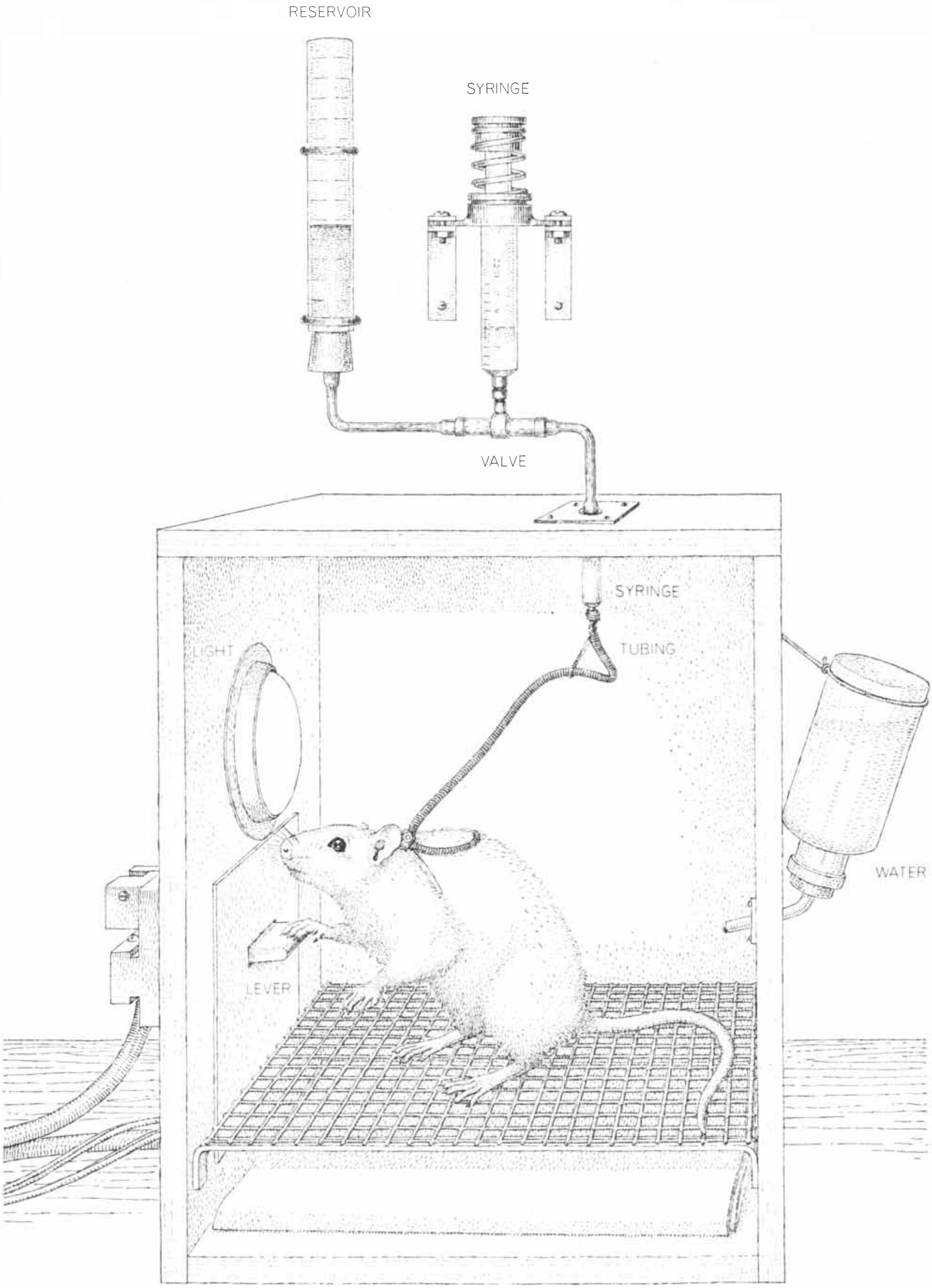
The high rate of sustained opiate-directed behavior among physicians suggests that such behavior is likely to develop in subjects who initiate the action of taking drugs and administer opiates to themselves. It is more than coincidence that operant conditioning, the most effective means of changing behavior known to experimental psychologists, entails some subject-initiated response. Operant conditioning works as follows: any subject-initiated response will occur more often in the future if it is followed by reinforcement, which can be loosely defined as a reward. If reinforcement is capricious, as it is in gambling, chance may reinforce some arbitrary action that is then established as a kind of superstitious ritual. If, however, a given action consistently causes a reinforcement to occur, then "reinforcement-seeking" behavior is strongly encouraged. Significantly the organism must first take an action before the action can be reinforced.

A passive recipient of opiates has not had his behavior changed by operant conditioning. The hospital patient who fails to develop opiate-directed behavior is of course such a passive recipient. He may learn verbal reinforcement-seeking such as vehemently demanding a "shot," but such indirect control of the reinforcement process can be extinguished by withholding reinforcement. On the other hand, a physician who gives himself an injection of morphine for pain or fatigue learns direct control of the reinforcement process. There is no way to separate reinforcement from behavior and thus no way to extinguish the response. Because reinforcement strengthens any response, the act of "taking a shot" is performed more frequently and urgently until it becomes a chronic obsessive compulsion.

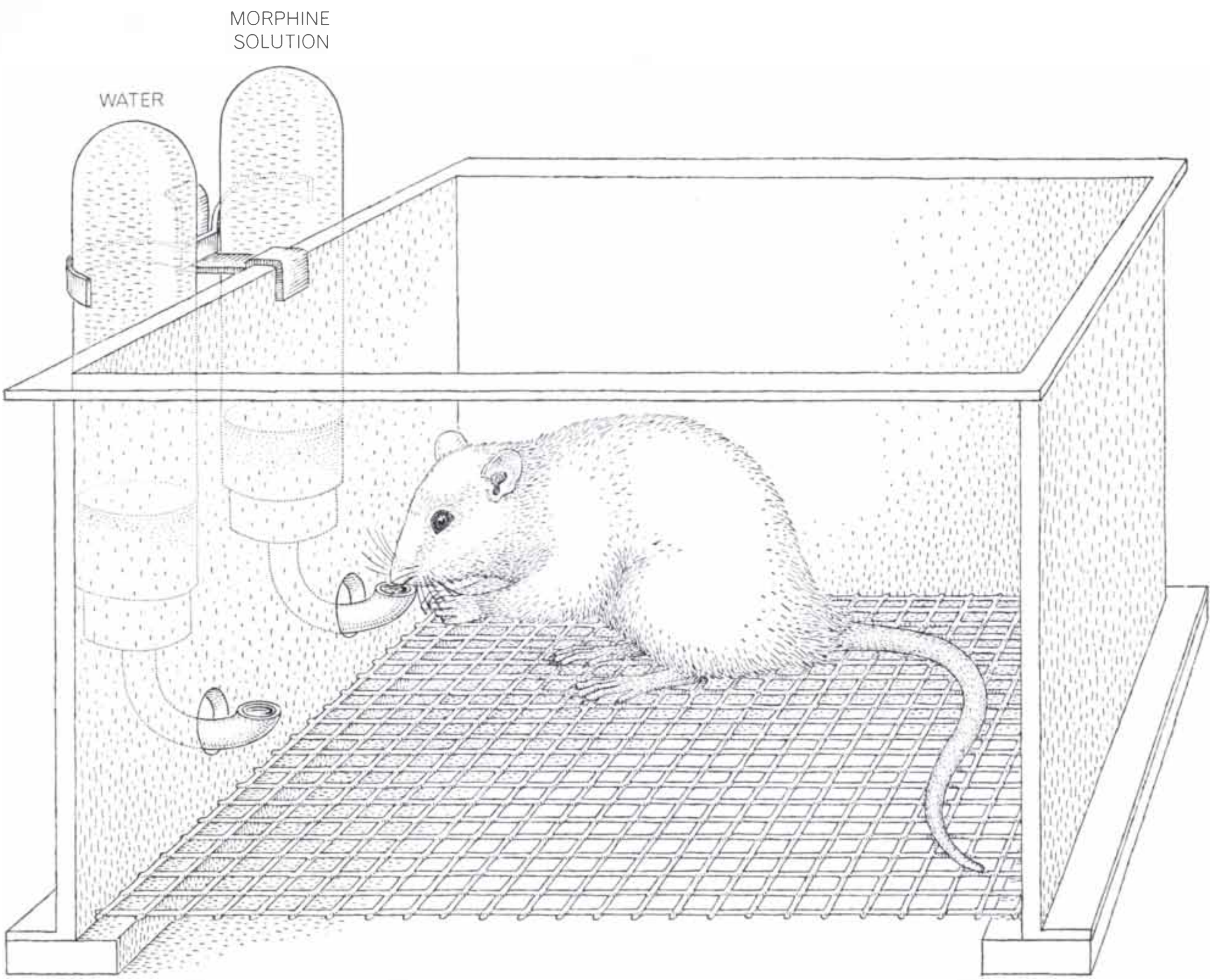
The physiological effect is the same whether an organism passively receives morphine or actively takes it. The organism develops a tolerance for the drug, so later dosages must be increased to reproduce the original effects. After developing a tolerance to morphine the organism becomes physiologically dependent on it, requiring continued intake to regulate its metabolic processes. If morphine is withheld, gross homeostatic imbalances occur that cause the distressing effects known as withdrawal symptoms.

According to a useful hypothesis put forward in 1943 by C. K. Himmelsbach of the National Institutes of Health, the depressant action of morphine is resisted when the body establishes opposing metabolic processes. When these excitative counteradaptations equalize the depressant actions of the opiates, the drug-user has developed tolerance and is also physiologically dependent on a given dosage to prevent withdrawal distress. When the opiates are cut off, the antidepressant counteradaptations are expressed unchecked in the form of withdrawal symptoms. Himmelsbach's concept implies that the effects produced by a lack of opiates are at the opposite end of a continuum from the direct effects of opiates, and that somewhere between them lies a "steady state."

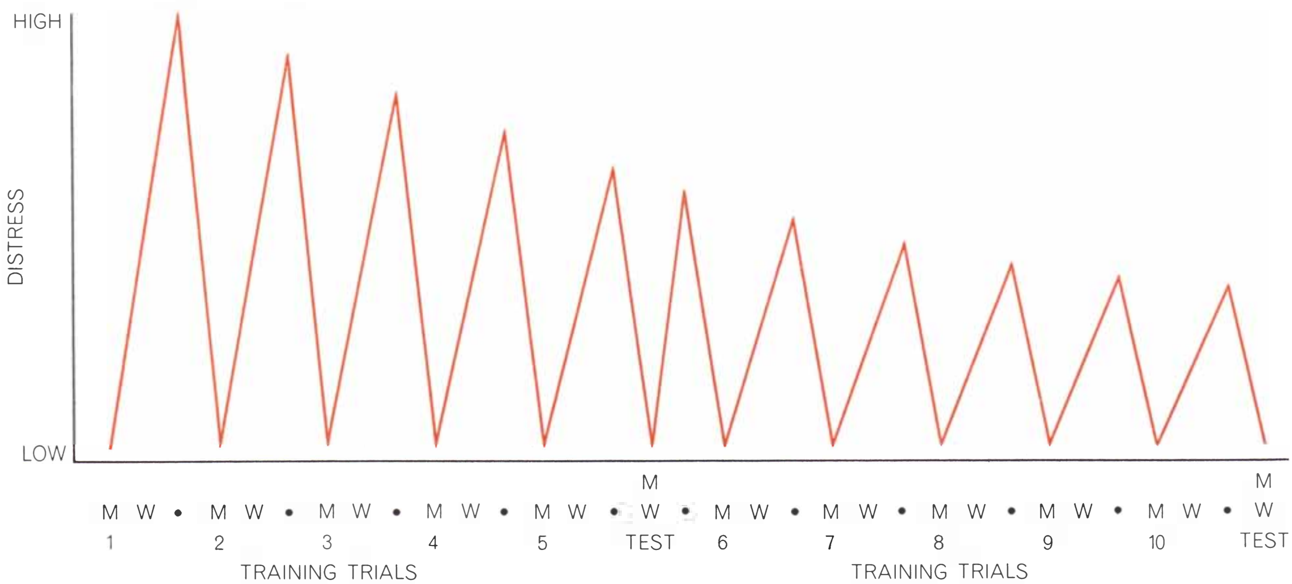
Morphine-users evince withdrawal symptoms a few hours after their last intake; the intensity of their distress increases to a peak about three days later. These symptoms, which range from subjective aches and malaise to measurable physical changes such as loss of body water, then diminish until physiological readjustment is more or less complete seven to 12 days after withdrawal began. The physiological effects of morphine are readily reproduced in animals, but it has been most difficult to instill in them the behavior characterized by opiate-seeking. I thought that possibly this was because animals had been, like hospital patients, mere recipients



RAT IN SELF-INJECTOR EXPERIMENT can initiate its own intake of morphine by pressing a lever (*left*). This act triggers a process by which morphine in solution is forced through tubing inside the animal's leash and thence into its abdominal cavity.



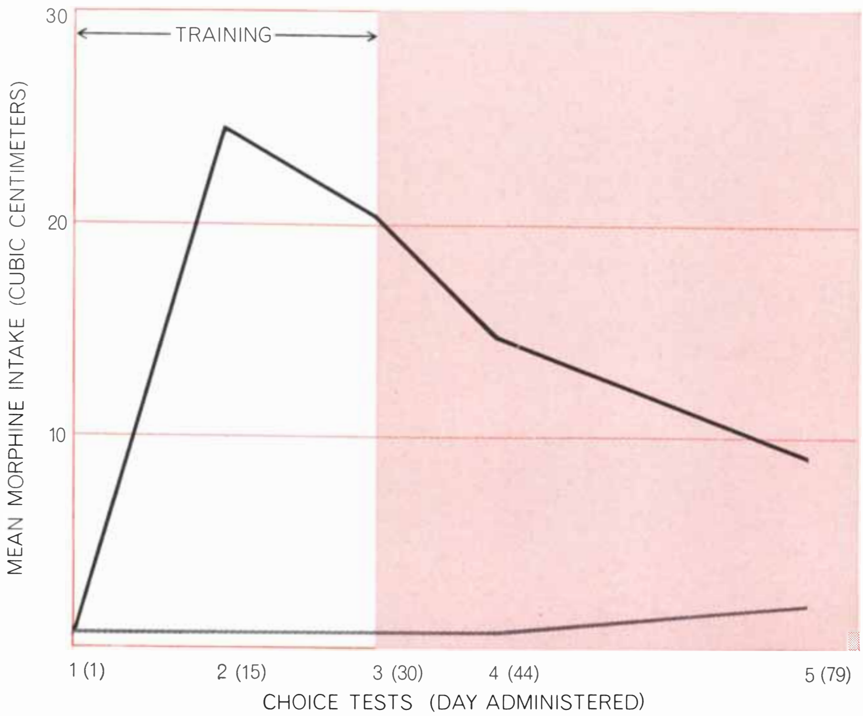
RAT IN ORAL-INTAKE EXPERIMENT has two drinking tubes in its cage. One contains water, the other a morphine solution. Rats find the taste of morphine aversive but voluntarily drink it, even in preference to water, after an intensive training procedure.



TRAINING CYCLES produce a pattern of distress, morphine-drinking, relief and more distress. This schematic representation of distress during 10 cycles is derived from an experiment conducted by the author. Each cycle consists of three 24-hour phases. In the first phase rats had only morphine (*M*); in the next they had only water (*W*); in the third phase (•) they had no fluids.

of morphine; if they were given an active role in the use of morphine, they might develop opiate-seeking behavior. In 1952 I could find no experiment in the literature specifically designed to test this operant-conditioning concept of addiction. The one isolated experiment that allowed animals some initiative in the intake of morphine had, however, produced fleeting changes in their behavior. In this experiment, conducted by S. D. S. Spragg of the University of Rochester, chimpanzees suffering from withdrawal distress developed behavior interpretable as a desire for morphine. When the motivating circumstance (withdrawal distress) subsided in about two weeks, it appeared that the chimpanzees could not have cared less about opiates.

Alfred R. Lindesmith, a sociologist at Indiana University, concluded in 1947 that the "use of narcotics for the conscious purpose of alleviating withdrawal distress causes addiction." His emphasis on the conscious, linguistic and social aspects of human addiction, however, led him to believe at that time that animals "cannot become addicted." Encouraged by Spragg's results but aware of Lindesmith's warning, I undertook in 1954 to turn laboratory animals into active and persistent users of morphine.



VOLUNTARY DRINKING OF MORPHINE by rats trained to self-administer drug (*black curve*) is compared with the voluntary morphine intake of rats trained as passive recipients (*gray curve*). Each rat in the control group was injected with the amount of morphine that a counterpart in the self-administering group drank. The five choice tests were made on the first, 15th and 30th days of training, and 14 and 49 days after training ended.

Animals learn to respond with a given action when that response is followed by reinforcement. If, in an experiment, a hungry animal receives a pellet of food just after pushing a lever, the food is said to reinforce, or strengthen, the response of pushing the lever. It seemed likely that morphine would reinforce such a response in an animal motivated by withdrawal distress. To test this idea, rats in a state of withdrawal were put one at a time into a device that would automatically give them an injection of morphine. Their bodies were restrained but their heads were free to move. When a rat held its head in a certain position (an operant, or self-initiated, response), it was reinforced with an injection of morphine. The rats learned to keep their heads in the rewarded position. Early experiments with such self-injectors tended to confirm that opiate-intake behavior is generated by operant conditioning and that reinforcement is due to the reduction of withdrawal symptoms.

Several investigators have developed more sophisticated self-injectors [see "Experimental Narcotic Addiction," by James R. Weeks; SCIENTIFIC AMERICAN, March, 1964]. W. Marvin Davis of the University of Mississippi and I developed the self-injector now used in my laboratory at Southeastern Louisiana College. A lever on one side of the cage triggers an automatic process by which fluid morphine descends through a tube within the animal's leash and into its abdominal cavity [*see illustration on page 81*]. All the human actions of securing, preparing and injecting morphine have been reduced to pressing a lever. In my experiments rats invariably learn to press the lever in response to stimuli provided by their own bodies, that is to say, in response to withdrawal symptoms.

Self-injectors are intriguing experimental devices, but they have limitations. A long-term study with many animals would be quite costly because each animal must have its own self-injector, and a high level of skill is required to build and maintain the devices over long periods. I decided to look for a simpler way of inducing rats to take morphine. Knowing that human addicts have not only taken opiates by injection but have also smoked, eaten and drunk them, I hoped that one of these other modes of administration might be made feasible for the rat. I decided to try to reinforce drinking as an operant response.

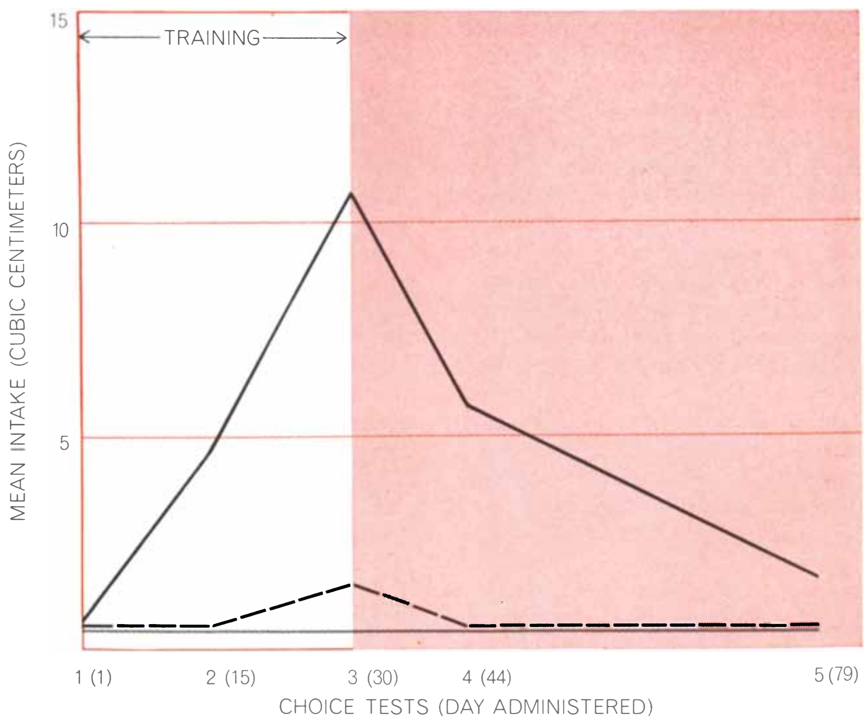
The first problem was to develop a standard, quantitative method of measuring the opiate-directed behavior of a number of rats. This was accomplished by giving a choice test to individually caged rats. Each was offered two graduated drinking tubes [*see top illustration on opposite page*], one filled with tap water, the other with a solution containing .5 milligram of morphine per cubic centimeter. When first confronted with such alternatives, rats drink large amounts of water but only tasting amounts of the bitter morphine solution. Clearly at the outset of such an experiment rats show no opiate-directed behavior.

Several steps were necessary to strengthen the opiate-intake response of the rats. Since they had to drink the morphine solution when they were suffering from withdrawal distress, they were first given daily injections of morphine for 25 days. When these injections ended, the rats entered a state of withdrawal and simultaneously were deprived of all liquids for 24 hours. Finally they were offered the morphine solution alone, and under the circumstances they drank it. Drinking the morphine reduced the withdrawal distress they were suffering, but it also introduced a new opiate-based physiological regime that soon gave rise to greater distress. A cyclical pattern was established: distress followed by morphine-drinking, followed by more distress and more morphine-drinking [*see bottom illustration on page 82*]. Since withdrawal symptoms reach a peak about three days after the last opiate intake, the cyclical training procedure made morphine available every third day for 30 days. Each of the 10 three-day cycles, designated training trials, offered an opportunity to reinforce the drinking response. To prevent dehydration I supplied the rats with water for 24 hours after opiate intake; thus each three-day cycle consisted of one day on no liquids, one day on morphine solution and one day on water.

This procedure was first applied in an experiment comparing the development of opiate-directed behavior in rats under active and passive conditions. After 25 days of preliminary injections 12 rats were given a choice test, on which none showed opiate-directed behavior. Then half of the rats, chosen at random, were assigned to an experimental group and the other half to a control group. The rats in the experimental group were allowed the self-initiated response of drinking the morphine solution every third day for 10 of the training trials. The rats in the control group were given water for two days of the three-day cycle (instead of water for one day and morphine for one). Although they never drank morphine, they were injected with the same amount of morphine that an arbitrarily paired rat in the experimental group obtained by drinking. Hence the intake of morphine was identical for the members of both groups, but the rats in the control group did not act to secure it and for them no opiate-intake response was reinforced.

As opiate-directed behavior developed it was measured by choice tests given after five training trials and again after 10 trials. Retention of the opiate-directed response was measured by choice tests given 14 days and again 49 days after training. The active, response-initiating rats greatly increased their voluntary morphine consumption on the two choice tests given during training, even though they had the option of drinking plain tap water [*see illustration on preceding page*]. This opiate-directed behavior was maintained even after withdrawal symptoms had subsided. In contrast, the rats in the control group continued to show no opiate-directed behavior although they had been given an equal amount of morphine.

To describe the change in morphine-drinking procedure as opiate-directed behavior is of course retrospective

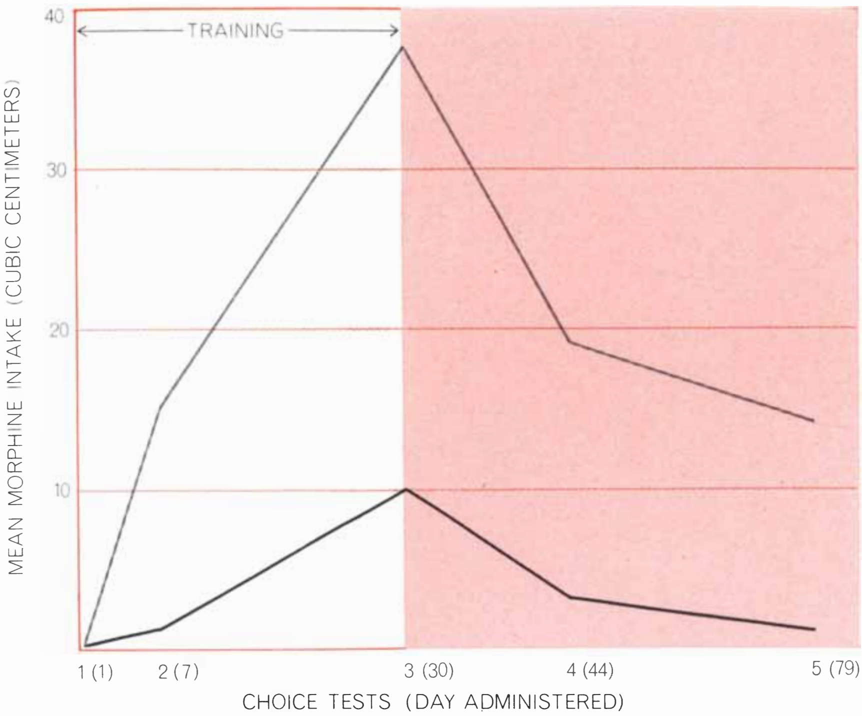


OPIATE-DIRECTED BEHAVIOR, not thirst, explains the increased consumption of rats trained to drink a morphine solution (*solid black curve*). Rats offered quinine solution (*gray curve*) and rats offered alum solution (*broken curve*) under identical conditions of thirst hardly increased their intake. Figures in parentheses give the day of each choice test.

reasoning. Another interpretation—that the rats would have increased their consumption of an equally distasteful liquid under the same conditions of thirst—had to be ruled out. This was done by reproducing the aversive character of the original morphine solution with solutions of quinine or alum. Five "naïve," or previously untested, rats were given a choice between a weak quinine solution and the morphine solution. The rats drank the quinine solution. Each day thereafter the quinine concentration was increased and the tube positions were changed. When the quinine concentration reached .6 milligram per cubic centimeter, the rats began drinking more morphine solution than quinine solution. The group of rats was retired and five new ones were given a choice between a .5 milligram per cubic centimeter quinine solution and the .5 milligram per cubic centimeter morphine solution. They slightly preferred to drink the quinine solution, but the ratio of their choices was accepted as being sufficiently close for the purposes of continuing the experiment. In the same way alum solution at 40 milligrams per cubic centimeter was equated with the original morphine solution.

