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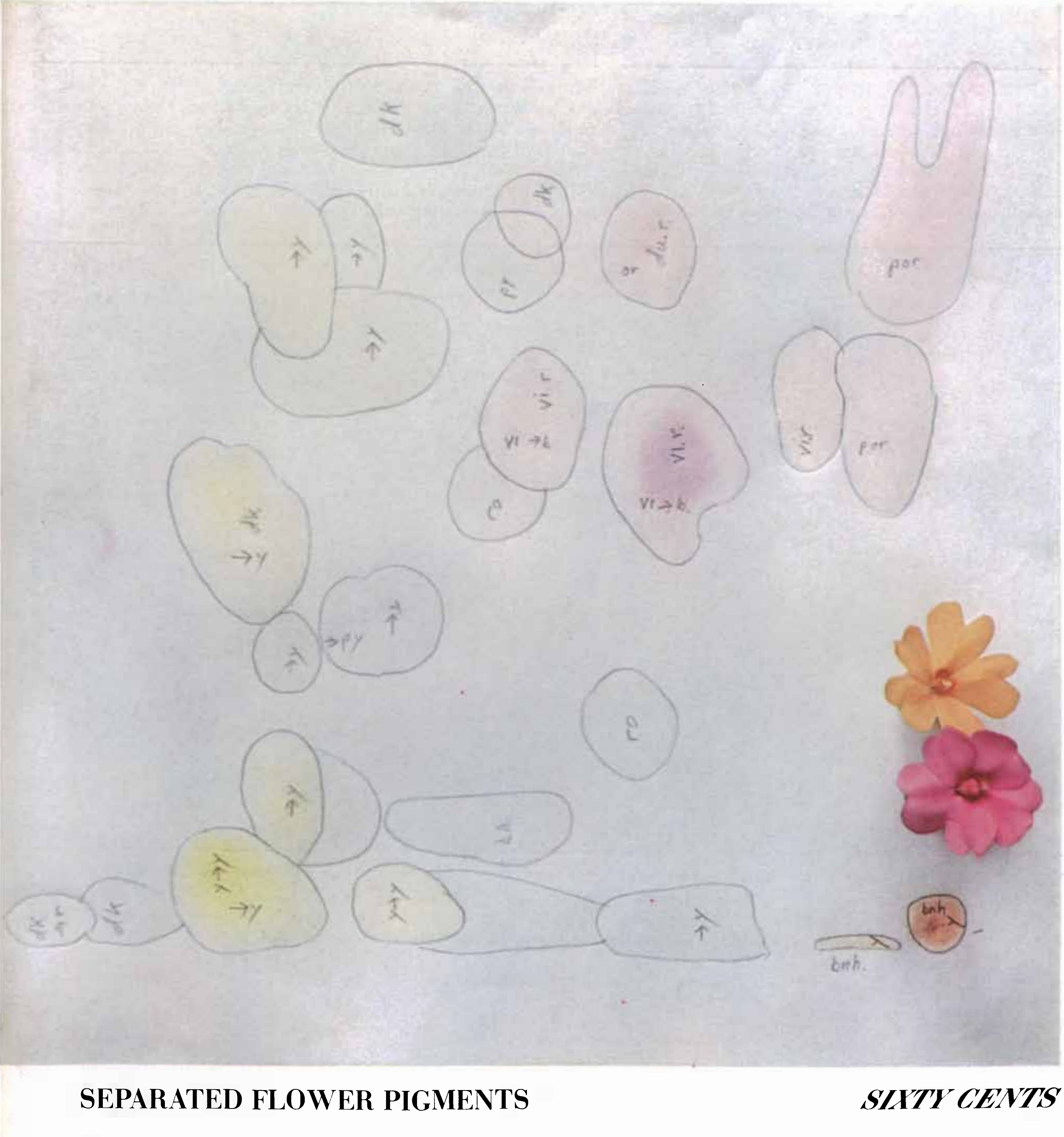
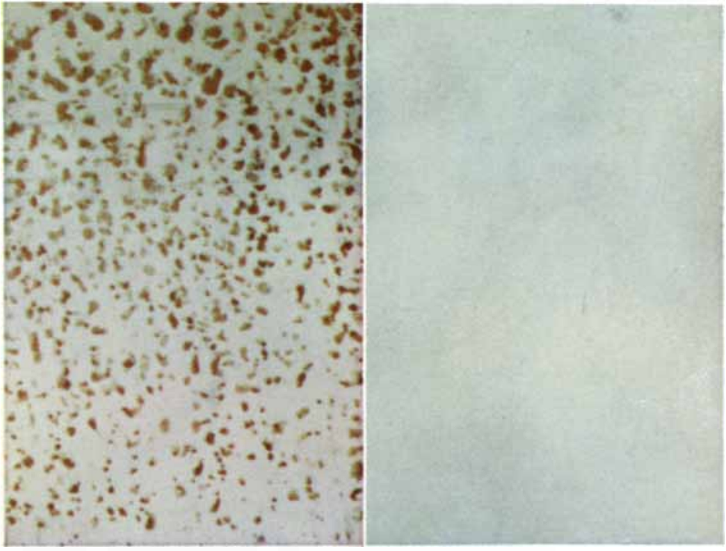


SEPARATED FLOWER PIGMENTS

SIXTY CENTS

June 1964



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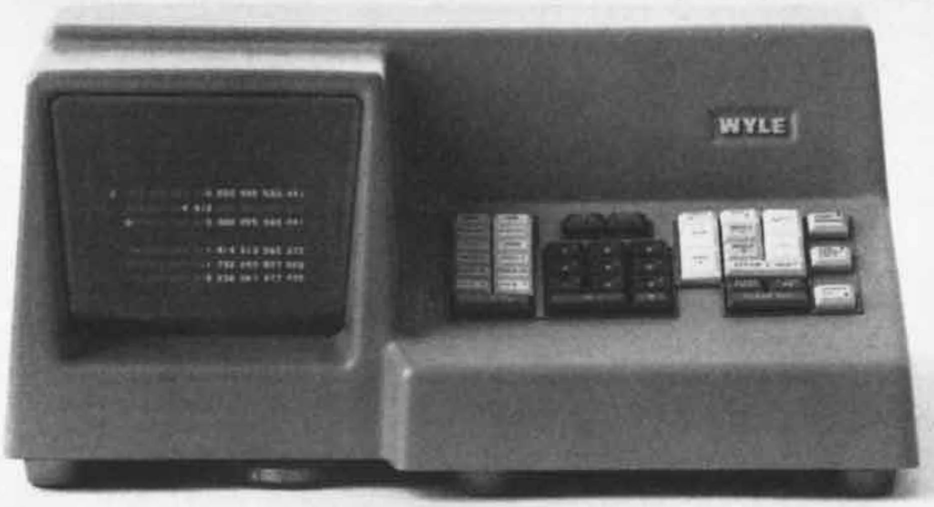

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Established 1845 **SCIENTIFIC AMERICAN** June 1964 Volume 210 Number 6

ARTICLES

DEPARTMENTS

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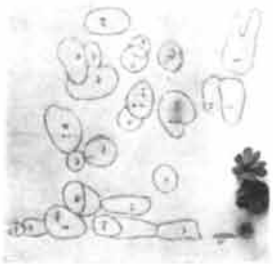

THE COVER

In the photograph on the cover are two flowers of the genus *Impatiens* (*lower right*). The magenta flower is *I. platypetala,* found in Java and Sumatra; the species of the orange flower, which grows on the nearby island of Celebes, is not certain. Because the two plants are so similar some taxonomists consider the second to be a variety of the first; others maintain that the second is a separate species and should be recognized as *I. aurantiaca*. Analysis of the flower pigments by the technique of paper chromatography strengthens the second viewpoint (see "Flower Pigments," page 84). A solution containing a mixture of pigments from flowers of both species was dropped on the spot just below the magenta flower. The right edge of the paper was then hung from a trough holding a solvent and the pigments descended in a line at different rates. The bottom edge of the paper was then placed in another solvent and the pigments ascended, again at different rates. The spots at which the various pigments stopped migrating are outlined in pencil. Some of the spots derived from *I. aurantiaca* do not appear in the chromatogram of *I. platypetala* alone.

THE ILLUSTRATIONS

Cover photograph by Paul Weller

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The Problems of Precise Measurements of Signal Waveforms in Noise

NONE OF THE "SIGNAL AVERAGING" DEVICES NOW AVAILABLE *REALLY* AVERAGE SIGNALS

EXCEPT NORTHERN SCIENTIFIC'S NS-513 DIGITAL MEMORY OSCILLOSCOPE

What these non-averaging "signal averagers" really do is add the recurrent waveforms. It is up to the customer to do the last tedious step, determine the number of signals that were totalled, and divide data points of interest by that number, if he wants absolute rather than relative values.

So urgent is the need to measure recurrent signals obscured by noise, nobody has complained very much.

But in Northern Scientific's Model NS-513 Digital Memory Oscilloscope, the recorded and displayed data have the dimension volts, not volt-seconds. A reading of 892 means 892 millivolts, and doesn't keep increasing in magnitude as more signals occur.

In this instrument each of the 512 data points approaches its final value in almost exactly the way a heavily damped galvanometer approaches its final value, in the case of measuring a d. c. voltage. As in the case of the damped galvanometer, voltage excursions due to noise have only the slightest effect on the position of the galvanometer, even if the noise spikes have much greater amplitude than the signal. By very close analogy, the recorded data points in the Northern Scientific instrument approach final values at rates determined by the operator-selected time constant, which can be as short as two seconds or as long as several hours.

The entire waveform, as recorded, is heavily damped and after reaching its near-final value, is almost unaffected by even a large number of persistently incorrect input signals. The operator may, of course, use a short time constant initially to obtain a quick approximation.

A few outstanding features of the NS-513 follows: Delivers direct voltage readings, not readings which depend upon sweep speeds and the number of signals averaged. No more growing, moving displayed waveforms, no more ambiguities ... Provides 0.1% accuracy ... Uses all silicon semiconductors ... Has built-in typewriter controls ... Provides point by point, or subtotal, digital readout for easy integration ... Has reversible sweep ... Has trigger circuits that respond to external trigger pulses or prominent signal features.

For further information, write for our new brochure, price and delivery information, or phone (608/238-4741).

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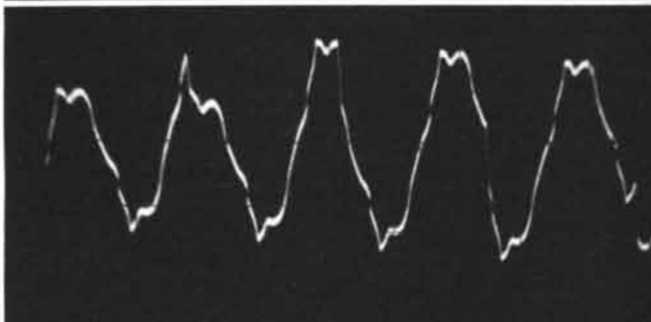
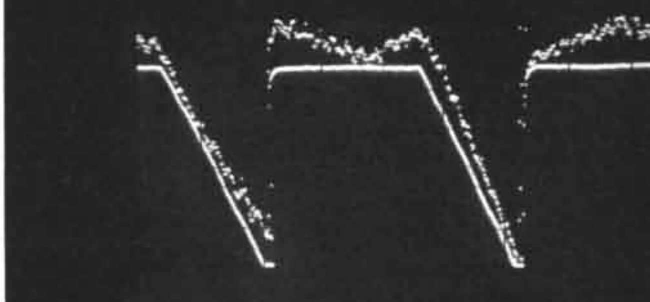
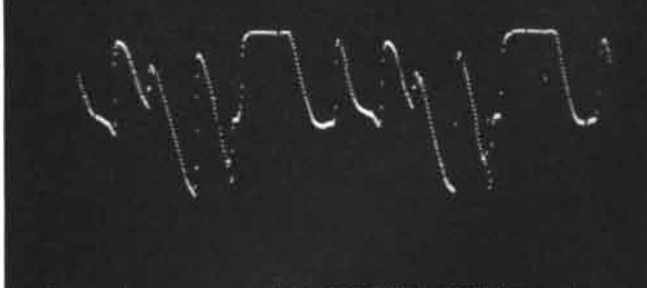
NOISY SIGNALS now clearly seen in a *truly easy* and *excitingly new way*...with the NS-513 Digital Memory Oscilloscope (above).



Noise and signal, as seen by standard oscilloscope at input to Model NS-513 Digital Memory Oscilloscope.



A quick measurement with a short time constant produces a reasonable first approximation, as shown by the jagged line of this multiple exposure photograph. Switching to a more appropriate time constant and measuring for several minutes produced the more accurate final waveform shown superimposed.



A complex waveform indicating the time resolution available with 512 coordinate points.

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Measuring Heats of Fusion of Salts with a Dynamic Adiabatic Calorimeter

Modification of and additions to known techniques have led to a fast and accurate method of measuring heats of fusion and specific heats of materials.

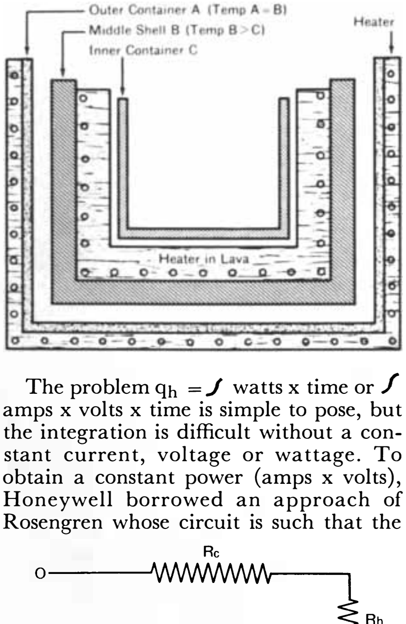
Fused salts are stable at high temperatures, have low vapor pressure, low viscosity and good electrical conductivity. They are also able to dissolve many different materials. Extremely useful in metallurgical processes, they have been used as heat transfer materials, power sources, control devices, and coolants and fuels in atomic reactors.

One area of interest to Honeywell scientists concerns heats of fusion of specific salts. Much older heat of fusion and specific heat data to be found in the calorimetric literature are inaccurate, particularly those on inorganic compounds with high melting points. At the same time present methods of obtaining accurate data are cumbersome, complex and time consuming.

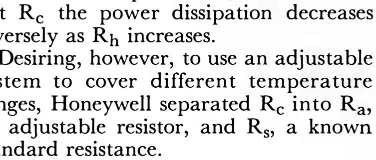
Modifying and adding to known techniques, Honeywell scientists have developed a calorimeter that gives direct reading, highly accurate data in as little as two hours.

A conventional calorimetry equation is $q_h = q_s + q_c + q_1$ or the heat supplied to the system equals the heat absorbed by the sample (q_s) plus the heat absorbed by the calorimeter (q_c) plus any heat loss (q_1).

Honeywell's approach (see illustration) is to eliminate q_1 by maintaining adiabatic conditions between the outer shell (A) and the next or middle shell (B) and to maintain a constant temperature gradient between a higher temperature in the middle shell (B) and a lower temperature in the inner shell (C) containing the sample. The equality of temperatures at (A) and (B) forbids heat from passing from the middle (B) to the outer shell (A) so that after the middle shell temperature reaches its control point all heat must pass to the sample. The outer-middle shell adiabatic condition and the middle-inner constant temperature gradient condition are maintained with two feed-back control systems. If these conditions are met q_1 can be ignored and $q_h = q_s + q_c$. If the sample is removed $q_h = q_c$ and q_c becomes known so that q_s can be determined by a simple subtraction. The problem then becomes how to accurately measure q_h.



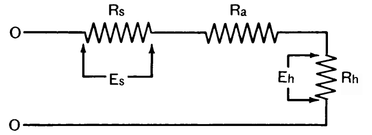
The problem $q_h = \int$ watts x time or $\int$ amps x volts x time is simple to pose, but the integration is difficult without a constant current, voltage or wattage. To obtain a constant power (amps x volts), Honeywell borrowed an approach of Rosengren whose circuit is such that the



difference in power dissipated by R_h will be negligible between any two temperatures if $R_c = \sqrt{R_{h1} \times R_{h2}}$ where R_{h1} is resistance at temperature 1 and R_{h2} is resistance at temperature 2, whereas without R_c the power dissipation decreases inversely as R_h increases.

Desiring, however, to use an adjustable system to cover different temperature ranges, Honeywell separated R_c into R_a, an adjustable resistor, and R_s, a known standard resistance.

Then, adding a potentiometer to measure E_s across R_s and E_h across R_h,



$E_s = R_s i_s$, where i_s is the same as i_h and R_s is known. Thus watts across R_h can be determined: $E_h E_s/R_s$ = watts of constant power.

With a strip chart recorder measuring the temperature of the sample only when power is demanded, a direct readout of the heat of fusion (q_h) is possible. The chart reads time directly between any two points. Therefore, when temperature ceases to climb, fusion is taking place and when temperature rises again fusion is completed.

Since q_h = watts x time, and watts ($E_h E_s/R_s$) is maintained constant, q_h becomes a known factor x time, so that by an easy conversion, time for fusion is in effect, q_h, the heat of fusion. By comparing plots with and without the sample, specific heat data are also easily obtained.

This chart, plotted automatically in two to three hours, replaces computations that took several weeks. Results have been impressive. In measuring the heat of fusion of benzoic acid in five runs, one was +1.7% above the Bureau of Standards figure, one +2% and three exactly on standard.

Work is continuing at Honeywell's Research Center. As heats of fusion of various salts are more readily measured and predicted, further uses are expected. If you are engaged in high temperature calorimetry and wish to know more about Honeywell's work in this area you are invited to write Dr. Cyril Solomons, Honeywell Research Center, Hopkins, Minn.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree in any branch of science you are invited to write Dr. John Dempsey, Director of Research, at this same address.

Honeywell

LETTERS

Sirs:

Leonard Berkowitz' reference to Aristotle's theory of catharsis ["The Effects of Observing Violence," by Leonard Berkowitz; SCIENTIFIC AMERICAN, February] is entirely unnecessary for his discussion of the effects of the spectacle of violence, and as he uses it, it makes no sense historically or psychologically.

Aristotle is talking precisely about "tragic" feelings, which are constrictive states of the organism: to open out foreboding and sadness to felt fear and grief. He is not referring at all to expansive feelings such as anger or lust; on the contrary, these would be *excited* by battle songs or comedy. In the context of Greek civic therapy it is inconceivable that public poets would want to reduce the aggressive or the lustful, although they might well want to diminish guilt and mourning....

The most important current context for Professor Berkowitz' violence hypothesis is in designing pacifist films, and I agree with him that showing violence, the brutality and horrors of war, probably has an exacerbating rather than a pacifist effect. (For the psychology, see "Designing Pacifist Films" in my *Utopian Essays*.)

Regarded simply as abreaction, letting off steam, a spectacle arousing fear and grief is different from one arousing rage, since a spectator in a theater can actually physically be chilled to the bone or have a good cry but he cannot actually kick or punch anybody. There is stimulation without discharge; no wonder Professor Berkowitz' subjects are left touchy. He should set up his experiment to allow a physical outlet—punching a bag—then he might find a cathartic effect.

But certainly Professor Berkowitz must know that Aristotle's catharsis is not a doctrine of mere abreaction. Nearly the entire *Poetics* is devoted to the management of the plot to the proper resolution so that the aroused feelings can be reintegrated. In the history of interpretation of the text, catharsis has been called "idealization," "transcendence," "poetic justice," "reconciliation" and so on. The emotions are neutralized when there is some new awareness. From this point of view Aristotle himself would agree with Professor Berkowitz' empirical observation of diminishing of aggression against the "good guy"; but this need not be merely superego inhibition. The difference is between Professor Berkowitz' stereotyped fictions, which can result only in conformist inhibition, and genuine poetry that gives insight and compassion, for example the much-remarked saddening and pacifist effect of the *Iliad,* in contrast to most war stories.

Allow me a last observation. We must remember that with regard to psychological, pedagogic and political matters, the ancients had as much empirical evidence as we do—they too lived in cities, brought up children, quarreled, practiced rhetoric. Generally too they had a simpler vision than we do. It is extremely unlikely that, on matters such as the effects of a good cry or of showing violence, they would be as far off base as Professor Berkowitz thinks.

PAUL GOODMAN

Institute for Policy Studies
Washington, D.C.

Sirs:

A number of readers have taken me to task for oversimplifying Aristotle's discussion of catharsis. My apologies if I did him an injustice. But when it comes to the matter of considering the possible effects of media violence, Aristotle's exact analysis is somewhat less important than the view generally attributed to him; authorities *have* quoted him in asserting the presumed social benefits of aggressive scenes, and it is this assertion (oversimplified though it may be) to which part of the article was addressed.

One other point about Aristotle's analysis. I believe that the "new awareness" resulting from the use of "genuine poetry" or "art" is not more likely to lead to a "drainage" of anger than is ordinary melodrama or mere reportage (as some have put it). Here we have to be careful in distinguishing between catharsis, a reduction in some emotional state, and a decreased probability of *overt* aggression due to inhibitions. Insight or self-awareness can arouse inhibitions ("I should not attack this person; I would behave the same way if I were in his place"). Compassion can arouse inhibitions ("He is acting in that awful manner only because of the way he has been treated or because he is suffering"). Indeed, we could say that the less justified movie-aggression condition produced compassion toward Kirk Douglas in just this way, and independent evidence indicates that inhibitions were aroused in the subjects feeling the compassion. And similarly, poetry or art that makes the audience conscious of the ideals of our society may also arouse inhibitions; our ideals proscribe certain forms of behavior as "bad" and thus not to be carried out. Contrary to what Mr. Goodman says, then, the diminishing of aggression against the "good guy" because of compassion for him, or because the audience is poetically reminded that all men are brothers, may well be the result of inhibitions....

To get on with the discussion, I am not certain what sort of film Mr. Goodman has in mind when he talks about movies showing the brutality and horrors of war. If the audience regards the violence as brutal and horrible, however, its effect probably would be to diminish the likelihood of aggression rather than have an exacerbating effect. The audience, in a sense, is made extremely aware of the harmful consequences of this behavior and inhibitions against this behavior are aroused....

Finally, as for the matter of movies providing stimulation without an opportunity for discharge, this is beside the point. The adherents of the symbolic-catharsis notion have contended that aggressive movies *in themselves* produce the release, not some activity afterward....

LEONARD BERKOWITZ

University of Wisconsin
Madison, Wis.

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Special Report: new from the innovators of 'thin-tin'– steel foil as thin as this page

One of the most significant innovations in packaging history occurred not long ago when U. S. Steel announced the development of "thin tin," a lightweight tinplate that enables canmakers to turn out 25% to 40% more cans from the same weight of tinplate. Now, from the same company, another product is in advanced stages of development: tinplated steel foil, a new material less than half as thick as "thin tin."

Steel foil is only 2 mils thick, about as thick as the page on which this news is printed. Laminated to paper or cardboard, it offers the package designer a combination of properties unlike any other packaging material. It has strength, bulge-resistance, puncture-resistance, rigidity, and virtually no bulk. It acts as a barrier against moisture and insects. It has wet strength. It can be attractively lithographed. And it can be thrown away, as a disposable bake pan is discarded, because it is inexpensive.

Give you ideas? If you have a packaging problem, write on your letterhead for a free sample and further information.

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U. S. Steel is introducing an average of two new or improved products each month. And it is a habit at U. S. Steel to suggest innovation in the use of all steel products. If you could benefit by this brand of thinking, do business with *U.S.Steel . . . where the big idea is innovation.*

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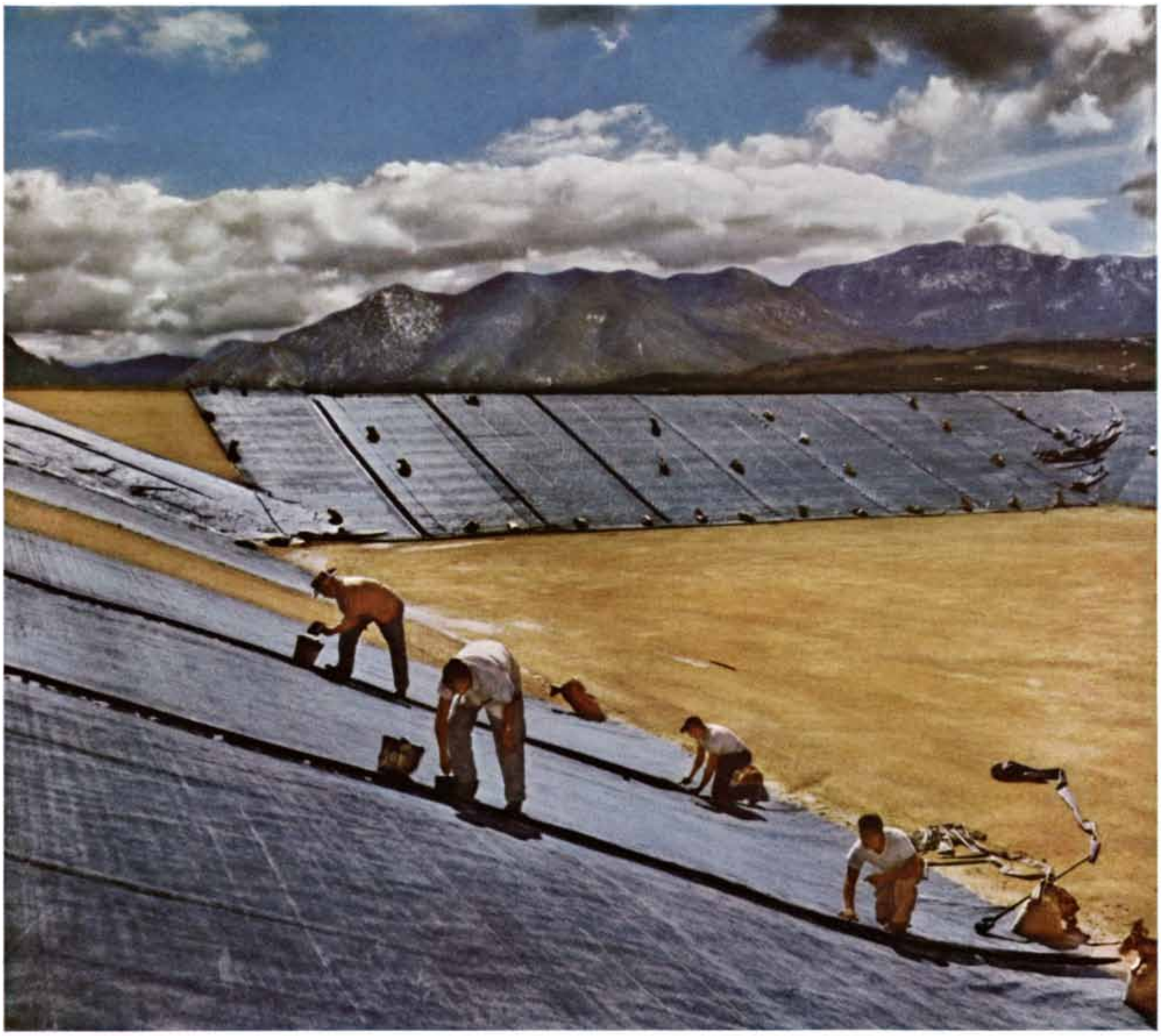

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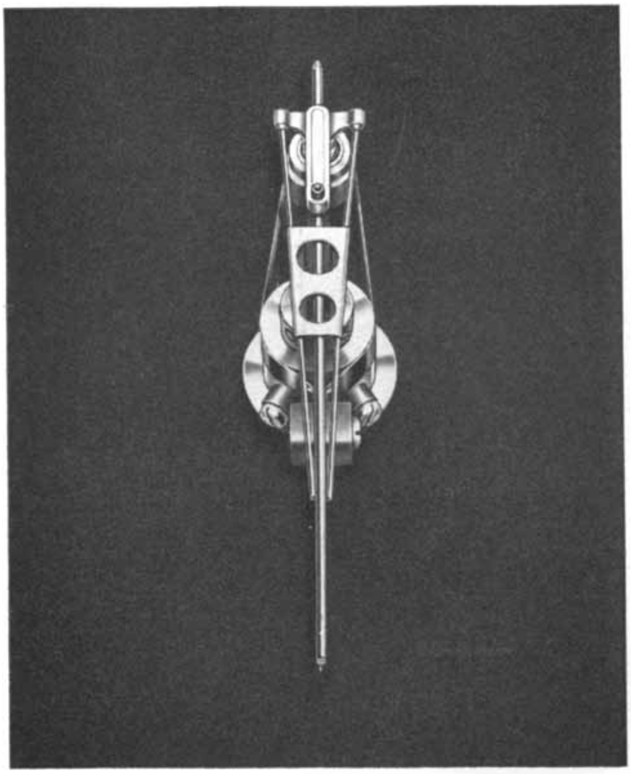

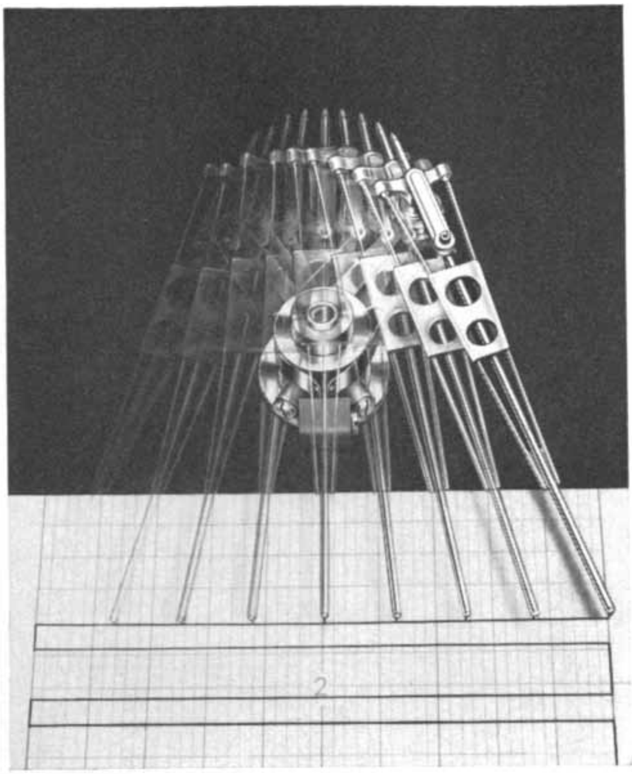

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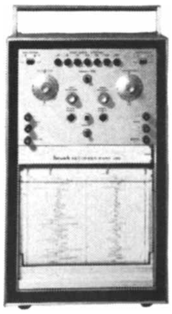


brush INSTRUMENTS

DIVISION OF CLEVITE 37TH AND PERKINS, CLEVELAND 14, OHIO

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1914: "For many years the laboratory of Prof. Kamerlingh Onnes at Leyden has been the center from which some of the most important advances in low-temperature physics have been announced. Of late attention has been centered on the remarkable influence of temperature on the electrical resistance of metals. This resistance is found to become practically zero before the absolute zero of temperature is reached. Recent newspaper accounts state in somewhat vague terms that remarkable new developments have followed in the train of this work on the conduction of electricity at low temperatures. The question arises: What happens to an electric current once started in a conductor of zero resistance? Its energy is not dissipated as heat, since the ohmic effect is nonexistent. Does the current continue to flow indefinitely? If so, a closed loop carrying a current would function as a permanent electromagnet. It is rumored that something of this kind has been observed. We shall await further news with interest."

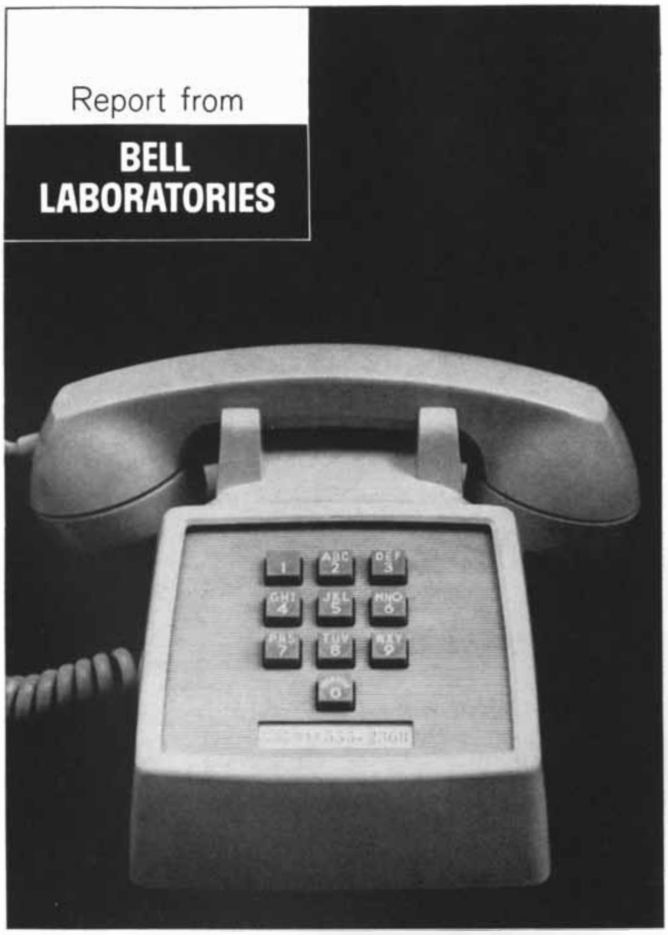
"According to press reports, Thomas A. Edison is now engaged with the problem of producing electricity directly from coal and declares that it will be accomplished someday. If Edison succeeds in solving this problem, it will be without doubt his greatest contribution to the good of man."

"Dr. Hans Reck of Berlin has discovered at Oldoway in the north of German East Africa the skeleton of a man who lived, in all probability, some 150,000 years ago."

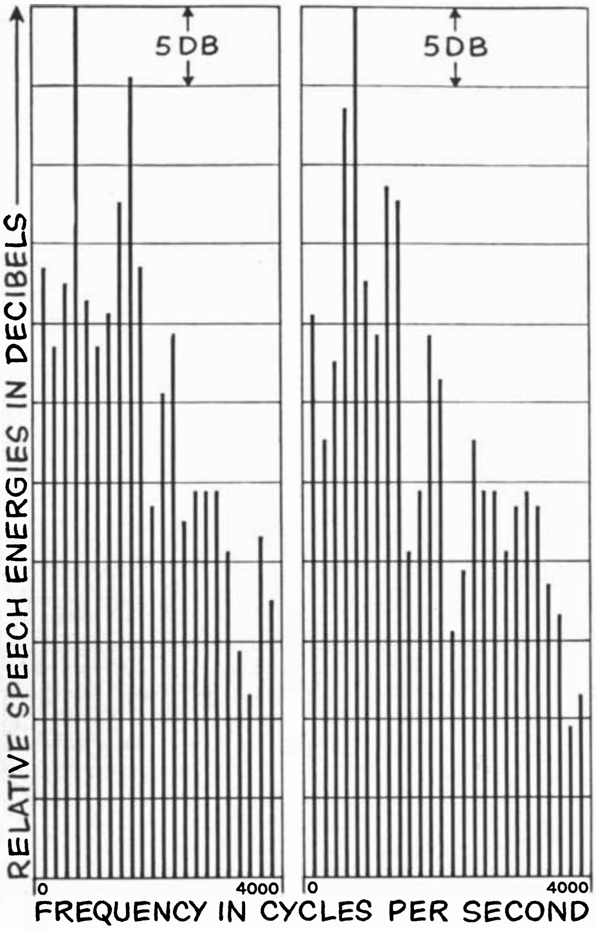
"The United States Government intends to strengthen the aeronautical branch of the Army. It is reported that an order for 30 aeroplanes has either actually been given or will be given. According to Secretary of War Garrison, the Army needs fliers badly. The United States has made no systematic effort ei-

Report from

BELL LABORATORIES



The new TOUCH-TONE® telephone designed by Bell Laboratories. Instead of direct-current pulses from a rotary dial, alternating-current tones are generated by a transistor oscillator within the set and sent, over the voice channel, to the central telephone office.



Fourier analyses of two 6-millisecond segments of male speech vowel sounds. Vertical bars show relative energies of successive harmonics of fundamental speech tones over approximate telephone transmission frequency band.

TONES FOR A TELEPHONE WITHOUT A DIAL

In developing the new TOUCH-TONE® pushbutton telephone (above, left), engineers at Bell Telephone Laboratories faced a challenging problem.

The pushbuttons on the new telephone trigger audio-frequency signals, or audible "musical tones," that register telephone-number digits in the central office. But human voices produce highly complex patterns of speech energy throughout this same range of frequencies (above, right). The problem was to arrange the pushbutton frequencies and design the central office receiver in such a way that automatic equipment would not misinterpret voices or room noises as digits.

Bell Laboratories people, drawing upon a fund of acoustical knowledge built up over years of research and development and upon the results of new experiments, found the solution in the use of multifrequency signaling tones for each digit.

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Scientific American.

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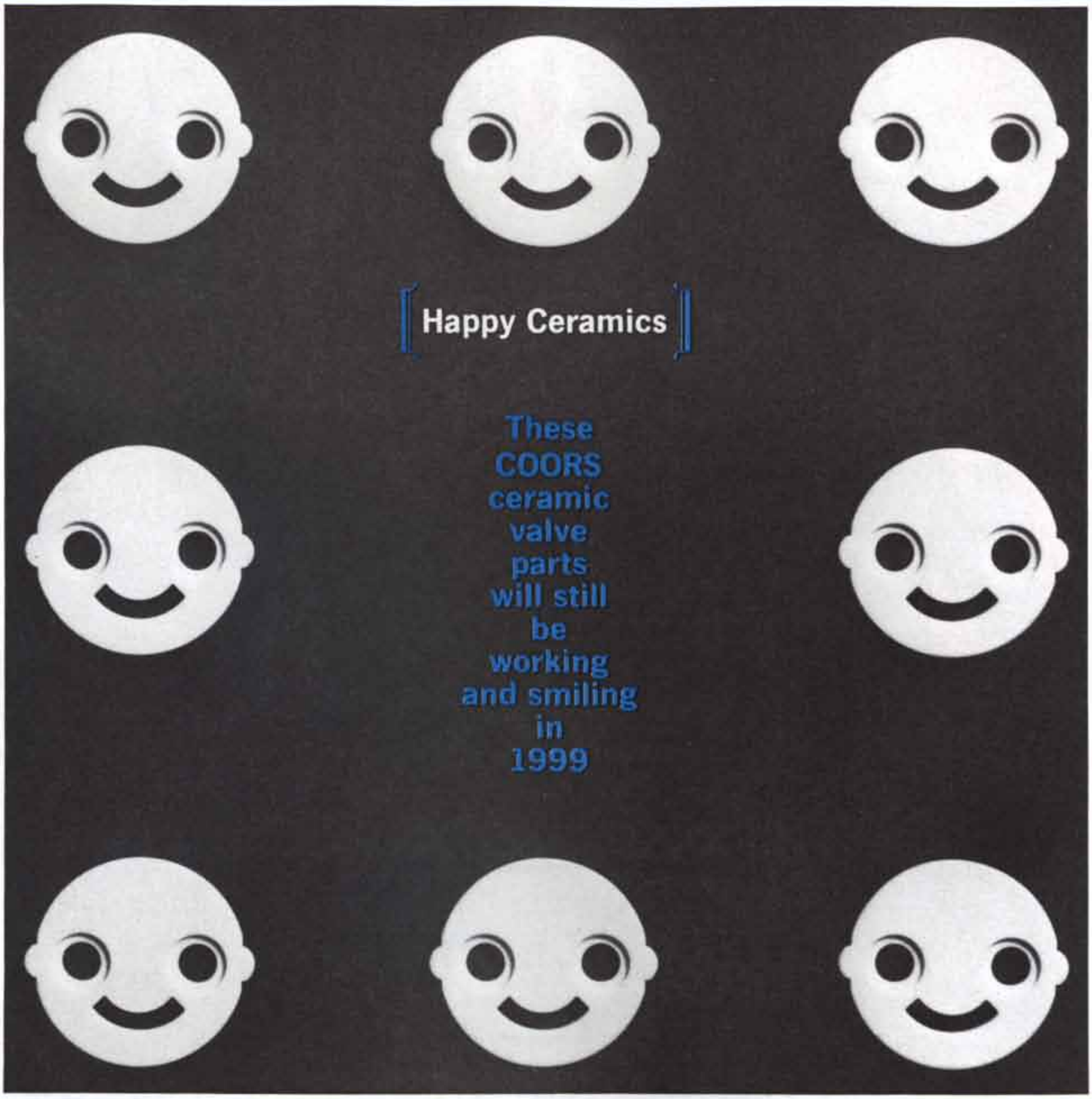
"In an article in the last number of the *Atlantic* Prof. Agassiz discusses the evidence of the existence of glaciers in Scotland and other parts of Europe in ancient times. He comes to the conclusion that there was a period when the climate of northern Europe was so much colder than at present that the summits of all the mountains were covered with perpetual snow and all of the valleys upon their sides were filled with rivers of ice, similar to those which are now moving slowly, constantly and with irresistible force down the valleys of the Swiss mountains."



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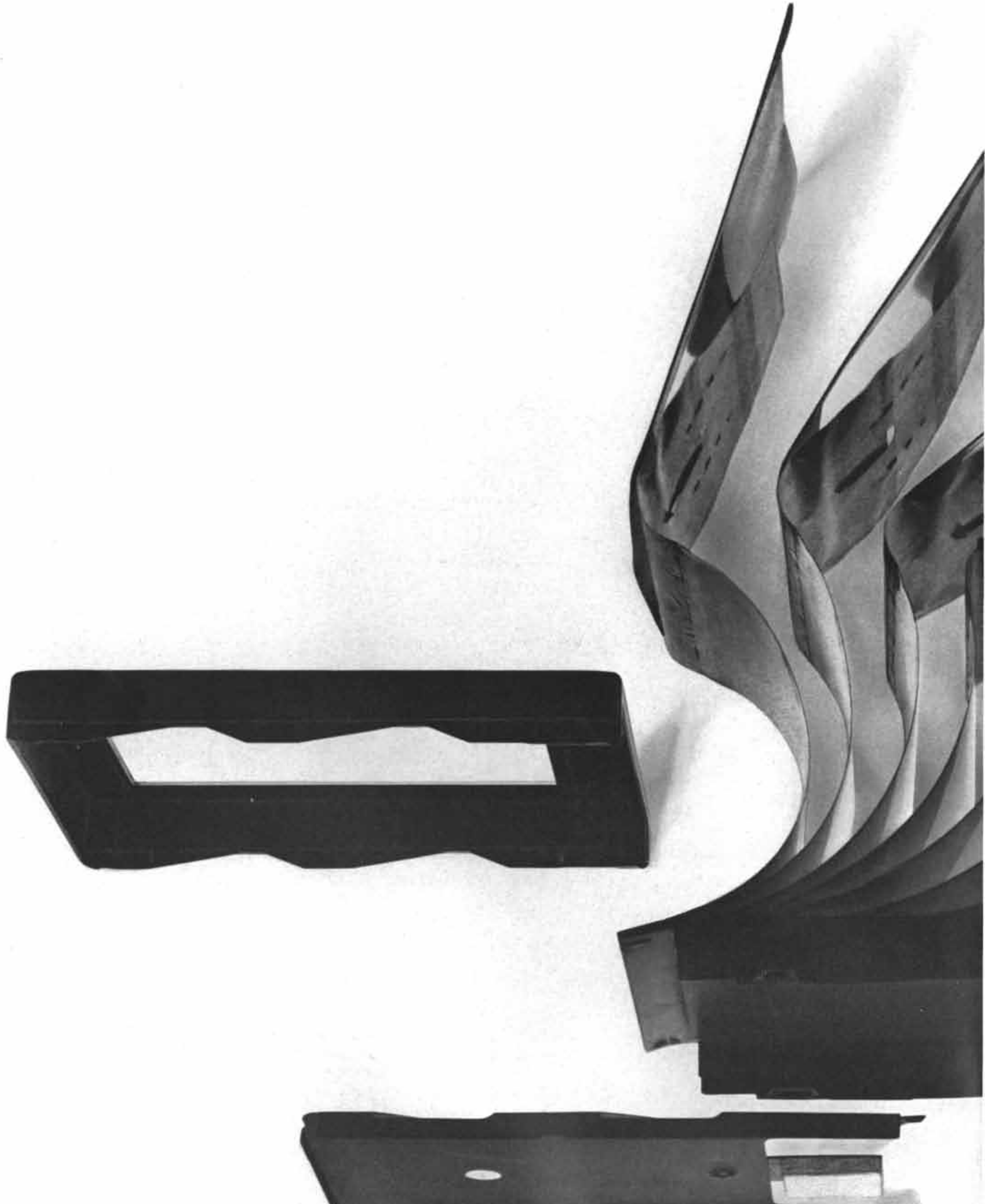

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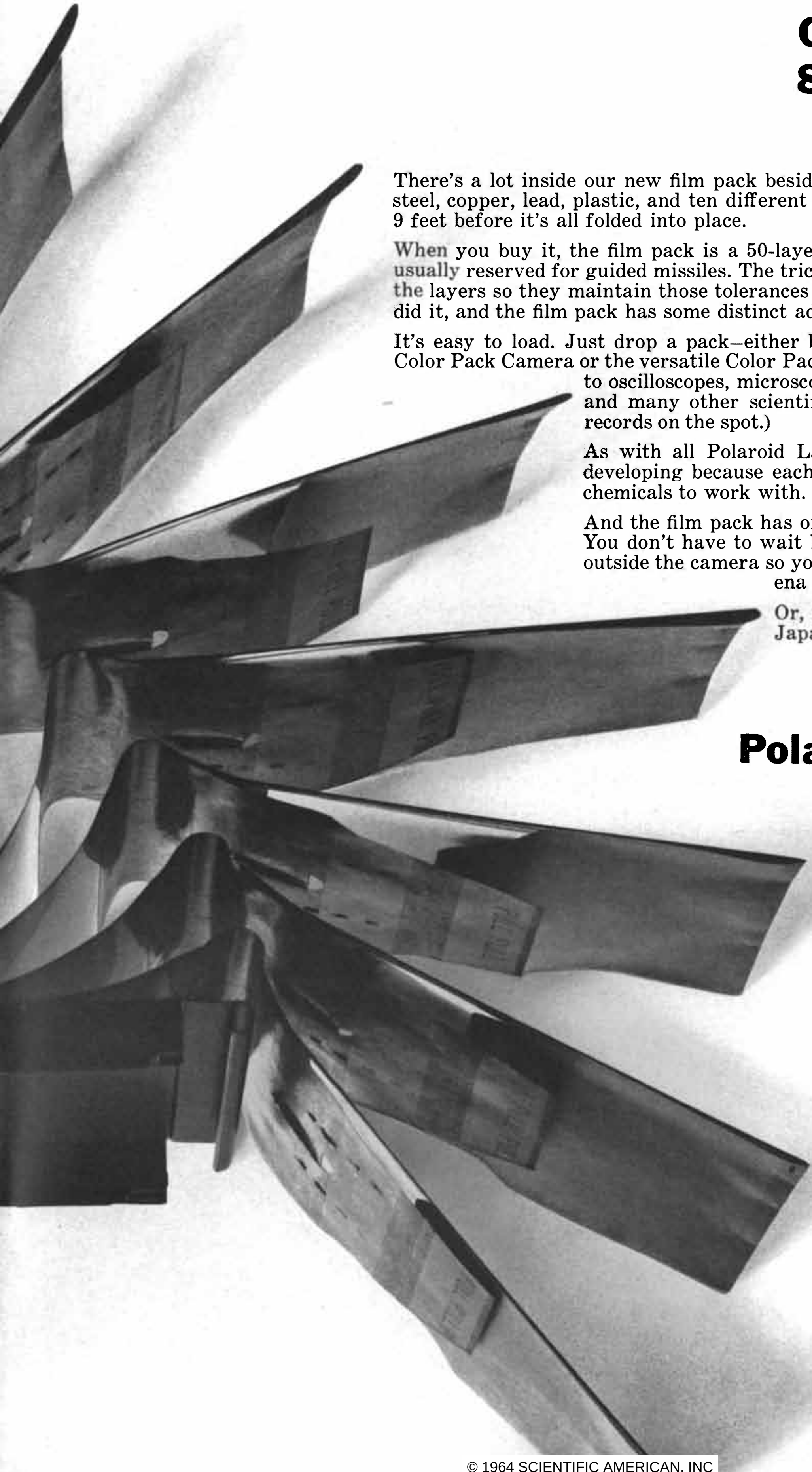

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THE AUTHORS

R. L. BISPLINGHOFF ("The Supersonic Transport") is associate administrator for advanced research and technology for the National Aeronautics and Space Administration. Bisplinghoff received an undergraduate degree in aeronautical engineering and an M.S. in physics from the University of Cincinnati in 1940 and 1942 respectively. He obtained an Sc.D. from the Swiss Federal Institute of Technology in Zurich in 1957. During World War II he supervised research in the Applied Loads and Structural Dynamics sections of the Naval Bureau of Aeronautics. In 1946 he became a member of the faculty of the Massachusetts Institute of Technology, where he served as deputy head of the department of aeronautical engineering from 1955 to 1962. He joined NASA in 1962 as director of the Office of Advanced Research and Technology. Bisplinghoff is a member of the U.S. Air Force Scientific Advisory Board and the Scientific Council of the U.S. Navy Operations Evaluation Group. He also serves as a consultant to the Armed Forces Special Weapons Project and the Air Force Research and Development Command.