Eighteen rats were then given morphine injections on the schedule followed in the preceding experiment and were randomly divided into three groups: (1) a group that repeated the training trials with morphine, (2) a group that was given training trials with quinine and (3) a group that was trained with the alum solution. For good measure the quinine and alum groups were injected with morphine during the trials so that differences in morphine intake would not account for any differences in their drinking behavior. The morphine-drinkers greatly increased their intake on the choice tests, but the quinine- and alum-drinkers did not [*see illustration on opposite page*]. It is evident from this experiment that the increased morphine consumption was not due to association of the aversive solution with the quenching of thirst but actually represented opiate-directed behavior.

Moreover, this behavior was sustained. A choice test was given 14 days after training, when withdrawal symptoms seemed extremely low. If relapse is defined as a return to opiates after the dissipation of withdrawal symptoms, then the rats appear to have relapsed. Even when tested 49 days after training, two experimental animals were voluntarily drinking 25 to 30 times more morphine for their weight than a hos-



REDUCED WITHDRAWAL SYMPTOMS led to reduced intake of morphine by rats continually injected with the drug (*black curve*) in an experiment conducted by the author. Rats in a control group drank more morphine (*gray curve*) although they received only a fifth of the total amount of morphine their counterparts got by injection. On choice tests 14 and 49 days after training the control group still drank large amounts of morphine.

pital patient would receive in a 24-hour period. Such a comparison is of limited meaning when both the species and the mode of intake differ, but it suffices to illustrate that the rats relapsed.

In a recent experiment I attempted to minimize the reinforcing effect of morphine while still allowing rats to drink the morphine solution. I reasoned that if withdrawal symptoms were suppressed, drinking the morphine solution would not be reinforced and little opiate-directed behavior would develop. Two groups of 13 rats were injected with a morphine solution and given pretraining choice tests, on which they failed to show any opiate-directed behavior. Then both groups were put through the drinking-tube procedure, with the experimental group given morphine injections at six-hour intervals throughout the 30-day training period. Not all reinforcing possibilities were removed, since some withdrawal symptoms appeared toward the end of the six-hour injection interval, but the injections did suppress most of the withdrawal symptoms. The control rats developed much more opiate-directed behavior than did the continuously injected experimental rats, even though the experimental rats received about five times more morphine [*see illustration above*]. The low intake of morphine by the continuously injected rats was not due to a morphine-induced depression of drinking, because the experimental rats drank more water on each of the choice tests than the control rats did. The experiment demonstrated that if the development of withdrawal symptoms is suppressed, the development of opiate-directed behavior is suppressed also.

Other experiments have confirmed or are consistent with this principle of suppressing opiate-directed behavior by withdrawal reduction. Marvin Davis and I showed in 1961 that higher levels of physiological dependence at the start of drinking-tube training give rise to a greater amount of opiate-directed behavior. Since the severity of withdrawal symptoms is related to the level of physiological dependence, these results are consistent with the withdrawal-reduction principle. A group of investigators at the U.S. Public Health Service Addiction Research Center in Lexington, Ky., has found recently that etonitazene, a morphine-like compound, reduces withdrawal symptoms in rats and that the rats increase their oral intake of this drug when in withdrawal. The investigators—Abraham Wikler, William R. Martin, Frank Pescor and Charles Eades—concluded that etonitazene, like morphine, will reinforce an oral-intake response.

The principle that opiate-directed behavior is generated by operant conditioning has been supported by still other studies, some of which involved the use of self-injectors. One experiment, conducted by H. D. Beach of Dalhousie University in Canada, showed that rats will learn to choose the arm of a Y-shaped maze that leads to an injection of morphine. The active, opiate-directed response in this variation of the operant-conditioning technique is choosing the path to the box where injections are given. Rats continued to choose this path even after three weeks without morphine reward.

It has been most fruitful to consider drug addiction in terms of the conditions that produce behavioral change. Several experimenters have obtained results consistent with the principle that opiate-directed behavioral changes are generated by operant conditioning and that the opiate-intake response is reinforced by the reduction of withdrawal distress. The fact that these behavioral changes seem to be brought about by conditioning suggests that we can apply other learning-conditioning principles to the problem.

It is known, for example, that learning by operant conditioning generates habit strength. Habit strength can be defined as the residuum of learning that persists in latent form after a response has been mastered. The strength of a habit is revealed by the likelihood of a response at a given level of motivation. A strong habit requires little motivation before it is expressed as a response; a weak habit needs strong motivation before a response occurs. For example, untrained, naïve rats have zero habit strength; even when they are highly motivated by withdrawal distress, they do not drink the morphine solution offered in pretraining choice tests. Once habit strength has been established it can be increased, but it does not spontaneously dissipate with time.

In learning-conditioning theory drives and motivation are commonly used as synonyms. To be more exact, a drive is the effect on behavior and experience produced by a motivating circumstance. Lack of food, for example, is a motivating circumstance that produces a hunger drive. Hunger, like all drives, is experienced as unpleasant—a tension that moves the organism to action. During the course of its activity the organism might hit on something to reduce its drive. For a hungry animal this would

be a food-getting action. For a sexually deprived animal it would be actions that lead to a sexual partner.

Drives have a survival value. It is easy to see that the hunger drive and the sex drive promote survival of the individual and the species. Moreover, the reduction of a drive is experienced pleasurably. Eating a steak when one is hungry produces a pleasant sensation. If one were not hungry, no drive would be reduced and eating a steak would not be so pleasant. Other examples could be given, but the principle is obvious: a pleasurable sensation is the subjective effect of drive-reduction.

Opiates can "short-circuit" the survival mechanism of drives. By their pharmacological action they directly reduce the sex drive, the hunger drive and other drives as well. The pleasurable sensation produced by opiates is simply a subjective effect that accompanies the simultaneous reduction of many drives.

The experimental evidence indicates that withdrawal is a motivated, high-drive state. The "fixed" state after a morphine injection is equated with the low-drive state at the other end of the continuum. In the fixed state the drives of pain, hunger, anxiety and sex have all been reduced to a very low level. Activity—an index of drive state—is also very low. Left to himself, the addict "goes on the nod," a sort of half-dozing stupor.

By imperceptible degrees, however, the low-drive, fixed state gives way as drives increase. Distress increases concurrently because drives are themselves inherently distressing. It is unpleasant to be hungry, anxious, thirsty, sexually deprived or in pain. At the end of the continuum lies the unqualified distress of withdrawal symptoms.

The addict learns to interpret his returning drives in terms of morphine need. He learns to respond to a returning sex drive not by seeking a sexual partner but by taking an injection of opiates that reduces the drive (and all other returning drives). Thus the label "sex drive" is not appropriate for the addict. Neither are the usual terms for other opiate-reduced drives; these drives have become opiate drives. To continue calling them by their original names is to distort the actual situation. The drives that lead to many activities in the nonaddict lead to only one activity in the addict and are all reduced by one simple action: the injection of an opiate.

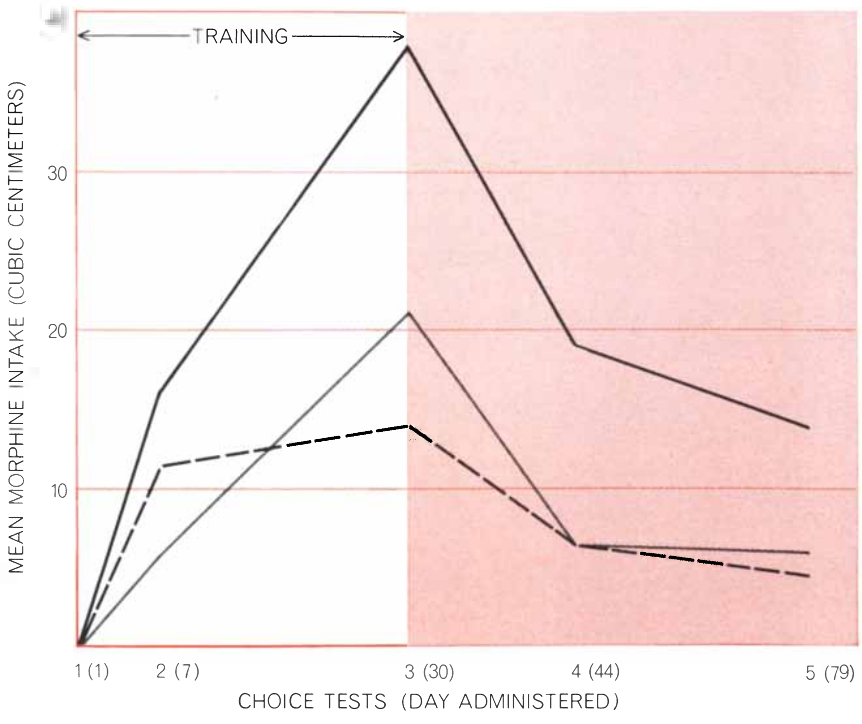
The addict's powerful opiate drives act on his strong, accumulated habit strength and give rise to an urgent tendency to make the opiate-intake response. By recruiting biological drives to energize it the opiate-intake habit becomes autonomous and independent of the chemical effects of opiates. Since the habit strength of the well-conditioned addict is great, his opiate drives must be reduced to a low level before his response tendency will dissolve. This explains the inclination of many addicts to take a "de luxe" dose, an amount far exceeding that needed for physical stability and comfort.

The tendency of an organism to respond with any given action is, according to the Yale University learning theorist C. L. Hull, a multiplicative function of habit strength and the drives that energize it. According to this formula, an addict's tendency to take a "fix" should decrease as biological drives decline with age. I have found that older rats develop less opiate-directed behavior than young rats do [*see illustration on this page*]. A report by Charles Winick of Columbia University makes an analogous point: it concludes that human addicts tend to stop using opiates as they grow older.

Many investigators have been able to extinguish the habit strength of rats by creating situations in which the self-initiated response recurs many times with no reinforcement. Eventually the organism stops responding. It is extremely difficult, however, to deprive a human being of all the reinforcement effects he derives from an opiate-directed response. There are many secondary reinforcement effects due to the acquisition of reinforcing properties by previously neutral or aversive stimuli. A clear example of the acquisition of such secondary reinforcing properties is provided by "needle fiends": addicts off the drug who like to jab themselves with needles or give themselves injections of water.

Another difficulty in trying to extinguish human habit strength is man's ability to distinguish between clinical-experimental and "real life" situations. The experimenter may set up, within the confines of a hospital, a reinforcement situation that effectively extinguishes the opiate-intake response. When the addict is released from the hospital, however, he is restored to a situation that causes his relapse.

So far it is not clear just what can be done about sustained opiate-directed behavior in human beings. But an ancient medical dictum states that the first step toward curing a disease is an adequate diagnosis. The accumulation of experimental evidence on behavioral change represents that first step.



REDUCED OPIATE-DIRECTED BEHAVIOR is manifested as an organism ages and drives decline, according to the experiment summarized in this graph. Young rats (*black curve*) drank more morphine than middle-aged rats (*gray curve*) and old rats (*broken curve*). All three groups were trained to drink the drug and were tested on five occasions.

GREAT NEBULA IN ORION was photographed with the 36-inch Crossley reflecting telescope at the Lick Observatory of the University of California. In long-exposure photographs such as this one the image of the nebula is spread over an area having twice the apparent diameter of the moon. The actual diameter of the nebula is 20 light-years; its distance from the earth is about 1,500 light-years. The nebula is composed mostly of hydrogen gas with a small admixture of helium and traces of heavier elements. Bright spikes radiating from closer stars are produced in telescope by diffraction of light around secondary mirror and its supports.

THE AGE OF THE ORION NEBULA

This magnificent swirl of gas is made luminous by the ultraviolet radiation of hot young stars that are embedded in it. Its motions indicate that it may have begun to shine only some 23,000 years ago

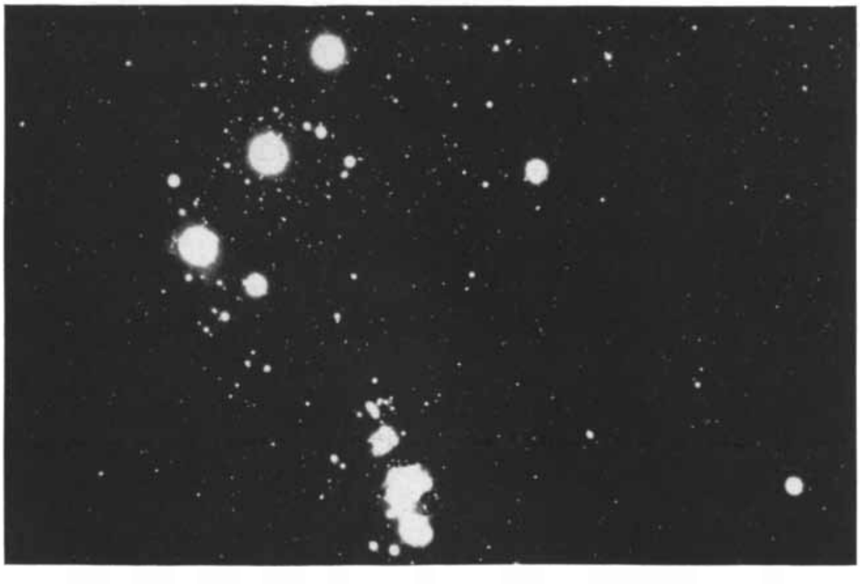
by Peter O. Vandervoort

The ancient idea that the heavens are perfect and immutable has long since been abandoned. But even though the principles of cosmic and stellar evolution are now firmly accepted, it is generally thought that large-scale celestial changes are so gradual they can be measured only on a time scale that is extremely long by ordinary standards. Recent studies indicate, however, that in at least one instance this is not so. If 25,000 years ago some cave dwellers had left a picture of the stars in Orion the Hunter, the most prominent constellation in the night sky during the winter, it is probable they would have omitted one of the most interesting objects now visible to the unaided eye. The missing "star" would have been the Great Nebula in Orion, which is located at the central position in the Hunter's sword. On the basis of observations made with optical and radio telescopes it is now estimated that the Great Nebula and the brightest stars with which it is associated started to shine no more than about 23,000 years ago.

What is seen with the unaided eye as the middle star in the sword is really a group of stars known as Theta Orionis. Four of these stars, commonly known as the Trapezium, make up the subgroup Theta-One Orionis. A short distance from the Trapezium is the pair of stars called Theta-Two Orionis. The Great Nebula shows up in a small telescope as an ill-defined, faintly luminous patch surrounding these stars. It is only in photographs of long exposure made with large telescopes that the vast extent and complex structure of the nebula become clearly visible. If it could be seen with the unaided eye as it is in such a photograph, its apparent diameter would be approximately twice that of the moon. Of course its true diameter is enormously greater: about 20 light-years. Its distance from the earth is about 1,500 light-years.

Until 100 years ago, when astronomical photography was still in its infancy, the physical nature of the Orion nebula and similar nebulae elsewhere was a matter of conjecture. Some astronomers thought that such nebulae might be composed of stars too numerous and faint to be observed individually. The question was settled in 1864, when Sir William Huggins made a visual examination of the spectrum of the Orion nebula and discovered that its light was concentrated in a few bright lines at distinct wavelengths. This meant that the light was produced by hot, glowing gases, since only incandescent gases were known to emit bright-line spectra in the laboratory. If the nebulosity had represented the total light of many faint stars, it would have had a starlike spectrum, in which the light is distributed continuously over almost all wavelengths (except for a few wavelengths at which dark lines appear). Huggins concluded that the Orion nebula must be a great cloud of hot interstellar gas.

Since Huggins' discovery many gaseous nebulae have been studied, and the physical processes that give rise to their luminosity are now fairly well understood. The Orion nebula, which is similar to many others, contains about 100 solar masses of gas, of which hydrogen constitutes about 65 percent, helium nearly 35 percent, oxygen and calcium less than .1 percent and other elements



CONSTELLATION OF ORION is the most prominent constellation in the northern skies during the winter months. Three bright stars in a straight line at top left represent the belt of Orion the Hunter. The three brightest objects extending downward from the belt (*bottom center*) are Orion's sword. The middle "star" of the sword is actually the Great Nebula. Photograph was made at the Yerkes Observatory of the University of Chicago.

CENTRAL REGION of the Orion nebula was photographed in red light by George H. Herbig with the 120-inch reflecting telescope of the Lick Observatory. Hydrogen gas in the nebula is quite luminous in the red wavelengths of the electromagnetic spectrum.

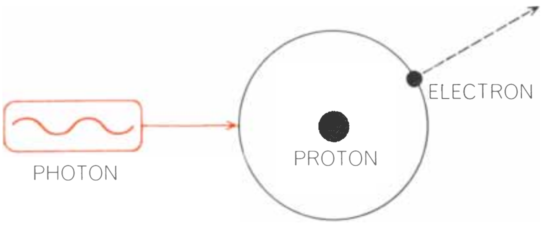
CENTRAL STARS of the Orion nebula produce most of the light visible in this photograph made by Herbig in infrared radiation. Hydrogen gas is quite faint in the infrared wavelengths. The bright patch at center contains four bright stars known as Theta-One Orionis or the Trapezium. Two brighter stars at upper right are called Theta-Two Orionis.

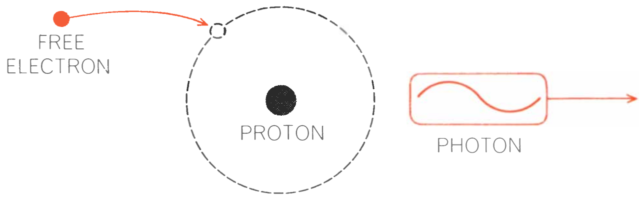
only trace amounts. Embedded in the gas is a cluster of several hundred stars. The brightest and hottest of these stars are the members of the Trapezium and Theta-Two Orionis, which have surface temperatures that range from 20,000 to 50,000 degrees Kelvin (degrees centigrade above absolute zero), as compared to less than 6,000 degrees for the sun. Because these stars are so hot, much of the electromagnetic radiation they emit lies at the extreme ultraviolet end of the spectrum, a region known as the Lyman continuum. It is this radiation that heats the gas of the nebula to incandescence.

By definition the Lyman continuum includes every wavelength at which a quantum of radiation (or photon) carries enough energy to remove the electron from a hydrogen atom that is in its "ground" state, or state of lowest energy. All wavelengths shorter than 912 angstrom units are included in the Lyman continuum. (The visible spectrum runs from 4,000 to 7,000 angstroms.) A photon whose wavelength is in the Lyman continuum is readily absorbed by a hydrogen atom; in the process the electron and proton that constitute the atom are separated and the atom is said to be photoionized. Since the nebula consists mainly of hydrogen, the photoionization of hydrogen governs the nebula's physical state.

Let us now trace what happens to the energy released from a hot star in the form of a photon in the Lyman continuum. Because the energy of the photon is usually above the minimum of 13.6 electron volts needed to ionize a hydrogen atom, there is energy left over after photoionization. This energy is carried away in the form of the kinetic energy possessed by the ejected electron, and a portion of it is subsequently transferred, through repeated collisions, to other particles in the gas cloud. Hence a fraction of the ultraviolet energy radiated by the hot stars is converted to thermal motions of the nebula.

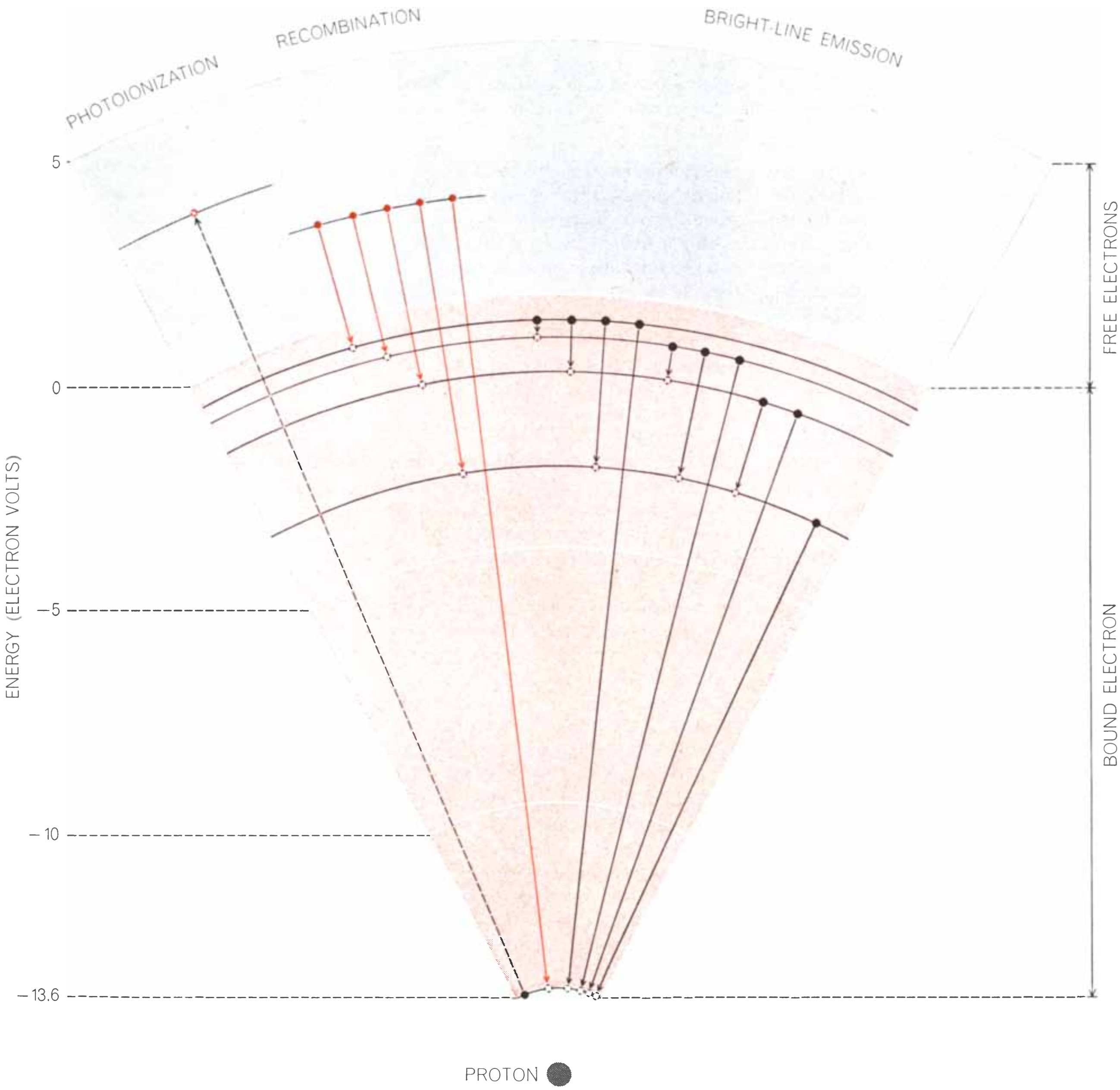
A free electron produced by photoionization will wander through the nebula for 1,000 years or so, on the average, before a chance encounter with a free proton (also produced by photoionization) will enable the two particles to recombine to form a hydrogen atom. The atom can form with the electron in the ground state or in any one of many higher energy levels. In either case the electron must give up its kinetic energy together with an amount of energy corresponding to the energy with which it is bound to the proton at its final energy level. It does this by emitting a



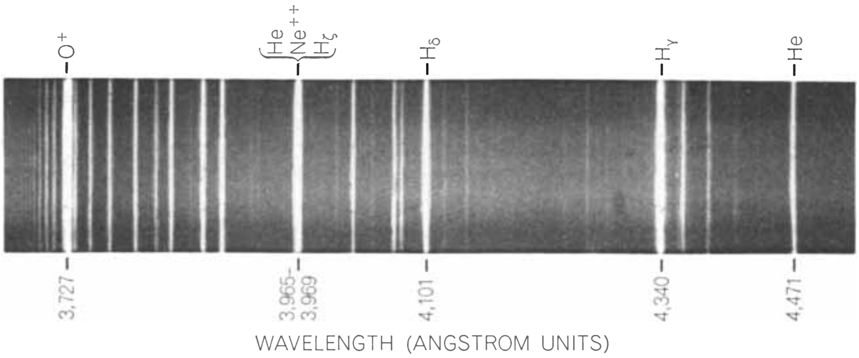


PHOTOIONIZATION of the hydrogen gas in a nebula occurs when a sufficiently energetic photon of starlight encounters an atom of hydrogen and forces the single electron of the hydrogen atom to be ejected from its "ground" state, or lowest energy level.

RECOMBINATION of a hydrogen ion (that is, a proton) and a free electron to form a neutral hydrogen atom results in the emission of a photon of visible light. The wavelength of the emitted photon depends in part on the kinetic energy of the free electron.



ENERGY LEVELS of the electron in a hydrogen atom are depicted in this diagram. Long black arcs represent energy levels of the bound electron; shorter black arcs at top left represent the kinetic energy levels of the free electrons. The scale at left indicates the kinetic energy of a free electron (*positive values*) or the energy levels of a bound electron (*negative values*). An electron that has been removed from its ground state by the process of photoionization (*broken black arrow*) may recombine directly with a proton at any one of several energy levels (*colored arrows*), emitting a characteristic photon of visible light. A bound electron may in turn "jump" from a higher to a lower energy level (*solid black arrows*), also emitting a characteristic photon.



SPECTROGRAM of the Orion nebula was made by Donald E. Osterbrock of the University of Wisconsin with the 100-inch reflecting telescope on Mount Wilson. The spectrum of the nebula consists of bright lines that are produced by the characteristic emissions of hydrogen, oxygen and other elements in the gaseous state. The wavelengths of several of these lines and the elements responsible for them are indicated. The superscript plus signs after some of the letters signify whether the element is singly or doubly ionized. The subscript Greek letters denote the characteristic emission lines of hydrogen.

photon of the proper energy. If the atom is formed at the ground level, the emitted photon will be in the Lyman continuum and will therefore have enough energy to photoionize another hydrogen atom elsewhere in the nebula. If the atom is formed at one of the higher energy levels, the photon will have too little energy to be in the Lyman continuum and will escape from the nebula without being absorbed.