HERBERT FRIEDMAN ("X-ray Astronomy") is superintendent of the Atmosphere and Astrophysics Division and chief scientist at the E. O. Hulburt Center for Space Research of the Naval Research Laboratory. He received a B.A. from Brooklyn College in 1936 and a Ph.D. from Johns Hopkins University in 1940. After teaching physics for a year at Johns Hopkins, he joined the staff of the Metallurgy Division at the Naval Research Laboratory. In 1942 he assumed supervision of the Electron Optics Branch and in 1958 he was appointed to his present post. Friedman conducted his first experiments in rocket astronomy with a captured V-2 rocket in 1949. He has since participated in more than 100 rocket experiments and several satellite launchings. These experiments have traced the effect of solar-cycle variations on X-ray and ultraviolet radiations from the sun, produced the first astronomical photographs made in X-ray and ultraviolet wavelengths, discovered the hydrogen corona around the earth and measured ultraviolet radiation from certain stars. Friedman was recently awarded the 1964 Eddington Medal of the Royal Astronomical Society of London.

HARRY RUBIN ("A Defective Cancer Virus") is professor of virology at the University of California at Berkeley. Soon after acquiring a doctorate in veterinary medicine from Cornell University in 1947, Rubin went to Mexico to do field work on the viruses responsible for hoof and mouth disease. He returned to this country in 1948 to join the virus laboratory of the U.S. Public Health Service in Montgomery, Ala. In 1952 he went to Berkeley as a postdoctoral fellow supported by the National Foundation for Infantile Paralysis. He did cancer research at the California Institute of Technology from 1953 to 1958, when he returned to Berkeley as associate professor of virology. Rubin received the Anne Frankel-Rosenthal cancer-research award of the American Association for the Advancement of Science in 1959, the Eli Lilly and Company Award in bacteriology and immunology from the American Society for Microbiology in 1961 and the Merck Research Award in 1963.

ALAN E. FISHER ("Chemical Stimulation of the Brain") is associate professor of psychology at the University of Pittsburgh. Fisher was graduated from Pennsylvania State University in 1949 and received an M.S. and a Ph.D. in psychology there in 1952 and 1955 respectively. He was a U.S. Public Health Service Fellow at McGill University from 1954 to 1955 and at the University of Wisconsin from 1955 to 1957. He joined the Pittsburgh faculty in 1957.

RAYMOND WOLFE ("Magnetothermoelectricity") is a physicist at the Bell Telephone Laboratories, where he supervises a group engaged in investigating materials for thermoelectric and ultrasonic devices. Born in Canada, Wolfe studied mathematics and physics at the University of Toronto, obtaining a B.A. in 1949 and an M.A. in 1950. He worked at the Research Laboratories of the Eastman Kodak Company from 1950 to 1952, when he went to England to study the theory of metals under N. F. Mott at Bristol University. He received a Ph.D. from Bristol in 1955. Remaining in England at the Research Laboratories of the General Electric Company, Wolfe continued his research on such semiconducting materials as bismuth telluride and diamonds. He became a member of the staff of the Bell Telephone Laboratories in 1957.

SARAH CLEVENGER ("Flower Pigments") is assistant professor of botany at Indiana State College. A graduate of Miami University in Ohio, she received a Ph.D. from Indiana University in 1957. Her interest in flower pigments stems from graduate work done under the direction of Charles W. Hagen, Jr., at Indiana University. Before joining the faculty of Indiana State she taught at Berea College in Kentucky.

ULRIC NEISSER ("Visual Search") is associate professor of psychology at Brandeis University. A native of Germany, he received an A.B. from Harvard College in 1950, an M.A. from Swarthmore College in 1952 and a Ph.D. in psychology from Harvard University in 1956. He joined the Brandeis faculty in 1957. Neisser has been associated with the Lincoln Laboratory of the Massachusetts Institute of Technology for several years as a member of the summer staff and as a consultant. The work described in this article was supported by the Lincoln Laboratory and the National Science Foundation.

JUNE GOODFIELD ("The Tunnel of Eupalinus") is assistant director of the Nuffield Foundation Unit for the History of Ideas in London. After obtaining a B.Sc. in zoology from the University of London in 1949, she did medical research for a year at the University of Oxford before joining the faculty of Cheltenham Ladies' College in 1950 as a senior biology teacher. She taught physics at the Benenden School from 1954 to 1956, when she became lecturer in the history and philosophy of science at the University of Leeds; she received a Ph.D. from Leeds in 1960. She has written and directed four films on the history of science for the British Film Institute, the Educational Foundation for Visual Aids in London and the U.S. National Science Foundation. She has also coauthored with her husband, Stephen Toulmin, several books and articles on the history and philosophy of science, including an article on the geometric alignment of the tunnel of Eupalinus that will appear shortly in *Isis.*

J. BRONOWSKI, who in this issue reviews Michael A. Arbib's *Brains, Machines, and Mathematics,* is deputy director of the Salk Institute for Biological Studies in San Diego.

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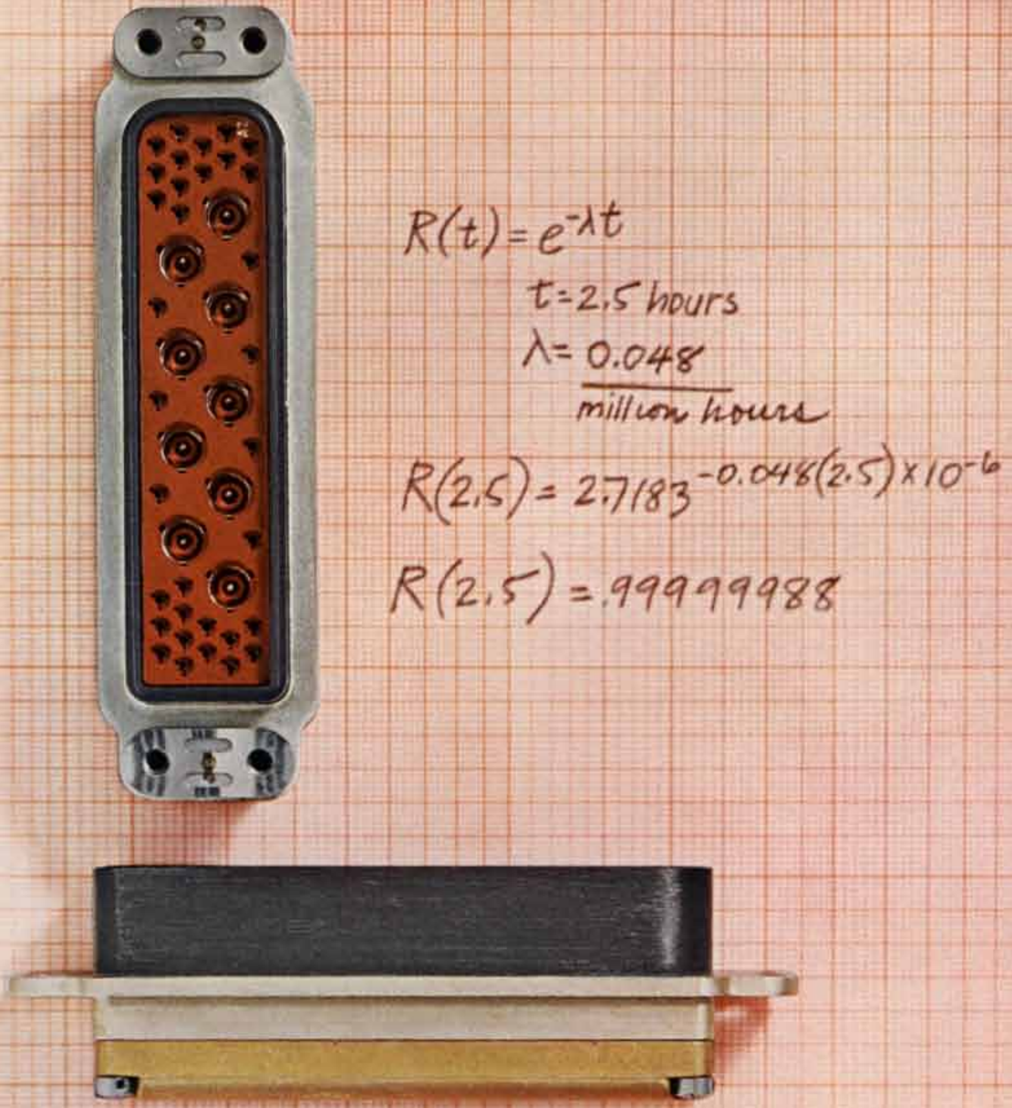

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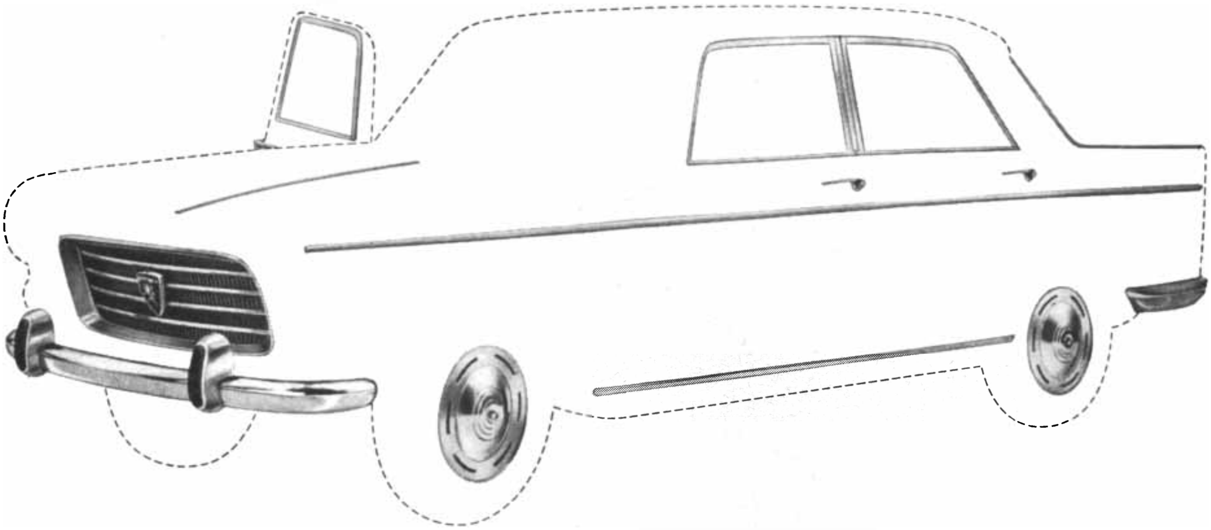

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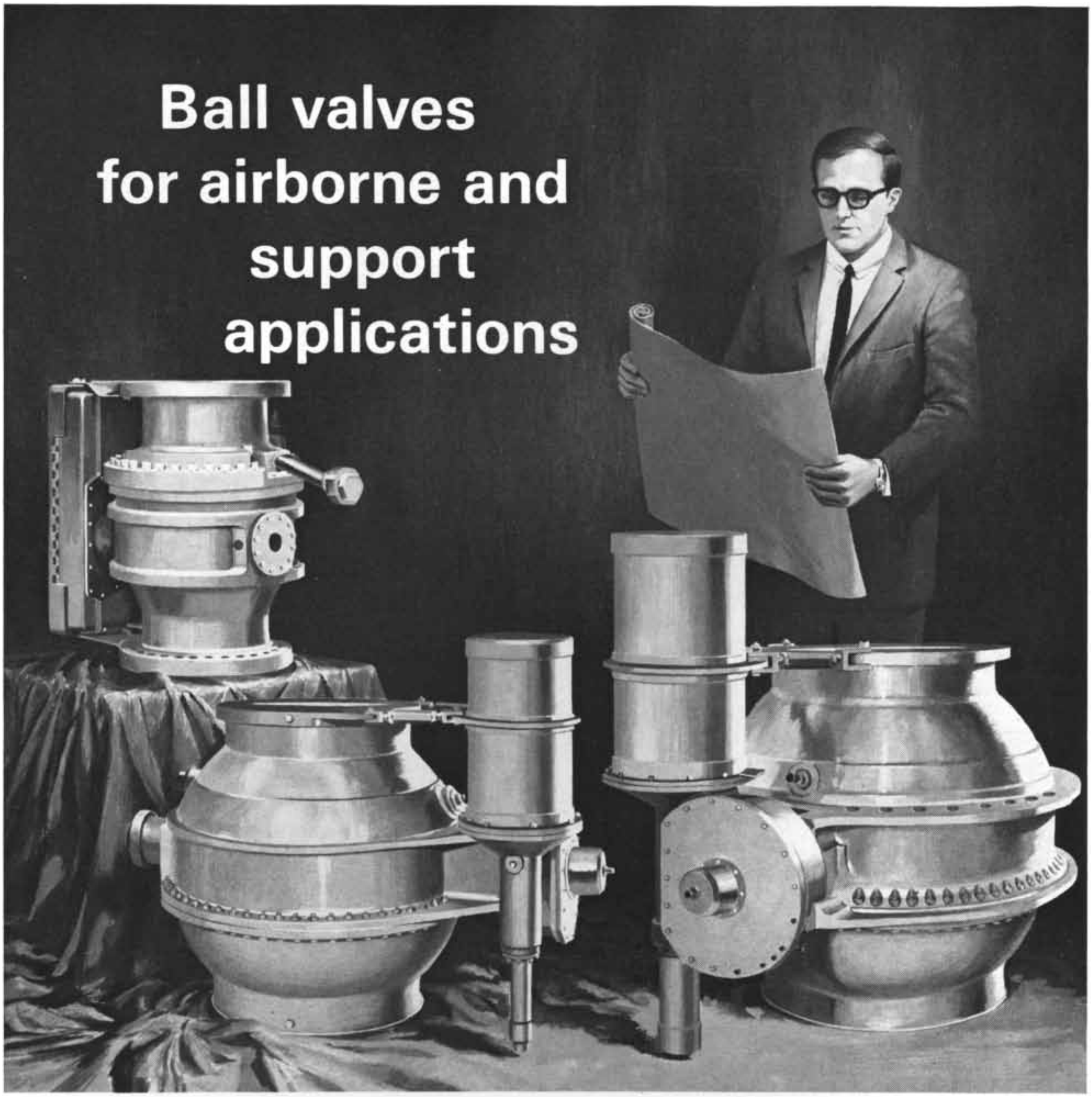

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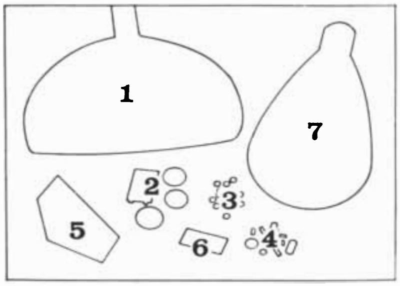

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Established 1845 SCIENTIFIC AMERICAN June 1964 Volume 210 Number 6

The Supersonic Transport

It is technologically feasible to build passenger aircraft capable of 2,000-mile-an-hour speeds. Several designs have been proposed; the chief problem is to attain satisfactorily economical operation

by R. L. Bisplinghoff

The supersonic airplane became a practical reality on October 17, 1947, when Captain Charles E. Yeager flew the rocket-powered research aircraft X-1 slightly faster than the speed of sound. That event was the culmination of an intense period of aeronautical research and development during and after World War II and marked the beginning of a new epoch in powered flight.

In the years since the flight of the X-1 aeronautical engineers have almost continuously examined the practicability of commercial aircraft that would fly faster than the speed of sound. Such examinations have become more pertinent in recent years with the successful employment by airlines of high-speed subsonic jet transports.

These studies reflect the traditional evolution of air transportation toward higher cruising speeds. Anyone who has considered this long-term trend has wondered if it would be finally halted at velocities approaching the speed of sound. There now appears to be no valid technical or economic reason why the trend should not continue well into the range of supersonic speeds.

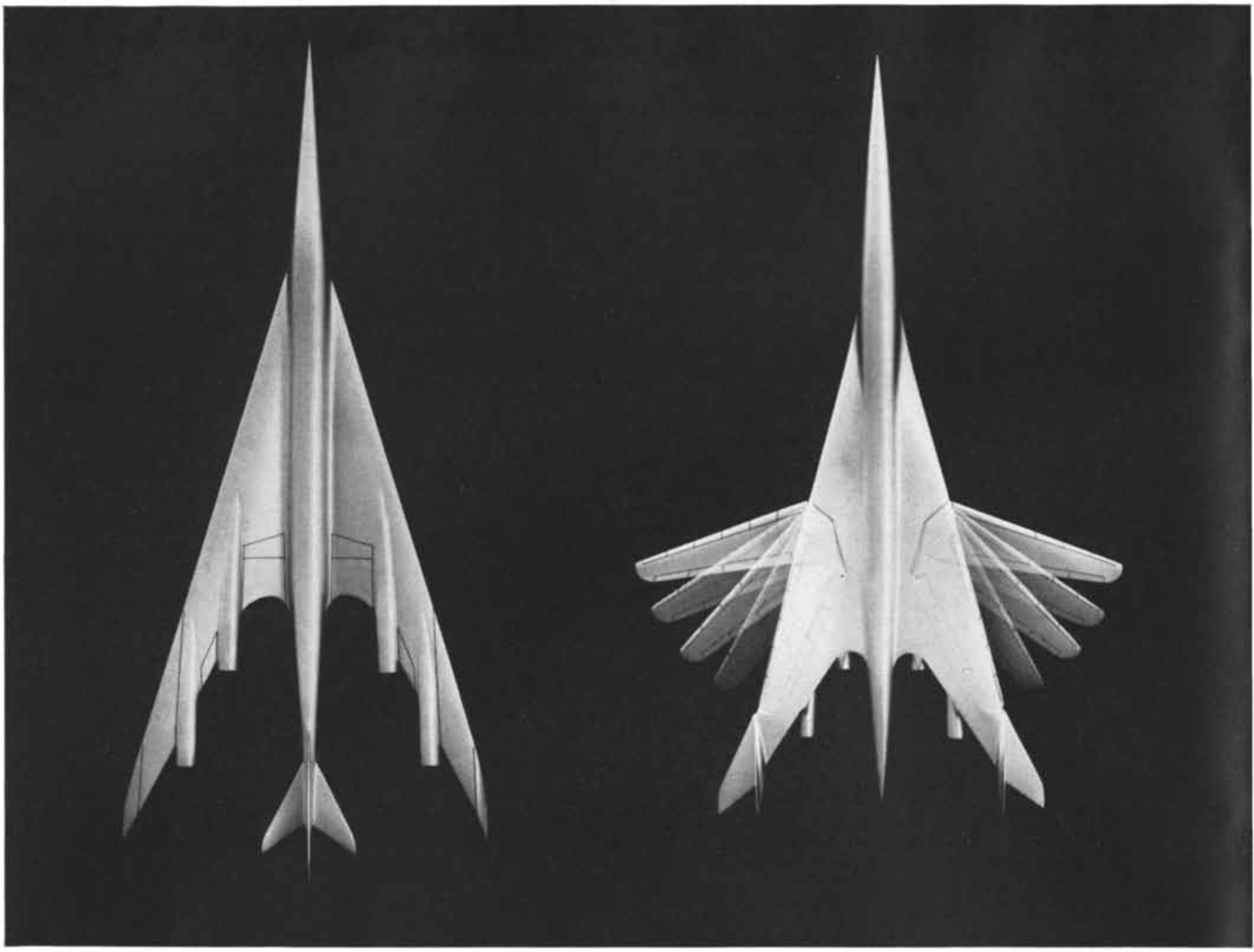
In such a vast and expensive undertaking as supersonic air transportation, however, technical questions cannot be separated entirely from those of economics and politics. It is important to recognize that in not too many years the supersonic transport will be a fact of life in the worldwide transportation system and that it promises to work important changes in the fabric of modern society. Such an airplane is now being developed by the British and French jointly and in the U.S. under the sponsorship of the Federal Government. Orders for more than 100 of these airplanes have already been placed by commercial airlines.

The supersonic transport, or SST, has been the object of considerable public debate in the U.S., and that debate promises to become even more intense. It is proper that such an undertaking should be questioned and debated and that its usefulness to, and effects on, society should be assessed fully. What should be the relative roles of the Government and the aviation industry in developing a suitable aircraft? At what speed should the designers aim? Is the technology available to build an airplane that would be both safe and profitable? These and many similar questions have been raised in the debate. This article will be mostly concerned with the technological questions.

Futuristic as supersonic commercial flight may seem, it actually represents an advanced stage in a development that has taken place over many years. Spin-stabilized ballistic projectiles such as artillery shells have long operated at supersonic velocities in the atmosphere. World War II stimulated intensive research into rocket propulsion and the aeronautics of supersonic flight, and on October 3, 1942, a German V-2 rocket became the first actively controlled, fin-stabilized projectile to achieve supersonic velocities. Thereby the V-2 demonstrated that a vehicle with active controls could remain stable in flight through the transonic speed range and beyond. Five years later the testing of the X-1 demonstrated that supersonic manned flight was possible.

Since then a variety of aircraft, including the record-holding X-15 (4,104 m.p.h.) and, most recently, the military A-11 (more than 2,000 m.p.h.) have made supersonic flight seem almost routine. The largest supersonic aircraft yet designed, the 2,000-m.p.h. B-70, should be ready for its maiden flight sometime this year. It remained for the British and French, however, to make the first definite commitment to build a supersonic airplane for commercial service. Their *Concorde* is an aluminum aircraft designed to carry 118 passengers in the 1,300-m.p.h. range.