If the hydrogen atom produced by recombination is at a higher energy level, it will subsequently undergo a sequence of transitions in which the electron drops to successively lower levels until it reaches the ground state. In each transition the atom emits a photon whose energy equals the change in the energy of the atom as it drops from level to level [*see illustrations on preceding page*]. Since the atom has a set of distinct energy levels, the emitted photons have distinct energies and therefore distinct wavelengths. This accounts for some of the bright lines originally observed by Huggins.

It can be calculated that a typical hydrogen atom in the Orion nebula can exist for about a year, on the average, before it is photoionized. Since its components can then remain free for 1,000 years or more before recombining, it is evident that most of the hydrogen in the nebula is ionized.

To summarize, a fraction of the energy released by the exciting stars as photons in the Lyman continuum is converted to thermal motion in the gas of the nebula, and the remainder reappears as photons of lower energy that are emitted by the hydrogen in the gas and escape from the nebula. On the average the kinetic energy of a free electron at the moment it is released by photoionization is slightly larger than its kinetic energy 1,000 years or so later, when it recombines with a proton. The energy it loses between photoionization and recombination remains in the gas as thermal energy. Every time an electron goes through the cycle of photoionization and recombination it adds a bit of thermal energy to the gas. Since temperature is directly related to thermal energy, the gas in the nebula tends to get hotter.

The temperature is kept from rising indefinitely by a cooling process that involves the emission of radiation by elements other than hydrogen, principally oxygen, nitrogen and neon. The physical evidence for this cooling process can be found in certain strong spectral lines known as forbidden lines. They are so named because they can be emitted only by a gas that is at a lower density than can be achieved in the laboratory. Densities that are sufficiently low prevail in gaseous nebulae.

The photons that produce these forbidden lines are emitted when an electron collides with an ion of some element other than hydrogen. Such an ion is an atom from which one or more electrons have been removed; in the nebular gas it is usually in its ground state. In a collision between an electron and an ion the electron can give up some of its kinetic energy and lift the ion to a higher energy level. Eventually the ion returns to the ground state either in one jump or in a series of jumps. Each transition results in the emission of a photon carrying a discrete amount of energy. These photons are not energetic enough to photoionize hydrogen atoms and thus cannot contribute to the further heating of the nebular gas. They leave the nebula and constitute the forbidden lines seen in the spectra of the Orion nebula and other gaseous nebulae [*see illustration at left*].

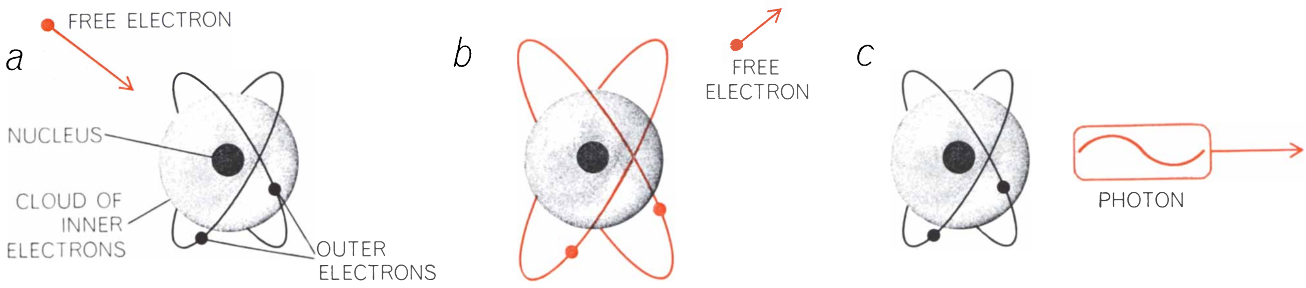
The temperature of the gas in a nebula comes to an equilibrium determined by the heating due to photoionization and recombination and the cooling due to the emission of radiation by ions that have been excited by collisions with electrons. By analyzing the strength of the forbidden lines in the spectrum of the Orion nebula it can be calculated that the temperature of the gas is about 9,000 degrees Kelvin.

From this discussion one might assume that the Orion nebula and others like it exist simply because a number of hot, blue stars happen to be embedded in masses of interstellar gas. It is now recognized, however, that this association is no accident. The clusters of stars in gaseous nebulae are very young—so young, in fact, that the gas in the nebulae must have been involved in the process of their formation.

The mechanism by which stars are formed is not understood in detail, but there is good reason to believe that the stars in a cluster are formed from a large cloud of interstellar gas. Turbulence or some other process might produce regions in the cloud in which the density of the gas is higher than the average density of the cloud. The gas in such a region can become detached from the gas in similar regions nearby, with the result that the cloud tends to break into many fragments. If such a fragment has enough mass, it will contract under the force of its own gravitation. As the fragment contracts, the temperature and pressure inside it rise steadily. Eventually the temperature and pressure at its center become so high that thermonuclear reactions begin to convert its hydrogen into helium. The energy released by the burning of hydrogen stops the contraction; at this point the gas fragment has become an ordinary star.

After the formation of the stars in a cluster there will be some interstellar gas left over from the original cloud. If the cluster contains some hot, blue stars, this gas will be heated to incandescence. The result is a gaseous nebula.

Since this picture rests on the assumption that the clusters in gaseous nebulae are quite young, let us see how their ages are determined. After a star has formed and has begun to burn hydrogen, it has a luminosity and surface temperature that are directly related to its mass. In general the more massive the star, the brighter and hotter it is.



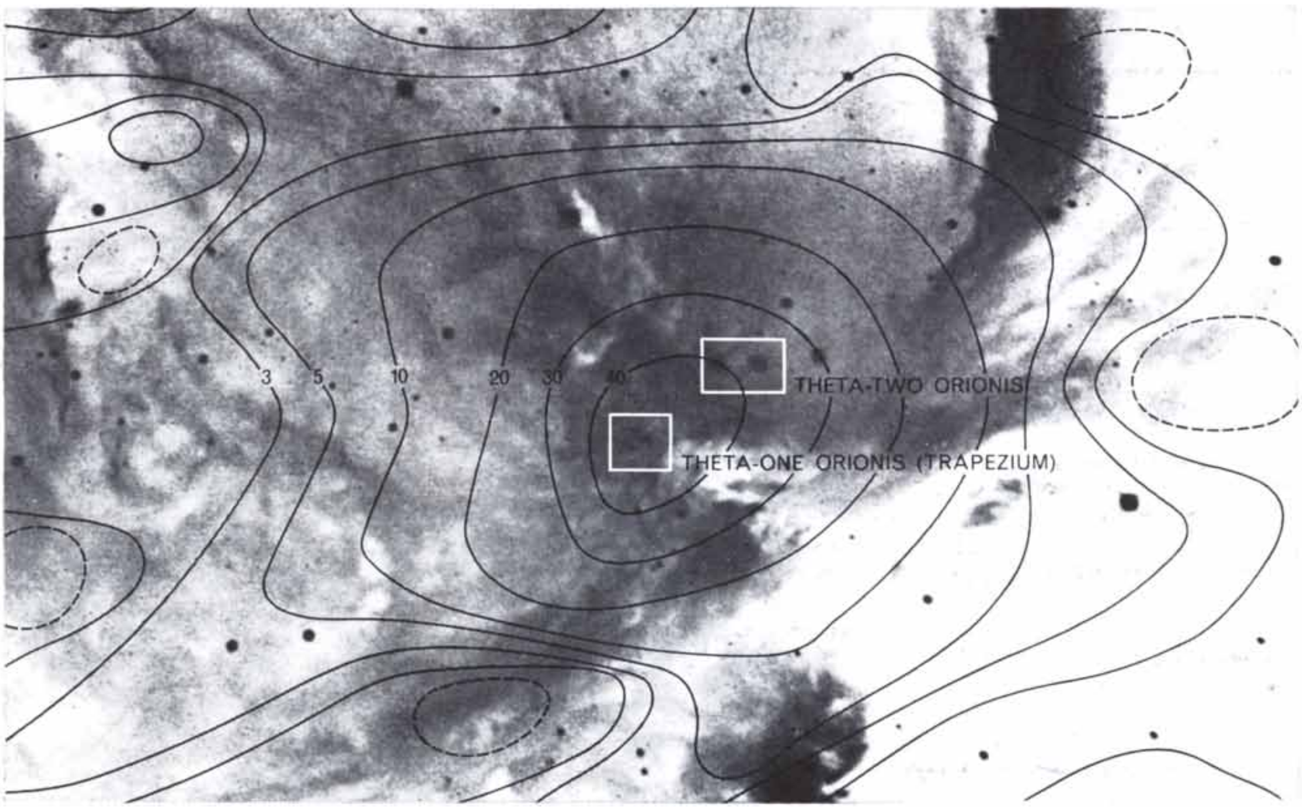
COLLISION between a doubly ionized atom of oxygen and a free electron results in the excitation of two outer electrons from their ground state (*left*) to a higher energy state (*middle*). The excited electrons can then shift back to their ground state (*right*), emitting a photon of light with a discrete wavelength. This mechanism is responsible for the so-called forbidden spectral lines of oxygen, nitrogen, neon and other elements that are emitted by a gas only at very low densities, such as those that prevail in a gaseous nebula.

When this relation is plotted, it produces what is called the "zero-age main sequence." ("Zero age" refers simply to the time at which a star has completed its formation and settled down to the normal condition of an ordinary star.)

When one plots the luminosities and surface temperatures of the stars clustered in a gaseous nebula, one finds that the cluster departs from the zero-age main sequence in two respects. The faintest and the brightest members of the cluster are found to be cooler than stars of corresponding luminosities that lie on the main sequence. These departures can be explained on the basis of the theory of stellar evolution, which shows that stars of large mass evolve more rapidly than stars of small mass.

The least massive (and faintest) stars have surface temperatures below those expected on the main sequence because they are still in the process of formation; having little mass, they contract slowly in response to gravitation. The stars of average mass contract more rapidly, and as we observe them they are burning their hydrogen normally. Hence they have reached the main sequence and exhibit the expected luminosities and surface temperatures. The most massive (and brightest) stars in the cluster contract the most rapidly of all. They also consume their hydrogen rapidly because they are so luminous and radiate so much energy. As we observe them, however, they have cooler surfaces than stars of corresponding luminosity on the zero-age main sequence because they have no more hydrogen available for conversion to helium and they have begun to undergo the change of condition that occurs when the burning of hydrogen stops.

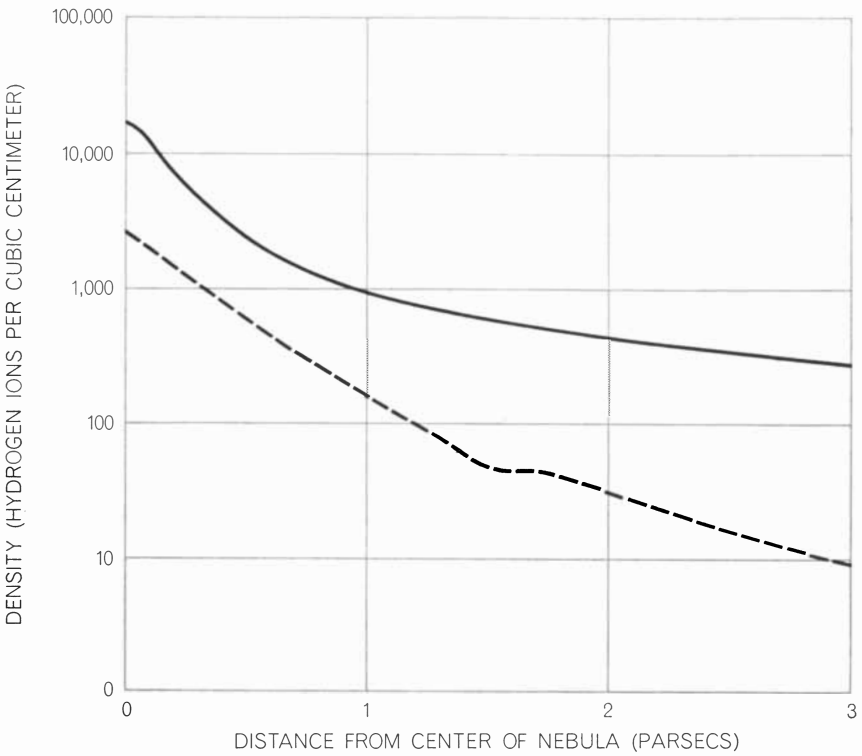
The stars that depart from the zero-



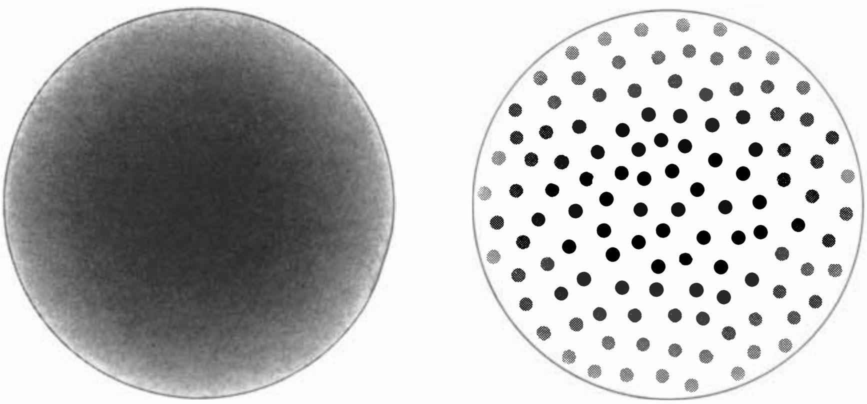
RADIO-CONTOUR MAP suggests that the Orion nebula is distributed symmetrically around a small group of stars at the center; its asymmetric appearance in direct photographs is a result of the uneven distribution of interstellar dust in foreground. The map was made by T. K. Menon of the National Radio Astronomy Observatory by measuring the distribution of radiation produced by ionized hydrogen at a wavelength of 3.75 centimeters. Distribution of gas in the nebula can then be deduced from these data.

age main sequence are evolving on a definite timetable. Consequently, with the help of the theory of stellar evolution we can use these stars to compute the age of the cluster as a whole. The clusters associated with gaseous nebulae are typically a few million years old. Specific estimates for the age of the cluster in the Orion nebula range from half a million to about three million years. Considering that our galaxy is thought to be 10 billion to 20 billion years old, such clusters are very young indeed.

The remarkable geometry of the Orion nebula and its star cluster leaves no doubt that the stars and gas are physically associated and have had a common history. The system has a well-defined center in the region of the Trapezium, which is the brightest part of the nebula and the site of the greatest concentration of stars. And although it may not appear so in photographs, the nebula is distributed quite symmetrically about the Trapezium. Its asymmetric appearance is due to the uneven absorption of light from the nebula by irregularly distributed interstellar dust in the volume of space between the nebula and us.



TWO ESTIMATES of the density of the hydrogen gas in the Orion nebula were obtained by two different techniques. Estimate derived from optical measurements of the strength of certain forbidden spectral lines emitted by singly ionized oxygen atoms (*solid curve*) ranges from 10 to 30 times larger than estimate derived from radio-astronomical measurements of the brightness of 3.75-centimeter radiation from ionized hydrogen atoms (*broken curve*). A parsec is a unit of astronomical distance equal to 3.26 light-years.

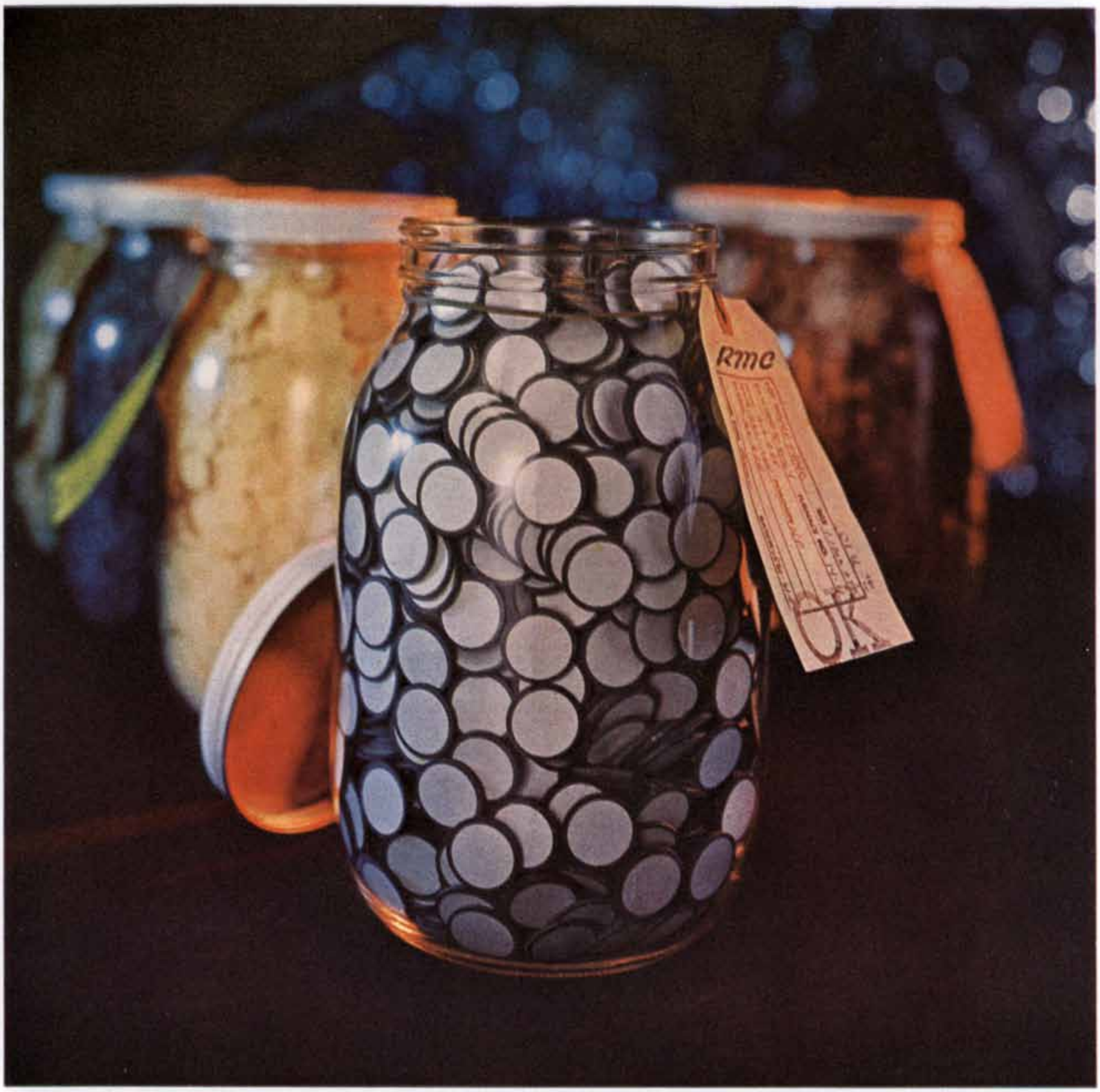


ESTIMATES CAN BE RECONCILED by supposing that hydrogen gas is not distributed smoothly throughout the nebula (*left*) but is concentrated in dense, localized regions (*right*). In the latter case the larger optical estimate would represent the higher densities in these localized regions, whereas the smaller radio-astronomical estimate would represent the average density in these regions and in the comparatively empty space surrounding them.

Since the dust is transparent to radio waves, which are also emitted by gaseous nebulae, the true shape of the Orion nebula can be investigated. Working with the 85-foot radio telescope at the National Radio Astronomy Observatory at Green Bank, W.Va., T. K. Menon has determined the distribution of radiation emanating from the nebula at a wavelength of 3.75 centimeters. The distribution turns out to be approximately circular, with the central region of highest intensity coinciding with the Trapezium [*see bottom illustration on preceding page*].

If it is assumed that this circular appearance actually represents a spherical cloud of ionized hydrogen, the variation in radio brightness can be used to calculate the distribution of the gas in space. The emission at radio frequencies arises from the collisions of electrons and protons; therefore the rate at which small unit volumes of gas emit radiation depends on the density of electrons and protons and on their kinetic energy, which is equivalent to the temperature of the gas. Menon assumed a temperature of 10,000 degrees K. and computed the distribution of electrons and protons needed to produce the observed variation in radio brightness. He found that the density of the gas varies from about 2,500 ionized hydrogen atoms per cubic centimeter at the center of the nebula to about 10 ionized atoms per cubic centimeter at a distance of three parsecs (roughly 10 light-years) from the center.

A similar computation of the density can be made using the strength of the forbidden lines in the nebula's optical spectrum, since these lines also result from collisions in the gas. The pair of lines emitted by singly ionized atoms of oxygen (atoms that each lack one electron) at the wavelengths 3,726 and 3,729 angstroms was used for this purpose by Donald E. Osterbrock and Edith M. Flather of the University of Wisconsin. The densities obtained from this analysis are 10 to 30 times larger than those computed by Menon. Osterbrock and Miss Flather showed that this kind of discrepancy would occur if the gas was not distributed smoothly throughout the nebula but was concen-



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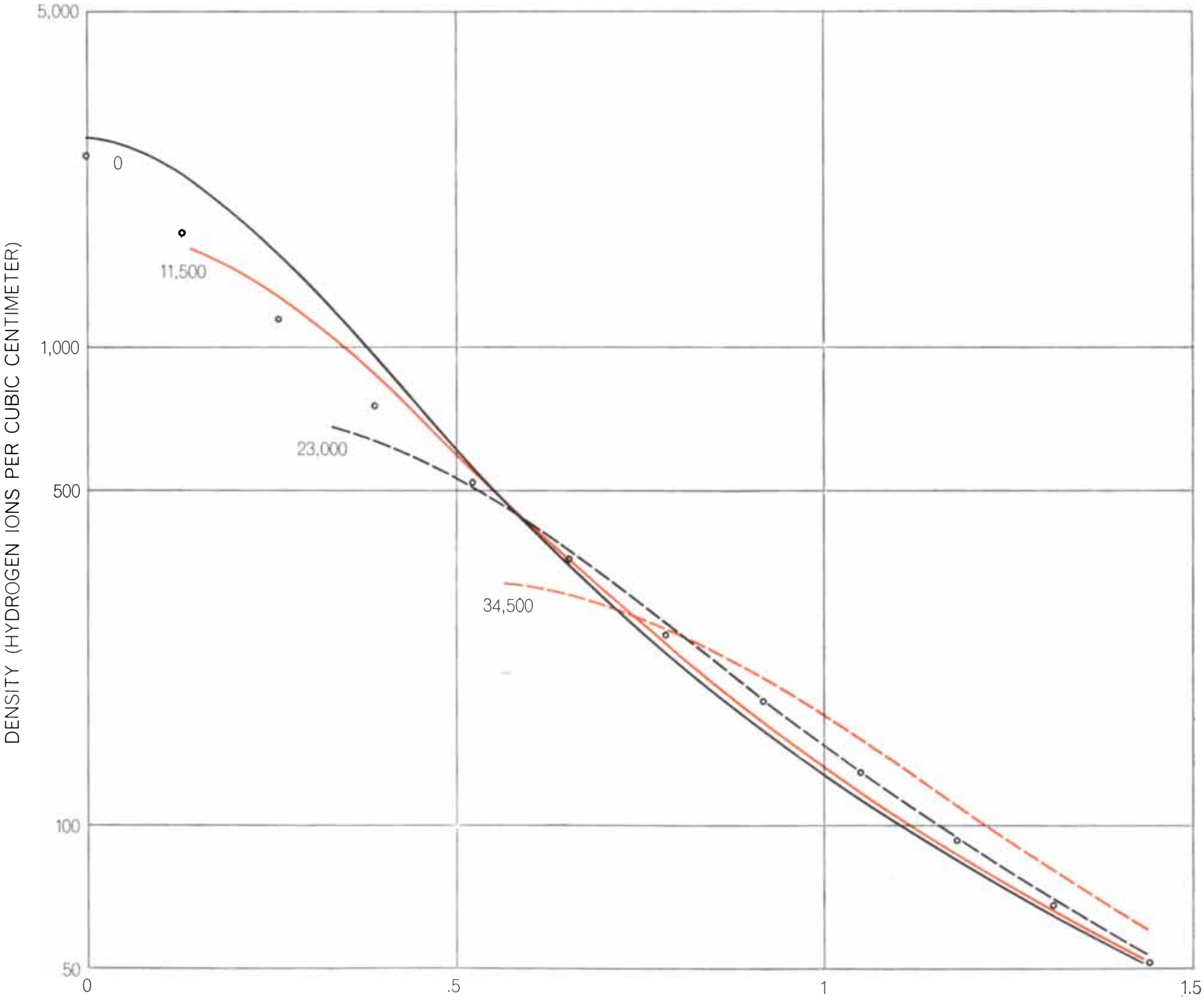
trated in regions of high density that occupied only a fraction of the total nebular volume.

Another feature of the nebula that can be investigated spectroscopically is the motion of the gas. This is done by measuring the Doppler shifts in the wavelengths of various spectral lines with respect to their normal wavelengths. The most recent and extensive such study has been made by O. C. Wilson, Guido Münch, Miss Flather and Mary F. Coffeen at the Mount Wilson and Palomar Observatories.