In the U.S. the National Aeronautics and Space Administration has for several years conducted a program of research directed specifically toward a supersonic commercial transport. The program was inaugurated in 1956 by the National Advisory Committee for Aeronautics, predecessor of NASA. In 1959 the research had developed enough data to indicate the technical feasibility of an SST. On December 11, 1959, NASA brought this information to the



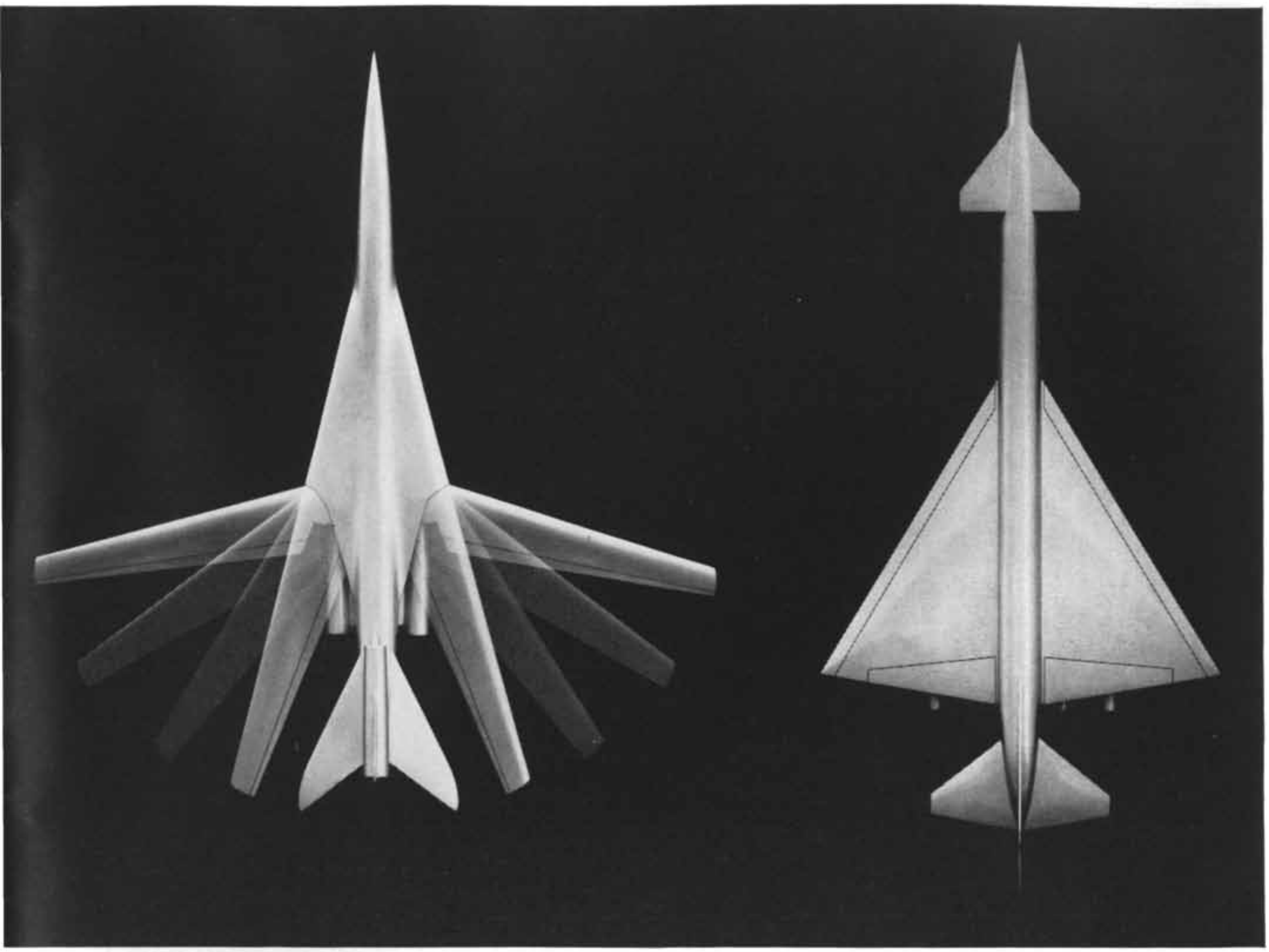
SUPERSONIC TRANSPORT DESIGNS evolved by the National Aeronautics and Space Administration in eight years of testing are portrayed by models, which are between 30 and 39 inches long. The designs have the class name of SCAT, which is short for "supersonic commercial air transport." From the left they are: SCAT 4, which has a fixed swept-back wing and resembles sub-

attention of the Federal Aviation Agency and proposed a national program for the development of such a vehicle. Thereafter the FAA, NASA and the Department of Defense joined in a plan for Federal assistance to the aviation industry as outlined by the three agencies in a 1961 publication entitled *Commercial Supersonic Transport Report*.

Once the technical feasibility of an SST had been established in a preliminary way, NASA concentrated its efforts on meeting some difficult requirements. These included the development of the technology of engines and airframes that would be more economical and durable than those acceptable for military service and reduction of sonic boom, which threatened to curtail supersonic flight over populous areas. NASA's progress in solving these problems played an important part in the decision, announced by President Kennedy in June, 1963, that the U.S. would begin development of a supersonic transport under the direction of the FAA. Recently several aircraft and engine manufacturers submitted design proposals to the FAA, and it is expected that the first contracts for development types will be awarded in due course.

The particular concern of NASA is the development of the advanced technology necessary to build a passenger-carrying airplane that is not only capable of supersonic flight but also safe, durable and economical to operate. To that end NASA has envisioned a Mach-3 aircraft, which means a plane able to fly at speeds up to three times the speed of sound. At an altitude of 70,000 feet, where the craft will actually cruise, Mach 3 is about 2,000 m.p.h. The aircraft will have a takeoff weight of about 400,000 pounds and should be able to carry a payload of some 26,000 pounds over a range of 3,700 miles. For comparison the longest-range model of the Boeing 707 has a takeoff weight of 316,000 pounds, a payload of 59,000 pounds and a range of more than 4,500 miles. It is expected that the supersonic transport will be able to operate from existing runways.

The design of every airplane makes use of a principle laid down some 60 years ago by the French engineer Louis Bréguet. Bréguet showed that the range of an airplane, or the maximum distance it can travel, depends on two main factors: flight efficiency and the ratio of the fuel weight to the gross weight at the start of flight. In evaluating the technical feasibility of



sonic jets now in use; SCAT 15, which has similar wings for supersonic flight but carries auxiliary wings that can be moved forward for flight at subsonic speeds; SCAT 16, which has relatively slender wings that can be varied in sweep; SCAT 17, which has a delta wing and a canard, or balancing surface, at the nose. NASA officials regard SCAT's 16 and 17 as the most promising.

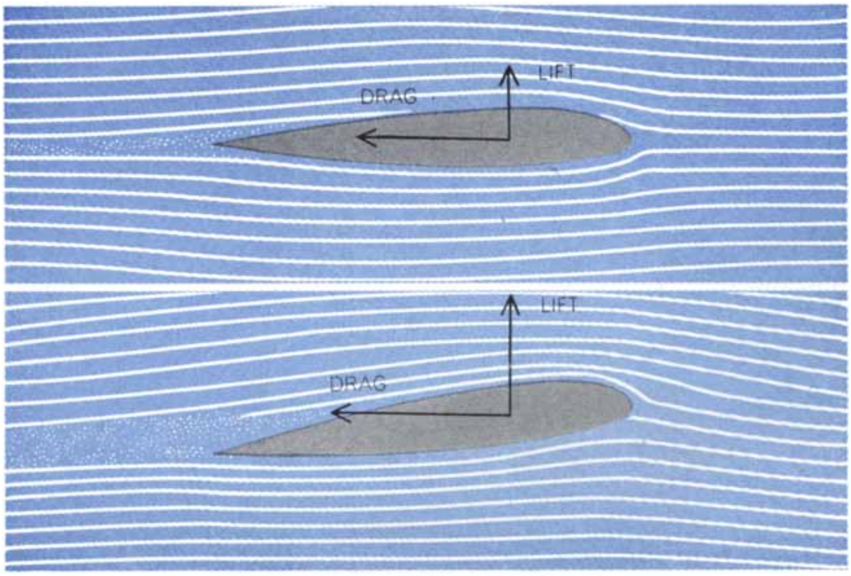
any new airplane the engineer establishes the desired flight range and then asks if he can achieve the flight efficiency and the fuel-to-gross-weight ratio needed to realize this range.

Bréguet conceived of flight efficiency as a composite measure of the aerodynamic and propulsive efficiencies of the airplane. It is represented by a numerical quantity calculated as follows: Mach number times the lift-to-drag ratio of the airplane, divided by the specific fuel consumption of the engines. The economic future of the supersonic transport is very much dependent on the success of aeronautical engineers in providing the highest possible value of this quantity.

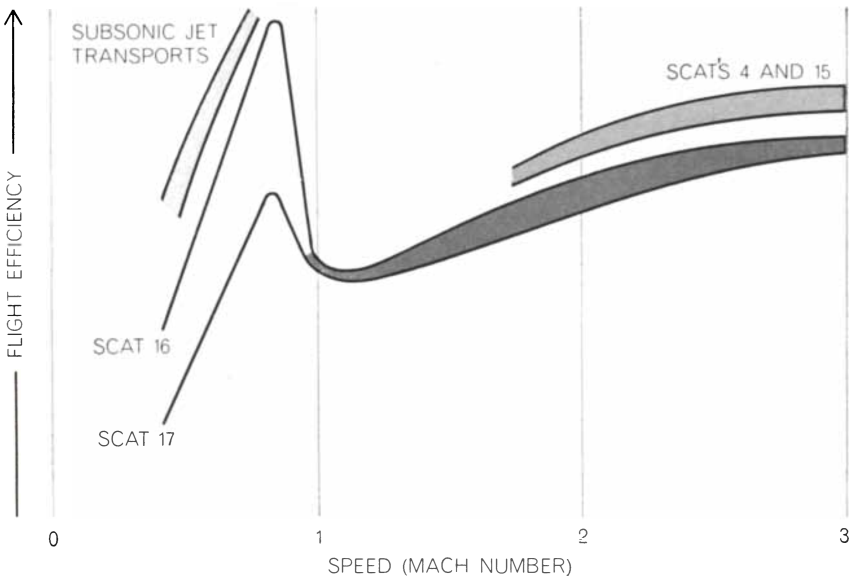
It is apparent from Bréguet's equation that if everything else remains the same, flight efficiency increases with increasing Mach number. That is one of the principal reasons why many engineers prefer speeds approaching Mach 3 for the SST. Far higher speeds are theoretically attainable, but for the present Mach 3 seems a reasonable upper limit for commercial flight because of the problems that higher speeds would present in overheating of materials and fuel.

The second component of flight efficiency is the lift-drag ratio of the airplane, denoted L/D. Lift is the upward force provided by the flow of air over the surfaces of the aircraft. Drag is the total resistance the aircraft encounters in driving through the air. The L/D ratio is a measure of aerodynamic efficiency. In an effort to optimize this ratio scientists of NASA's Langley and Ames research centers devised several aerodynamic designs for what they call a SCAT, which is an acronym for "supersonic commercial air transport." Four of these designs, known as SCAT's 4, 15, 16 and 17, are the products of eight years of research. Each design has characteristics that make it somewhat different from the others. SCAT 4 possesses a fixed arrow-like swept-back wing and has a general appearance not unlike that of the current subsonic jets. SCAT 15 also has arrow-like swept wings but has auxiliary wings that can be swept forward to allow efficient flight at subsonic speeds. SCAT 16 has fairly slender wings and somewhat resembles the present subsonic jets, but it includes a provision for varying the sweep of the full wing in flight. SCAT 17 is a delta-wing design with a canard, or balancing surface, at the nose.

NASA engineers conducted extensive wind-tunnel tests of the four SCAT models at the Langley and Ames centers to evaluate and compare their aerodynamic characteristics. The bottom illustration on the opposite page shows the results of these tests and demonstrates the chief dilemma faced by the designer of an SST: as he seeks the benefits of increased Mach number, he finds that the L/D ratio deteriorates. In general, configurations with the best L/D ratio in supersonic flight are quite poor in subsonic flight. SCAT 16, with its variable-sweep wing, although it would perform poorly at supersonic speeds, is far better than the other designs in the subsonic speed range. Since subsonic flight efficiency is important during the climb-out, landing and holding portions of the flight, the engineer must demand a reasonably high L/D ratio at flight speeds below Mach 1. It is evident that we must discover how to combine the supersonic L/D characteristics of SCAT 4 with the subsonic performance of SCAT 16. We are optimistic that this can be done.



LIFT AND DRAG are key aerodynamic factors. Air flowing under a wing gives direct lift; air over a wing creates lift through negative pressure. In level flight (*top*) lift is good and drag low; up to a point lift increases more than drag in a climb (*bottom*).



FLIGHT EFFICIENCIES of subsonic jet aircraft now in commercial use are compared with those predicted for the four SCAT's. An ideal supersonic transport would combine subsonic efficiency of SCAT 16 and efficiency of SCAT's 4 and 15 at speeds near Mach 3.

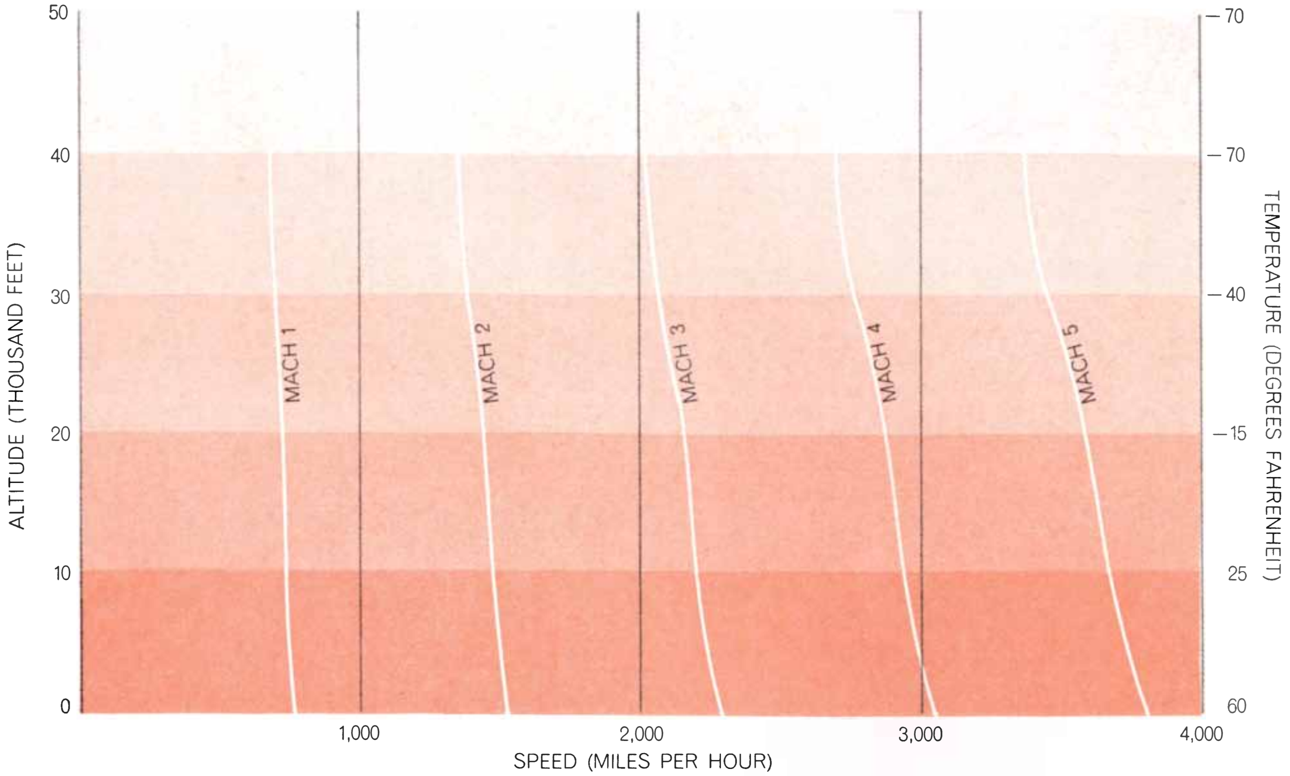
The third factor in Bréguet's equation of flight efficiency is specific fuel consumption, which means the weight in pounds of fuel burned per hour for each pound of engine thrust. To obtain good specific fuel consumption over the whole range of operating conditions from subsonic to supersonic speed, the engine designer is faced with the same incompatible flight conditions as the aerodynamicist. At subsonic speeds thrust is produced most efficiently by moving a large volume of air at fairly low velocity; at supersonic speeds it is more efficient to produce the same thrust by moving a smaller volume of air at higher velocity. The former is best accomplished by a turbofan engine, the latter by a turbojet engine, and the problem of the supersonic-engine designer is to combine the best features of each [*see illustration on page 30*].

The turbofan engine has a large fan that drives part of the incoming air through a section of the engine surrounding the compressor; this secondary air is ejected through ducts or is bypassed to the tail pipe to mix with the hot gases ejected by the turbine. If additional fuel is burned with the secondary air at the ducts, it is a "duct-burning turbofan engine"; if additional fuel is burned with the secondary air in the tail pipe, it is a "mixed-burning turbofan engine."

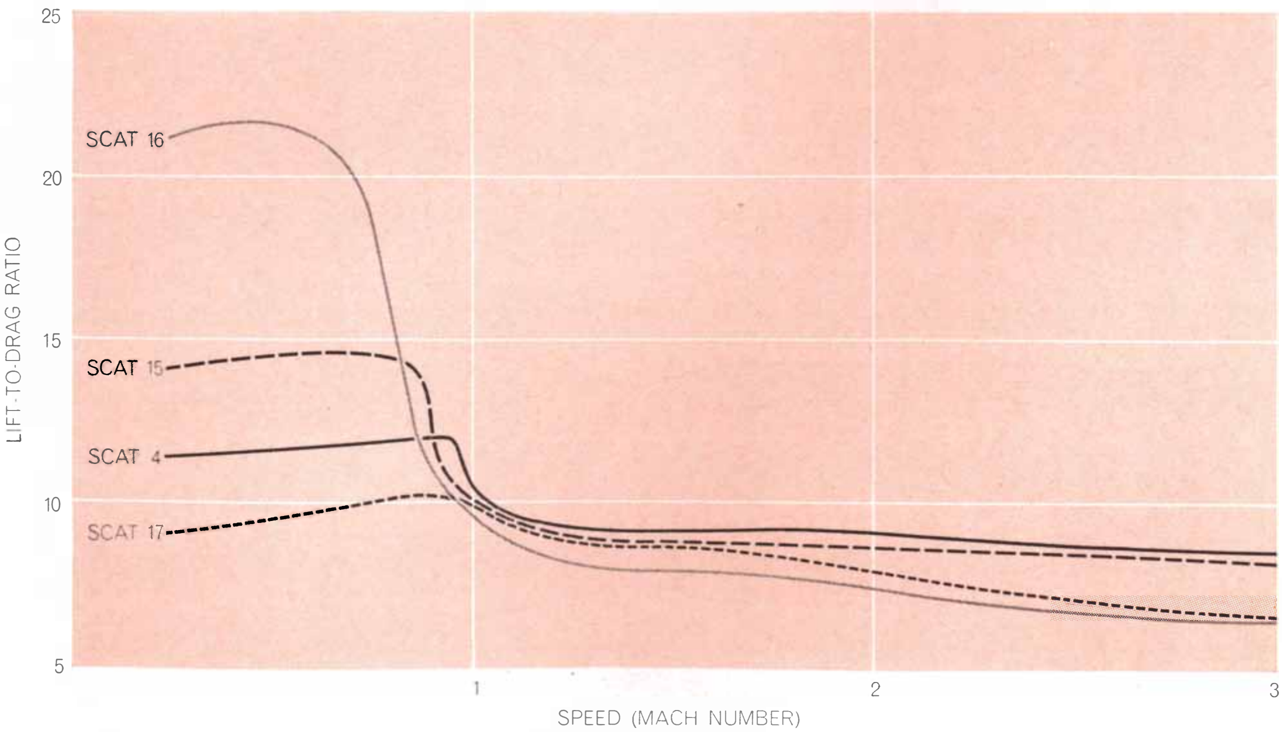
The turbojet engine has no fan; all the air is passed through the compressor-turbine combination. Burning takes place in combustion chambers between the compressor and the turbine. To provide extra thrust, some turbojet engines are also equipped with afterburners, which permit extra fuel to be burned in the tail pipe. As a consequence of this design a turbojet engine produces a high-velocity jet of exhaust gas that is more efficient for supersonic flight than the low-velocity exhaust of a turbofan engine.

The advanced engine required for the supersonic transport does not now exist, and its development will take much time and effort. The engine will demand, for example, higher turbine-inlet temperatures than those employed in present engines.

What, then, can be expected for supersonic flight efficiencies and how will they compare with those achieved by today's subsonic jets? The bottom illustration on this page shows the results of combining the factors assessed above to obtain plots of flight efficiency at various speeds. It can easily be seen from



MACH NUMBERS show the ratio of an airplane's speed to the speed of sound. As the atmospheric temperature drops with altitude, the speed of sound decreases and the Mach number for a given flying speed increases. At sea level Mach 3 is about 2,280 miles per hour, at 50,000 feet it is about 1,980 m.p.h. Above 50,000 feet, in the part of the stratosphere that a supersonic transport would use, there is little temperature change, and so at such altitudes a given Mach number represents a fairly constant relation.



RATIO OF LIFT TO DRAG is an important factor in aircraft flight efficiency. The ratios shown here were derived from NASA wind-tunnel tests of the four SCAT designs. The decline of the lift-drag ratio at supersonic speeds is a major problem faced by designers of the supersonic transport; moreover, they must provide in their design for high lift-drag ratios at subsonic flight, which the aircraft will have to perform during a portion of the climb after takeoff and in the descent preparatory to landing.

this diagram that if engineers can combine the properties of SCAT's 4 and 15 at Mach 3 and the properties of SCAT 16 at speeds below Mach 1, flight efficiencies comparable to those of the subsonic jets are possible. NASA's best-informed workers are confident that these desirable combinations can be achieved through additional well-planned research and careful design.

As Bréguet pointed out, flight efficiency is not the whole story in the achievement of range. In order to extend range a designer must also strive for a high ratio of fuel load to gross weight at the beginning of the flight. This is tantamount to saying that for a given fuel load and payload of passengers and baggage he must reduce the structural weight as much as possible. That has been the perennial problem of the engineer from the earliest days of aviation. William B. Stout, who designed the famous Ford trimotor transport in the late 1920's, liked to say that the aircraft engineer's main task in life was to "simplicate and add lightness." His advice is no less important today than it was then.

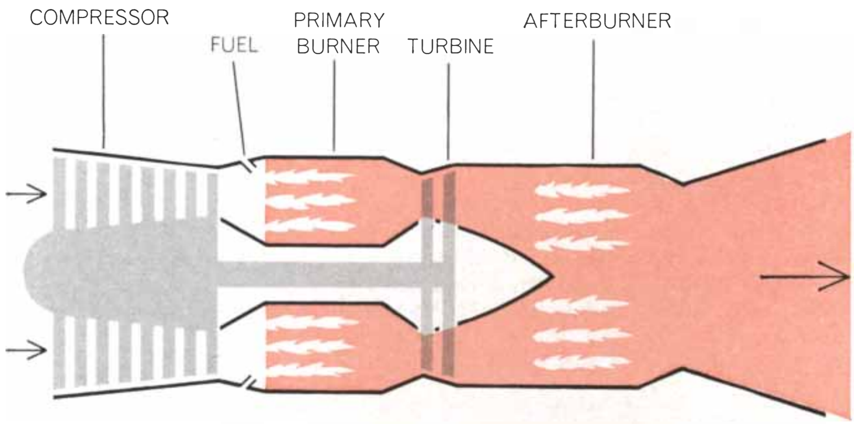
The special structural design problems introduced by the supersonic transport can be summarized succinctly as speed and longevity. The principal problem introduced by speed is aerodynamic heating, produced by the impact and friction of air molecules. At Mach 3 and an altitude of 70,000 feet the leading edge of the wing is heated to a temperature of some 550 degrees Fahrenheit. This is well beyond the temperature at which the usual materials of commercial airliner construction retain adequate strength.

The problem of longevity is one of providing adequate airframe safety and serviceability for a period longer than 10 years, or some 30,000 to 50,000 hours of flying time. A lifetime of this order is essential if the airplane is to be commercially profitable. As the aircraft structure is exposed to alternating stresses day after day and year after year, there is a tendency for the metal to become fatigued and ultimately to fracture. Metal fatigue is a progressive phenomenon originating with tiny cracks that gradually grow under repeated stress until a fracture occurs. One can expect crack growth to be accelerated in structures exposed to the high temperatures of supersonic flight.

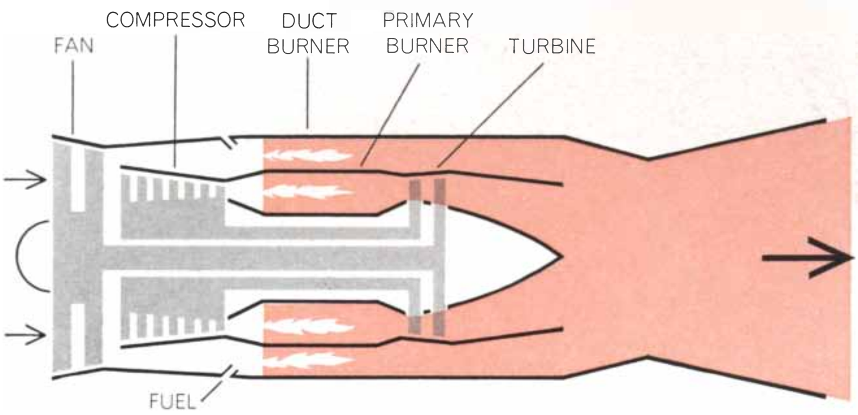
Prolonged screening of materials by NASA's Langley and Lewis laboratories has identified a titanium alloy that appears to meet the unique and stringent requirements for strength, stiffness and high temperatures of an SST. The alloy contains 90 per cent titanium, 8 per cent aluminum, 1 per cent molybdenum and 1 per cent vanadium.