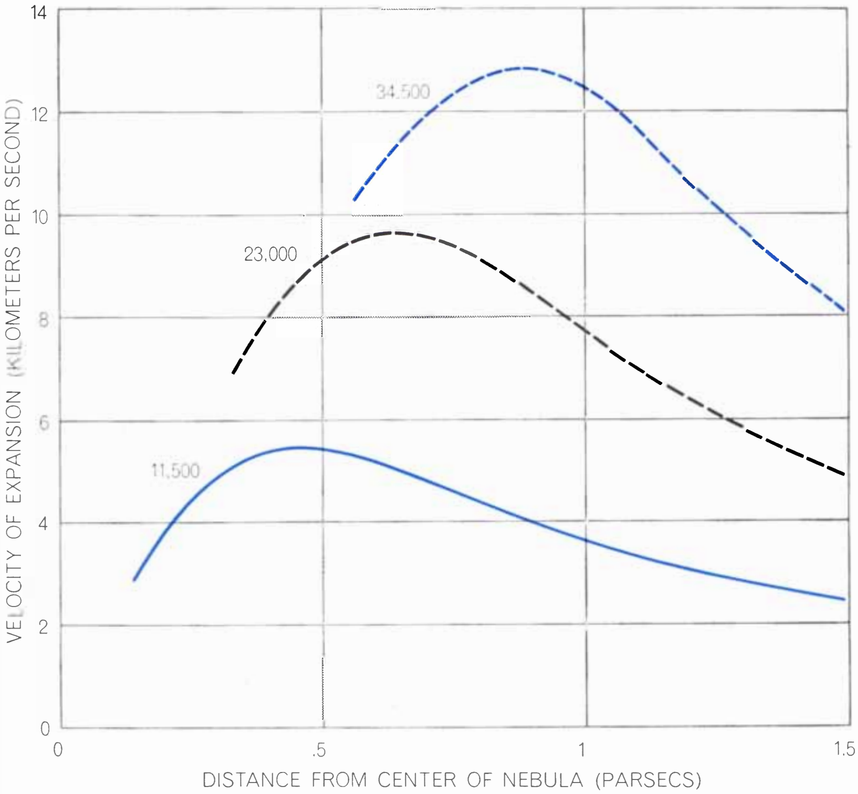
Their work shows that the motion of the gas can be resolved into two components. The first is a highly irregular pattern of turbulent motions. Different portions of the gas are moving with respect to one another with velocities as high as 25 kilometers per second, or about 60,000 miles per hour. The second component is a general expansion of the nebula and is made up of two subcomponents. One subcomponent, derived from the lines of singly ionized atoms of oxygen, shows an expansion velocity of about seven kilometers per second; the second subcomponent, derived from the lines of doubly ionized atoms of oxygen, shows an expansion velocity of about 10 kilometers per second.

The difference between the two values is significant: it indicates that different regions of the Orion nebula are expanding with different velocities. The oxygen in the nebula is photoionized by the ultraviolet radiation of the brightest stars in much the same way the hydrogen is. Since the amount of ultraviolet radiation is considerably larger in the central region of the nebula, where these stars are located, than in the outer regions, each atom tends to be doubly ionized if it is near the center of the nebula but only singly ionized if it is in the outer parts. It therefore appears that the region expanding at only seven kilometers per second is farther from the center of the nebula than the region expanding at 10 kilometers per second.

With these various observational results available I became interested in trying to develop a theoretical model of the Orion nebula that would test current ideas about the formation and expansion of gaseous nebulae. According to these ideas the Orion nebula



THEORETICAL DISTRIBUTION of hydrogen gas in the Orion nebula was calculated by the author for four different stages in the expansion of the nebula; the age in years associated with each distribution curve is indicated. Small open circles represent density estimates derived from radio-astronomical measurements. These estimates appear to fit the theoretical values best at an age between 11,500 and 23,000 years. Because of technical difficulties the densities near center of the nebula have not been calculated.



THEORETICAL VELOCITY OF EXPANSION of Orion nebula was calculated for three different ages in life of nebula. Model attains observed velocity of expansion (about 10 kilometers per second) only at an age of about 23,000 years (*broken black curve*).

must have been a stationary cloud of cold, un-ionized gas with a temperature of about 100 degrees K. before the exciting stars formed and began heating the gas. Once the gas was heated its pressure was much greater near the center of the nebula than in the outer parts because the gas is so highly concentrated near the center. The expansion of the nebula results from this excess pressure at the center.

To construct a theoretical model of the expansion of the Orion nebula I had to guess the initial distribution of the un-ionized gas in the original cloud. I then assumed that the exciting stars began radiating abruptly in the Lyman continuum. When I calculated how the gas became ionized and heated, I found that both processes occurred very rapidly without setting the gas in motion. To calculate the expansion of the gas it was necessary to solve the equations of motion that describe the acceleration of the gas in response to the excess pressure at the center. The results of these calculations can be shown by plotting the calculated density and velocity of expansion at various distances from the center for successive times during the expansion [*see illustration on preceding page and illustration above*].

The model shows that 23,000 years after the initial heating of the gas the velocities of expansion in regions not too far from the center are as high as 10 kilometers per second and that outside these regions the velocities decrease with increasing distance from the center. At about the same time, or perhaps slightly earlier, the model has a distribution of gas density that is quite close to that derived from the observations by Menon. (Menon's distribution, rather than the higher values found by Osterbrock and Miss Flather, is the correct one to use in this comparison because it gives the average density of gas in the nebula.) Thus at an age of 23,000 years the model gives a satisfactory representation of the present, *observed* state of the Orion nebula. (We of course are seeing the nebula as it actually existed when its electromagnetic radiation left it some 1,500 years ago.)

Although this agreement seems to indicate that the model does represent the expansion of the Orion nebula, the model must be viewed with important reservations. For example, a period of between 10,000 and 20,000 years is required for the formation of one of the exciting stars, so it is a crude approximation to treat the onset of their radiation as abrupt. Moreover, the model neglects fluctuations in density and the turbulent motions of the gas. Nevertheless, it is reasonable to conclude that the age of the Orion nebula, measured from the time when radiation in the Lyman continuum first ionized and heated the gas, is on the order of 20,000 years.

The age of the exciting stars cannot be much different, because the age of the nebula determines the time at which the exciting stars became luminous. As it happens, there is an independent line of evidence that supports a low age for these stars. Several years ago the Soviet astronomer P. P. Parenago studied the motions of the four stars in the Trapezium and found that they are moving away from each other at such velocities that if they were formed close together, which seems likely, they would have moved to their present positions in just about 10,000 years. This establishes their approximate age, because if they were much older than that, they would now be much farther apart.

It seems entirely reasonable, then, that although most of the members of the cluster of stars embedded in the Orion nebula are about a million years old, the stars in the Trapezium, the two stars in Theta-Two Orionis and the Great Nebula itself are somewhere between 10,000 and 23,000 years old. This range in estimates is quite satisfactory when one considers the uncertainties involved.

Not many years ago astronomers assumed as a working hypothesis that all the stars in a given cluster were formed at a single, moderately well-defined time. The first important evidence against this view was presented in 1962 by George H. Herbig of the Lick Observatory, who showed that in some clusters (including the cluster in the Orion nebula) the faintest stars seem to be significantly older than the brighter stars. The low age now found for the Orion nebula and its exciting stars is consistent with Herbig's results.

If the Orion nebula and its exciting stars were formed no more than a few thousand years ago, it is quite likely that similar stars and nebulae are in the process of forming even now. If we can improve our understanding of the past history of the Orion nebula, we may learn to recognize clouds of interstellar gas in which gaseous nebulae will form in the future. But it is to the astronomers of the distant future that we must leave the task of observing such clouds as they become luminous and achieve the prominence that now belongs to the Great Nebula in Orion.

The Greeks and the Hebrews

The relation between these two peoples of the ancient Mediterranean is seldom mentioned. Evidence that the oldest language of Crete is Semitic, however, suggests that the two cultures have common roots

by Cyrus H. Gordon

The classical civilizations of Greece and Judea have traditionally been regarded as entirely distinct cultures, yet today two lines of evidence are combining to support the hypothesis that they have a common background. One line of evidence falls within the realm of historical and literary scholarship; the strength of its case lies in vivid parallels between early Greek and early Hebrew literature. The other is essentially archaeological and linguistic: in the past few years it has become increasingly apparent that the oldest inscriptions found on the island of Crete are written in a Semitic tongue. My own familiarity with both kinds of evidence arises from the study of the ancient texts, monuments and history of the Mediterranean; it is coincidence rather than intention that has brought me to this dual examination.

One profound but not always recognized result of the overthrow of the medieval age of faith by the modern age of skepticism was a suspension of belief in the historical validity of both Holy Scripture and pagan legend. On the one hand, the narratives of the Old Testament were often viewed exclusively as sacred writings with no relation to reality; on the other, the Greek legends that reflect the history of another area of the eastern Mediterranean in a period roughly contemporaneous with the Old Testament were often downgraded to a status only a little superior to nursery tales. Greek thought and Hebrew religion, however, continued to command general respect. One consequence of this view is that "rational" Greece and "spiritual" Israel have been kept poles apart in Western thought, as though the ancient Greeks had never known religious inspiration and their Semitic neighbors had been devoid of reason.

The rise of skepticism undoubtedly played an invaluable role in freeing men's minds from the fetters of superstition. It is significant, however, that it required an almost childlike faith in the validity of ancient literature to open the modern era of archaeological discovery. The great 19th-century archaeologist Heinrich Schliemann loved and believed in Homer. If Schliemann had not trusted the *Iliad,* he would never have sought, let alone uncovered, Troy and Mycenae (after which the earliest Greek civilization is named). Arthur Evans, who believed in the historical reality of the legendary King Minos, dug at Knossos on Crete and revealed Minoan civilization. Scholars who believed in the historical veracity of Scripture similarly uncovered the buried cities not only of the Holy Land but also of the entire Old Testament world from Iran to Egypt.

Until quite recently biblical archaeologists have had an advantage over their colleagues who study ancient Europe. Before the 19th century there were no intelligible texts older than Homer and the Bible; everything earlier was therefore "prehistoric." Old Testament studies were radically changed by the decipherment in the 19th century of Egyptian hieroglyphics and Babylonian cuneiform. The parallel Greek and Egyptian inscriptions on the Rosetta stone and Darius' trilingual cuneiform texts at Behistun in Iran were keys that eventually helped the decipherers to extend the span of recorded history back to about 3000 B.C. At the turn of the century Evans found a number of Cretan gem stones and other objects engraved with either realistic or stylized pictographs. He also found many clay tablets inscribed in the related Cretan scripts called Linear A and Linear B, but since no one could decipher them classical archaeologists continued to call Minoan and Mycenaean civilization "prehistoric."

In 1928 a Mycenaean tomb was uncovered by a plowman at the ancient site of Ras Shamra in Syria. Archaeologists were quick to react to this evidence of Greek connections with an ancient Semitic region. Beginning in 1929, French expeditions under Claude F. A. Schaeffer have worked steadily at Ras Shamra. Among the many treasures that have been uncovered are inscribed tablets, dating from the early 14th century B.C. to the early 12th century, that record a rich epic literature in a northwest Semitic dialect akin to Phoenician and biblical Hebrew. The city at Ras Shamra was soon identified as ancient Ugarit. Its narratives not only acknowledge a debt to Minoan Crete but also contain many parallels bridging the gap between Homer and the Bible. Ugarit's god of arts and crafts is described in the texts as having his workshop on Crete and as having come originally from Egypt. The hero of one major epic poem, King Kret (whose name is reminiscent of Crete), is involved in the loss and recovery of a destined bride paralleling King Menelaus' classic difficulties over Helen in the *Iliad.*

In reading Homer most of us are inclined, consciously or unconsciously, to impose the cool virtues of Western medieval chivalry on the actions of the Greek heroes; King Kret, in contrast, is unabashedly Oriental. Deprived of his betrothed, his first action is to summon up El, the head of the Ugaritic pantheon, in hysterical fashion:

He enters his chamber and cries
While repeating words he weeps

His tears are shed like shekels
earthward
Like fifth-shekels on the bed.
As he cries he falls asleep
As he weeps deep sleep overcomes him
Yea he lies down in deep sleep.
Then he is startled!
For in his dream El descends
In his vision the Father of Man.
He draws near, asking Kret:
"Who is Kret that he should cry?
E'en the Good One, Lad of El, that
he should weep?"

The friendly El lends a helping hand; he instructs Kret in the ritual necessary to win the aid of the redoubtable deity Baal and advises him to march with an army to the city of Udum, whose king, Pebel, is holding Kret's destined bride. Kret is warned that Pebel will try to buy him off with rich gifts; he is to reject the bribe and to demand the maiden as follows:

"What need have I of silver and
yellow gold
A share of her estate
And eternal slaves
Three horses and a chariot
From the yard of a handmaid's son?
Nay, what is not in my house you
shall give.
Give me the Lady Hurrai
The well-bred
Your firstborn
Whose charm is like Anath's charm
Whose beauty is like Astarte's beauty."

In considerably less time than it took the Greek armies to capture Troy, Kret gets the girl; later El blesses the marriage:

El takes a cup in the hand
A goblet in the right hand . . .
"The wife that you take, O Kret,
The wife you take to your house
The girl you bring into your court
Shall bear you seven sons
And an eighth (a daughter), Octavia."

At this time in the eastern Mediterranean, on the eve of the emergence of the Greeks and the Hebrews as historical peoples conquering their own "promised lands," it is not surprising that epic literature should concern itself with the heroic adventures of royalty. In both Ugaritic and Homeric literature the aristocrats alone are worthy of attention. Nonetheless, when one finds such a basic theme of the *Iliad*—a royal quarrel over an abducted woman, conducted with the assistance of the gods—

ROYAL HUNT is depicted on the interior of a gold basin found at Ras Shamra (*details are shown in the drawing below the photograph*). The charioteer-king pursues a bounding ibex; a group of cattle (two bulls, a cow and a bull calf) completes the scene. Horses, dog, chariot and hunter resemble those in similar scenes from Egypt and Greece; only the royal hunter's beard looks distinctively Semitic. Seven inches in diameter, the basin was made after 1450 B.C. but before 1365 B.C., following the Mycenaean occupation of Knossos.

foreshadowed in the literature of a Semitic city in the 14th century B.C., familiar literary material appears in a fresh light and old faces take on a new cast. The narrative of Abraham in Genesis, for example, shows a similar coloring of royal epic.

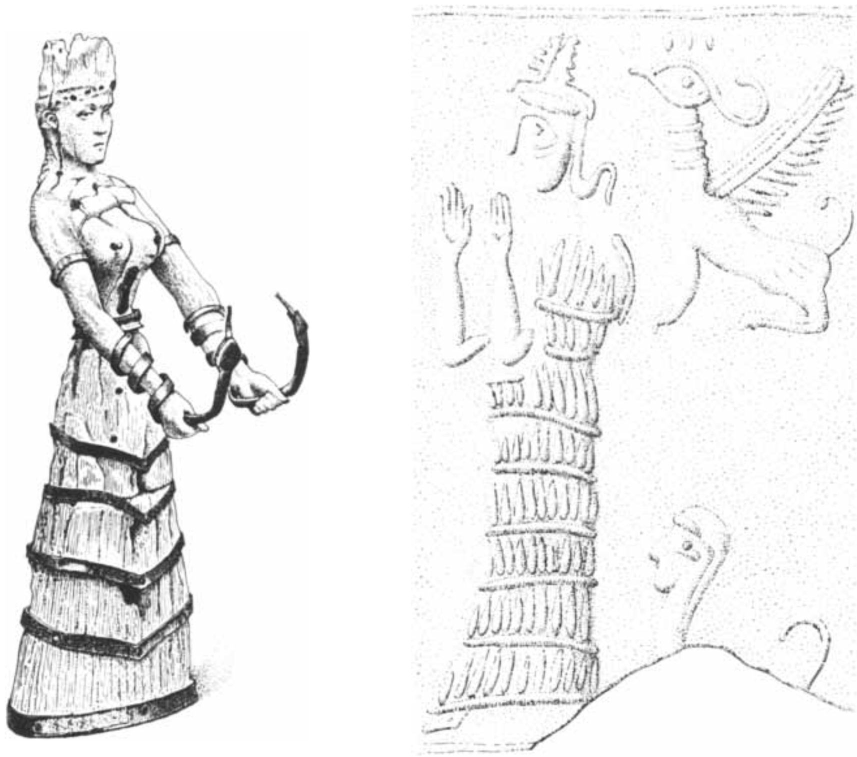
Of Abraham and Sarah it is said respectively, "Kings shall stem from you" and "Kings of peoples shall issue from her" (Genesis 17). Abraham commands his own troops; he heads a coalition with three other chieftains to vanquish a coalition of invading kings (Genesis 14). Twice Sarah is taken away from him—into the harem of Pharaoh and later into the harem of the Philistine king Abimelech. Both times Abraham recovers her unsullied (as Achilles did Briseis, although Menelaus was less fortunate in the case of Helen). Thanks to the bridge provided by the Ugaritic epic, the sense of these familiar biblical texts is enriched.

The reader may well ask why the discovery of a Ugaritic epic was required in order to evoke the hypothesis that both the Semitic and the Greek classics have a common eastern Mediterranean background. The answer lies not in any lack of ancient parallels but rather in the artificial boundary between the two cultures that is built into our education. Both ancient Greece and ancient Israel recognized the strong bonds that had united them from remote times. The Hebrews included the Ionian Greeks in the Table of Nations; Noah's son Japheth (whose name is equated with Iapetos, one of the Titans of Greek myth) numbered Javan (Yawan, the ancestor of the Ionians) among his sons (Genesis 10). If it is assumed that the Japheth of the Table of Nations is the same as the Japheth of Noah's blessing (Genesis 9:27), a particularly close relation between the ancestors of the Greeks and the Hebrews can be inferred from the text: "May God make room for Japheth, that he dwell among the tents of Shem." Nor is tented pastoralism the sole Semitic way of life recorded in the Old Testament. The Israelite tribes of Zebulun, Dan and Asher are described as seafaring peoples: "Zebulun shall dwell by the sea coast, yea he is by the coast of ships with his flank by Sidon"

CRETE'S EASY ACCESS to the seaports of three continents made the island a strategic base for the Semitic sea lords of the second millennium B.C. From Crete their merchant vessels could call on the European mainland, on the eastern Mediterranean coast of Asia and on the African littoral from the Nile delta westward. Cretan sites famed for their inscriptions are located on the map; Linear B tablets have also been unearthed at Mycenae, Pylos and Thebes. Hattusa, in eastern Anatolia, was the Hittites' capital city.

(Genesis 49:13); "Why does Dan stay in ships and Asher live by the sea coast, dwelling by his harbors" (Judges 5:17). Evidently some Hebrew tribes shared the seas with such nautical peoples as the Phoenicians and the Greeks.

The Greek legends are even more explicit about ancient ties with the Semites. King Minos, the Greeks said, was the son of Europa, herself a princess of Semitic Phoenicia. Another Phoenician (albeit one from Africa), Danaos, became king of Argos; after him the early Greek heroes were called Danaoi. Moreover, Europa's brother, Cadmus, became king of Thebes and introduced the art of writing to Greece. Scarcely two years ago the historical kernel of the Cadmus legend was underscored when a hoard of cylinder seals from western Asia, dating back to the 14th and 13th centuries B.C., was accidentally uncovered by construction workers at Thebes.



FLOUNCED SKIRT is worn by a goddess with extended arms, worshiped both in Mesopotamia and the eastern Mediterranean. The Cretan divinity (*left*) wears a five-tiered skirt; the goddess represented on a cylinder seal from Ugarit (*right*) is dressed in similar fashion.

The study of Ugaritic texts has occupied my attention for some years. In the light of the ties between Ugarit and Crete and the parallels between early Hebrew and early Greek literature, I took a special interest in Michael Ventris' brilliant achievement of 1952, which demonstrated that one kind of inscription from Crete, known as Linear B, recorded Greek words in a system of syllabic signs. Of the three principal kinds of inscription found on Crete, Linear B is the youngest, dating from the 15th century B.C. and thereafter. Linear A was in use before 1700 B.C. Oldest of all are the pictographs, some of which may have been inscribed as early as 1800 B.C. All three systems, however, overlap chronologically. Many of the pictographs are repeated in simplified outline in both the Linear A script and the Linear B.

After Ventris' breakthrough a straightforward situation presented itself. Since the scripts of the Linear B and Linear A tablets used essentially the same signs for the same sounds (a number of identical names appear in both systems), it should now have been possible to decipher Linear A, provided that the language it recorded belonged to a known family. Chronologically the language should have been that of the Minoans, who preceded the Greeks on Crete. Minos, the king of the Minoans, had had a Phoenician mother. Could Minoan be a Semitic language?

The first evidence I could uncover favoring such a view consisted of a tablet bearing an inventory of pots, recorded both in pictographs and in Linear A [*see illustration on page 109*]. Ventris' decipherment had been confirmed by a similar inventory in pictographs and Linear B. In December, 1956, by applying the phonetic values established by Ventris to the Linear A signs on the pot-inventory tablet, I proved to my satisfaction that several of the Minoan words were Semitic names for different kinds of pots.

The bulk of the tablets uncovered on Crete, whether in Linear A or Linear B, are simply inventories. There are, however, 18 inscriptions in Linear A that appear on stone objects apparently dedicated as votive offerings at various Minoan shrines. In 1961 the British scholar W. C. Brice published a new edition of these and other Linear A inscriptions, containing drawings and photographs superior in clarity to anything previously available. An examination of the 18 texts confirmed my suspicions of five years earlier. Rendered phonetically, the inscriptions recorded a Semitic dialect closely related to Ugaritic, Phoenician and Hebrew. Unlike the inventory tablets, these inscriptions show sentence structure; one libation table, for example, bears an inscription stating that it was donated "so that the city may thrive."

The 18 texts come from a variety of sites in eastern and central Crete; this distribution indicates that the Semitic language of the inscriptions was not some localized dialect but the official language of all Minoan Crete. Thus the tongue of the people who controlled the island's administration and religion was of the kind the ancient Greeks called Phoenician. This does not mean that the population of Crete during this period was exclusively Semitic. For example, the Linear A tablets provide many personal names; some, such as David, are Semitic but others are not. A number of the names are Egyptian; at least two are names that were common among the Hurrians, a non-Semitic people of Asia Minor.

The largest single group of Linear A texts—some 150 of them—are from the site known as Hagia Triada. They include ritual texts recording offerings of food and drink to such West Semitic gods as Addu (one of Baal's alternate names) and Yamm (the sea god corresponding to Poseidon), to the goddess Tinit and to three other deities familiar in Ugaritic texts: Kret, the deified hero, Agaru and Gupanu (as well as Gupanu's female counterpart Gupanatu).

Still another kind of writing to be found on Crete consists of relatively recent but unintelligible inscriptions cut

PHAISTOS DISK is inscribed on both faces with a spiral text written in pictographs. The lines separating groups of pictographs presumably mark off individual words. Although not the same as Egyptian hieroglyphs, the symbols appear to have originated in the Nile delta. Several of them can be recognized in simplified form among the symbols of Crete's two scripts: Linear A and Linear B.

in stone and using Greek letters. Scholars call these enigmatic inscriptions "Eteocretan," which is to say "genuine Cretan"; the implication is that, even though Greek letters are used, the language they record is the original tongue of Crete. These inscriptions are generally dated between 600 and 300 B.C. In 1962 I studied four Eteocretan texts; they proved to record a late stage of the Minoan language. Since that date, decipherment of two bilingual inscriptions, in Greek and Eteocretan, has further affirmed this identity.

We now know enough Minoan to read the Semitic nouns for four different kinds of pots, for "wine" and "wheat," for "town" and "city," for "people," "man" and "mother." We can decipher the verbs "to be," "to give" and "to set up as an offering," the pronouns "he," "his" and "all," the numbers "seven," "nine" and "10," the conjunction "and" and the preposition "to." We can translate synonymous phrases, such as "fellow citizens" and "people of his city," in which all the elements are West Semitic.

It has taken eight years to achieve these modest gains. It came as a blow to me to discover recently in the writings of a fourth-century Latin author, L. Septimius, that the dissolute Emperor Nero (who ruled from A.D. 54 to 68) recognized ancient texts discovered on Crete during his reign as being Phoenician. In effect, the decipherment of Linear A amounts to the rediscovery of what was still known in Rome during at least the first four centuries of the Christian era. How much time and labor might have been saved had more credence been given to L. Septimius!

Minoan script employs the principle of acrophony; this means that the phonetic value of each symbol is the opening sound of the word it depicts. How acrophony works can be demonstrated by applying it to some of the pictographs on the Phaistos disk, which is the most noteworthy pictographic text discovered on Crete [*see illustrations on this page*]. For example, the pictograph of a man on the disk is equated with the Ugaritic word for "man," *bunushu;* thus the pictograph stands for the syllable "*bu*." This is the phonetic value established by Ventris for the Linear B form of the same sign, the pictographic origin of which he did not surmise.

One of the two commonest "words" on the Phaistos disk—it occurs five times —is a pictograph of a horn plus one of a bird. The Semitic word for "horn" is *k(a)rn,* and in this case we assign the syllable *kr* (with the vocalic *r*, as in the English word "butter") to the horn pictograph. The Ugaritic and Syriac word

PHAISTOS DISK	LINEAR A	WORD DEPICTED	PHONETIC VALUE
	VARIANT	*BUNUSHU* = MAN	*BU*
	VARIANT	*KUDR* = BIRD OF PREY	*KU*
	VARIANT	*TUPPÛḪ* = APPLE	*TU*

ACROPHONIC PRINCIPLE provides that the phonetic value of a symbol consist of the opening sound of the word depicted by the symbol. In the three cases illustrated the phonetic values for the symbols in linear script were determined independently by the late Michael Ventris. The author has related two of these script symbols to pictographs appearing on the Phaistos disk and has also demonstrated, in all three cases, that commonplace Ugaritic words for the objects portrayed yield the correct acrophonic sounds.

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for a bird of prey is *kudr,* and we assign the syllable *ku* to the bird pictograph. This is the same value determined by Ventris for the pictograph's Linear B equivalent on the basis of quite different—and purely cryptanalytic—reasons. "Horn" plus "bird" is thus pronounced *kr-ku,* which probably means "town." (In the Eteocretan texts "town" is spelled *kark* in unmistakable Greek letters.) A number of additional readings from the disk are possible. My colleagues and I interpret one sequence of nine signs, divided into two word groups, as declaring "I have eaten in the house of Haddu." (Haddu, a variant of Addu, is another name for Baal.) Although we are a long way from achieving a complete and consistent decipherment of the Phaistos disk, I suggest that it bears a ritual text associated with a shrine to Baal in the palace at Phaistos.

The bird pictograph on the Phaistos disk also appears, in a modified but recognizable form, on a bowl found near Apodulu. Another pictograph on the bowl is evidently an apple—*tuppûḫ* in Ugaritic and *tuffâḫ* (plural) in Arabic. Ventris established the value *tu* for the equivalent of this sign in Linear B; perhaps we now know why. In learning English the pupil says "*a* is for *apple*"; in learning early Minoan he may have said "*tu* is for *tuppûḫ*."