As can be seen in the bottom illustration on page 32, the titanium alloy has appreciably greater tensile strength at high temperatures than the conventional aluminum alloys used in transport aircraft. It also is superior in this respect to typical steels that possess relatively good high-temperature characteristics. Titanium, however, will produce a higher ratio of structural weight to gross weight than aluminum, at least in the present state of technology. The aeronautical engineer must conclude that if the assumed flight efficiencies of an SST and a subsonic transport are roughly comparable, the former can achieve the range of the latter only by sacrificing payload, or it can achieve comparable payloads only by sacrificing range. To put it another way, the problem is that the estimated ratio of payload to gross weight for the SST as now envisioned is approximately 8 per cent compared with about 15 per cent for the subsonic jet of comparable range. We are confident that this problem too can be reduced by additional research.

One of the most widely discussed problems facing the designer of the supersonic transport is sonic boom [see "Sonic Boom," by Herbert A. Wilson,

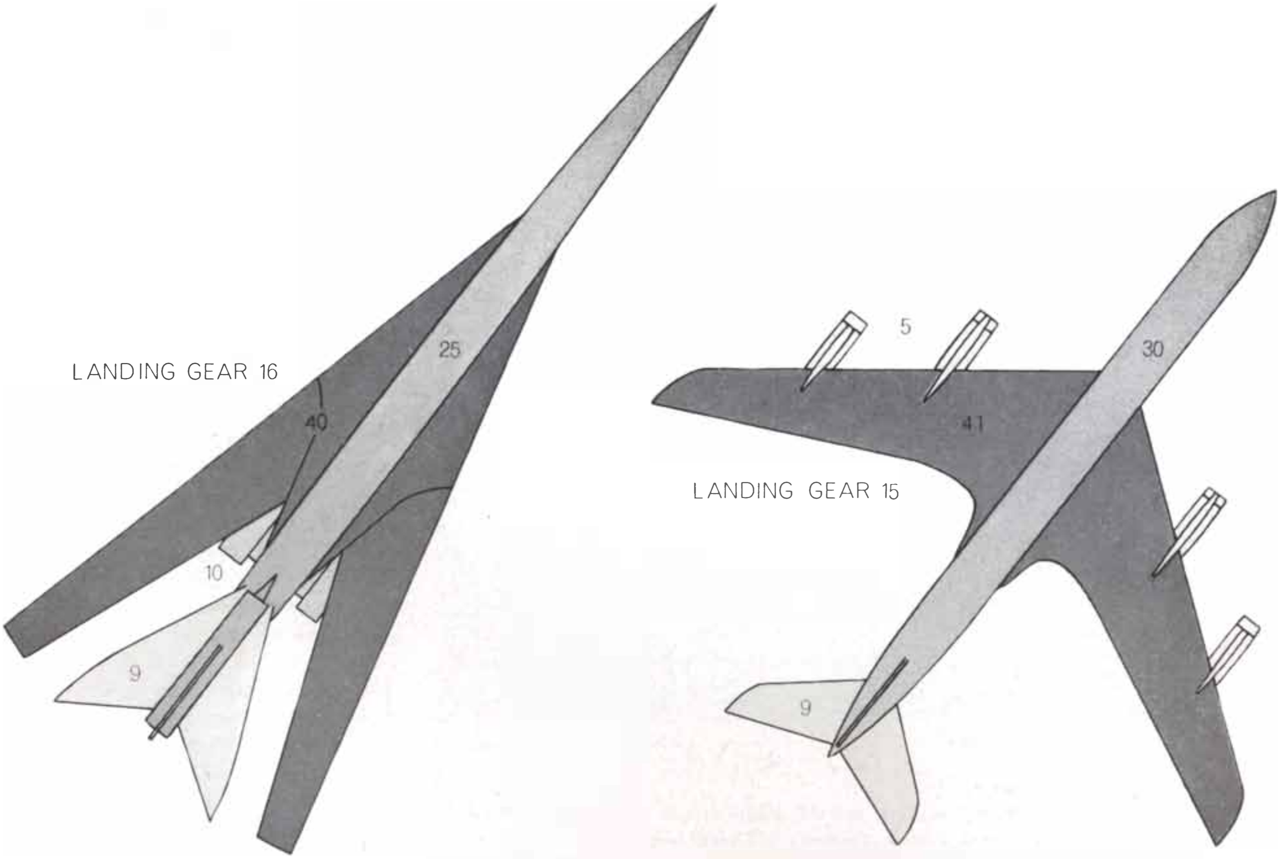


TURBOJET ENGINE

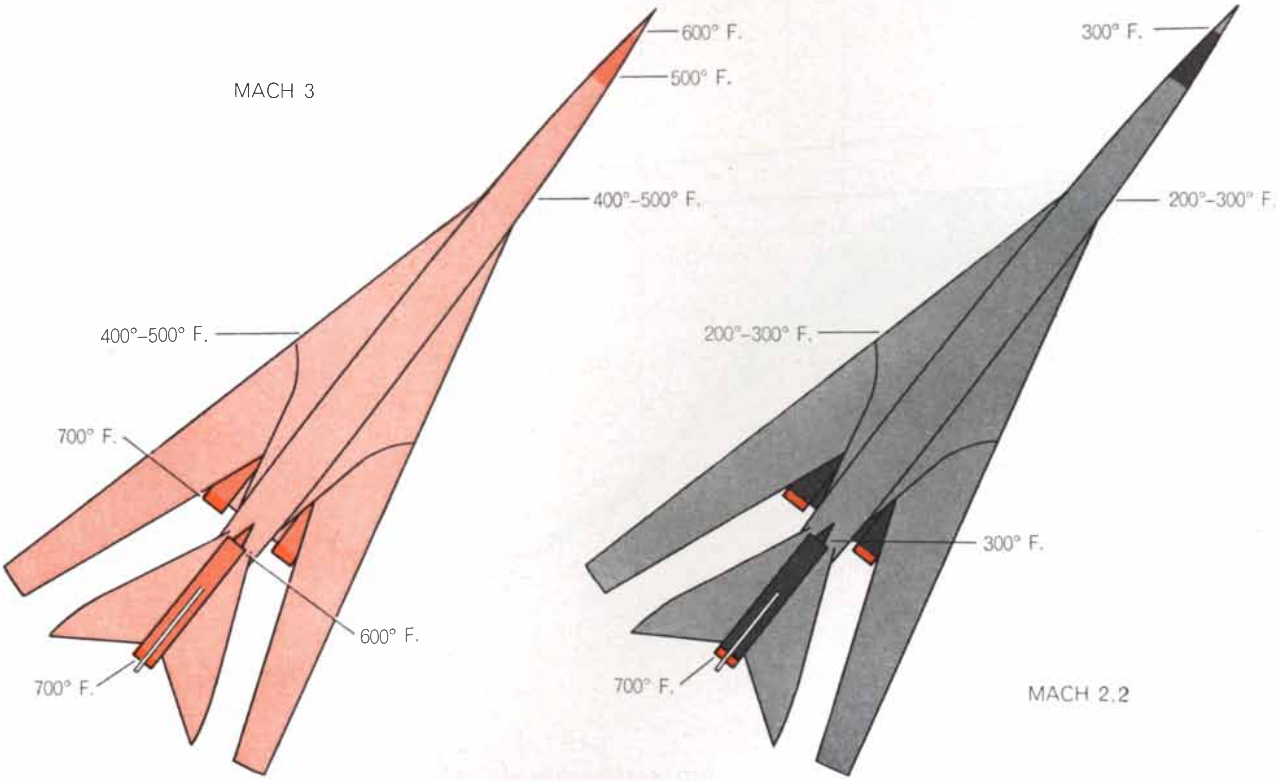


TURBOFAN ENGINE

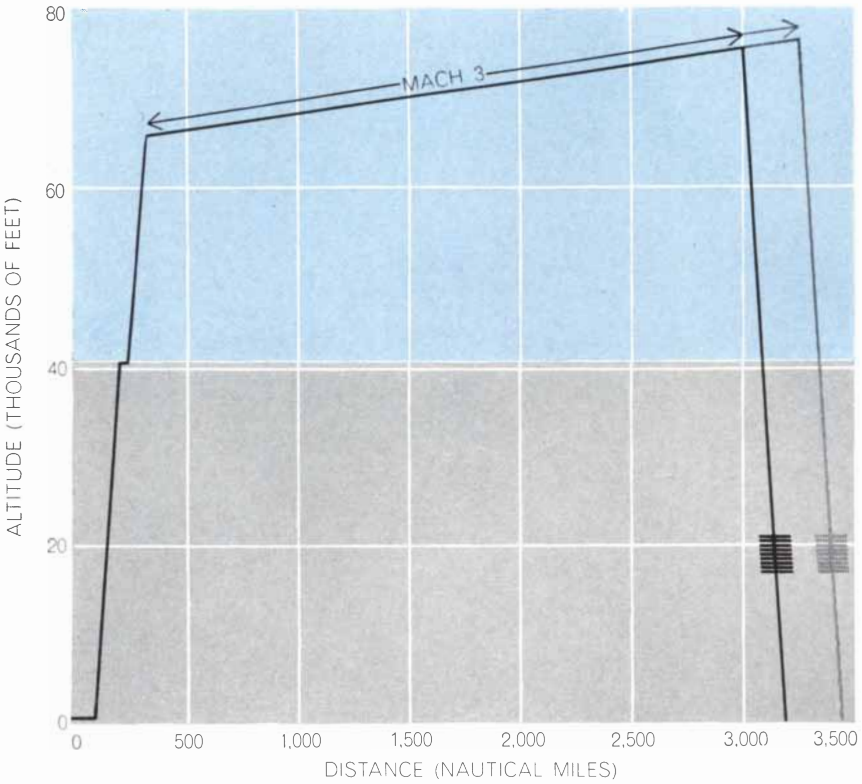
BASIC ENGINE TYPES suitable for use in a supersonic transport are depicted schematically. A turbojet (*top*) concentrates all its air in a small, high-speed jet and is best for supersonic flight. A turbofan (*bottom*), which moves a large quantity of air at lower speed by passing part of the air around the compressor, performs best at subsonic speeds. In each of these engine types it is possible to burn additional fuel in a duct or in an afterburner. Neither of these engines has yet been built for supersonic commercial flight.



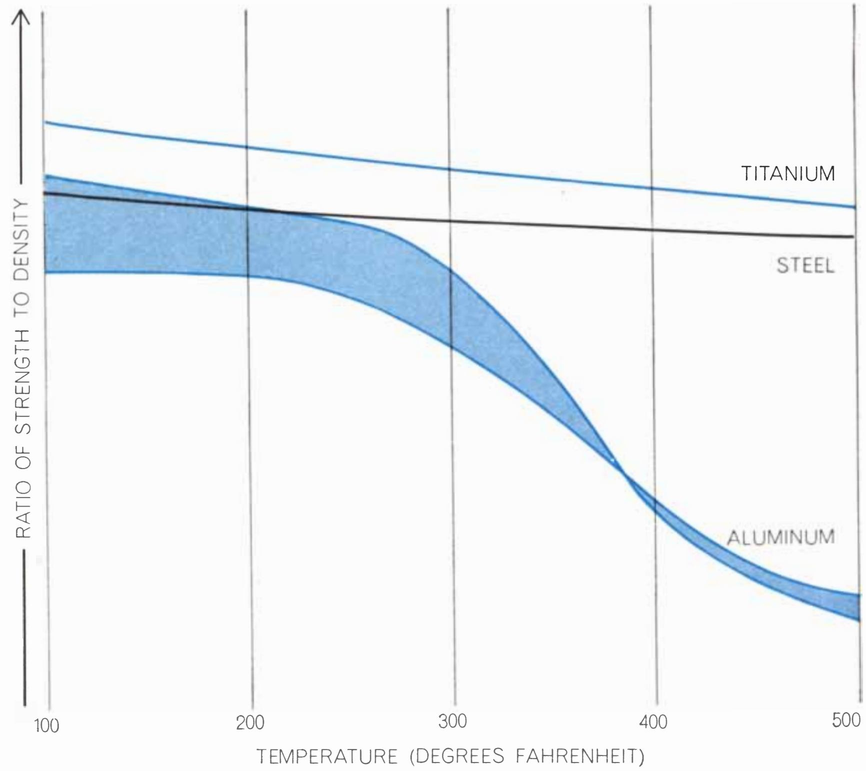
STRUCTURAL WEIGHTS of a SCAT 16 and a Boeing 707-320B, typical of the subsonic jets now in commercial service, are compared. The numerals give the weight of each structure as a percentage of the total weight of the airframe. In the SCAT 16 the airframe would account for about 29 per cent of the total weight of the aircraft; in the Boeing 707-320B it is about 23 per cent.



AIRFRAME HEATING becomes a major problem at supersonic speeds. Except at the engine exhausts, it is caused by the friction of air molecules on the surface of the aircraft. Materials used in subsonic airplanes would lose tensile strength at supersonic speeds, as shown in bottom illustration on next page; designers therefore have had to seek new materials for supersonic craft.



TYPICAL PROFILE of a Mach-3 flight is plotted. Plane climbs rapidly to 40,000 feet, where it attains supersonic speed. Climb continues to 70,000 feet, where cruise begins. Extra capability is required for waiting to land or for flight to an alternate destination.



TENSILE STRENGTH of materials that can be used in aircraft construction is shown under conditions of increasing temperature. Titanium is regarded as most promising for supersonic transports because of its high resistance to the heat that would be encountered.

Jr.; SCIENTIFIC AMERICAN, January, 1962]. Shock-wave phenomena were explained theoretically by the Austrian physicist and philosopher Ernst Mach a half-century before the first sonic boom was heard. Mach arrived at his explanation by considering the laws of propagation of a disturbance or pressure impulse in a compressible fluid.

In air the pressure disturbance we recognize as sound establishes the speed at which sound travels. Therefore an airplane moving at subsonic speed creates fairly mild pressure disturbances that move faster than the plane itself. A supersonic plane, however, gets ahead of its own pressure disturbances; they stream out behind in the form of a shock wave that creates a sudden change of pressure as it reaches any particular point. The area in which the shock wave can be heard takes the form of a cone with the airplane at the apex.

The term "sonic boom" is used to describe the atmospheric disturbance produced when the lower edge of the conical Mach wave produced by a supersonic airplane sweeps over the surface of the ground. The zone of intersection of the Mach cone with the ground is bounded by a hyperbola. The boom is audible simultaneously at all points along the hyperbola, and it is eventually heard at all points on the ground over which the hyperbola sweeps. When a heavy aircraft flies at supersonic speed near the ground, the sonic boom is usually heard as a sharp report. When the sonic boom is produced by an aircraft of modest weight at high altitudes, the effect is more like that of distant thunder.

NASA's Langley laboratory has established the variables that govern the pressure changes in the shock wave. This investigation has established that above the speed of sound, increases of speed have comparatively little effect on sonic boom. The chief factors affecting the strength and character of sonic boom are the shape and weight of the airplane and its distance above the ground.

To minimize the annoyance of sonic boom, the supersonic transport will not be permitted the wide choice in altitude and speed pattern now enjoyed by today's commercial aircraft. In order to prevent any sonic boom while it is at low altitudes, the supersonic airplane will be required to climb subsonically to at least 40,000 feet before it accelerates to supersonic speed. For the same reason it must decelerate at the end of its trip so that subsonic flight is resumed before the aircraft descends below 40,000 feet.

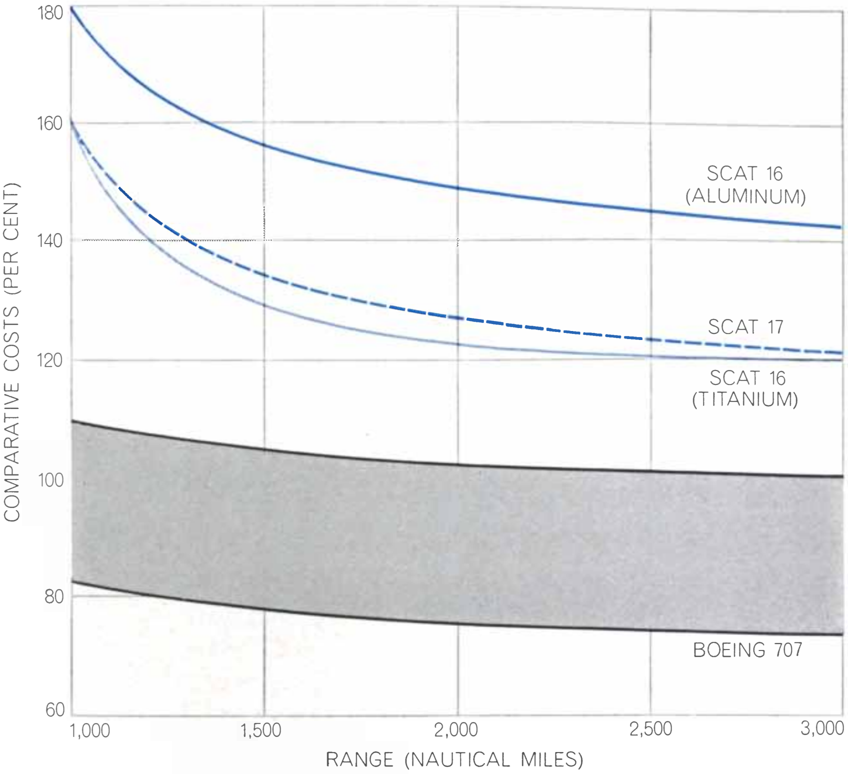
An interesting sonic boom comparison can be made between projected designs of Mach-2.2 and Mach-3 aircraft of the same weight. Because the Mach-3 airplane will cruise at least 10,000 feet higher than the Mach-2.2 airplane, the former would create a smaller sonic boom at ground level than would the latter.

Sonic boom, of course, is not the only noise problem associated with the supersonic transport, but in general the SST should not be noisier in flight than planes of lower speed. One factor that promises to alleviate the noise problem in the vicinity of the airport is the inherent excess power required for the supersonic transport to accelerate past the speed of sound. Because of this excess of power beyond that required for takeoff, the airplane will be able to climb away from the airport more quickly and steeply than present-day transports. At each point below its climb path it will be at least no noisier than the subsonic jet, and advancements through research and development are expected to achieve even lower noise levels.

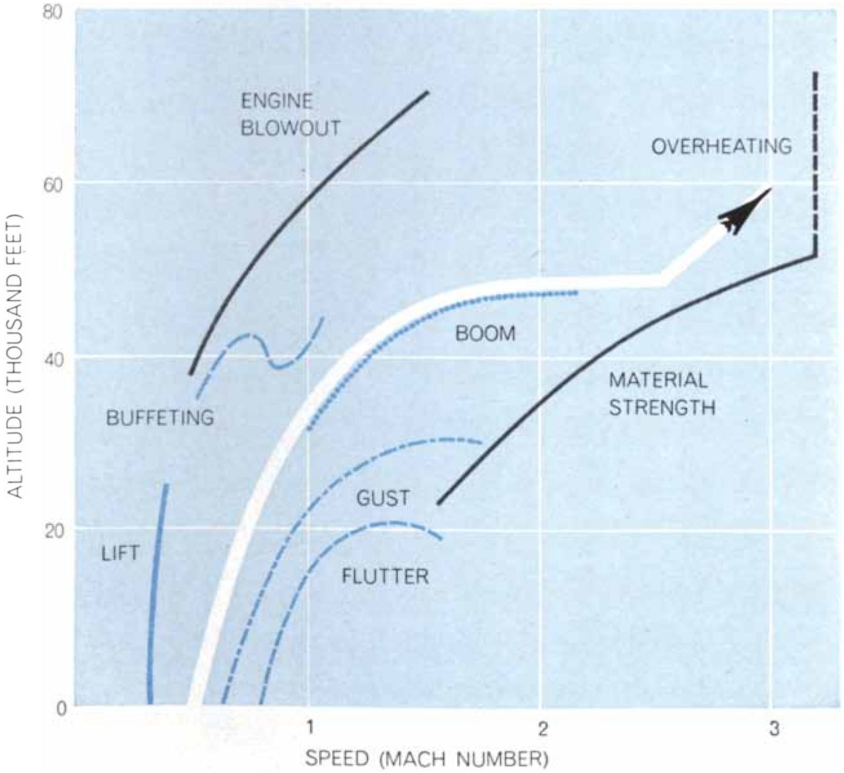
At the airport itself, however, noise will present more of a problem than it does for the present jets because supersonic engines will be larger. Inasmuch as these engines, like others, must be run up to full power on the ground for short periods for the purpose of check-out, the check-out period probably will require the use of advanced noise suppressors.

As man penetrates the earth's protective atmospheric blanket and exposes himself to conditions on the fringes of space, careful consideration must be given to his health and well-being. Such considerations are of major importance in the nation's space program, and similar attention must be given to the transportation of passengers at altitudes above 70,000 feet. It now appears that, except for the conditions associated with solar flares, such environmental factors as radiation and ozone contamination of the atmosphere will not pose significant health hazards.

D. L. Dye and W. R. Sheldon of the Boeing Company have concluded, for example, that during a flight at 70,000 feet over the earth's poles, where radiation hazards are known to be most severe, the potential number of body cells killed by galactic cosmic rays would be



OPERATING COSTS computed for three SCAT designs are compared with those attained by the Boeing 707. Gray band indicates the reduction in seat-mile costs achieved by the 707 since 1958, when it began commercial service; presumably SCAT's also would improve.

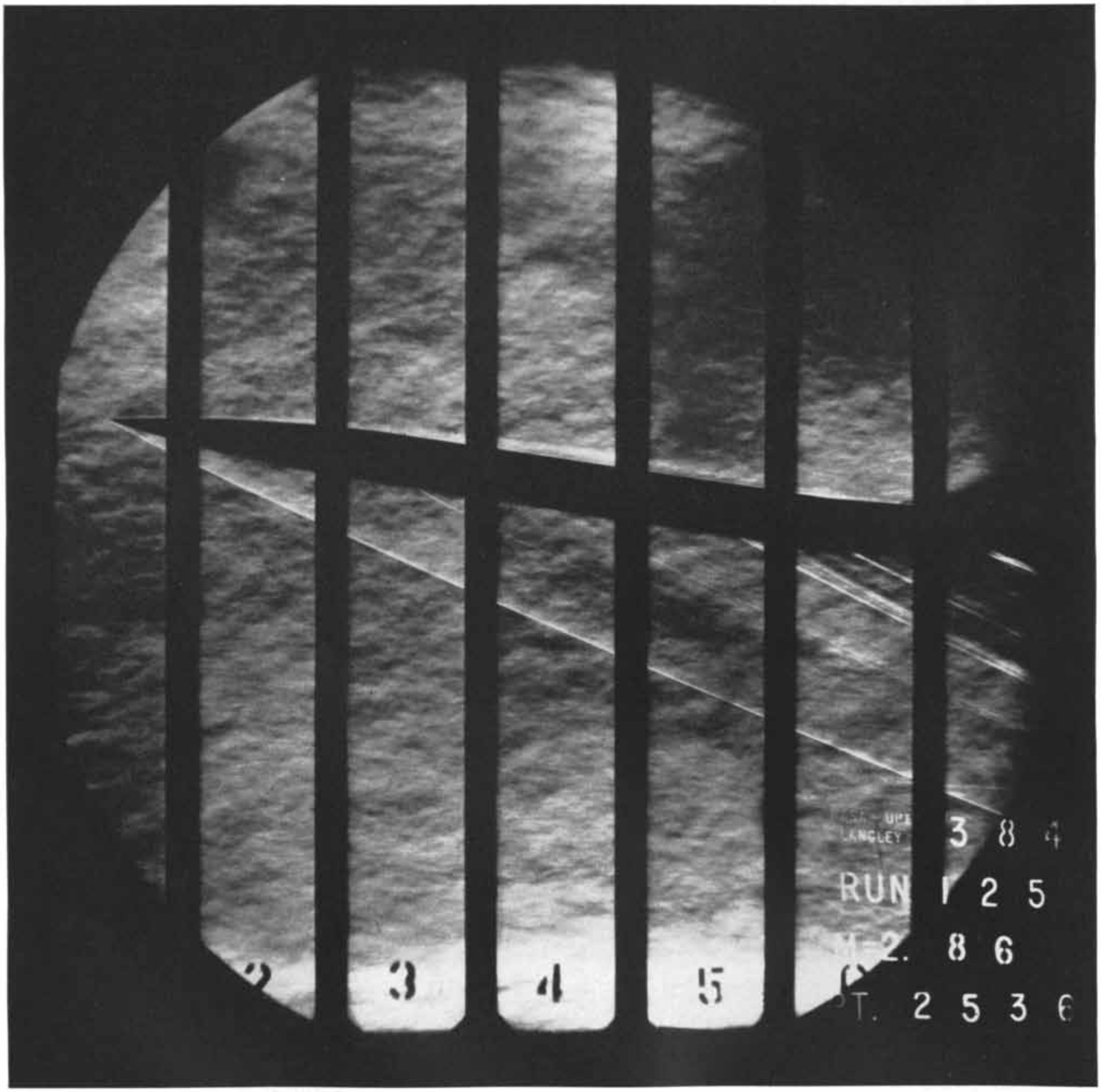


AERODYNAMIC AND MECHANICAL LIMITS confronted by a supersonic transport mean that for maximum safety and efficiency it must normally operate in or near the white corridor. Similar limits confront any aircraft; supersonic flight only extends the problem.

negligible when the sun is quiet. Although high-energy protons produced during a major solar flare might cause serious cell damage, it appears that the flare's onset would be gradual enough so that the hazard could be evaluated and avoided if necessary. Dye and Sheldon have estimated that the total cosmic ray exposure during a long-range flight in a supersonic airliner will be roughly the same as that experienced for a comparable flight in today's subsonic jets. The reason is that SST passengers will be exposed to the more hazardous environment for a shorter period.

Supersonic aircraft up to the present time have been developed to meet military objectives. Such objectives naturally place a high premium on performance and mission accomplishment and a somewhat lower premium on cost of operation. In the highly competitive air transportation market the supersonic transport must achieve economical operation—that is, operation at costs comparable to those of present transports.

Lloyd T. Goodmanson, William T. Hamilton and Maynard L. Pennell of the Boeing Company have compared the predicted seat-mile costs of SCAT designs with those of the Boeing 707 subsonic transport [*see top illustration on preceding page*]. The data contrast the 707 with an aluminum SCAT-16 design cruising at Mach 2 and titanium SCAT's 16 and 17 cruising at Mach 3. The superior position of the Mach-3 design with respect to that for Mach 2 is evident from the illustration. It is also



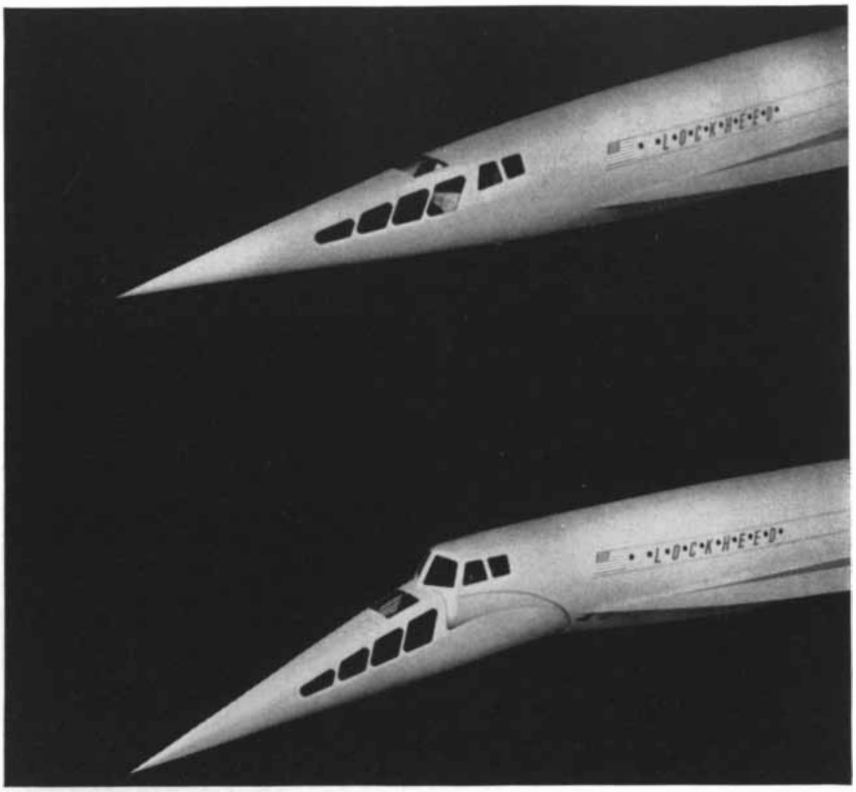
SONIC BOOM, an inevitable product of flight at supersonic speeds, is simulated with a SCAT-15 model in a NASA wind tunnel. In this Schlieren photograph Mach waves, or pressure disturbances, set up by the nose and other protuberances such as wings and engine pods stream back from the airplane. The Mach angle, which is the angle the waves make with the axis of the aircraft, decreases with increasing speed; in this photograph the speed is Mach 2.86. The vertical bars reinforce the window in the tunnel.

evident that substantial improvements must be achieved in all designs in order for the supersonic transport to be competitive with current subsonic jet transports. Additional study and continued refinement of design should do much to achieve these improvements. But it is too early to predict that seat-mile costs for supersonic travel can be reduced to match those of today's highly refined subsonic jets.

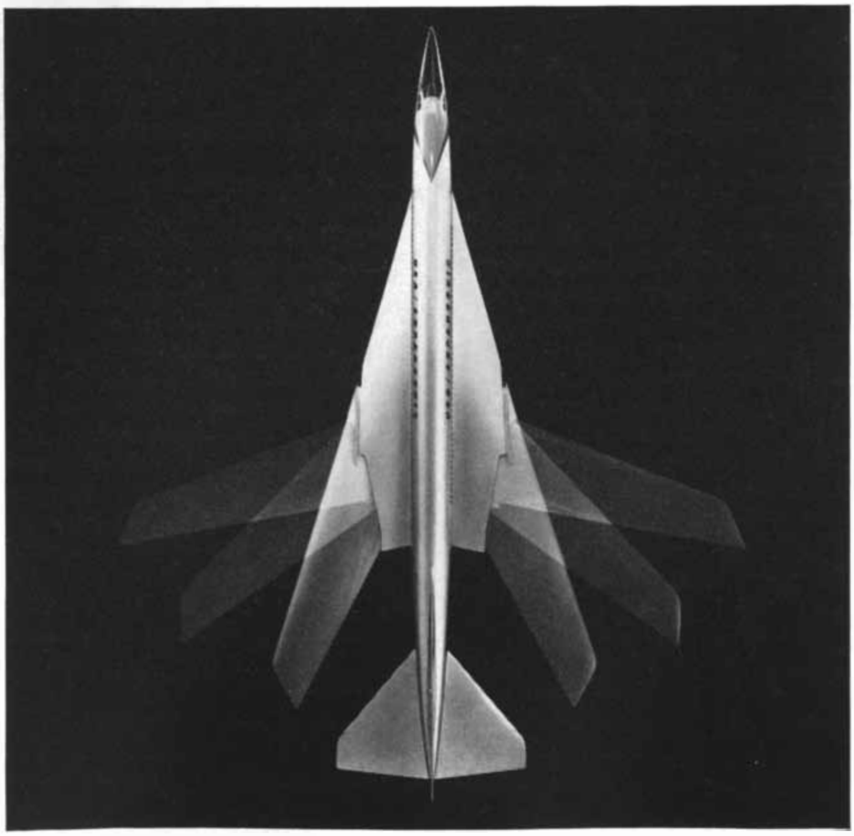
It is not entirely justifiable, however, to compare the supersonic transport with its subsonic predecessor solely on the basis of seat-mile cost. There is also the very important possibility that the significant speed increase will yield an increase in airplane "productivity," measured in passenger-miles over a given period of time. The productivity of the subsonic jet is significantly higher than that of its piston predecessor, and there are some grounds for believing that the Mach-3 supersonic transport's productivity will be higher than that of the subsonic jet. But a true measurement of this quantity is extremely difficult to obtain in advance.

Although it is not possible in a single article to discuss all aspects of the SST, I have attempted to show that it is technically feasible. But it should also be clear from my discussion that today's technology is not advanced enough to build an SST that would be economically attractive to the airlines. More refinement is needed.

The venerable factors of lift, drag and thrust are still the controlling elements in airplane design. We are faced, however, with the new and highly important factor of sonic boom with its major influence on airplane weight and configuration. In addition, more than ever before the economic success or failure of a proposed airplane is dependent on small differences in the efficiency of component parts. For example, our studies of propulsion for supersonic transports show that the performance of inlet and exhaust nozzles is of crucial importance. An improvement of 1 per cent in the gross thrust coefficient of a nozzle could permit a reduction of about 5 per cent in the gross weight of the airplane for a given payload. Such improvements, which typify the technological advances required for supersonic commercial air transport, are within the grasp of a well-organized program of research and development making maximum use of the nation's industrial, university and governmental resources.



ARTICULATED NOSE is a feature of the delta-wing supersonic transport design submitted to the Federal Aviation Agency by Lockheed Aircraft Corporation. The purpose of the movable nose is to improve visibility from the pilot's compartment during takeoff and landing.



VARIABLE WING SWEEP characterizes supersonic transport design that the Boeing Company submitted to FAA; it resembles the SCAT 16. A third design, proposed by North American Aviation Incorporated, resembles the supersonic military aircraft B-70.

X-RAY ASTRONOMY

Rocket-borne instruments have detected two powerful sources of X radiation in the sky. They may identify extremely faint little stars with superdense cores composed largely of neutrons

by Herbert Friedman

The energetic phenomena that take place in stars, galaxies and cosmic space radiate surplus energy in the form of electromagnetic waves ranging in length from a few thousandths of an angstrom unit (a ten-billionth of a meter) to hundreds of kilometers. Until recently, however, astronomers had available for study only those wavelengths able to pass through two principal "windows" in the atmosphere, one in the optical and the other in the radio region of the spectrum. In order to observe the full spectrum of celestial radiation, instruments must be placed above the main mass of the atmosphere. High-altitude balloons are useful for some observations, but the only undimmed view of the heavens is that obtainable from rockets or artificial satellites.

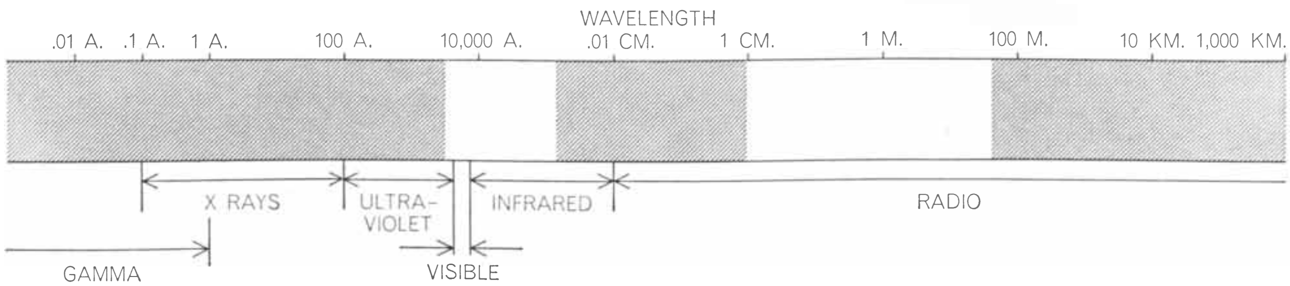
The first celestial body whose radiation in the X-ray region of the spectrum (from .1 to 100 angstroms) was studied intensively by rocket-borne instruments was the sun [see "Rocket Astronomy," by Herbert Friedman; SCIENTIFIC AMERICAN, June, 1959]. Astrophysicists had calculated the amount of X radiation to be expected from various other potential sources and had concluded that X rays from outside the solar system would probably be too faint to be detected by conventional rocket instruments. Exploratory scans of the night sky seemed to bear out this prediction: early flights failed to turn up any new sources of X radiation.

Then in June, 1962, an instrumented rocket launched from the White Sands Missile Range in New Mexico detected an extremely powerful source of X rays in the general direction of the center of the galaxy. Subsequent flights have confirmed the existence of this source and have located other sources elsewhere in the sky. The unexpected intensity and character of the X-ray emissions from these sources have made it necessary to postulate new mechanisms to explain the production of the rays. It now appears that the emissions may originate in the incredibly dense cores of "neutron stars," the tiny, invisible remnants of collapsed supernovae.

The strong X-ray source near the galactic center was discovered by Herbert Gursky, Riccardo Giacconi and Frank R. Paolini of the American Science and Engineering Corporation and Bruno B. Rossi of the Massachusetts Institute of Technology. The discovery was made in the course of an experiment aimed at detecting X rays produced on the moon by impinging solar X rays. For this experiment they equipped an Aerobee rocket with a pair of X-ray-sensitive Geiger counters, each of which had a field of view of about 100 degrees of arc [*see bottom illustration on page 39*]. The rocket was stabilized by rapid spinning, so that its axis pointed toward the zenith. As the flight progressed, the counters repeatedly swept out a great circle of the sky that included the moon.

When the counter records were analyzed, they showed no evidence of X-ray emission from the moon, but they did show a broad peak of X-ray emission somewhere in the direction of the galactic center. The wavelength of these X rays was about three angstroms. When the counters were aimed away from the direction of peak response, the X-ray count fell to a low but steady background level.

The same experiment was repeated twice during the following year by Gursky and his colleagues. A rocket launched in October, 1962, could not confirm the single strong emission source because the galactic center is not visible from New Mexico in the fall, but two possible weaker sources were detected above the steady back-



ELECTROMAGNETIC SPECTRUM ranges from short-wavelength, high-frequency gamma rays (*left*) to long-wavelength, low-frequency radio waves (*right*). An angstrom unit (A.) is a ten-billionth of a meter. The X-ray region of the spectrum extends from .1 to 100 angstroms. "Windows" in the earth's atmosphere that admit electromagnetic radiation are indicated by unhatched areas.

ground count. A third flight in June, 1963, succeeded in detecting strong X radiation from the same general region that gave rise to the recording of the previous June.

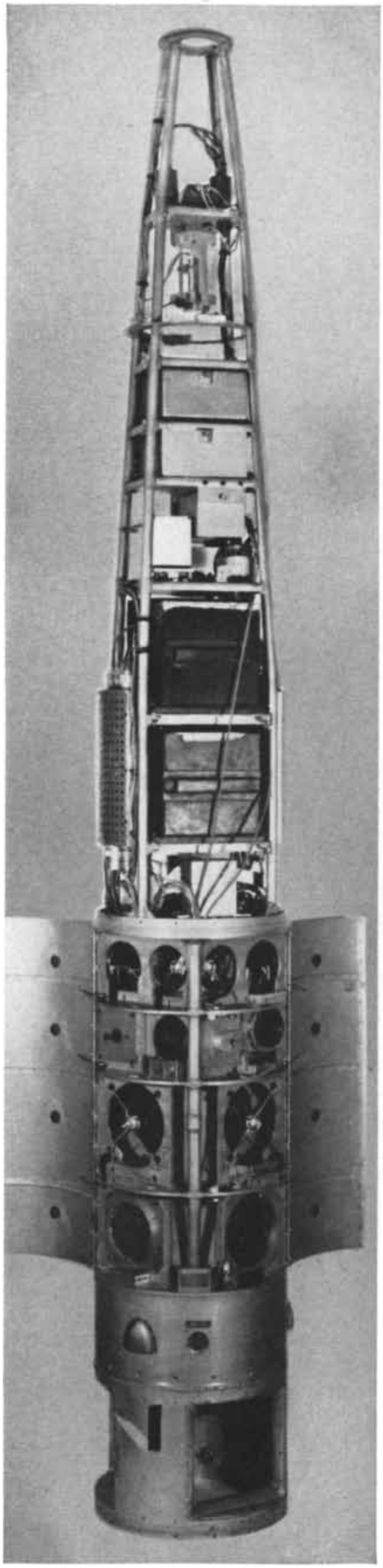
Meanwhile my colleagues (Stuart Bowyer, Edward T. Byram and Talbot A. Chubb) and I at the Naval Research Laboratory had launched another Aerobee rocket from the White Sands Missile Range in April, 1963. Our rocket was equipped with an X-ray counter about 10 times more sensitive than those flown by Gursky's group, but it covered about the same wavelength range: one to eight angstroms. In front of the counter was a hexagonal honeycomb collimator that limited the field of view to 10 degrees of arc [*see top illustrations on page 39*]. The rocket was deliberately given a slow spin to make it develop a large precession cone, or wobble, around its line of flight. As a result the circle of sky swept out by each spin of the rocket slowly revolved in such a way that almost the entire sky above the horizon was scanned during the flight [*see illustration on page 40*].

At the time the center of the galaxy was below the horizon and therefore invisible to the rocket, but roughly 58 per cent of the celestial sphere was covered. In this large expanse of sky the detector recorded one outstanding X-ray source in the constellation of Scorpius, about 20 degrees away from the direction of the galactic center. Closer examination of the data revealed another source, about an eighth as bright, coincident with the Crab nebula. No other discrete sources were distinguishable above the general background radiation.

As the X-ray counter swept the sky it passed over the Scorpius region eight times. In spite of the relatively rapid rate of scanning, the X-ray signal was strong and clear on each pass. A map of the eight scans was then used to plot equal-intensity contours, which approximated to concentric circles centered at 16 hours 15 minutes right ascension and −15 degrees declination [*see illustration on page 41*]. The detector was not capable of distinguishing between a point source and a diffuse gas cloud as large as two degrees in diameter.

The intensity of the X radiation from the Scorpius source is remarkable. It is comparable to that emitted by the quiet sun in the same wavelength range. Yet the entire neighborhood around the source is devoid of any visibly bright star, nebulosity or radio emission. What kind of celestial object could produce such intense X-ray emission and still re-

AEROBEE ROCKET was launched on April 29, 1963, from the White Sands Missile Range in New Mexico by the author and his colleagues at the Naval Research Laboratory. The rocket was equipped with a sensitive X-ray counter that covered a wavelength range of one to eight angstroms (*see top illustrations on page 39*). In the time that the rocket was above the earth's atmosphere it observed two powerful X-ray sources in the sky: one in the direction of the constellation of Scorpius and another coincident with the Crab nebula.



INSTRUMENT SECTION of an Aerobee rocket has been stripped of its outer skin to reveal its contents. The X-ray counter is behind the circular window at bottom left.

main invisible in the optical and radio wavelengths?

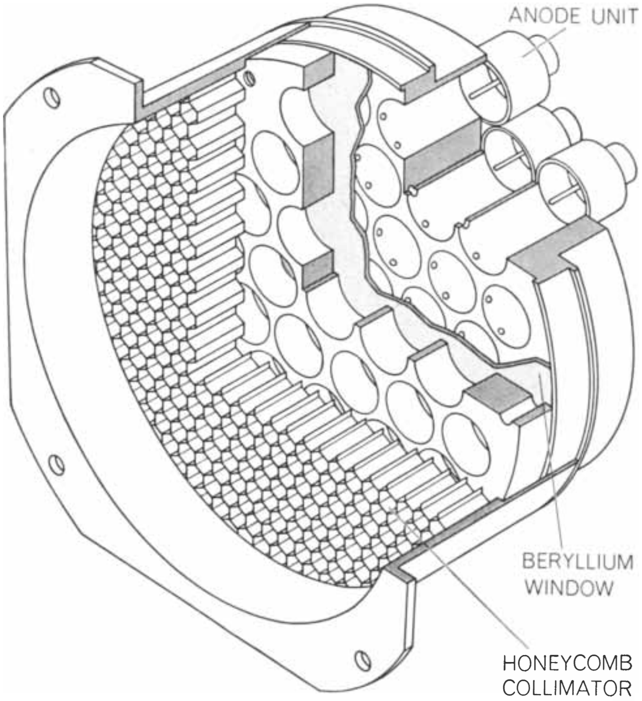
A neutron star seems to meet all the requirements. The concept of a neutron star was first proposed in 1934 by Walter Baade and Fritz Zwicky of the Mount Wilson Observatory and the details of its theoretical structure and evolution were later worked out by J. Robert Oppenheimer and G. M. Volkoff, then at the University of California at Berkeley. Briefly, a neutron star is what remains after the collapse of a large star due to the depletion of its source of energy. A neutron star would contain about as much mass as the sun compressed into a sphere roughly 10 miles in diameter. Its superdense core would consist almost entirely of neutrons and would be up to 100 million times denser than the core of a very compact white-dwarf star. The surface temperature of a neutron star would be about 10 million degrees Kelvin (degrees centigrade above absolute zero) and the temperature in its core as high as six billion degrees. Because of these high temperatures a neutron star would emit about 10 billion times more energy in the form of X rays than in the form of visible light. This is just the reverse of the ratio produced by the undisturbed sun.

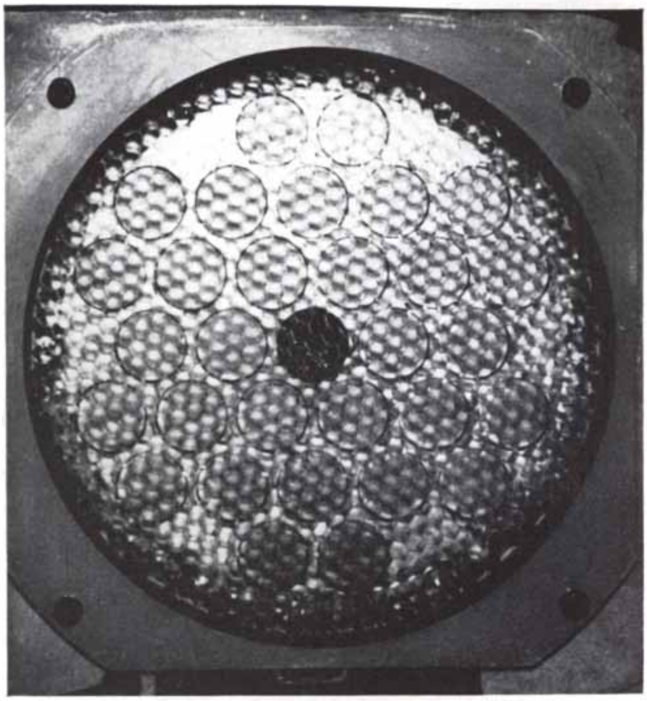
Recently Hong-Yee Chiu of the Goddard Institute for Space Studies undertook to develop a model of a neutron star from which some of its radiative characteristics could be determined. He hoped to find out if emissions from such a star could be detected in the ultraviolet or X-ray regions of the electromagnetic spectrum. When we compared his predictions with our observations of the X-ray sources in Scorpius and the Crab nebula, the agreement was surprisingly close. Early this year Chiu and A. G. W. Cameron of the Goddard Institute and Donald C. Morton of Princeton University published more refined calculations of the X radiation to be expected from a neutron-star source; these estimates agreed even better with our observations.

To understand how X rays could be produced in a neutron star, let us consider how such a star may have evolved. A star is supported against the inward force of gravitation by the internal pressure maintained by its high central temperature. If this vital balance is disturbed, the star quickly adjusts to a new equilibrium by shrinking or expanding. Even at the center of the sun, where the density is seven times that of lead, the behavior of the gas never departs from the ideal gas law (pressure is proportional to density times temperature). Inside a white-dwarf star, however, temperatures are not significantly higher than they are inside the sun (about 13 million degrees), yet the density often reaches several tons per cubic inch, and as a result the ideal gas law breaks down. The British astrophysicist Sir Arthur Stanley Eddington suggested in 1924 that the high density of a white-dwarf star could only be explained by supposing that the atoms in the core were completely stripped of their electrons, enabling the bare nuclei to pack tightly together. The sheer squashing of material would produce the condition known as electron degeneracy. Although the nuclei themselves would continue to follow the ideal gas law, the degenerate electrons would now produce a pressure so much higher than the nuclear-gas pressure that the latter could be considered negligible in comparison. If the density in a white-dwarf star were to be increased 100,000-fold, even the nucleons (that is, the neutrons and protons) would be compressed to the point at which they would begin to touch. This condition of nucleon degeneracy must exist in a neutron star.