What do these text decipherments and parallels between early Greek and early Hebrew literature suggest? In my opinion the conclusion is inescapable that both the Greek and the Hebrew heritage are rooted in a single cosmopolitan culture that flourished throughout the eastern Mediterranean during the second millennium B.C. with Crete as its major center. From this viewpoint the still unreconstructed history of the region before, during and somewhat after this era must in general have unfolded along the following lines.

Starting in the fourth millennium B.C., before writing was widespread, Sumerian civilization had already arisen in Mesopotamia and Egyptian civilization in the Nile valley. Both cultures required contact with the outside world. Sumerian life demanded a supply of stone and metal, and the native soil yielded neither. Egyptian fleets and caravans brought raw materials and finished goods to Egypt from widely separated regions of Asia and Africa. Travel was of course slower then than it is now, but the ancients got there just the same; what they lacked in velocity they made up in patience.

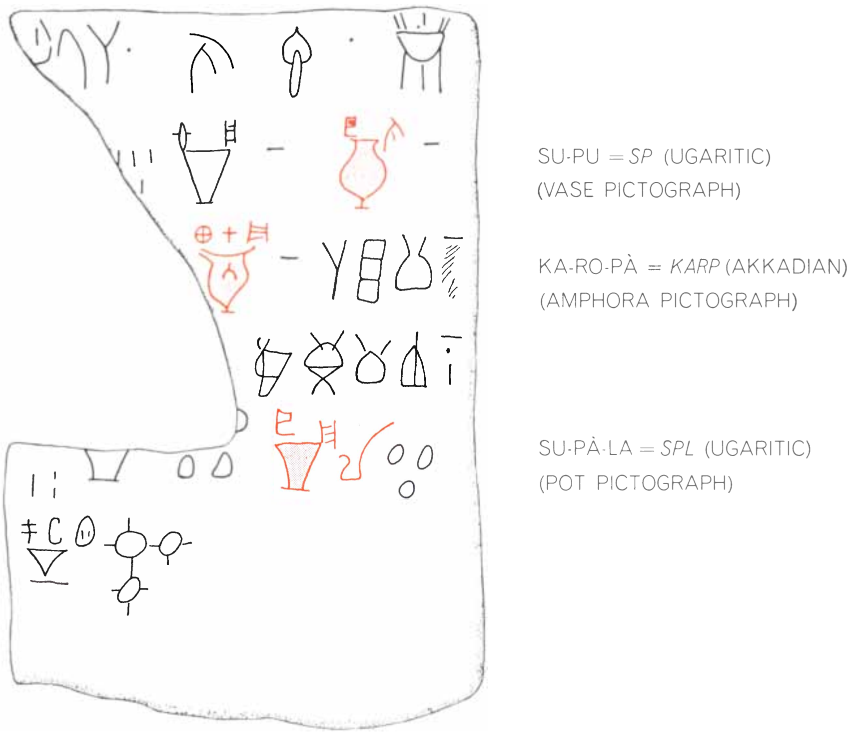
Both material and cultural interchange was effected by itinerant merchants and by the establishment of commercial offices and colonies abroad. Not only goods but also people were imported and exported as commodities; a craftsman who could turn out a useful product was a more valuable acquisition than mere samples of his wares. The process of cultural diffusion was more often than not peaceful, because traders usually prefer the stability of peace to the uncertainties of war. But then as now wars brought in their wake waves of refugees who carried their talents to other lands.

All these forms of cultural mobility operated in the Mediterranean region during prehistoric times. By the third millennium B.C. there occurred in the eastern Mediterranean an intermingling of several gifted peoples, some of whom were literate. The Sumerians and their Semitic contemporaries and successors, the Akkadians, fostered commercial interests throughout the Levant. Occasionally they backed up those interests with invasions, culminating in Sargon's and Naram-Sin's waves of conquest that reached the shores of the Mediterranean between 2400 and 2300 B.C. Meanwhile Egypt was also trading in the Levant and had established colonies at such key Levantine ports as Byblos.

We must not regard those ancient empires as separated from each other by rigid boundaries. Instead they were interpenetrating commercial empires. Mesopotamia and Egypt had common interests in Syria and Palestine; they learned to live with each other because it was good business. At the same time they were natural rivals because they were the only lands in the Near East with agricultural resources that could maintain an enduring high civilization.

Canaan (as Syria and Palestine together were then known) was a land bridge between Africa and Asia. Coastal shipping connected its shores with the rest of the Mediterranean region; its Red Sea ports on the Gulf of ʻAqaba joined it to East Africa and the Indian Ocean. Caravans brought to or through Canaan the products of many lands, including the frankincense and myrrh of Arabia Felix. Indo-Europeans—that is, those who spoke languages related to Sanskrit, Greek, Latin and many others, including English—penetrated the eastern Mediterranean in increasing numbers from 2000 B.C. on. Some of them founded the Hittite Empire in Anatolia; the Hittites served as a link between savage Europe and civilized Asia and came to rival Mesopotamia and Egypt in the exploitation of Canaan.

Even earlier a group of western Semites, speaking dialects closely related to



INVENTORY OF POTTERY, from Hagia Triada, combines Linear A symbols with pictographs that show what types of vessels are being counted. In three cases (*color*) when the author used the phonetic values established for the symbols by Ventris, he found the resulting words to be Semitic names for various pot types (*see syllables and equivalents, right*).

UGARITIC	PHONETIC EQUIVALENT	HEBREW	GREEK	LATIN
𐎀	a	a	a	a
𐎁	b	b	b	b
𐎂	g	g	g	C
𐎃	ḫ			
𐎄	d	d	d	d
𐎅	h	h	E	e
𐎆	w	w		F
𐎇	z	z	z	
𐎈	ḥ	ḥ	H	h
𐎉	ṭ	ṭ	T	
𐎊	y	y	I	i
𐎋	k	k	k	k
𐎌	š			
𐎍	l	l	l	l
𐎎	m	m	m	m
𐎏	ḏ			
𐎐	n	n	n	n
𐎑	ẓ			
𐎒	s	s	X	
𐎓	ʿ	ʿ	O	o
𐎔	p	p	p	p
𐎕	ṣ	ṣ		
𐎖	q	q		q
𐎗	r	r	r	r
𐎘	ṯ	Š	s	s
𐎙	ǵ			
𐎚	t	t	t	t
𐎛	i			
𐎜	u		u	u
𐎝	ś			

CUNEIFORM CHARACTERS (*extreme left column*) **are transcribed from one of several 14th-century B.C. alphabet tablets unearthed at Ugarit. As the remaining columns indicate, all of the Hebrew alphabet and most of the Greek and Latin alphabets retain the same sequence of letters in spite of changes due to the history of transmission. Occasional capital letters mark instances where demonstrable identity exists in spite of apparent differences.**

Hebrew, came to control the ports and sea-lanes of the eastern Mediterranean. The Egyptians called them Keftiu; ancient Greek tradition refers to them as Phoenicians. They were not concerned with affairs inland; their way of life was built around access to the sea. From the third millennium B.C. on these Semites were able to synthesize the accomplishments of the Egyptians, Mesopotamians and other talented predecessors. By 1800 B.C. the seafaring Semites were in control of the entire eastern Mediterranean, including the waters and shores of Greece, of Anatolia, of Syria, Lebanon and Palestine, and the Nile delta. They were not the only seafarers present, nor did they inhabit every community throughout the region; they were, however, the controlling element that imposed order on the whole area.

Greek sources describe these Semites correctly as thalassocrats, or "sea lords." Since the prosperity of the seafaring Semites hinged on Mediterranean trade, they developed the island of Crete as their main base; it was closer than any other island to the continents of Europe, Asia and Africa. Around 1800 B.C. the sea lords were in control of central and eastern Crete, and it was then that the great Minoan palaces were first built.

The main body of the Minoan invaders came to Crete from the Nile delta. It is quite possible that they were among the Semites forced out of the delta by the strong and nationalistic Pharaohs of the 12th Dynasty, who reunited the upper and lower kingdoms of Egypt. In any case the art and architecture of the Minoans reflect the warm climate of their homeland: the palaces are exposed to the elements and there are no built-in hearths to provide warmth. Later, when the Mycenaean Greeks from the north inherited and modified Minoan civilization, they introduced the hearth.

The Minoans have a unique place in Western history. They nurtured the first high and literate culture on European soil. The earliest Greek civilization, the Mycenaean, was based directly on the Minoan culture. Before the Hebrews conquered Palestine around 1200 B.C. they, like the Minoans, were western Semites living in the Nile delta. Thus approximately the same eastern Mediterranean culture strongly influenced both Greek and Hebrew civilization, although the Hebrews did not depart from the Nile delta until some 600 years after the Minoans.

At some time after 1450 B.C. the

Mycenaean Greeks seized Knossos, the urban center of the Minoan thalassocracy. The Minoans held out in other parts of Crete, but it was clear that they would have to emigrate or face extinction. In order to base themselves in a more secure area many of the Semitic sea lords of Crete migrated with their followers to the Phoenician cities on the Levant coast, notably to Ugarit. In Ugarit, and perhaps elsewhere, the immigration brought a dramatic flowering of the arts around 1400 B.C. Among the manifestations of the upsurge at Ugarit was a new poetic literature that looked to Crete for its artistic roots.

Thereafter Semites and Greeks diverged for a considerable time, each group creating its own distinctive way of life out of a common heritage. One factor accelerating divergence was the succession of empires in the first millennium B.C.—Assyrian, neo-Babylonian and Persian—that engulfed the Near East but left European Greece relatively untouched. By 500 B.C. a sharp eye and ear would have been required to detect the ancient bonds between the Athens of Pericles and the Judah of Ezra. Yet the bonds had been there, as one further example will demonstrate.

The notion that sexual attraction is due to the fact that the two sexes were once one appears to have been current in the eastern Mediterranean before the emergence of either the Hebrews or the Greeks. When this concept is encountered in Greek literature—as in Plato's *Symposium*, in which Aristophanes says of the joining of man and woman that the action reunites "our original nature, making one of two"—we ascribe it to philosophy. When woman is made from a part of Adam, however, and it is stated in Genesis 2:24 "Therefore man ... clings to his wife, and they become one flesh," we consider it divine revelation. That we do not at once recognize the common source of both concepts is attributable to our ingrained habit of keeping the two cultures in separate compartments.

Now that the first decipherments of Linear A are demonstrating anew that no such separate compartments exist, there is much to be expected from a united front in eastern Mediterranean archaeological studies. Perhaps the prime target area should be the Nile delta; in spite of technical difficulties, evidence may be unearthed there that will cast new light on the delta Semites who in successive waves established the first high culture in Europe and the first Hebrew commonwealth in Palestine.

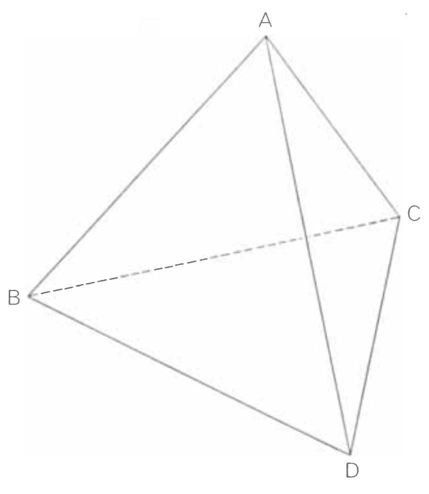
MATHEMATICAL GAMES

Tetrahedrons in nature and architecture, and puzzles involving this simplest polyhedron

by Martin Gardner

Any four points (*A, B, C, D*) in space that are not all on the same plane mark the corners of four triangles [*see illustration below*]. These triangles in turn are the faces of a tetrahedron, the simplest of all polyhedrons (solids bounded by polygons). If each face of a tetrahedron is an equilateral triangle, it is a regular tetrahedron, the simplest of the five platonic solids. Indeed, it is so simple that it was known in ancient Egypt and was probably studied by mathematicians as early as the cube.

The Greek Pythagoreans believed that fire was composed of tetrahedral particles too small to be seen. Because the tetrahedron has fewer faces and sharper corners than any other regular convex solid, they argued, tetrahedral particles would form the least stable and most "penetrating" of the four elements: earth, air, fire and water. We know better today, and yet there is a sense in which this Pythagorean guess, like so many guesses of that school, was a shrewd one, for the tetrahedral structure does turn up in many aspects of the microworld. The so-called carbon atom, without which organic molecules and life as we know it would not be possible, is actually an atom of carbon joined by chemical bonds to four other atoms vibrating at the vertices of a tetrahedron. For example, a molecule of carbon tetrachloride, the familiar cleaning fluid, consists of one carbon atom bonded in this way to four atoms of chlorine. Many crystal lattices, including that of diamond, have a tetrahedral structure. When water freezes, its molecules are locked by hydrogen bonds into a tetrahedral pattern [see "Water," by Arthur M. Buswell and Worth H. Rodebush; SCIENTIFIC AMERICAN, April, 1956]. An important copper ore that has a tetrahedral lattice is called tetrahedrite because it is found so often in large, well-developed tetrahedral crystals.



Regular tetrahedron

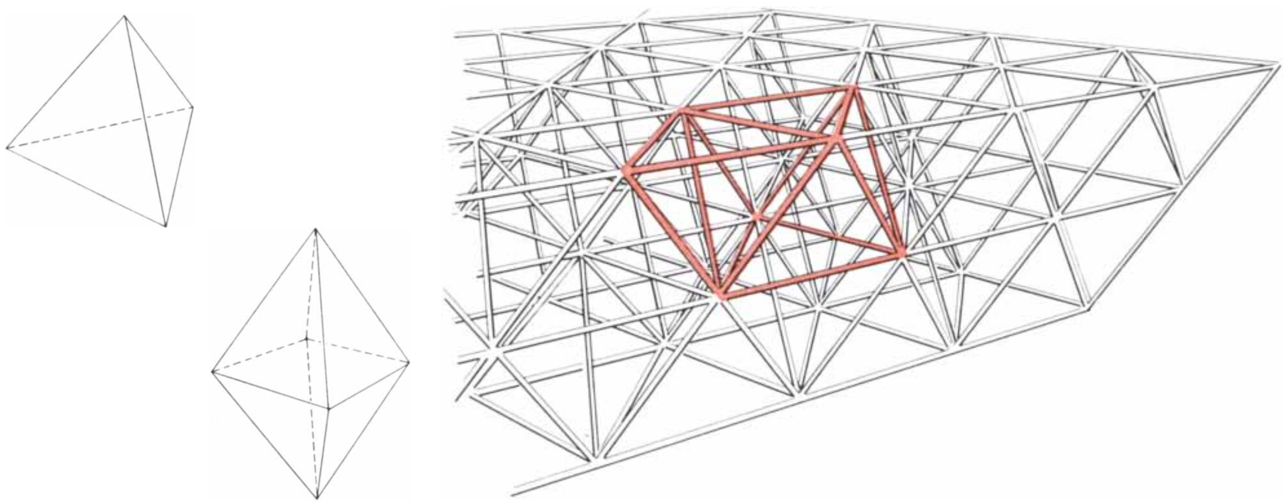
Squares of the same size fit together like a checkerboard to fill the plane, and in a similar way cubes join to fill space. Because equilateral triangles also tile a plane, one might suppose that regular and congruent tetrahedrons would also pack snugly to fill space. This seems so intuitively evident that even Aristotle, in his work *On the Heavens*, declared it to be the case. The fact is that among the platonic solids the cube alone has this property. If the tetrahedron also had it, it would long ago have rivaled the cube in popularity for packaging.

Interestingly, regular tetrahedrons and octahedrons (regular solids bounded by eight triangles) *will* pack to fill space if they are arranged alternately as shown at the top of the opposite page. They are the only two regular convex solids that fit together to fill space. Note that every triangle in the lattice is the face of both a tetrahedron and an octahedron, and that every vertex is surrounded by eight tetrahedrons and six octahedrons. This beautifully regular structure has been exploited in recent years by the inventor-architect R. Buckminster Fuller. The cantilevered truss he calls the "octet" consists of aluminum tubing joined in a network that traces the edges of an octahedral-tetrahedral honeycomb. (A stimulating classroom project is to model such a honeycomb by joining the ends of a large number of rods or soda straws that are all the same length.) Fuller's more famous "geodesic" domes are essentially tetrahedral lattices intended, like his octet, to achieve maximum rigidity at minimum weight and cost.

Fuller is not the first well-known American inventor to be fascinated by the tetrahedron's great strength-to-weight ratio. After Alexander Graham Bell achieved fame as the inventor of the telephone he developed an almost obsessive interest in tetrahedrons. Efforts to build airplanes in the 1890's had failed because engines lacked the power to keep the craft airborne, and Bell decided that the answer lay in constructing enormous silk-covered, man-carrying kites honeycombed with a tetrahedral lattice of aluminum tubing. At his summer home in Baddeck, Nova Scotia, he built and flew a fantastic variety of such kites. To observe his kites in flight he had an 80-foot-high platform constructed at the top vertex of a tetrahedral skeleton formed by three trusses, each of which was a tetrahedral network. On the ground he built a wooden observation hut also shaped like a tetrahedron. When the Alexander Graham Bell Museum was built at Baddeck in 1955, a tetrahedral pattern was used throughout the building as a basic architectural motif.

Bell would surely have been delighted by recent adaptations of the tetrahedral shape to packaging. If you pinch together the bottom of a paper tube and tape it to form a straight edge, then do the same thing at the top of the tube but at right angles, a tetrahedron results. If the tube's circumference is 4 units and its height is the square root of 3, the tetrahedron will be regular [*bottom of opposite page*]. This efficient method of construction underlies Tetra Pak, the trade name for a paper container developed in Sweden in the mid-1950's. It first swept through Europe and is now being used increasingly in the U.S., chiefly as a milk container and coffee creamer.

I hope I am not revealing a war secret by disclosing a quite different application of the tetrahedral shape. During World War II the four-pronged device shown at top left on page 114 (it might be interpreted as a model of the carbon atom!) was used for puncturing the tires of enemy vehicles. Hundreds of them can be tossed along a road and every one will land with one spike pointing straight up; moreover,



Tetrahedron and octahedron (left) *and space tesselated by the two polyhedrons arranged alternately*

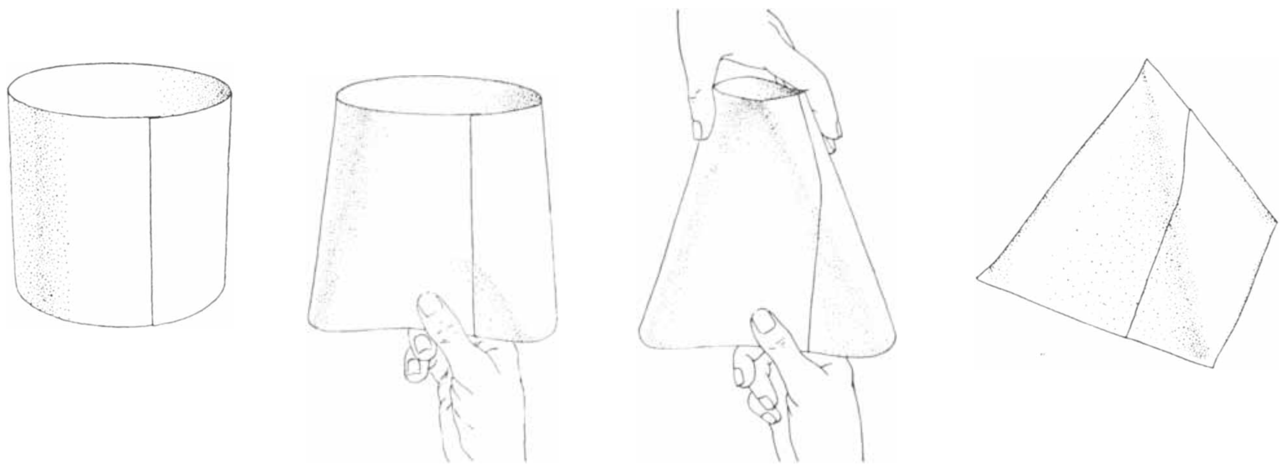
the shape permits maximum penetration of a tire.

The four-dimensional analogue of the tetrahedron is called a pentatope. If a point at the center of an equilateral triangle is joined to each vertex, the result is a projection on the plane of a tetrahedron's skeleton. In similar fashion we can join a point at the center of a tetrahedron to the four vertices and obtain a projection in three-space of the skeleton of a pentatope [*top right on next page*]. It is easy to see that the pentatope has five vertices, 10 edges, 10 triangular faces and five tetrahedral cells. (In this projection we see four small cells and one large one. On the pentatope itself, if it is regular, all five cells are congruent.) Any five points in four-dimensional space that are not on the same three-space hyperplane mark the corners of a pentatope, and each set of four points establishes the corners of a tetrahedral cell. If the five points are so placed in four-space that each pair is the same distance apart, the figure is a regular pentatope, one of the six regular convex solids of the fourth dimension.

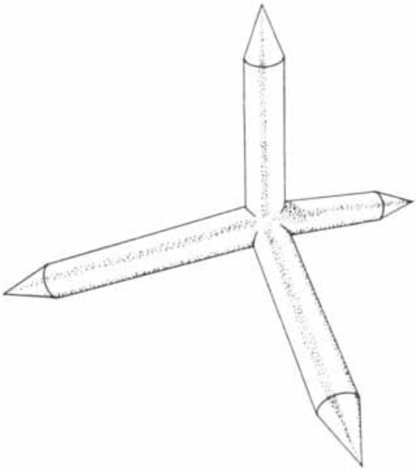
Just as a tetrahedron's four faces can be unfolded to make a plane figure consisting of a central triangle with a triangle attached to each edge, so the five tetrahedral cells of a pentatope that form its hypersurface can be "unfolded" into three-space to make a stellated tetrahedron: a central tetrahedron with a tetrahedron on each face [*see bottom illustration on next page*]. If we only knew how to fold such a solid through the fourth dimension, we could fold it into a pentatopal container for hypercream!

A strange, little-known property of the regular tetrahedron—a property it does not share with any other platonic solid—is involved in a perplexing magic trick that can be presented as a demonstration of one's ability to sense color vibrations with the fingers. First construct a small model of a regular tetrahedron, its faces congruent with the triangles in the top illustration on page 115. (A quick way to make such a model has been proposed by Charles W. Trigg. Cut the pattern shown in the middle illustration from stiff paper or light cardboard. Crease all lines the same way, fold the white triangles into a tetrahedron, then tuck the shaded triangles into open edges to form a stable, no-paste-required model.) Place the model on the black triangle at the top of the pattern (or on a board made by copying the pattern with different colors for each of the numbered shades). While your back is turned, someone "rolls" the model at random over the pattern by tipping it over an edge from triangle to triangle. He stops whenever he pleases, notes the color on which it rests and lets it remain there while he counts slowly to 10. Then he *slides* the tetrahedron back to the black triangle. You turn around, pick up the tetrahedron, feel its underside and name the color on which it last rested.

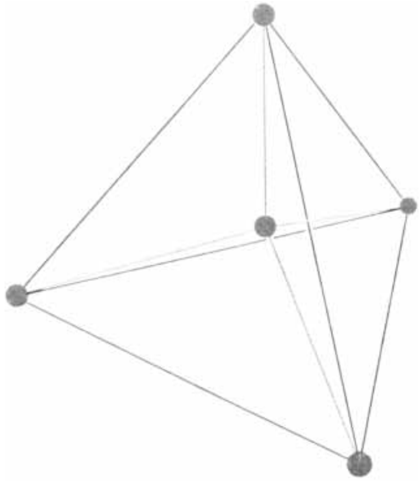
The secret combines geometry with



Making a tetrahedral container



Tetrahedral tire-puncturing device



Projection in three-space of a pentatope

a card hustler's dodge. A common method of marking a deck of cards while a game is in progress is to obtain a smear of what is called "daub" on the tip of a finger, then press it to the margin of a card at a spot that codes the card's value. The daub leaves only a dim smudge, indistinguishable from the kind of dirt marks that normally dull the margins of cards that have been much used. Make some daub by rubbing a pencil point heavily over the same spot on a piece of paper. Slide a fingertip over the graphite, then press the tip lightly against the corner of one face of the tetrahedron. The idea is to leave such a faint smudge that no one but you will ever notice it.

Place the secretly marked tetrahedron on the black triangle with the mark at the top corner and facing the pattern. At the end of the trick the location of the smudge will code the color on which the model last rested. As you pretend to feel the base of the model, look directly down at it. The smudge will be at one of four positions, each of which indicates a different color [*see bottom illustration on opposite page*]. I leave it to the reader to discover why the trick cannot fail.

The following puzzles involving tetrahedrons are not difficult, but some have surprising solutions. They will be answered next month.

1. A regular tetrahedron is cut simultaneously by six different planes. Each slices the solid exactly in half by passing through one edge and bisecting the opposite edge. How many pieces result?

2. Can any triangle cut from paper be folded along three lines to form a (not necessarily regular) tetrahedron? If not, give the conditions that must be met.

3. Inside a room shaped like a regular tetrahedron a bug crawls from point *A* to point *B* [*see top illustration on page 116*]. The room is 20 feet on a side and each point is seven feet from a vertex, on an altitude of a triangular wall. What is the length of the bug's shortest path?

4. What is the largest number of spots that can be painted on a sphere so that the distance between every pair is the same?