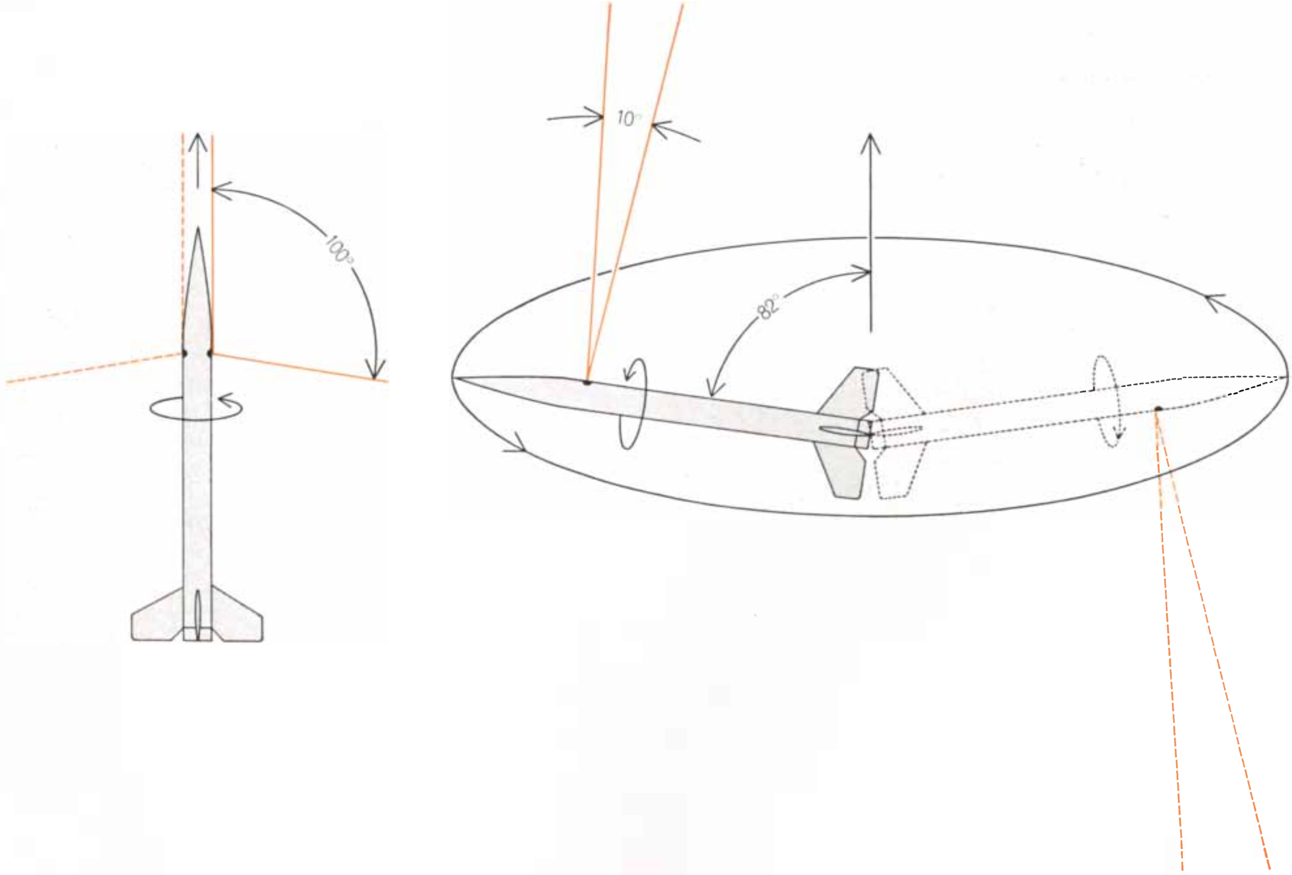
In the course of evolution of a star such as the sun, the nuclear fuel is consumed slowly. As the source of energy is gradually depleted, the star shrinks and its density increases until electron-degeneracy pressure is approached. Thereafter the rate of cooling becomes progressively slower. Within the age of the galaxy it is not certain that any star has had enough time to cool off completely by this process, but considerable numbers have reached the white-dwarf stage. A typical white dwarf has a density of about 10 tons per cubic inch and a size comparable to that of the planet Jupiter, with only a thin radiating layer at the surface remaining at white heat.

If the mass of a star originally exceeds 1.44 times the mass of the sun (a threshold known as Chandrasekhar's limit) it cannot follow the gradual evolutionary path just described; it is doomed to end its life in a catastrophic supernova explosion. Because the inward force of gravity is too large to be balanced by electron-degeneracy pressure, the temperature of the core must rise to balance gravity. At various temperature levels different nuclear fuels are ignited. Thus the star ages in successive stages, first burning hydrogen to form helium, then helium to form carbon, carbon to form oxygen, neon and magnesium, magnesium to form sulfur and sulfur to form iron. The duration





X-RAY COUNTER used by the author's group was about 10 times more sensitive than any that had flown earlier. Its components are shown in the cutaway drawing at left. The honeycomb collimator in front of the counter limits the field of view to 10 degrees of arc.

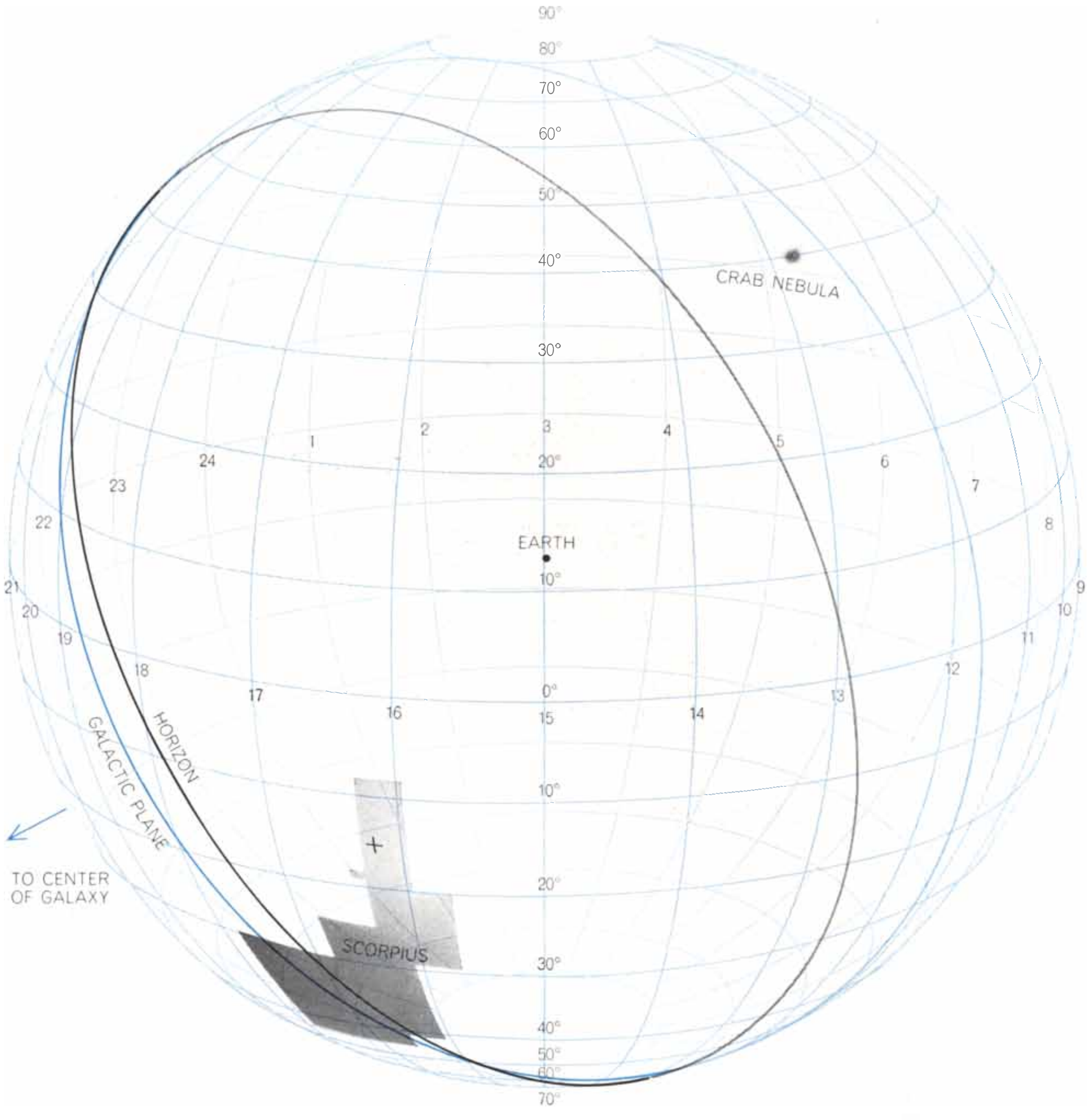


TWO ROCKET-SCANNING TECHNIQUES are illustrated here. The rocket at the left has been stabilized by rapid spinning, so that its axis points toward the zenith. Its X-ray counters sweep out a 100-degree-wide field extending from the horizon to the zenith. The rocket at the right is similar to that flown by the author's group. It has been deliberately given a slow spin to make it develop a large precession cone, or wobble, along its line of flight. As a result the circle of sky swept out by each spin of the rocket slowly revolves in such a way that almost the entire sky above the horizon is scanned during the flight. The 10-degree-wide field of view of the X-ray counter in this rocket enables it to make much more precise measurements than those made by the rocket at the left.

of the various stages of burning may be as long as 10 billion years (hydrogen to helium) or as short as one year (sulfur to iron).

As each stage nears its end, a period of gravitational collapse ensues. These contraction periods may last from 100 to 10,000 years, depending on the mass of the star. The energy derived from each contraction raises the temperature of the core until the next stage of nuclear synthesis is ignited. Temperatures range from a low of 10 million degrees for the fusion of hydrogen up to about five billion degrees for the conversion of sulfur to iron. At the lower temperature levels, surplus energy is dissipated in the form of visible light quanta, or photons. At the higher temperature levels, protons are converted into neutrons with the consequent emission of neutrinos.

If the temperature in the iron core of the star exceeds five billion degrees, electron-positron pairs are produced in such great abundance that their density reaches several tons per cubic foot. At this point a new and still more rapid process may become dominant. Electrons and positrons can collide and annihilate one another to form neutrino-antineutrino pairs. According to Chiu and Philip Morrison of Cornell University, a star can dissipate all its energy by this means in little more than a day. To compensate for the rapid escape

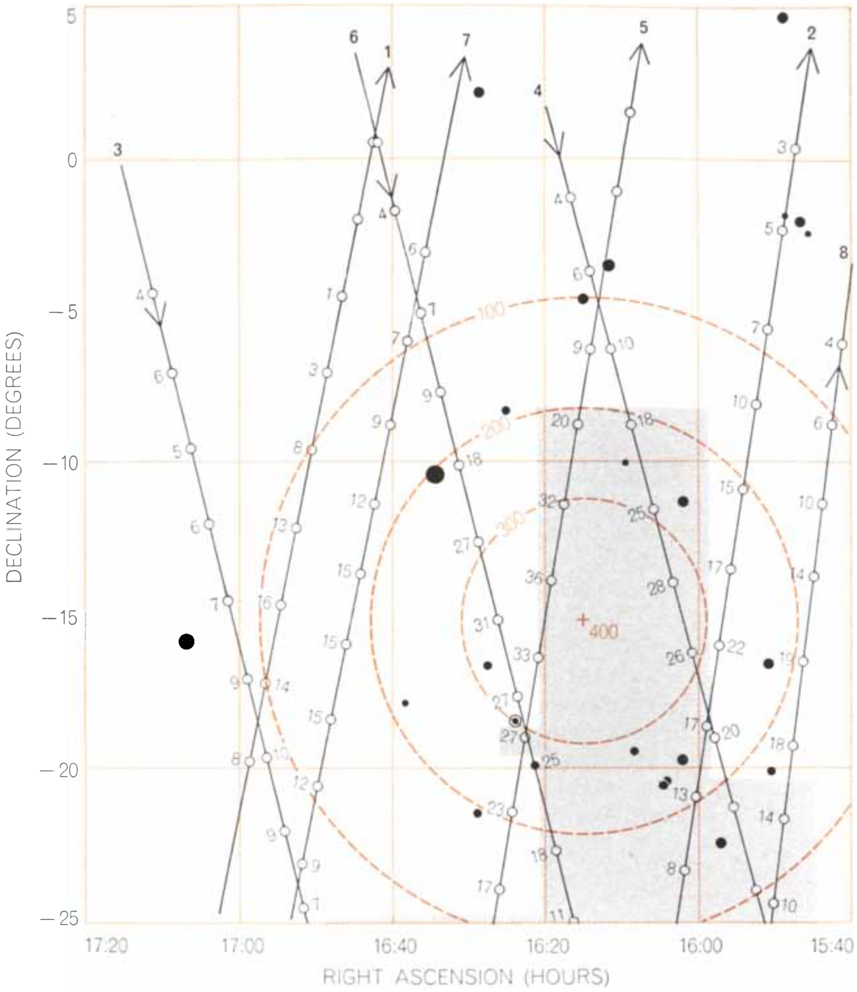


NEARLY 60 PER CENT OF CELESTIAL SPHERE ***(area to right of black circle)*** **was viewed by the author's X-ray detector during the April 1963 rocket flight. The brightest X-ray source observed is marked by a small cross in the constellation of Scorpius (*large gray area*). Another source, about an eighth as bright, was detected in the vicinity of the Crab nebula (*gray dot on back of sphere*). At the time the galactic center was below the horizon and therefore invisible to the rocket. The numbers down the center of the drawing denote declination (corresponding to geographic latitude) in degrees; the numbers around the middle, right ascension (corresponding to longitude) in hours. An enlarged view of the region around the Scorpius source appears on the opposite page.**

of energy through neutrino radiation, the star must call on its gravitational energy. It begins to shrink rapidly and the temperature in its core rises accordingly. This rise in temperature in turn increases the rate of neutrino radiation and causes the star to contract still more rapidly; the collapse of the star becomes a runaway process.

As the temperature in the core approaches six billion degrees, the equilibrium shifts suddenly. Iron and related elements are converted into helium, with the release of excess neutrons. The mean binding energy of the 56 nucleons in the common isotope of iron is 8.8 million electron volts (mev) per nucleon and that of the 13 helium nuclei and four neutrons produced by the breakup of iron is only 6.6 mev per nucleon. Thus the breakup process requires an input of energy of 2.2 mev per nucleon. The only available source of energy adequate to support this reaction is the star's gravitation. All the energy the star has used up in going from hydrogen to iron must now be returned to convert iron back to helium. The star resists this rapid process of refrigeration by contracting still further. Gravitational energy is used up without increasing the temperature; the result is a catastrophic implosion. When this total collapse begins, the core has already contracted to a density of between 100 and 1,000 tons per cubic inch. The implosion takes only the time required for free fall: about one second.

With the collapse of the core the pressure that has supported the outer regions of the star is suddenly removed. The outer material also falls inward, almost as rapidly as the core implodes, and the dynamic energy of its fall is converted into heat. The resulting rise in temperature accelerates the nuclear burning of the lighter elements in the outer regions. At three billion degrees the oxygen zone near the surface is burned completely in about one second and a supernova outburst results. If the mass of material in the oxygen zone is equal to one solar mass, the energy released per second is comparable to the normal solar output for a billion years. The exploding supernova shines with a light equal to 200 million suns for two or three weeks.



X RAYS FROM SCORPIUS **appear to come from a source that is undistinguished by any visibly bright star, nebulosity or radio emission. The source is indicated by a small cross at the center of the three concentric circles. The heavily numbered arrows are tracks made by the X-ray counter as it passed over this region in Scorpius eight times; the lighter numbers next to the small open circles along each track denote the counts recorded per .09 second. The circles approximate equal-intensity contours at 100, 200 and 300 counts per second. The estimate of 400 counts per second at the center is extrapolated from these values. The detector could not distinguish between a point source and a diffuse gas cloud as large as two degrees in diameter. Stars are represented by black dots, which vary in size according to the star's magnitude. A black dot inside an open circle designates a source of radio emission. The gray area represents less than half the total extent of Scorpius.**

What happens to the imploded core? When the infalling material exceeds a density of 100 tons per cubic inch and the temperature reaches six billion degrees, protons absorb electrons and are converted into neutrons at such a high rate that the core turns into a mass of neutrons while the collapse is in progress. It is difficult to determine just when the core attains a stable configuration. Present estimates place the limit of stable density at about 100 million tons per cubic inch and the core temperature at about six billion degrees. At this high pressure and temperature, neutrino radiation would dissipate energy so rapidly that the core would not have time to rebound. The result would be a superdense neutron star. (This whole discussion of the formation of a neutron star is, of course, quite general, and many of the details are still in dispute.)

Chiu and Morton have examined the type and intensity of radiation that might be emitted from the surface of a neutron star. Because degenerate matter conducts heat very efficiently, the core must be fairly uniform in temperature. Enveloping the core is a half-mile-thick mantle of electron-degenerate but otherwise normal material similar to that found in the core of a white dwarf. The top few yards of this mantle consist of normal, nondegenerate matter, from which energy is radiated directly into space. The entire thermal gradient from core to surface takes place in this thin topmost layer, which, in Chiu's models, has a temperature of between one million and 10 million degrees.

Morton's models predict a somewhat hotter surface temperature: from about

RELATIVE SIZES of the sun, a white-dwarf star and a neutron star are depicted in this drawing. The diameter of the sun (which would be more than 40 inches if the entire sun were shown to scale) is nearly a million miles. The diameter of a white dwarf is about 6,000 miles and that of a neutron star about 10 miles. Yet all three stars have approximately the same mass. The density in the core of

four million to 16 million degrees. X rays produced in the atmosphere of a neutron star at these temperatures would match the measured intensity of the Scorpius source if the star were between 300 and 4,000 light-years away. A neutron star at this distance could not be detected by any existing optical telescope or by any yet contemplated for an orbiting astronomical observatory.

Although the Scorpius X-ray source is detectable only by means of its X-ray emission, the Crab nebula is a conspicuous source of radiation in a wide range of wavelengths. It is the third most powerful source of radio waves in the sky. Its visible nebula is six light-years across and is expanding at a rate of some 700 miles per second. The nebula is the residue of a violent supernova explosion observed by Chinese and Japanese astronomers in A.D. 1054, when it suddenly appeared in the sky with a brightness that temporarily exceeded that of Venus. No visible remnant of the original star has ever been detected in the nebula.

Morton has calculated that a neutron star at the center of the Crab nebula must have a surface temperature of 7.6 million degrees if it is to satisfy the observed X-ray intensity. The apparent visual magnitude of such a star would be 28—far below the limits of detectability.

Although our X-ray observations agree remarkably well with the predictions of neutron-star models, other hypothetical mechanisms for the production of celestial X rays should not be disregarded. It is possible that the observed radiation arises from the rapid gyration of high-energy electrons in a strong magnetic field; such radiation is known as synchrotron radiation [*see illustration "a" on page 44*]. The polarization of light in the tangled filaments of the Crab nebula is characteristic of synchrotron radiation. Whether the X rays from the Crab nebula come from a thermal source, such as a neutron star, or from synchrotron radiation may eventually be settled by more refined spectral measurements.

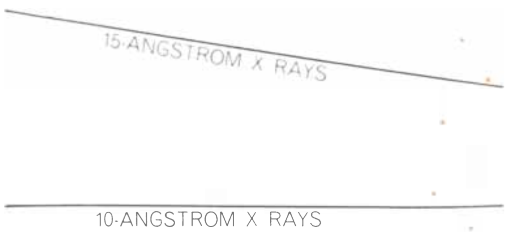
If we attribute both the Scorpius and the Crab X-ray sources to neutron stars, we are forced to explain why the two sources appear so dissimilar in other wavelengths. In particular, why does the Scorpius source exhibit no radio emission or visible nebulosity? Morton has suggested that since the Crab supernova exploded in the central plane of the galaxy, the galaxy's magnetic field was strong enough to confine the expanding gas to a visible nebula. The Scorpius source, on the other hand, is 20 degrees above the galactic plane and may have exploded in a region where the magnetic field was too weak to confine a nebula. In any case, the statistics on supernova explosions in general are still too few to reveal any clear patterns of appearance and behavior.

Is there any evidence for the occurrence of a supernova explosion in the immediate neighborhood of the Scorpius X-ray source? Oriental records contain several references to brilliant novae or supernovae in Scorpius. Morton has noted four possible supernova explosions in the Chinese and Japanese chronicles that were fairly close to the observed X-ray source. A medieval Arabic reference is particularly intriguing: in 827 Haly and Giafar Ben Mohammad Albumazar in Babylon reported a new star in Scorpius that was as bright as the quarter-moon and was visible for four months. This object, however, may have been a comet.

Assuming that the rate of appearance of supernovae in our galaxy is one a century, there would now be about 100 million neutron stars in the entire galaxy. Of these only a few would have been produced within the past 1,000 years and would therefore have surface temperatures high enough to emit substantial amounts of X radiation. Emission from these sources could be detected at distances of up to 3,000 light-years. Even if there were large dust clouds between the earth and a neutron star, they would absorb very little X radiation with a wavelength shorter than 10 angstroms. Thus, with improved techniques, we may find as many as 50 neutron stars in our part of the galaxy.

The observations of Gursky and his colleagues raised the possibility that the galactic center is itself a source of intense X radiation. According to the Japanese astrophysicists S. Hayakawa and M. Matsuoka, X rays could be produced in gas clouds at the center of the galaxy by the interaction of cosmic ray protons and helium nuclei. X rays produced in this way would be sufficiently intense to be detected by present rocket instruments.

An alternative mechanism for the production of X rays at the galactic center has been proposed by Robert J. Gould and Geoffrey R. Burbidge of the University of California at San Diego. They suggest that various elements, including aluminum and iron, may have



OPACITY OF THE GALAXY to X rays coming toward the earth from extragalactic sources varies with direction. Only X rays

the sun is about two pounds per cubic inch, in the core of a white dwarf about 10 tons per cubic inch and in the core of a neutron star about 100 million tons per cubic inch. In the core of a white dwarf atoms are stripped of their electrons, enabling the bare nuclei to pack tightly together. A neutron star consists almost entirely of neutrons, which are compressed until they touch.

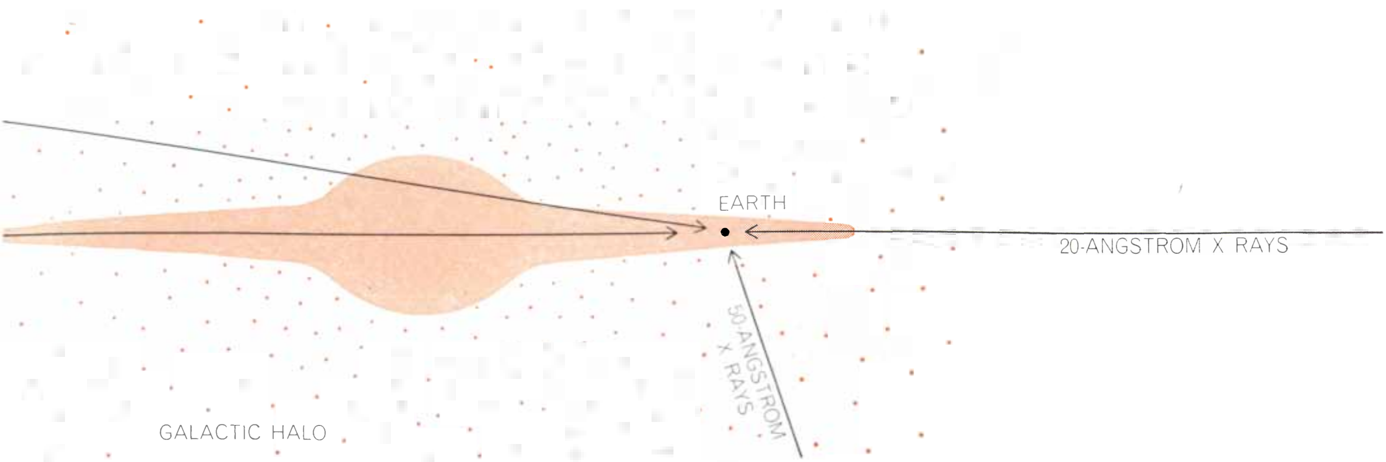
become ionized in this region by losing an electron from one of their inner shells. In this case the ionization would be caused by a shower of protons and electrons emitted by old stars in the neighborhood of the galactic center rather than by cosmic ray particles. The filling of an inner-shell vacancy by an electron from outside the atom or from an outer shell would then lead to a release of energy in the form of an X ray [*see illustrations "b" and "c" on next page*]. The intensity of these X rays would also be within the present limits of detectability.