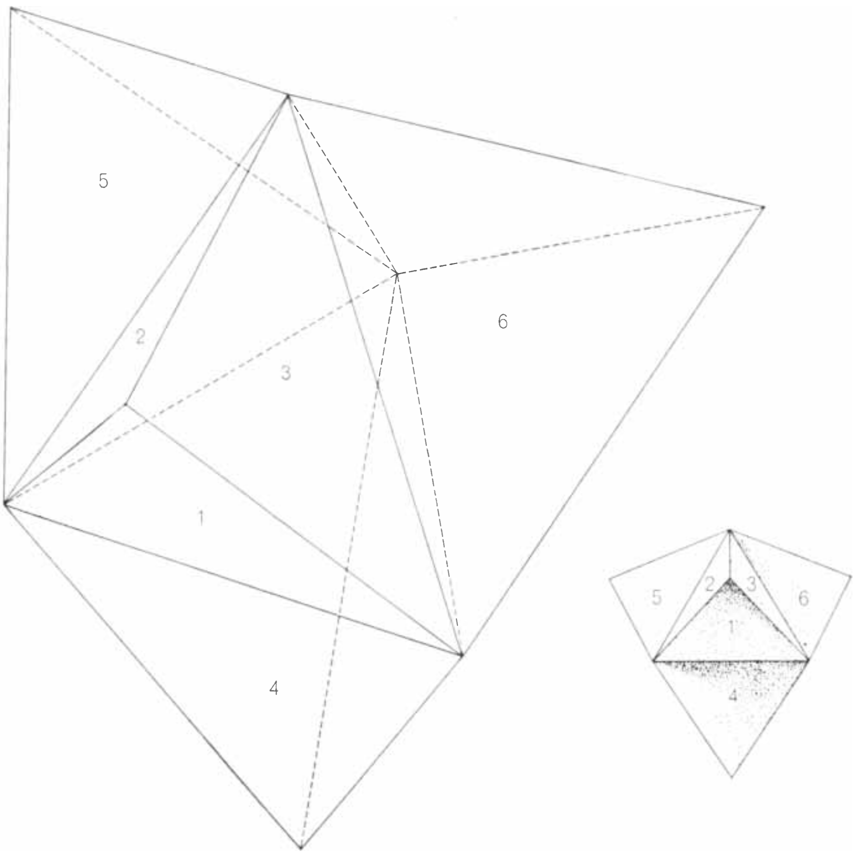
5. If a regular tetrahedron one inch on a side is cut from each corner of a tetrahedron with a side of two inches, what kind of solid is left?

6. Is it possible to label each face of a tetrahedron with a different number so that the sum of the three faces meeting at each vertex is the same? Is it possible to label each *edge* so that the sum of the three edges meeting at each vertex is the same? In both cases numbers may be rational or irrational.

7. What is the length of the side of the largest regular tetrahedron that can be packed into a cubical space one foot on a side?

8. How many different tetrahedrons can be made by joining four equilateral cardboard triangles each of which has a different color? Two tetrahedrons are considered alike only if one can be turned and placed beside the other so that the color patterns of the two figures match. If the patterns can be made to match only by mirror reflection, they are considered different.

9. If each side of a regular tetrahedron is painted either red or blue, it is easy to see that only five different models can be made: one all red, one all blue, one with one red side, one with one blue side and one with two red and two blue sides. If each side is painted either red, white or blue, how many different models can be made?



Pentatope unfolded into three-space

As before, rotations are not regarded as different. Readers with a more advanced knowledge of mathematics may enjoy finding the formula for the number of different tetrahedrons given n possible colorings for each face.

These are the answers to Dr. Matrix' problems presented in this department in January:

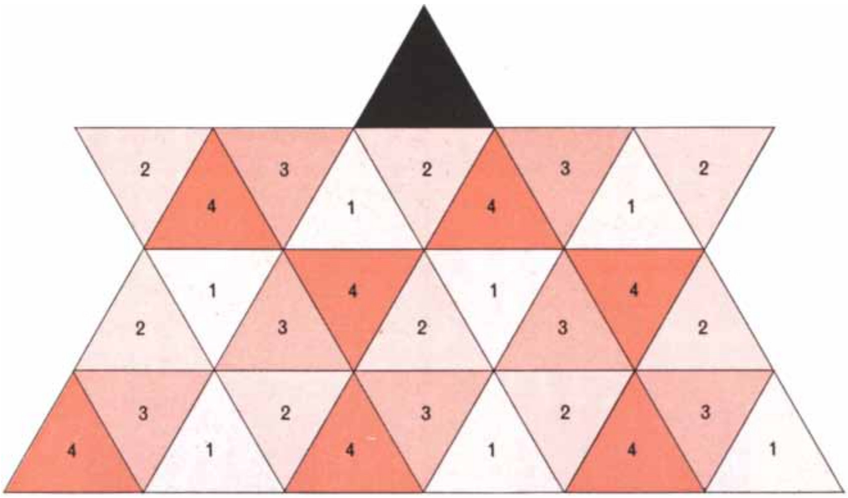
1. The only four-digit set that is self-replicating in the sense explained last month is 7641. When a number is reversed and the smaller version is subtracted from the larger, the resulting digits must sum to a multiple of 9. If the reader knew this, his search for the four-digit number was considerably narrowed, since only four digits summing to 9, 18 or 27 need have been considered.

As a related diversion, put down any four digits (not all alike) in descending order, reverse and subtract; then repeat the entire procedure with the new number. After seven or fewer repetitions you will reach the digits 7641 in one order or another. A similar procedure with any three digits will quickly reach the digits 954, the unique three-digit self-replicating set. For details and generalizations consult D. R. Kaprekar, "An Interesting Property of the Number 6174" (*Scripta Mathematica,* Vol. 21, 1955, page 304), and J. H. Jordan, "Self Producing Sequences of Digits" (*American Mathematical Monthly,* Vol. 71, January, 1964, pages 61–64).

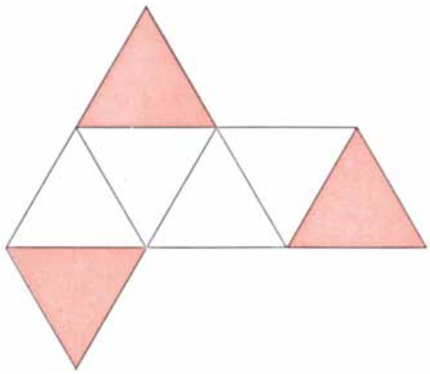
2. The hotel room number is 497. This number plus 2 is 499; multiplied by 2, the result is 994. The integers 497 and 2 are the only pair that, when multiplied and added, yield two three-digit numbers, one the reverse of the other. There are three pairs of numbers that behave in the same way to give two-digit results: $24 + 3 = 27$, $24 \times 3 = 72$; $47 + 2 = 49$, $47 \times 2 = 94$; $9 + 9 = 18$, $9 \times 9 = 81$.

3. These are the only possible ways to apply five or fewer plus or minus signs to the ascending and descending series so that the sum is 65: $123 + 4 - 56 - 7 - 8 + 9 = 65$; $-98 + 76 + 54 + 32 + 1 = 65$.

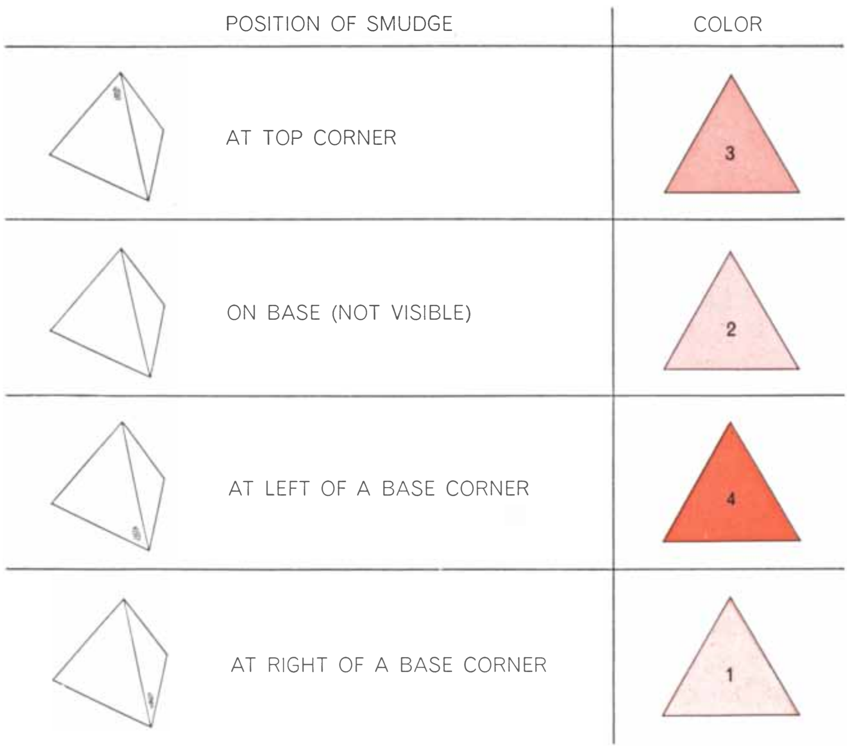
4. The bottom illustration on the next page shows one way to place four marks on a 12-inch ruler so that all integral lengths from one through 12 inches can be measured. It is easy to prove that 10 is the maximum number of different lengths that can be measured by a ruler with only three marks. If the three marks and the ruler's two ends are numbered by their distance from 0 at one



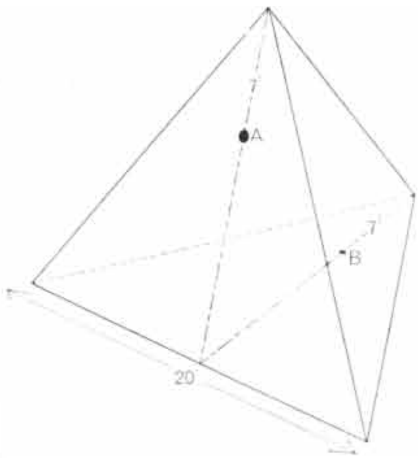
Board pattern for the magic trick



Pattern for folding a tetrahedral counter

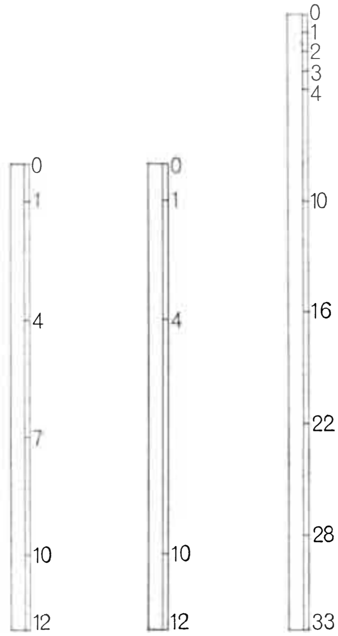


Key to the magic trick

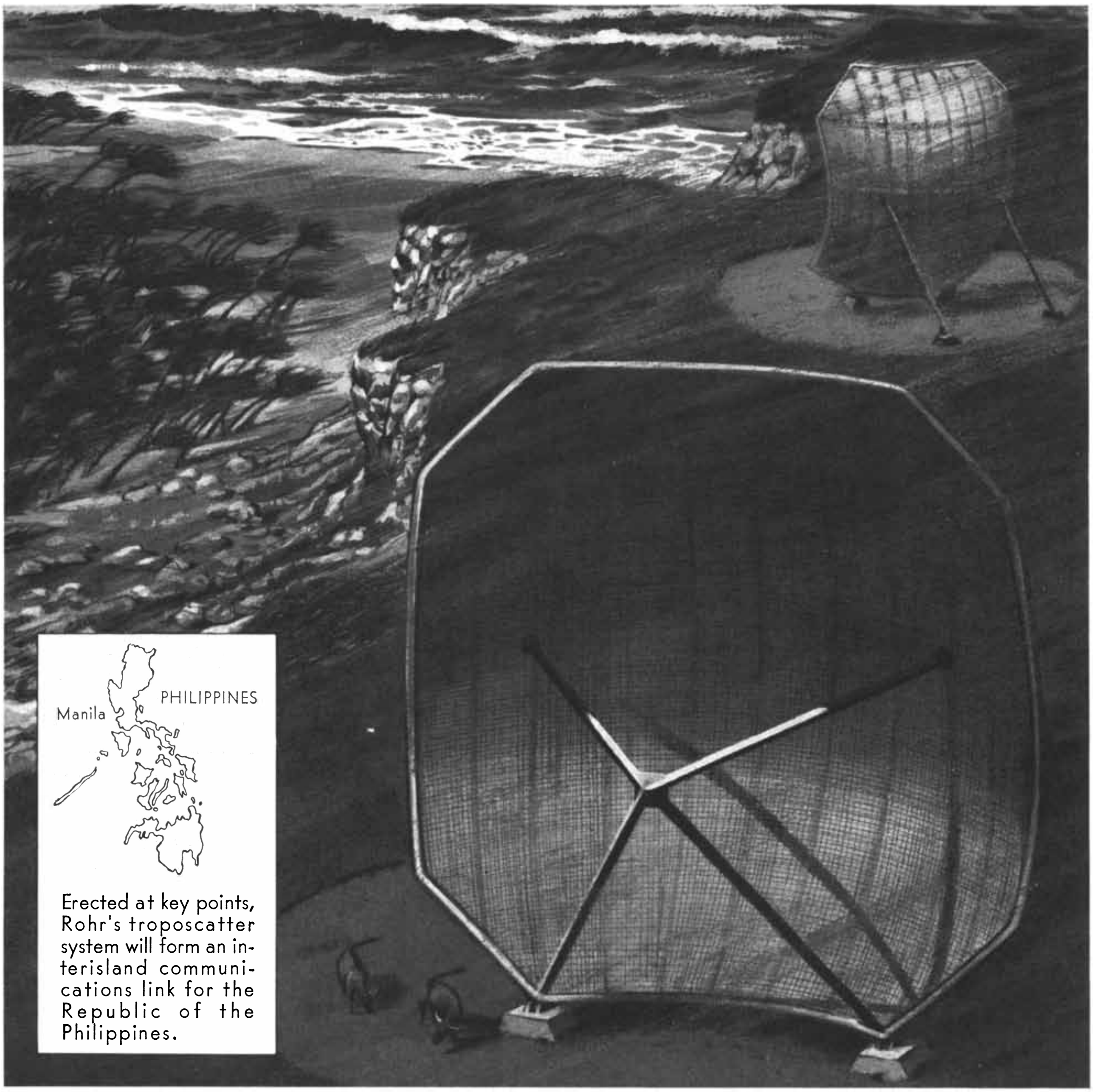


The bug problem

end, every measurable length corresponds to a difference between two of the five numbers. The number of different ways to pair five distinct numbers is $4 + 3 + 2 + 1 = 10$, so clearly 10 is the maximum. One way to place three marks on a 12-inch ruler so that 10 different lengths can be measured is shown in the middle drawing. It is not possible to measure 10 lengths with three marks on a 10-inch ruler. Eight marks, the minimum, can be placed on a 33-inch ruler as shown in the drawing at the right to measure all integral lengths from one through 33. Henry Ernest Dudeney, who discusses this problem briefly in his *Modern Puzzles,* found 15 other ways to place the marks but was unable to discover a general method for approaching such problems.



Solutions to last month's ruler problems



THEY NEEDED TROPOS FOR THE TROPICS

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THE AMATEUR SCIENTIST

On constructing and using a photoelectric colorimeter for various chemical analyses

Conducted by C. L. Stong

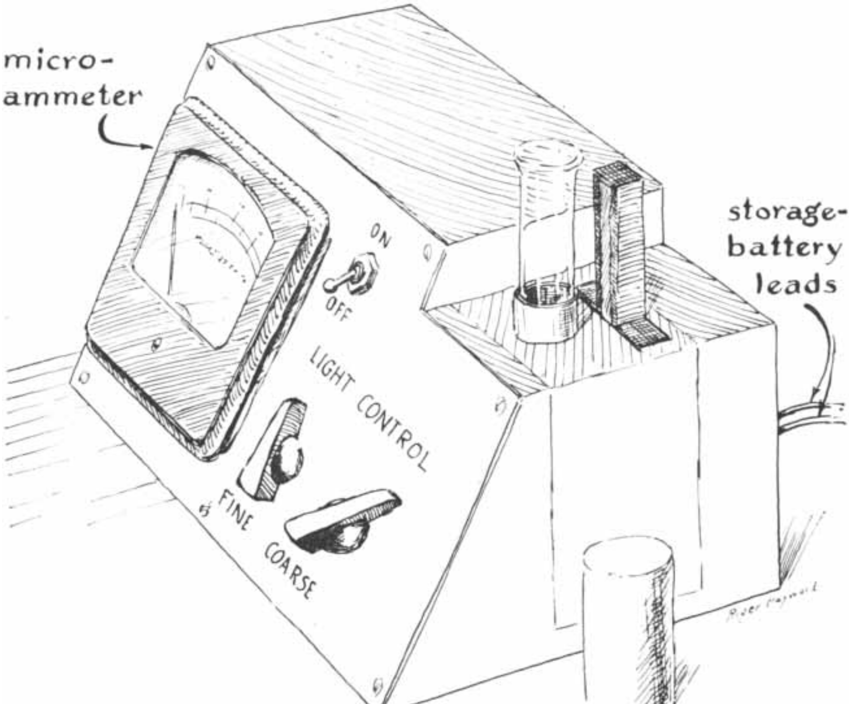
Among the first questions a chemist asks when he attempts to analyze an unknown material is: What color does the substance form in solution? The answer, if it is obtained with sufficient accuracy, may serve not only to identify the sample but also to determine its concentration in the solution. For this reason the colorimeter, an apparatus used for measuring the relative opacity of solutions to light of known color, has become a workhorse of the modern chemical laboratory.

Commercial colorimeters are highly precise instruments that generally cost more than most amateurs would care to spend. An inexpensive version that can be made at home has now been specially designed for amateur construction by Sam Epstein, chief chemist of the Federated Metals Division of the American Smelting and Refining Company in Los Angeles. Epstein has tested the apparatus extensively and reports that it can analyze accurately most substances of interest to the home experimenter. He writes: "Colorimetric analysis is based on the fact that various substances characteristically absorb light more strongly in certain portions of the spectrum than in other portions and conversely transmit more light at some colors than at others. The method can be applied to the analysis of anything that is colored or that can be made to form a colored compound in solution. Solutions of copper sulfate, for example, transmit blue hues more strongly than greens, yellows and reds. Potassium permanganate solutions, on the other hand, transmit reds and blues strongly but absorb greens and yellows, with the result that the transmitted light appears reddish violet.

"Such phenomena are described by the laws of the German physicists Johann Heinrich Lambert and August Beer. Lambert's law states that for a given concentration equally thick layers of a solution will absorb equal fractions of transmitted light of any color. Beer's law states that light is absorbed by a solution in proportion to the concentration in the solution of the substance in question. Lambert's law can be demonstrated by pouring coffee into a cup: the bottom of the cup becomes progressively darker as the cup is filled. Beer's law can be similarly demonstrated by adding coffee to a cup of water: the solution darkens as the concentration of coffee increases. At first glance these laws may appear to be self-evident and even trivial. As expressed in mathematical terms, however, they serve as reliable guides for the theoretical study of solutions, for developing analytical systems and for the design of colorimetric apparatus.

"The earliest method of colorimetric analysis was based on Beer's law. It consists of matching the color of an unknown solution with one of known concentration and equal depth. The method requires the preparation of a series of solutions of gradually increasing concentration. All solutions, including the unknown one, are placed in test tubes that have flat bottoms. The tubes are lighted from below and are examined by looking down the tube toward the light source. The intensity of the light transmitted by the unknown solution is then compared serially with the known solutions until the best match is observed.

"By making use of both Lambert's and Beer's laws an improved apparatus was devised. It requires the preparation of only one comparison solution of known concentration. In this apparatus the two solutions are viewed simultaneously through a pair of rods of optical glass. The ends of the rods are polished



General view of the colorimeter

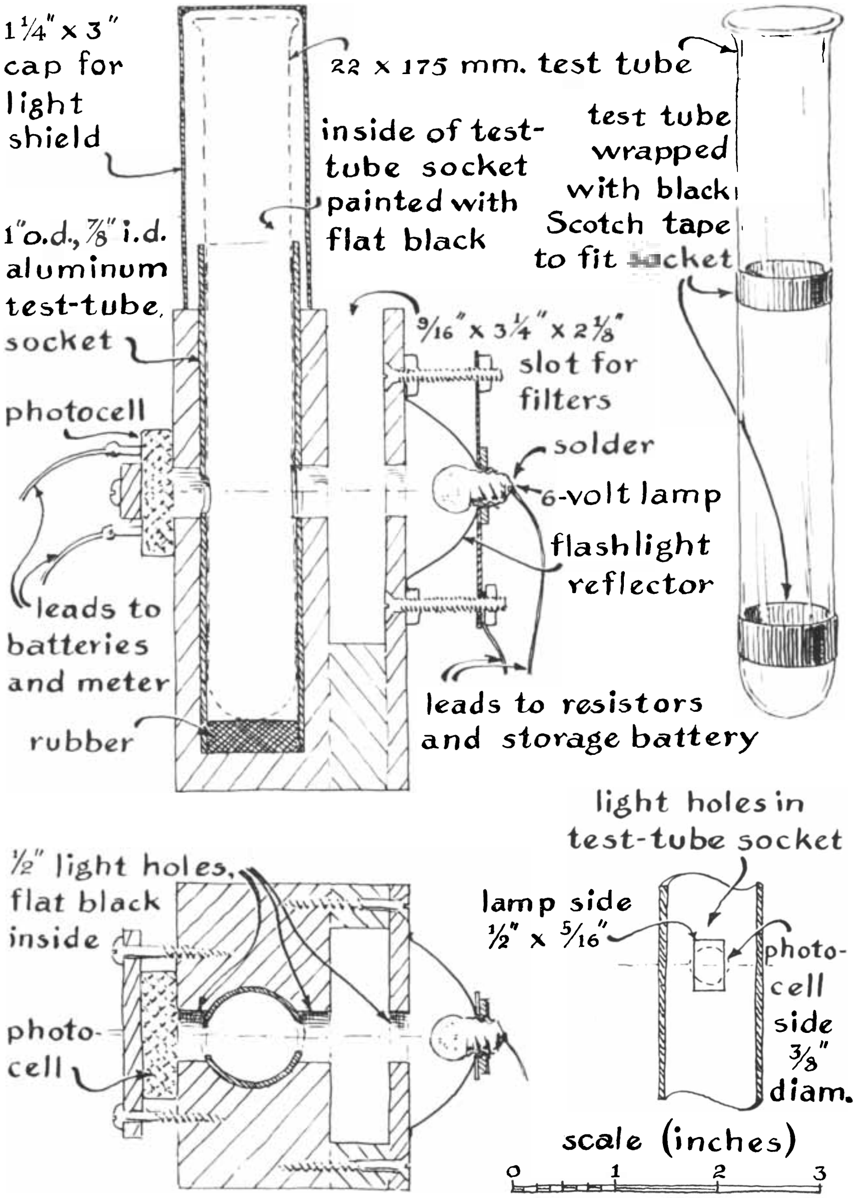
to optical flatness. The rods are partially immersed in the solutions, which are lighted from below. The depth of the fluids traversed by the light can be varied by raising or lowering the rods. The rods are moved by a mechanism equipped with calibrated drums that indicate the relative intensity of the transmitted light. By means of a simple calculation one can then determine the concentration of the unknown solution.

"The accuracy that can be achieved by these methods is limited by two factors. First, the observer must estimate the point at which the solutions match. Observations tend to vary with individuals and with fatigue and similar subjective factors. Second, the laws of Lambert and Beer are valid only for light of a single color. Manual comparisons are made with white light, which of course is multicolored. For these reasons the construction of colorimeters of the highest accuracy had to await the development of photoelectric sensing devices.

"Photocell instruments of two basic types have been developed. In one—the spectrophotometer—white light is dispersed into the spectral colors by either a prism or a diffraction grating. An adjustable slit between the dispersion element and the unknown sample admits dispersed light of any desired color to the sample. The colored beam transmitted by the sample falls on the photocell with an intensity that is indicated by an associated meter. The most elaborate models include a motor-driven dispersing element for scanning the complete spectrum and a synchronously driven paper chart that moves below a calibrated recording pen. The resulting graph, the absorption spectrum of the sample solution, displays the relative transmission of all colors.

"In the similar but simpler instrument known as the colorimeter, a glass or gelatin filter of selected color admits light to the sample. The transmission is indicated by a photocell and its associated meter. In general, filters transmit a broader band of color than a prism or a diffraction grating equipped with an aperture slit. For this reason colorimeters generate somewhat less precise and detailed information than spectrophotometers.

"Professionals usually make the initial determination of a solution's absorption spectrum with the spectrophotometer. This step is essential in setting up an analytical procedure. The spectrophotometer can also be used for subsequent routine work, but such work can be performed adequately with the less



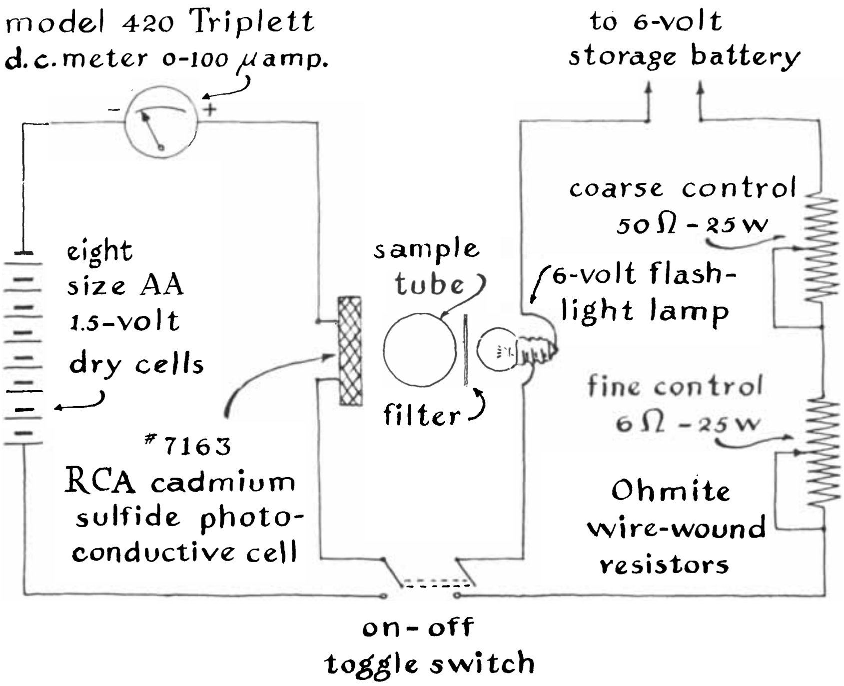
Details of the colorimeter's construction

costly colorimeter. The amateur merely selects a filter of the color that has been found by means of the spectrophotometer to be most strongly absorbed.

"After an appropriate filter has been selected the colorimeter is calibrated by preparing serial dilutions of the solution to be analyzed. The intensity of the light transmitted by each dilution is measured and recorded in the form of a graph by plotting transmission against concentration. The strength of any unknown solution of the substance can then be ascertained by measuring the transmission and determining the corresponding concentration by referring to the graph.

"A reliable photoelectric colorimeter is easy to build. Its essential parts include a flashlight lamp powered by a storage battery, a rheostat for regulating the intensity of the light given off by the lamp, a set of gelatin color filters, a cadmium sulfide photocell energized by dry cells, a microammeter and an appropriate cabinet for housing the assembly and holding the test sample. (I tried to energize the lamp from an ordinary power line through a step-down transformer but found that variations in the voltage caused false indications. Hence I solved the problem by substituting the storage battery.)

"The photocell is simply connected in series with the dry cells and microammeter. I find this circuit adequate. The photocell draws less than .0001 ampere, so dry batteries last a long time. One precaution should be observed when assembling the circuit: Hold the termi-



Schematic circuit diagram for the colorimeter

nals of the photocell tightly with long-nosed pliers when soldering the leads. The pliers keep the terminals cool and prevent heat from damaging the cell.

"I use Wratten gelatin filters for transmitting desired colors. The material is sold by photographic-supply dealers in sheets that measure three inches square. The sheets must be handled carefully by the edges to avoid smudges and fingerprints, which are difficult to remove without damaging the filters. Gelatin filters transmit a much wider band of color than the two-inch-square glass filters normally used in colorimeters. On the other hand, the gelatin material is adequate and is priced at only about $1 a sheet, in contrast to $12 for glass filters. Glass filters are stocked by many laboratory-supply dealers. Experimenters willing to make the larger investment should procure filters of the type used in the Klett-Summerson photoelectric colorimeter.

"The color of filters is expressed in millimicrons. (One millimicron is equal to 10 angstrom units. For example, a 515-millimicron filter transmits mostly green light with a wavelength of 5,150 angstroms.) The numbers by which Wratten filters are identified, however, are not related to their color. Instead the transmission characteristics of these filters are designated by number in the *Handbook of Chemistry and Physics*.

"Unknown solutions are placed in a conventional test tube that is inserted in the aluminum tube-holder of the instrument [*see illustration on page 118*]. To adjust the instrument for operation first place any filter in position and use clear water for the test solution. Put an opaque cover over the top of the test tube. Adjust the light intensity so that the meter indicates about 50 microamperes. Rotate the tube-holder back and forth until the meter indicates maximum current. This is the position of best alignment of the holes in the aluminum tube with the optical system. With a pencil make a pair of reference marks on the holder and on the top of the housing so that the holder can be returned to its optimum position if it is accidentally turned.

"Until the experimenter becomes familiar with the operation of the instrument the coarse control should be turned to the position of full resistance (minimum lamp current) before the power is switched on and the filters are changed. Never withdraw a filter when the lamp is lighted unless the sample-holder contains an opaque test tube, which is most conveniently made by wrapping a layer of black Scotch electrical tape around the tube. Otherwise the meter may be damaged by overload. It is a good idea to keep the opaque tube and a filter in place in the colorimeter when it is not in use in order to protect the photocell and lamp reflector from dust.

"An interesting introductory experiment can be made with potassium permanganate. Insert a green Wratten filter (No. 58) in the filter compartment of the instrument, adjust the coarse lamp control for minimum lamp current and switch on the power. Place a sample test tube of clear water in the sample-holder of the instrument and adjust the lamp intensity until the meter indicates exactly 100 microamperes, using first the coarse adjustment and then the fine one. The response of the photocell is somewhat sluggish, so wait about 15 seconds after each adjustment for the meter to reach its final position. Incidentally, test tubes that contain samples for analysis should be thoroughly clean and dry on the outside before they are placed in the holder. Cultivate the habit of holding the sample tubes near the top to avoid smudges and fingerprints in the region through which the light passes.

"Next remove the tube and after 15 seconds record the new, or 'blank,' reading of the meter. Now make up a solution of potassium permanganate of arbitrary concentration and transfer 25 milliliters to a clean test tube. Place the tube in the instrument and measure the transmission. If the measured transmission does not fall between 35 and 45 microamperes, return the sample to the vessel in which it was prepared and either add more chemical or dilute with water as necessary to produce a meter reading of between 35 and 45 microamperes. This is a cut-and-try procedure. You may have to repeat it several times.

"When the pointer at last falls within the desired range, record the exact indication. Remove the 25-milliliter sample, dilute it to half strength by adding 25 milliliters of water, rinse the test tube with three or four small portions of the diluted solution, fill the sample-holder with 25 milliliters of the diluted solution and again measure and record the transmission. The meter will now indicate a somewhat higher current. Repeat the dilution procedure—cutting the concentration in half each time—until the meter indicates between 90 and 99 microamperes. Record the exact meter indication for each dilution. Each time, just before inserting the test tube with the newly diluted solution, check the blank reading on the meter. It should not change appreciably with time, but any slight drift should be compensated by readjustment of the fine control.

"The first solution of potassium permanganate measured—the one that produces a meter response between 35 and 45 microamperes—should be assigned an arbitrary concentration number of 100.

The dilutions are then designated successively as 50 percent, 25 percent, 12.5 percent and so on. The transmission values, in microamperes, are now plotted against the dilutions on semilogarithmic graph paper, with the transmission plotted logarithmically. The result, if a No. 58 Wratten filter is used, will resemble the accompanying calibration graph [*at top on next page*]. Solutions that conform to Beer's law, such as those of potassium permanganate, generate curves in the form of straight lines. The curvature observed in the calibration curve *A* is caused by the wide transmission characteristic of the filter. Compare it with the associated curve *B* made of the same solution with a highly selective filter that transmitted wavelengths close to 515 millimicrons.

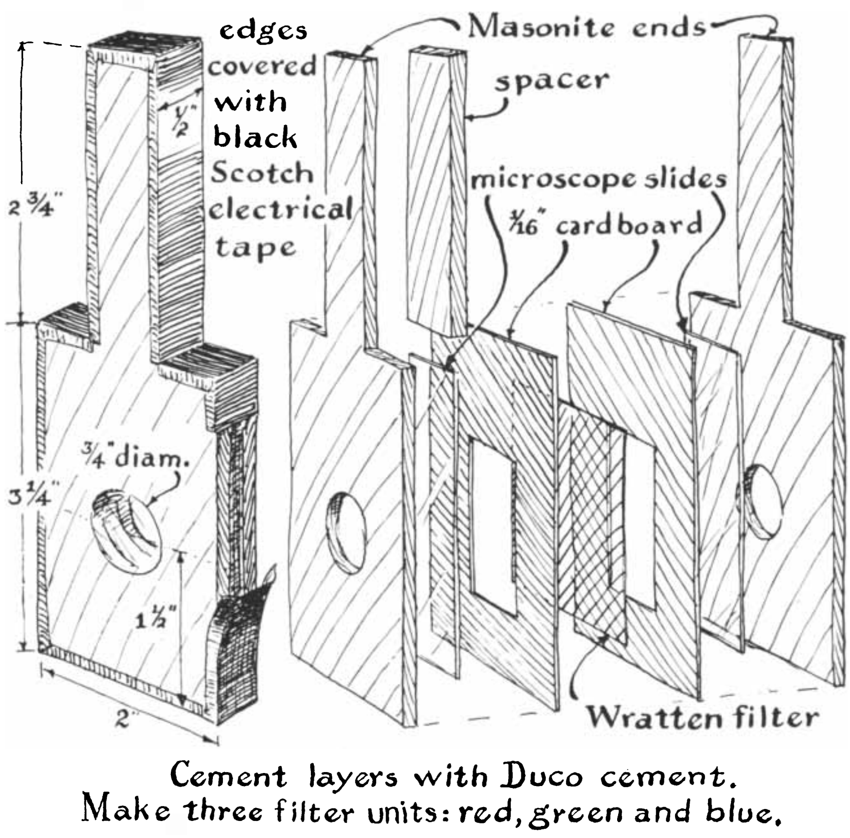
"Many substances produce curved calibration graphs even when they are measured with a sharply selective filter. Solutions of potassium dichromate, for example, do not yield straight graphs. This and kindred substances do not obey Beer's law because they exist in more than one form. In the case of chromium the solution contains both chromate ions (CrO_4^{--}) and dichromate ions ($Cr_2O_7^{--}$). The fact of nonlinearity does not invalidate the calibration curve for analytical purposes, however. It simply limits the accuracy and range to a greater or lesser extent, depending on the amount of curvature.

"The following experiments illustrate tested procedures that are common to all photometric analysis. Each substance requires unique processing before it reaches the colorimeter. For the most reliable results distilled water and chemicals of reagent grade should be used. The impurities contained by materials of lower grade may distort the results. The most consistent results require the accurate measurement of weight and volume. For the same reason all solutions should be mixed thoroughly.

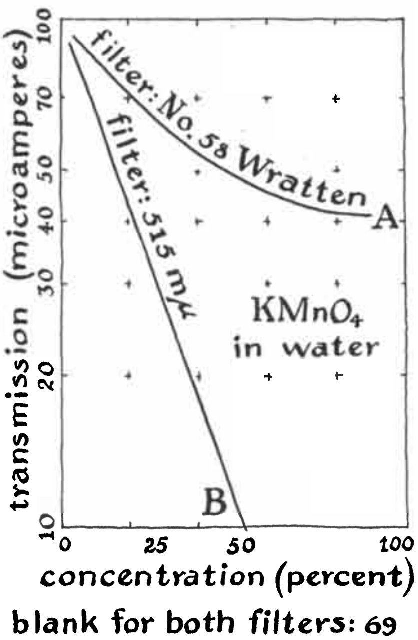
"For the analysis of copper the colorimetric technique takes advantage of the fact that copper solutions containing ammonia are deep blue in color. To make a typical analysis, first dissolve .5 gram of pure copper wire in 20 milliliters of nitric acid mixed with an equal volume of distilled water. Work in a well-ventilated room. Heat the solution in a covered beaker to 35 degrees centigrade. When the material has dissolved, boil to complete the reaction and to drive out the brown fumes. Cool and dilute the resulting copper nitrate solution with enough distilled water to make 500 milliliters. Mix thoroughly. To 100 milliliters of this solution add 50 milliliters of concentrated ammonium hydroxide and enough water to make 200 milliliters of solution. Mix. Rinse a clean colorimeter tube several times with small portions of the solution, fill it about a third full and measure the transmission with the red filter (after first determining the blank reading with pure water). Repeat this procedure with portions of the original solution in the amounts of 75, 50, 25 and 10 milliliters. Plot the resulting meter readings against the dilutions to produce a standard reference graph of the metal. The graph should resemble the second accompanying curve [*at bottom on next page*].

"With the reference graph at hand it is easy to demonstrate that copper sulfate ($CuSO_4 \cdot 5H_2O$), for example, contains 25.5 percent metallic copper. First, examine a small crystal of the salt with a magnifying glass. White areas indicate loss of the water of crystallization. Such samples should be discarded. Select .25 gram of material from a solidly blue crystal and dissolve it in a small amount of water. Add 50 milliliters of ordinary ammonia water to the solution and enough distilled water to make 200 milliliters. Mix. Measure the transmission after adjusting the light intensity to give the blank reading for the copper calibration curve. The amount of copper, as determined by reference to the calibration graph, should be very close to 25 percent of the weight of the crystal.

"Copper is a constituent of many aluminum alloys. Dissolve one gram of thin drillings from a piece of solid aluminum rod by immersing the drillings in 30 milliliters of hydrochloric acid diluted 50 percent with water. (Do not add all the acid at once.) When the violent reaction is concluded, add three milliliters of concentrated nitric acid and boil until the solids have completely dissolved (with the possible exception of silicon, which, if it is present, will remain as a black powder). Cool and transfer the material to a 200-milliliter volumetric flask. Add 20 milliliters of 20 percent citric acid and mix well. (To make a 20 percent solution of citric acid dissolve 200 grams of the acid in one liter of water.) Then add 50 milliliters of concentrated ammonium hydroxide, mix again, cool and dilute with water until the level of the solution is even with the mark on the neck of the volumetric flask. Mix again. The citric acid prevents the aluminum from precipitating as aluminum hydroxide when the ammonia is added. Filter the solution through a highly retentive paper (such



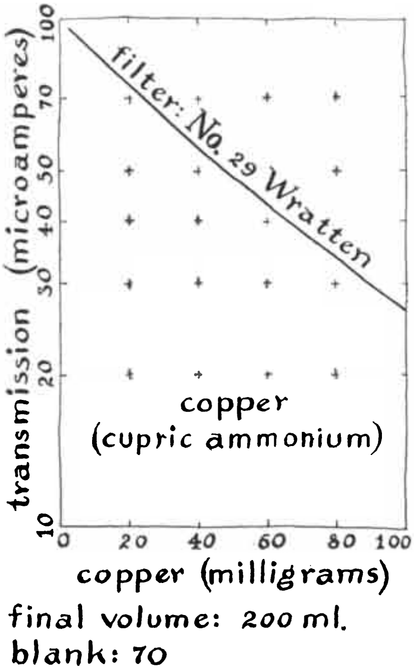
Holder for a color filter



Potassium permanganate readings

as Whatman No. 42) directly into the colorimeter tube. Rinse the tube several times with small portions of the filtrate and finally measure the transmission of a sample. Find the percentage of copper in the aluminum rod by dividing the indicated number of milligrams by 10.

"The analysis of aluminum can also be made colorimetrically. Aluminum combines with an organic chemical, the ammonium salt of aurin tricarboxylic



Cupric ammonium readings

acid, marketed by the Eastman Kodak Company as Aluminon, to form a red compound known as lake. Measurements are made with the No. 58 green Wratten filter. The analysis requires both a standard solution and a color-developer solution.

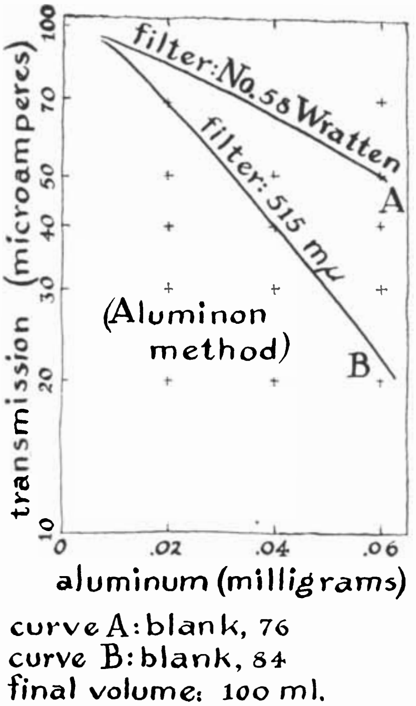
"Ordinary aluminum foil is pure enough to be used as a standard. Dissolve one gram with 30 milliliters of a 50 percent dilution by volume of hydrochloric acid in a covered beaker. Add the acid in small amounts. Heat until the solution becomes clear and then cool it. Dilute to 1,000 milliliters with water and mix. Pipette out 10 milliliters of this solution and again dilute to 1,000 milliliters and mix. This is the standard solution. It contains .01 milligram of aluminum per milliliter.

"The color-developer is prepared by dissolving exactly .5 gram of Aluminon (Eastman organic chemical No. P4468) in 500 milliliters of water. Add .25 ounce of plain Knox gelatin to a beaker containing about 100 milliliters of water and place it in a pan of boiling water until the gelatin dissolves. Dilute to 500 milliliters. Dissolve 250 grams of ammonium acetate in enough water to make a 500-milliliter solution. Mix the three solutions, add 40 milliliters of glacial acetic acid and about three grams of sodium benzoate (to prevent the growth of mold) and mix thoroughly. Store the solution in a dark bottle.

"Mix exactly 15 milliliters of color-developer in a 100-milliliter volumetric flask with 10 milliliters of water and immediately place the flask in boiling water. After exactly five minutes remove the flask, cool it to room temperature with running tap water and dilute the solution to 100 milliliters with water. Mix well. Use this solution to determine the blank value.

"Pipette one milliliter of the standard aluminum solution into a 100-milliliter flask and add nine milliliters of water and 15 milliliters of color-developer. Mix. Place the flask in boiling water and repeat the procedure followed in the blank determination. Make a transmission reading on the solution. Complete the calibration curve by making up five other solutions containing two, three, four, five and six milliliters of the standard solution. Reduce the amount of water added before heating by one milliliter each time. The graph should resemble the accompanying curve *A* [*opposite page*]. Also shown is the improved slope, curve *B*, obtained by the use of a 515-millimicron filter.

"The antacid ingredient in buffered



Readings from solutions of aluminum

aspirin is aluminum hydroxide. A tablet can easily be analyzed for its aluminum content. Dissolve a tablet in 30 milliliters of 1:1 hydrochloric acid by boiling for a few minutes. Filter the solution into a 200-milliliter volumetric flask and wash the paper three or four times with 20-milliliter portions of hot water containing a few drops of hydrochloric acid, allowing the wash water to run into the flask. Cool to room temperature and dilute to the mark. Pipette one milliliter into a 100-milliliter flask, add nine milliliters of water, the color-developer and so on as before. Find the aluminum content of the solution. The analyzed sample solution of one brand of aspirin indicated a content of .0325 milligram of aluminum. The sample represented only one two-hundredth of the total actual amount. The tablet therefore contained about 6.5 milligrams of aluminum.

"Although a research chemist chooses the proper filter for a substance by referring to its absorption spectrum, the lack of a spectrophotometer need not prevent the amateur from making valid determinations. In general, the following combinations will yield fairly accurate results. Use a green filter for red solutions, a red one for blue solutions and a blue one for yellow solutions. A closing note of caution: Many metallic salts and other chemicals are toxic. Handle them accordingly."

BOOKS

An unconvincing indictment of the evils of technology

by A. Rupert Hall

THE TECHNOLOGICAL SOCIETY, by Jacques Ellul. Alfred A. Knopf ($10.95).

No one can ever have been convinced that this is literally the best of all possible worlds. Starvation, disease and war have always appeared to be remediable evils. They are with us still, and if the first two have been checked, war now impinges on our thoughts more dreadfully. Nevertheless, although we all admit that our ancestors' manner of living had some advantages over our own, most of us would prefer not to return to it; one may play in imagination with one's role as an 18th-century lord or lady, but who would be his footman or her housemaid? Who would not rather risk psychiatry than being tried as a witch?

Jacques Ellul, professor of history and sociology at the University of Bordeaux, is the rare mortal who would not hesitate to plunge himself and all mankind backward in time. His book *The Technological Society* is, as it were, a study of Satan by a Jesuit, or of Marxism by Joseph Welch of the John Birch Society. According to Ellul, humanity has become the prisoner of machine-like efficiency. Nowhere is to be found the simple Samoan paradise, the Eden where native philosophers or Celtic monks pursued their meditations undisturbed. Man has climbed, like some besotted mouse, into the squirrel cage of a technology that all his furious energy can only drive faster, rendering escape ever more impossible.

As is truly said by John Wilkinson, the skillful and enthusiastic translator of this horrifying book, Ellul is no ignorant Luddite. He does not simply regard machines as evil; he regards virtually every common feature of life in the U.S. and Europe as evil, except perhaps a newborn babe. The introduction of machinery—the "industrial revolution"—was a symptom of the passage of humanity from the light into the shadow, yet it was not in itself a sufficient cause of our downfall. The Romans were worshipers of "technique," which is Ellul's term for the "one best way" of doing things, the insistence on means before ends, the love of doing something because it works, the neglect of morality and human values. Technique is not only machinery and industrial production and the nuclear bomb, although these are part of it. It is also police bureaucracy and fluoridation; pesticides and the civil service; television, Madison Avenue, newspapers and *Das Kapital;* it is modern medicine and *Scientific American* as well as the Tennessee Valley Authority and General Motors; it is economic planning and the airplane. In short, it is the entire way in which we live. Ellul insists:

"Technique has progressively mastered *all* the elements of civilization. We have already pointed this out with regard to man's economic and intellectual activities. But man himself is overpowered by technique and becomes its object. The technique which takes man for its object thus becomes the center of society; this extraordinary event (which seems to surprise no one) is often designated as *technical civilization.* The terminology is exact and we must fully grasp its importance. *Technical civilization* means that our civilization is constructed *by* technique (makes a part of civilization only what belongs to technique), *for* technique (in that everything in this civilization must serve a technical end), and *is* exclusively technique (in that it excludes whatever is not technique or reduces it to technical form)."

Two consequences seem to follow from the breadth of this conception. First, technique is inseparable from the evolution of man. *Homo faber* we all know: the shaping of a stone ax is no less a technique than the engineering of a chemical plant. Ritual and magic are just as much techniques as subliminal advertising. What, then, is the peculiar corruption of the modern world that renders the application of the qualification "technical" appropriate? It is (according to Ellul, after Karl Marx) that a change in quantity is equivalent to a change in quality. There is presumably a level of technical proficiency in some fields, if not all, that is tolerable and indeed indispensable for the survival of civilized man. Ellul does not say what this is, nor does he clearly differentiate between the role of tolerable techniques in a good society and the predominance of malicious techniques in a diseased one. He believes that we of the modern world cannot ever hope to isolate and forbid evil techniques (biological warfare, lying propaganda) while encouraging good ones (broadcasting Beethoven, vaccination). If I understand him correctly, he sees the technical world on one side and the human world of generosity and laziness, charity and vindictiveness on the other; there is no way to amalgamate the better features of both.

It could obviously be objected that in lumping together "techniques" of every kind Ellul has lost a distinction that ought to be significant. Surely there is a difference between making good knives to cut bread and making false news to corrupt a population? Is not the tool or the machine indifferent as to ends and purposes, which are determined by human will? No, this approach is firmly rejected by Ellul, for whom "all techniques are inseparably united. Everything hangs together in the technical world, as it does in the mechanical." He contends that the practice of techniques, the ideal of the "one best way," is monolithic and autonomous, utterly resistant to moral considerations external to itself. "Not even the moral conversion of the technicians could make a difference. At best, they would cease to be good technicians." Like a Calvinist in the eyes of a Catholic, the technician is damned by definition. As an example, Ellul argues (not quite accurately) that it was necessary to master all the techniques needed for making nuclear weapons in order to design and build nuclear power stations.

(The use of the bomb was of course an application of the "one best way" principle, but the instances in which the most extreme means of destruction available have been eschewed in war are not discussed here.) Hence there can be no reliance on the anchor of moral choice once men are sliding on the slopes of technique.

Yet it is not the purpose of *The Technological Society* to condemn or to terrify. Ellul reminds the reader more than once that the book is a work of description and analysis; if the reader reacts emotionally, he should look for the cause within himself, not in the book. No one can doubt, however, that Ellul himself lives on black bread and spring water. His sympathies are, as his translator remarks, sufficiently obvious; one would be blind to find here a Baedeker of something that was submitted for admiration. Perhaps it would be too much to ask that his account of the fall of man be quite dispassionate; it certainly is not, nor is it wholly impartial. Ellul can see no single redeeming feature in technique, and as he heaps up evidence against it he summons none in its favor.

The "one best way" to concentrate 10 million minds on a piece of nonsense or falsehood none will defend; are we also to despise the best ways to save 10 million lives? Perhaps of this 10 million not a tenth of 1 percent will ever rise to those heights of human dignity, freedom and culture Ellul most applauds, yet by any test the number of cultivated men and women living today is many times larger than in any epoch of the past. To argue that technique has done nothing for humanity is patently absurd. Without it we would still be in the trees; without its refinement we would still be living in those conditions of hardship, starvation and superstition that have dominated history.

It is to be expected that Ellul would attach little value to mere material amenities; no doubt he has faced dentists and surgeons with courage. For him the medieval baron knew as great a luxury in the spaces of his castle as we enjoy in overstuffed chairs. But what of the poor man at his gate? Did the peasant revel in relaxed comfort over a blaze of sticks illegally garnered in the baron's woods? A fair assessment of the technological society would at least state its positive achievements: good health and longevity, abundant food, clothing and housing, the promise of education and leisure for all, travel—actual or vicarious—and all the breadth of experience it affords.

The West enjoys these things; the East clamors for them and will possess them too. Every sensitive person must regret that the advantages of technology are still denied far too many people in the world; much remains to be done before we can say that science and power are matched by charity and equity. Yet much has been done. To degrade all this as retrogression is nonsensical, an inhuman and absurd projection of spiritual and intellectual arrogance.

However imperfect Ellul's factual analysis is (and it has notable lapses apart from those of omission), or indeed however perfect it may be, there are features of the book that impair its usefulness even as a tract. A social reformer —and surely anyone sharing Ellul's opinions should strive desperately to avert the catastrophe he foresees—must believe in the possibility of reform and propose plausible means of bringing it about. The prophet whose cry is only "Woe, ye are damned" walks unheeded. Ellul is such a prophet. Humanity's present course can only be altered, he maintains, if total war destroys it, or God descends to convert it, or some kind of revolution establishes a worldwide Erewhon. None of these possibilities allows for the gradual improvement of the technological civilization we have known for approximately 200 years into any sort of society Ellul might find admirable.

Indeed, the difficulty of discerning what kind of society Ellul *would* find admirable, or what kind he believes suited to man's nature, contributes not a little to one's reluctance to take his cry of woe seriously. As far as one can discover, the nearest approximation is medieval Christendom. This society, as Lynn White, Jr., has undertaken to show in his recent *Medieval Technology and Social Change,* was not without its technical attributes, but it is perhaps needless to add that Ellul takes no account of them. For the sake of argument, however, let us discount the advances in agriculture, industrial production and warfare described in that book as mere figments of White's imagination. The belief that the medieval world was untechnical (in Ellul's broader sense) and therefore free remains patently false. The dweller in the manor, the prisoner of feudalism, was bound by chains of law, custom and impotence far more stringent than any the factory system has imposed. The modern French or American farmer would revolt against any government limiting his use of his own land as inexorable tradition and privilege limited the rights of 13th-century villagers. Any contention that the medieval world was more just, more prosperous, more content—in short, a better place in which to live than the world we inhabit today—must be rejected as sheer sentimentality.

One difficulty besetting those who lament the injury done to man by advancing time is the necessity for this implicit assumption that things were better in the past. It would make no sense to complain of man's enslavement to the machine if he had not once been free, nor to regret the prostitution of his modern entertainments if cockfighting and bull-baiting are not regarded as wholesome, manly sports. After all, "worse" is the comparative form; even "bad" implies failure to reach some standard attained in the past or attainable in the future. It is often easier to leave these comparisons unexplored, and Ellul gives way to this temptation. It is easier to castigate what we do now without thoroughly investigating whether or not things have ever been, or are likely to be, so much better in their sum total. Some, such as Aldous Huxley, have found in deeper personal enlightenment an alternative to the sterility of modern materialism, but it was never explained how this was to be made accessible to all. To Rachel Carson insecticides were poison, but she did not explain how their abandonment could fail to result in lower crop yields and higher human mortality.

This is not to say that the ills deplored by social critics from Isaiah to Miss Carson are not indeed deplorable, nor that the selfish pursuit of human advantage may cause pernicious, irreversible changes in nature. So it is with the ills catalogued by Ellul. As inhabitants of the technological society we have no cause for complacency and good reason to distrust it; indeed, it is part of Ellul's argument that the descent into hell is without pain. Deluded by propaganda, seduced by prosperity, numbed by drugs, we do not sufficiently dread the clinical concentration camp of the future world. ("It will not seem insane," writes Ellul, "for everything will be ordered, and the stains of human passion will be lost amid the chromium gleam. We shall have nothing more to lose, and nothing to win.... We shall be rewarded with everything our hearts ever desired.") The proddings of an Orwell only break the rhythm of our ruminating jaws as, with eyes intent on the fatal screen, we sink ever farther from reality.

That is the reiterated, fundamental lesson of Ellul's book. Modern men are

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By Victor Keppler

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My Baby Magazine pays $10 to $15 for pictures of expectant and new mothers, babies and children under three.

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How to sell the same picture more than once

Furthermore, you usually retain all rights to your pictures, which means you can sell them over and over again. Arthur d'Arazien, one of today's top photographers, has sold reprint rights to the same Rocky Mountain landscape over 18 times, for a total of $5,800 — and he still owns the picture.

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the opposite of what they seem and preach. They speak of religion and practice deviltries. They bow to morality and obey their desires. They pray for knowledge and grasp at power. Freedom is a farce, democracy a sham. Politics is a contest between Tweedledum and Tweedledee: "The structures of the modern state and its organs of government are subordinate to the techniques dependent on the state. If we were to consider in turn each of the indispensable services of the modern state, we would find that they are becoming more and more alike, regardless of the theories of government under which they operate." All we think we are is false; all the principles, morals, ambitions, traditions and hopes inherited from the past are myths and meretricious slogans; only technique is real and only its laws are obeyed—not the laws of God, of nature or of man. The technicians themselves, the "they" of our world, are not the masters but the creatures of the system. This is Ellul's teaching, and who can deny its partial content of truth?

The fact remains that if Ellul is right, his book is useless. It warns us of disasters we are powerless to ward off, and so his warnings could only be of value if the basic premise—that the dominance of technique is inevitable—were to be proved incorrect. This logical dilemma Ellul has created for himself; *The Technological Society* must be a book without influence on events unless the views it propounds are false. Some readers may also be swayed by another reflection: Ellul has more belief in technique and less in humanity than any technician. Most of us who believe, with Francis Bacon, that knowledge and power have done great good as well as evil hope that humanity—resilient, resourceful, adaptive—will not only escape the horrors that are feared for the future but also alleviate some of the ills we now experience and regret. We have faith, not wholly unjustified by history, in our species and its future. We cannot bring ourselves to look forward with *only* the despair, disgust and rage Ellul obviously feels (see "A Look at the Future" at the end of the book). We do not even see that his dire predictions will necessarily be verified. The first biblical murder was done with the jawbone of an ass, yet man has survived successively more dreadful weapons. All great scientists and virtually all creative artists and philosophers have possessed this faith in humanity; so have all great social reformers. Ellul appears to be without it. His analysis leaves him with no basis for rational optimism. His *diabolus ex machina*—technique—is greater than man.

A reviewer cannot in general think well of a book that counsels despair; one can hardly even condone a volume that seems to offer as its most practical hope a course of events that would bring chaos, misery and death to nine-tenths of the human race in a matter of months. Such would be the result of a rapid abandonment of technique, which with all its faults is the fruit of the application to our problems of the best intelligence we have. The fruition of intelligence demands technique; the renunciation of technique involves the abnegation of intellect and a return to prayer as the only shield between man and destruction. This argument returns us to the dilemma I have mentioned: we can only act purposefully if Ellul's thesis is false. If he is right, that is, if human intellect has reached the ultimate impasse in our civilization because our intellect and our nature have entered into a mutually destructive antagonism, then as he says there is no hope for us but a miracle. Yet the odd thing about man is his survival against overwhelming odds; he may continue to survive them. To have despaired in the past would have been mistaken; is it right to despair now?

The Technological Society is to be thoroughly commended to all those who still imagine that social problems can be tackled with can openers; it is a complete cure for unreasoning euphoria. (It might be observed, however, that Samuel Butler's *Erewhon* is a briefer and wittier book.) Those who are already constructively concerned about the multifarious evils and problems of our civilization will not find that Ellul offers them any food for thought or suggestions for action. If they wish to implement a faith in humanity, they must look elsewhere than to *The Technological Society*.

Short Reviews

SIGNS AND WONDERS UPON PHARAOH, by John A. Wilson. The University of Chicago Press ($5.95). An informal, anecdotal, entertaining history of Egyptology, with the main emphasis on the American contribution. It is only with the facts brought together by so knowledgeable a specialist as Wilson that one realizes how long Americans have been fascinated by ancient Egypt and what a motley of desires and ambitions underlay the activities of the many Americans who explored the land, dug up and studied its treasures and helped to re-create the story of its civilization. Thomas Jefferson urged John Ledyard to visit Egypt and report to him on its antiquities. The Peabody Museum in Salem, Mass., began in 1800 to exhibit Egyptian objects brought home by Yankee ship captains. Architecture and decoration in the Egyptian style are surprisingly abundant in the U.S.: obelisk forms in many old cemeteries, monuments, the famous "Tombs" prison in New York, which imitated the temple style, the Great Seal of the United States with its unfinished pyramid. Lieutenant Commander Henry H. Gorringe of the U.S. Navy on his own initiative brought back from Egypt the 70-foot, 224-ton obelisk that in 1881 was erected in New York's Central Park. Charles E. Wilbour, a member of the notorious Tweed ring who fled to Egypt when the ring was exposed and spent some seven or eight years there living plushly off his plunder, became one of the foremost Egyptologists of the time.

American Egyptology came of age at the beginning of the 20th century with the brilliant work of two Middle Westerners: James Henry Breasted, who started out to study for the ministry at the Chicago Theological Seminary and then, when he won a prize for Hebrew, turned first to the study of Semitic languages and later to Egyptology, and George Andrew Reisner, who is regarded as the preeminent excavator of Egyptian antiquities during the first part of this century. Wilson's book is filled with diverting material about not only American Egyptologists but also such figures as Wallis Budge, a recorder and popularizer of antiquities and an incomparable smuggler of them; Sir Flinders Petrie; Rev. Archibald H. Sayce, who spent many years on a houseboat on the Nile; the Earl of Cromer, the noted British Agent and Consul General in Egypt, who ruled the land for 20 years; the prodigiously industrious Sir Gaston Maspero, who made marvelous guesses on the basis of inadequate evidence; the British spinster Amelia B. Edwards, for many years the chief promoter of interest in Egyptian archaeology. Good illustrations.

ON THE ORIGIN OF THE SPECIES, BY CHARLES DARWIN: A FACSIMILE OF THE FIRST EDITION. Harvard University Press ($5.95). *The Origin of Species* was published on November 24, 1859; the first edition was sold out that day. It is unlikely that any scientific treatise has ever encountered such instantaneous demand or that any scientific

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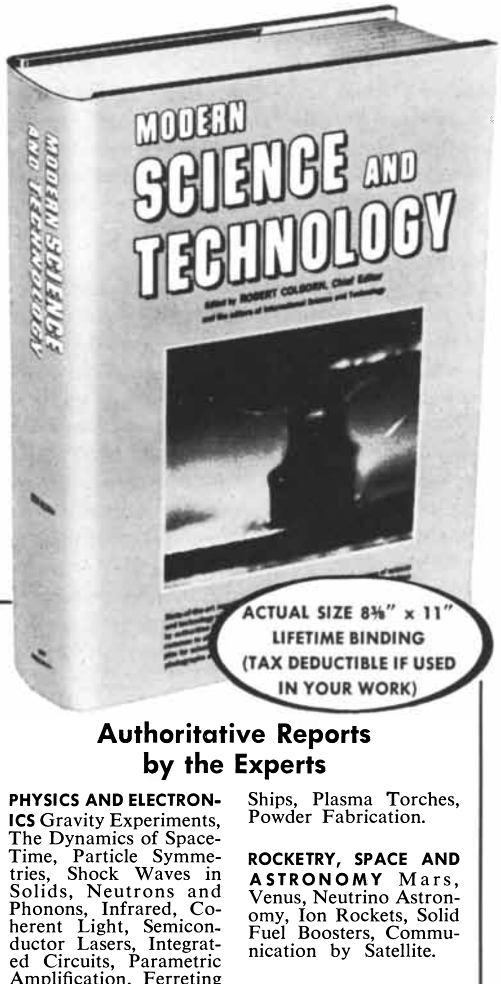

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book of modern times has had such a profound and enduring effect on almost all departments of human thought and affairs. The book's two most important ideas, natural selection and variability, although accepted by many of the best scientists of the time, affronted a wide variety of people, from plain men to theologians to geologists. During Darwin's lifetime six editions of *The Origin* were published. In the process the text underwent some revisions and modifications, particularly in the sixth edition. This being the last, it is the one most commonly used and studied today. It is therefore of importance to see what Darwin wrote originally, to be able to read his first formulation before it was altered by reconsideration and response to criticisms. A variorum edition was published some years ago that traces the changes, but it is a very large book and only for the specialist. The present volume, on the other hand, is suitable for any student of biology and evolution. Its usefulness is enhanced by an excellent introduction by Ernst Mayr.

ANDREAS VESALIUS OF BRUSSELS, by C. D. O'Malley. University of California Press ($10). A scholarly, minutely detailed biography of the celebrated anatomist, with particular emphasis on analysis, interpretation and comparison of his epochal treatise *De humani corporis fabrica* with contemporary anatomical opinions. No biography has appeared since Moritz Roth's work of 1892, and since then much new information has been uncovered about Vesalius' education in Paris, Padua, Pisa and Bologna, his relation to his contemporaries and his long service as physician to kings, emperors and other noblemen who either ate themselves into the grave like Charles V or contrived to pick up wounds or diseases that even Vesalius was unable to mend. In spite of the fresh material uncovered in the past 50 or 60 years, large gaps remain in our knowledge of Vesalius' doings, and O'Malley, although a keen researcher, is unable to do more than entertain various conjectures and speculations as to what probably happened. Even the death of Vesalius in 1564, which occurred after a wretched sea voyage while he was returning from a pilgrimage to Jerusalem, is supported by only a thin tissue of facts. The holes in the story have tempted the author to insert a good deal of filler, the result of which is that the biography is long-winded at times and tedious to anyone but the most dedicated student of anatomy. All the same, this is an honorable and solid contribution to the history of medicine. Many illustrations.

SCHRÖDINGER - PLANCK - EINSTEIN - LORENTZ: BRIEFE ZUR WELLENMECHANIK, edited by K. Przibram. Springer-Verlag ($2.50). A collection of correspondence between Erwin Schrödinger, Max Planck, Albert Einstein and Hendrik Lorentz dealing with the invention of wave mechanics. These letters, most of them written in 1926, about the time Schrödinger was bringing his system to completion, are of remarkable interest. Addressing himself to each of the eminent men, Schrödinger explains some of the peculiar problems and difficulties that confronted him as he worked out his poetic theory explaining the bizarre economy of the atom. His correspondents in turn express their wonder and admiration and ask searching questions. A few long letters from Lorentz, to which Schrödinger gave meticulous reply, stand out in this exchange of ideas. Einstein wrote much more briefly, but as always there is magic in his queries and suggestions. A few of his later letters are engagingly depreciatory about the prevailing notion that uncertainty and indeterminism give an intrinsically fair picture of physical reality and that just because quantum mechanics works and helps us through our calculations it faithfully portrays the way things are. If, Einstein says, all there is to physics is a search for theories that work, and if one must shun more comprehensive manifestos because they, for the time being at least, defy our comprehension, all that remains of that great and honorable science can be of interest only to "shopkeepers and engineers"—"*ein trauriges Pfuschwerk.*"

A HISTORY OF THE WORLD'S AIRLINES, by R. E. G. Davies. Oxford University Press ($17.50). Commercial airlines had their beginnings even before World War I. For example, in 1909 a company was founded in Germany that over the next three years made almost 900 flights and carried more than 1,900 passengers. In 1914 the St. Petersburg–Tampa Airboat Line began a regular passenger service flying passengers across Tampa Bay, two flights a day for four months, one passenger on each 20-mile trip at $5 a head for a 20-minute journey. The flowering, of course, came after World War II, when dozens of companies came into being in Europe, Britain and the U.S. Hundreds of flying services were initiated in all parts of the world, most of them short-lived, uncertain and precarious but all contributing to the spectacular and in some ways frightening march of aviation. Although his book is packed with statistics, financial details, schedules and other data that at first glance may seem dry and uninviting, Davies' history is in fact an engrossing survey of the flying business that specialists will find indispensable and the ordinary reader endlessly diverting. Good illustrations.

CELESTIAL OBJECTS FOR COMMON TELESCOPES, by Rev. T. W. Webb. Dover Publications, Inc. ($4.50). A two-volume edition, revised by Margaret W. Mayall, of a classic handbook first published in 1859 for the amateur astronomer. In her preface Mrs. Mayall states that, although large portions have simply been reprinted from the sixth edition, revised by Rev. T. E. Espin in 1917, the work continues to possess not only historical value but also descriptive information both "delightful and meaningful" to modern observers. Paperbacked.

VEGETATION AND FLORA OF THE SONORAN DESERT, by Forrest Shreve and Ira L. Wiggins. Stanford University Press ($22.50). A monumental two-volume work on the principal plant communities of the Sonoran Desert, which includes parts of California, Arizona, the Mexican state of Sonora and most of Lower California. The first part, by the late Forrest Shreve, was published separately in 1951 and has for some years been out of print; the second part, which is new, covers both woody and herbaceous plants. Plates and maps.

EDUCATION AND THE ATOM, by Glenn T. Seaborg and Daniel M. Wilkes. NUCLEAR POWER, U.S.A., by Walter H. Zinn, Frank K. Pittman and John F. Hogerton. RADIOISOTOPES AND RADIATION, by John H. Lawrence, Bernard Manowitz and Benjamin S. Loeb. RESEARCH, U.S.A., by Albert V. Crewe and Joseph J. Katz. McGraw-Hill Book Company ($18 each). These four volumes, which in finish and profusion of illustrations remind one of annual stockholders' reports of wealthy corporations, are in fact something of that kind, the Atomic Energy Commission being perhaps the wealthiest corporation in the U.S. Nonetheless, allowing for their self-advertising, they are books of merit. Their purpose is to explain in some detail the work of the A.E.C. in the development of reactors, in the support of nuclear research, in the use of radioisotopes and radiation in medicine, agriculture and industry and in promoting science education and information. The volume by Zinn, Pittman and Hogerton on nuclear power is of uncommon interest, particularly in its description of the strange forms conferred on nuclear reactors to adapt them to many different purposes and conditions. One may also find much information on radioisotopes and new paths of research. Many of the illustrations are first-rate, and most of the writing is clear and unpretentious, accessible to teen-agers and adults alike.

TALKS TO TEACHERS ON PSYCHOLOGY AND TO STUDENTS ON SOME OF LIFE'S IDEALS, by William James. Dover Publications, Inc. ($1). This paperback consists of a few public lectures on psychology that James gave in 1892 to teachers, the material consisting in large part of abridgments of his famous treatise, and a few talks to students that are primarily concerned with moral and philosophical questions. For one of the talks alone—"On a Certain Blindness in Human Beings"—the volume is worth having. No one has ever described so well that universal affliction, the blindness we all have in regard to the feelings of creatures and people different from ourselves.

EDWARDIAN ENGLAND, 1901–1914, edited and with a preface by Simon Nowell-Smith. Oxford University Press ($15). Fifteen essays on various aspects of the deceptively sunlit afternoon of the world from 1901 to 1914, just before it was transformed into the wild, deadly, uncertain household we occupy today. Included are essays on the political scene, economy, domestic life, reading, art, architecture, science, the theater, the Royal Navy and Royal Army. A remorselessly nostalgic and attractive book. Fine illustrations.

MATHEMATICS AND PSYCHOLOGY, by George A. Miller. John Wiley & Sons, Inc. ($3.45). Concerned with the use of mathematics by psychologists in psychological theory and measurement, this volume consists of skillfully edited excerpts from the writings of Daniel Bernoulli, Johann Friedrich Herbart, Gustav Fechner, L. L. Thurstone, Edward Titchener, S. S. Stevens, Kenneth Craik and others. Miller bridges the excerpts with informative interpretive passages.

MUSKRAT POPULATIONS, by Paul Errington. The Iowa State University Press ($8.50). The late Paul Errington, before his death in 1962 professor of zoology at Iowa State University, spent tens of thousands of hours during a quarter of a century of fieldwork in assembling information on the distribution of the muskrat, which is said to be not only the most economically important wild furbearing animal in the world but also the most widely distributed. The results of this extraordinary devotion to a scientific question are reported in this massive monograph.

A HISTORY OF CHEMISTRY, by J. R. Partington. St. Martin's Press ($42). The fourth volume of Partington's great history, earlier installments of which have been reviewed in this department, covers the development of all branches of chemistry in the 19th century and part of the 20th. Lucid, masterful in its grasp of details and singularly readable for a work of such scholarship.

ATLAS AND GLOSSARY OF PRIMARY SEDIMENTARY STRUCTURES, by F. P. Pettijohn and Paul Edwin Potter. Springer-Verlag ($14.75). This must surely be one of the handsomest geology textbooks ever published. It is basically a collection of 117 photographs—selected and presented with rare good taste—showing the remarkably diverse geological formations of sedimentary origin, including some formations in the making. Although the book is intended for geologists and students of geology, it will please anyone with a hankering to know the wherefore of strangely layered rocks. The written descriptions are given in English, Spanish, French and German.

Notes

WATCHERS OF THE SKIES, by Willy Ley. The Viking Press ($8.50). An "informal history" of astronomy from Babylon to the modern search for life on other planets.

THE NATURAL RADIATION ENVIRONMENT, edited by John A. S. Adams and Wayne M. Lowder. The University of Chicago Press ($15). This volume in the "Rice University Semicentennial Series" consists of papers on the physical properties and natural distribution of radiation and its sources in the environment, presented at an international symposium at Rice University in 1963.

THE LIVER: VOLUME II, edited by Ch. Rouiller. Academic Press ($24). This second volume, completing a treatise on the liver, offers a summary of the present state of knowledge of this organ based on morphological, biochemical and physiological studies. Illustrations and extensive bibliographies.

RELATIVITY GROUPS AND TOPOLOGY, edited by C. DeWitt and B. S. DeWitt. Gordon and Breach Science Publishers, Inc. ($9.50). Lectures delivered during the 1963 session of the Summer School of Theoretical Physics of the University of Grenoble, devoted both to the theory of general relativity and to the group-theoretical and topological issues that arise in the theory.

THE STATESMAN'S YEAR-BOOK, 1964–65, edited by S. H. Steinberg. St. Martin's Press ($10). The 101st edition of this tubby little reference book, which is so packed with statistical and historical information about the states of the world that no scholar is willing to relinquish his copy until the next edition is available.

THE FRENCH REVOLUTION, by Albert Mathiez. Grosset & Dunlap ($2.65). A soft-cover reprint of a superb work of scholarship that offers its bounty to the serious student and the general reader alike.

THEBES IN THE TIME OF AMUNHOTEP III, by Elizabeth Riefstahl. University of Oklahoma Press ($2.75). A learned and graceful book in "The Centers of Civilization Series" about life in the capital of Upper and Lower Egypt in the 14th century B.C.

THE CHICAGO SCHOOL OF ARCHITECTURE, by Carl W. Condit. The University of Chicago Press ($8.50). A history of commercial and public building in the Chicago area from 1875 to 1925, covering the work of such innovators as William Le Baron Jenney, Louis Sullivan and Frank Lloyd Wright. Abundantly illustrated.

SELECTED PAPERS ON VIROLOGY, edited by Nicholas Hahon. Prentice-Hall, Inc. ($10). A collection of 40 papers, with brief introductory headnotes, on the emergence of virology, beginning with Edward Jenner's classic paper of 1789 and concluding with a discussion entitled "The Quest for Human Cancer Viruses."

RESEARCH IN GEOPHYSICS, edited by Hugh Odishaw. The M.I.T. Press ($25). The papers in this two-volume cooperative work review research and progress in the study of the sun, the upper atmosphere, space and the solid earth.

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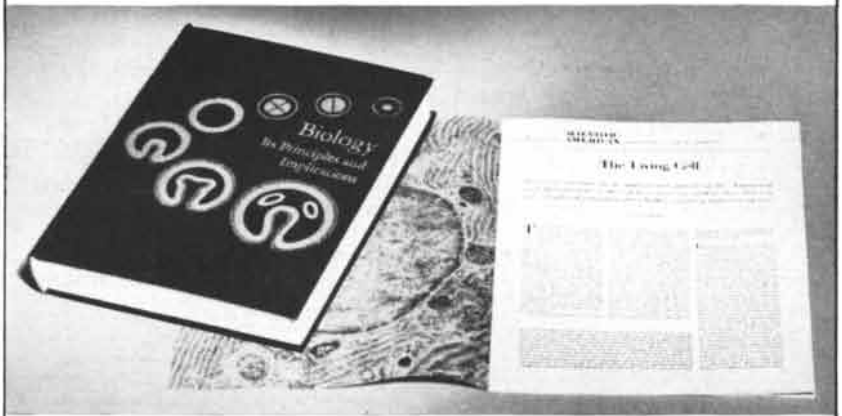

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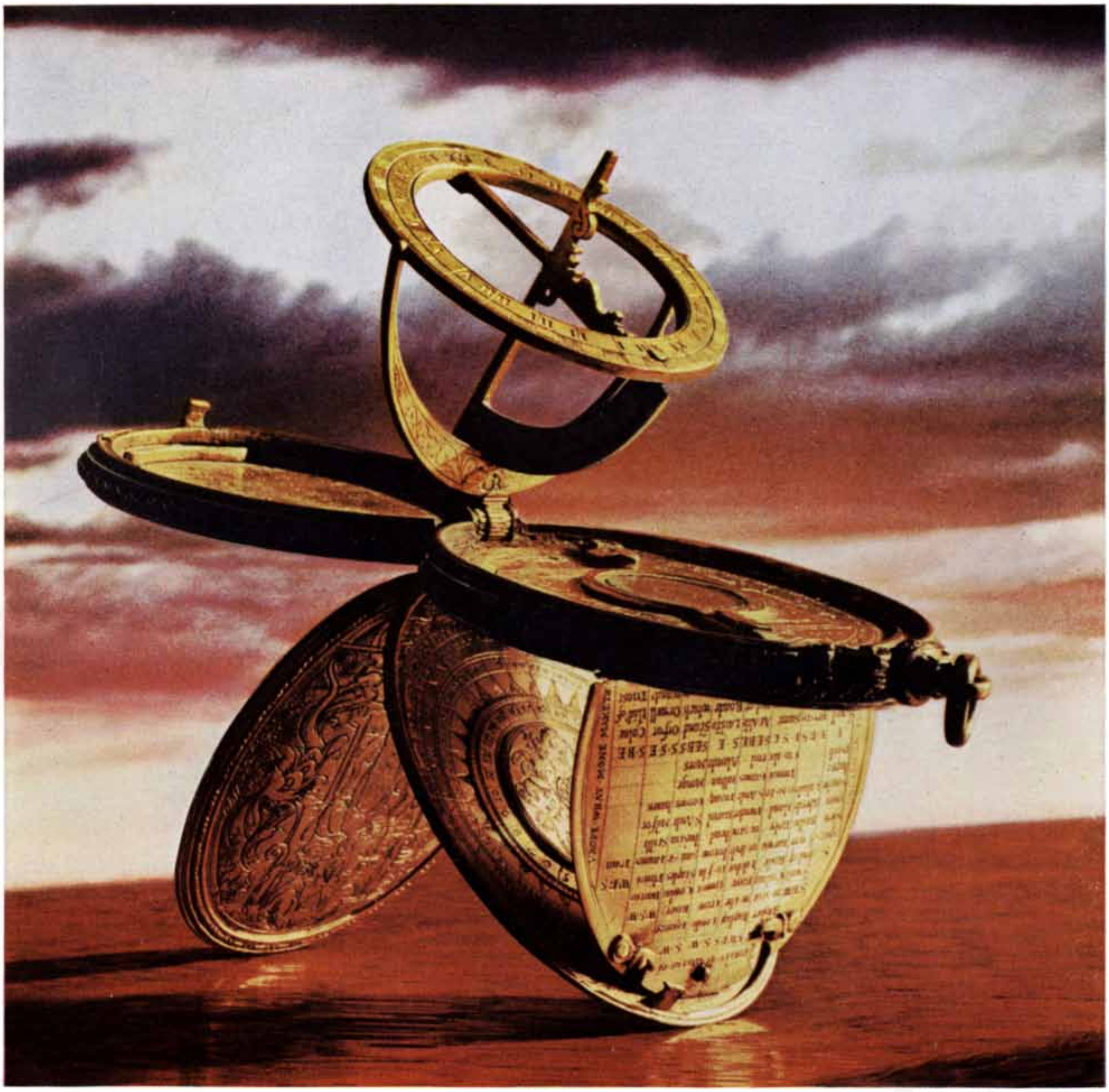

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