The origin of the weak but steady background count of X radiation detected on all the flights is difficult to determine. Although this radiation may be produced in the earth's atmosphere, there is substantial evidence that it comes from an external source. In fact, Gould and Burbidge have suggested that it may even originate outside the galaxy. They have calculated the X radiation to be expected from the hypothetical neutron-star populations of all the external galaxies combined; the total intensity is comparable to the observed X-ray background.

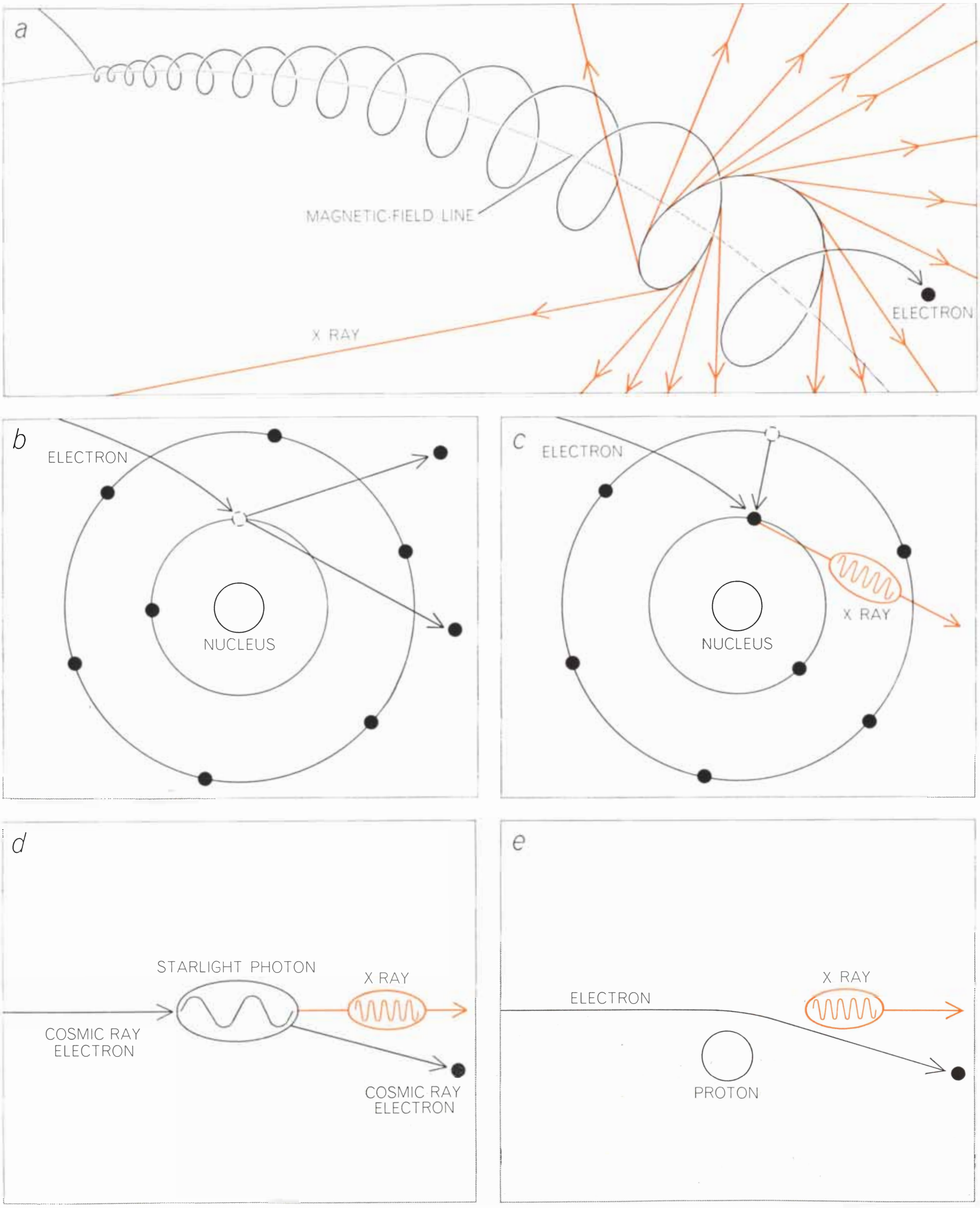
It is also possible that the uniform background count may be the result of synchrotron radiation produced by the gyration of cosmic ray electrons in the weak magnetic field of the galactic halo, or corona. The galactic halo is a sphere of low-density gas that surrounds the disk of the galaxy. Computations show, however, that the intensity of X rays produced by this means would be a million times weaker than the observed X-ray background in the direction of the galactic pole and 10,000 times weaker in the direction of the galactic center.

A much more likely source of the weak background X rays is the scattering of cosmic ray electrons by starlight [*see illustration "d" on next page*]. When a cosmic ray electron and a photon of starlight collide, about .01 per cent of the electron's energy is transferred to the photon, which is thereby promoted to the status of an X ray. Morrison and J. E. Felton have computed the intensity of such X rays to be expected from the galactic halo; their figure is between 100 and 1,000 times weaker than the intensity measured in the rocket experiments. If all space were filled with cosmic ray electrons to a density of about 1 per cent of the halo density, however, the computed X-ray intensity would exactly match the observed background intensity.

The steady background of X radiation can be used to test several current cosmological theories. For instance, a particularly knotty problem is to explain both the expansion of the universe and the condensation of galaxies if gravity is the only force considered; the energy required to maintain universal expansion against the force of gravity should inhibit local gravitational condensation. One is forced into the unsatisfactory position of postulating vague fluctuation phenomena to initiate condensation. To escape this dilemma Thomas Gold of Cornell and Fred Hoyle of the California Institute of Technology have proposed that a galaxy condenses by local cooling in a hot intergalactic gas, which exerts pressure on the surface of the cooler pocket. As soon as the gas in the compressed region reaches a certain



with wavelengths shorter than 10 angstroms can penetrate to the earth from beyond the far edge of the galactic disk. In directions away from the disk the opacity is much less and X rays with wavelengths as long as 50 angstroms may be detectable. Because of the galaxy's spiral structure opacity also varies with direction within the galactic plane. The galactic halo is relatively transparent.



HYPOTHETICAL MECHANISMS for the production of celestial X rays are alternatives to the neutron-star theory. The rapid gyration of high-energy electrons in a strong magnetic field (*a*) throws off a spray of X rays (*colored lines*) in all directions. (Only the X rays emitted in one turn of the electron are shown here.) This process, known as synchrotron radiation, could take place in almost any hot cosmic gas. X rays could also be produced in the gas at the center of the galaxy by a process that begins with the ionization of an inner shell of an atom such as iron by protons or electrons from old stars near the galactic center (*b*). An X ray is emitted when the inner-shell vacancy is filled by an electron from outside the atom or from an outer shell (*c*). (In actuality there would be many more shells than the two shown here.) A likely source for the weak background X rays observed on all the flights is the scattering of cosmic ray electrons by photons of starlight in the low-density gas of the galactic halo (*d*). Cosmic ray electrons emitted by the neutron-decay process would also produce X rays when they interacted with protons in the hot intergalactic gas (*e*). The X rays in *c* through *e* are represented as tiny packets of energy that share some characteristics of both particles and waves.

threshold density, gravitation takes over and completes the process of condensation.

Gold and Hoyle estimate that the temperature of the intergalactic gas required for the first stage of this process must be about a billion degrees. In one model of the steady-state universe, in which neutrons rather than protons are being created continuously, such a temperature can be generated by the decay of neutrons into protons and electrons. This model, called the "hot universe" hypothesis, has the attractive feature of requiring the thermal energy of the intergalactic gas to be comparable to the observed energies of cosmic rays; it thus provides an adequate source of energy for the acceleration of cosmic ray particles to their enormous energies.

The high-energy electrons produced in the hot intergalactic gas by the neutron-decay process would emit X rays when they interacted with intergalactic protons [*see illustration "e" on opposite page*]. The anticipated X-ray intensity from this source, however, is about 20 times higher than the observed background count. The measured intensity would seem to indicate that the temperature of the "hot" universe could be no more than 10 million degrees, rather than the billion degrees suggested by Gold and Hoyle.

The techniques of X-ray astronomy can also be employed to determine the density and distribution of hydrogen gas within our galaxy. The transparency of interstellar gas increases as the wavelength of the transmitted radiation decreases. Hence the wavelength threshold below which radiation is transmitted indicates the density of gas along the line of sight. Just where on the spectrum this threshold will occur depends, of course, on the intensity of the source being observed. For sources of X radiation fairly good wavelength resolution is possible; thus rocket data can be analyzed to determine with fair precision the density of interstellar gas in various directions [*see bottom illustration on pages 42 and 43*].

This technique could also be extended to determine the source of the observed background radiation if it is indeed extragalactic in origin. The intensity of the background radiation at different X-ray wavelengths would indicate whether these emissions originated primarily in galactic halos and intergalactic space or at the centers of external galaxies. A peak at about 50 angstroms would indicate galactic-halo or intergalactic emission; radiation from galactic centers would be filtered down to about 15 angstroms by the gas in these galaxies before being transmitted in our direction.

From the foregoing account it is clear that the first crude results of X-ray astronomy have provided astrophysicists with a wealth of new information. One could hardly imagine a more exciting beginning for the new rocket astronomy than the detection of a neutron star. For the immediate future it is essential to repeat and verify the first observations. Substantial increases in instrument sensitivity are easily possible and should lead to the detection of many new sources. Laboratory versions of large focusing telescopes for X rays have already been built with a resolution better than 20 seconds of arc. To support the neutron-star interpretation it is crucial to prove that the Scorpius and Crab objects are truly point sources. It will take some years, however, before a satellite-borne X-ray telescope can scan a large region of the sky with good enough resolution to pinpoint a neutron star.

In the meantime it may be feasible to take advantage of the lunar-occultation technique that has been applied so successfully for measuring the positions and dimensions of the newly discovered quasi-stellar radio sources [see "Quasi-Stellar Radio Sources," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, December, 1963]. An occultation of the entire Crab nebula by the moon, for example, takes roughly five minutes, or about the same time that an Aerobee rocket remains above the X-ray-absorbing atmosphere. A stabilized Aerobee rocket has recently been developed that can point to a selected object in the sky with an accuracy of better than 2 degrees of arc. It is possible to launch such a rocket, aimed toward the Crab, just before lunar occultation begins. If the X-ray intensity dwindles during the occultation in proportion to the nebular surface blacked out by the moon, we shall have evidence that the source is an extended region emitting synchrotron radiation. But if the source disappears abruptly within one or two seconds of arc we shall have strong evidence that the X-ray source is a neutron star. We shall have an opportunity to perform this experiment next month and we hope to have the rocket and instruments ready. Unfortunately, if this date is missed, we shall have to wait until the next lunar occultation of the Crab nebula, which will not occur until 1972.

CRAB NEBULA in the constellation of Taurus is the second most powerful source of X radiation in the sky. Whether these X rays come from a thermal source, such as a neutron star, or from synchrotron radiation in the expanding gas is not known as yet. The nebula is the residue of a violent supernova explosion observed by Oriental astronomers in A.D. 1054. This photograph was made by red light with the 200-inch telescope on Palomar Mountain.

A Defective Cancer Virus

The Rous sarcoma virus is uniquely efficient in producing tumors. Its carcinogenic effect seems to be related to an inability to form a protein coat and reproduce itself without help from another virus

by Harry Rubin

In 1910 Peyton Rous of the Rockefeller Institute isolated a virus from a tumor growing in a Plymouth Rock hen and found that the virus could initiate a similar tumor when it was inoculated in another chicken. This unequivocal demonstration that a virus could cause malignant growth aroused considerable excitement. Rous and his collaborators conducted a long, intensive study of the properties of the Rous sarcoma virus, or RSV as it has come to be called. ("Sarcoma" is the term for a metastasizing tumor of the connective tissue.) After a while interest in the subject waned because no one was able to find evidence that viruses induced cancers in any animal but the chicken. In recent years, however, it has been discovered that viruses are associated with several kinds of tumor in mammals, notably in mice, and these findings have stimulated a new wave of investigation.

Significantly this renascence of interest in the relation of viruses and cancer has brought back into prominence the virus that first indicated the relation: RSV. Compared with the other tumor viruses, RSV turns out to be unique. It produces a prompt and direct transformation of cells such as no other virus has yet shown. To put it another way, RSV seems to be a specialist in carcinogenesis, or the production of malignant growth, whereas the other tumor viruses transform cells only occasionally and after a long delay in the animals they infect, as if the development of the malignancy were just an accidental byproduct of their multiplication. More than ever, therefore, RSV stands out as the strongest of all the clues for solving the mystery of virus-induced malignancy. What is there about this particular virus that makes it so carcinogenic?

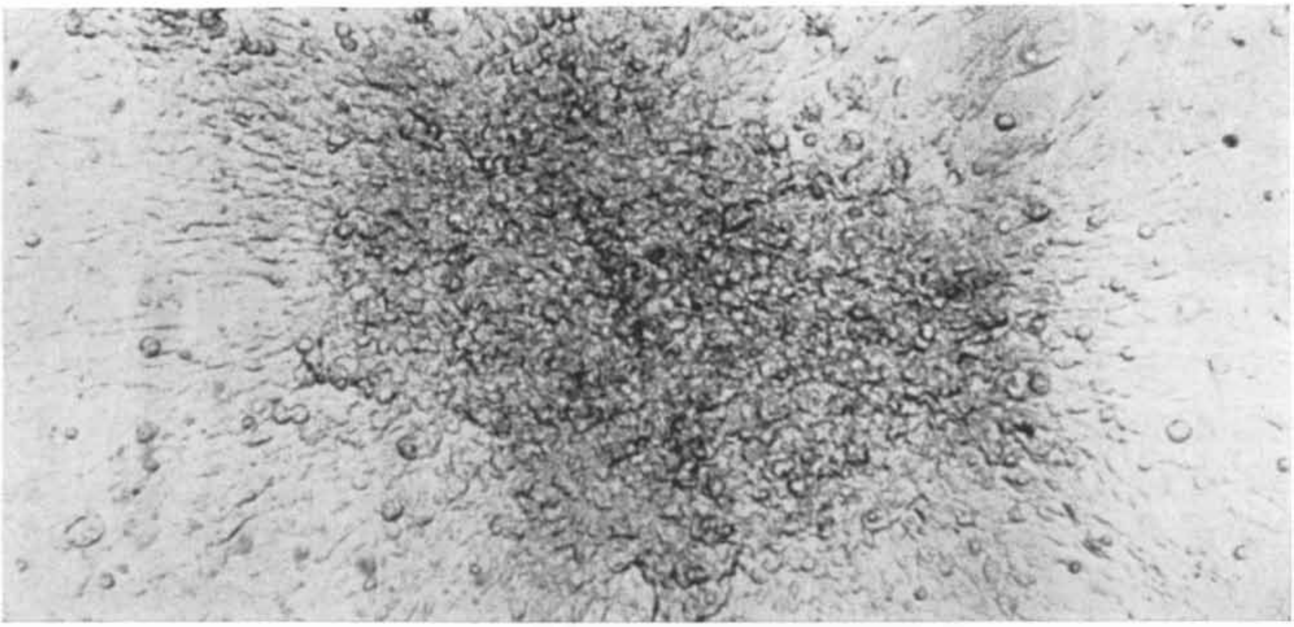
With the advent about 10 years ago of versatile tissue-culture techniques for studying viruses, a new search got under way for an answer to this question. It is now established that RSV does indeed possess a fundamental property that may well account for its carcinogenic action. Somewhat surprisingly, the property in question turned out to be a defect of the virus—a defect that makes it unable to reproduce itself completely unless it has the help of another virus. To understand how the defect was discovered and how it may be connected with the transformation of cells, we must first consider the comparative behavior of RSV and the other tumor viruses.

In its general structure and behavior RSV is a perfectly typical medium-sized virus. It has a core of nucleic acid and a coat of protein and lipid; as in many viruses the nucleic acid is not deoxyribonucleic acid (DNA) but ribonucleic acid (RNA). RSV infects a cell by attaching itself to the cell membrane and penetrating the cell. Some time later (from about 12 to 48 hours) the cell begins to release a steady stream of new virus particles identical with the RSV parent. All this is quite expected. It is only when we examine the effects of the virus on the infected animal or on groups of cells that we see how RSV differs from other viruses.

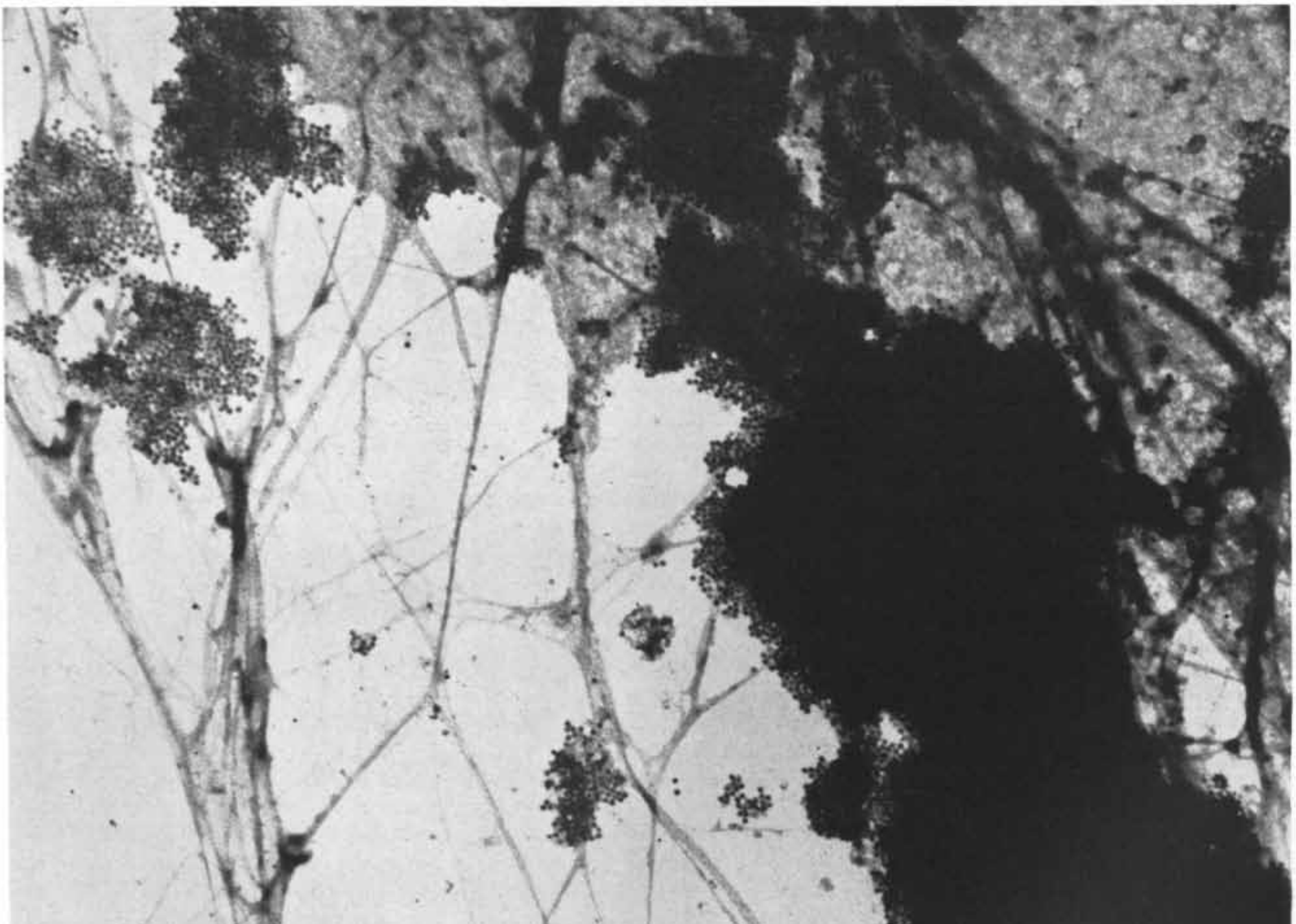
When a high concentration of RSV is injected into the skin of a chicken's wing, typical sarcoma cells begin to develop at the site within two days. In five to six days these form a tumor visible to the naked eye. The tumor grows rapidly and often invades the whole wing by the end of two weeks. The cancer then frequently metastasizes to the lung and liver and eventually kills the chicken. Young chickens succumb to the sarcoma most readily, but older ones are also susceptible, except for a few of certain strains in which white blood cells manage to destroy the sarcoma cells. Apart from these exceptional cases RSV is remarkably efficient in inducing malignant growth that kills the infected animal.

All the other known tumor viruses act very differently from this. Let us consider each separately. One of the most common diseases of chickens is leukosis; it is caused by a group of viruses that produce leukemias and other fatal conditions. The leukosis viruses are about the same size as RSV (about a 250,000th of an inch in diameter) and have much the same composition, with a core of RNA and a coat of protein resembling that of RSV. When these viruses infect chickens, however, they do not produce a tumor at the site of the inoculation. Instead they cause a generalized reaction that usually does not develop until several months after the inoculation. Moreover, they are likely to produce disease only if they infect young chicks; older chickens are generally immune to leukosis viruses.

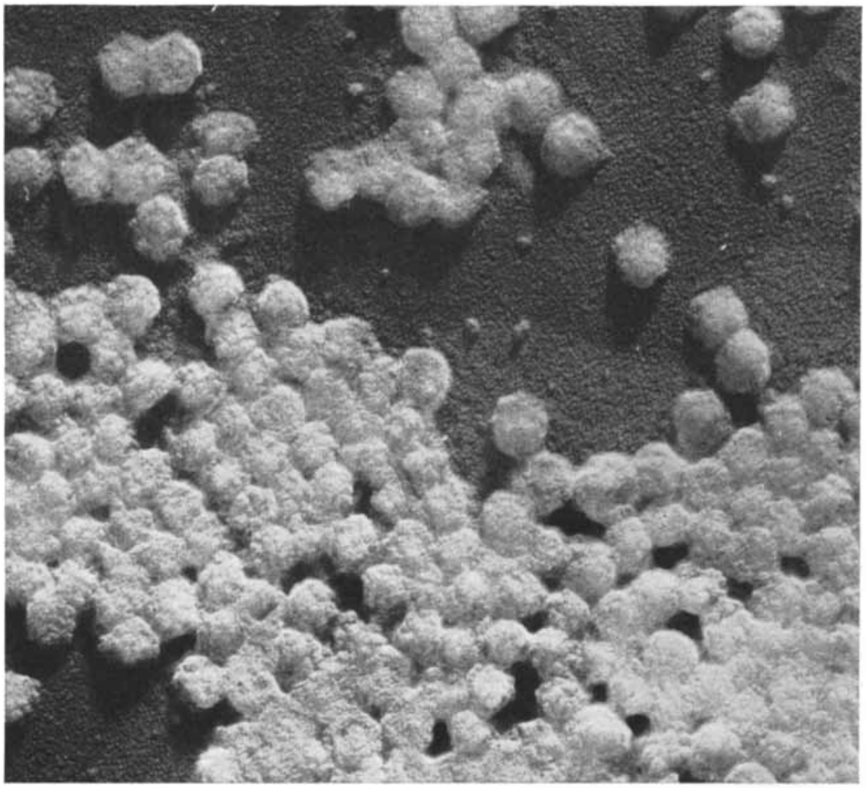
RSV can also be distinguished from most of the viruses capable of causing cancers in mammals. One class of these viruses is associated with mammary cancer and leukemia in mice. Judging from their appearance in the electron microscope, they have about the same size and structure and mature in the same part of the infected cell as RSV and the chicken leukosis viruses, so it seems likely that their composition also is about the same. Their carcinogenic effect is like that of the chicken leukosis viruses and totally unlike that of RSV. When they are inoculated into a mouse, they multiply in its cells, but they do not produce a tumor or leukemia until many months later, if at all. Often these viruses are transmitted from parent mice



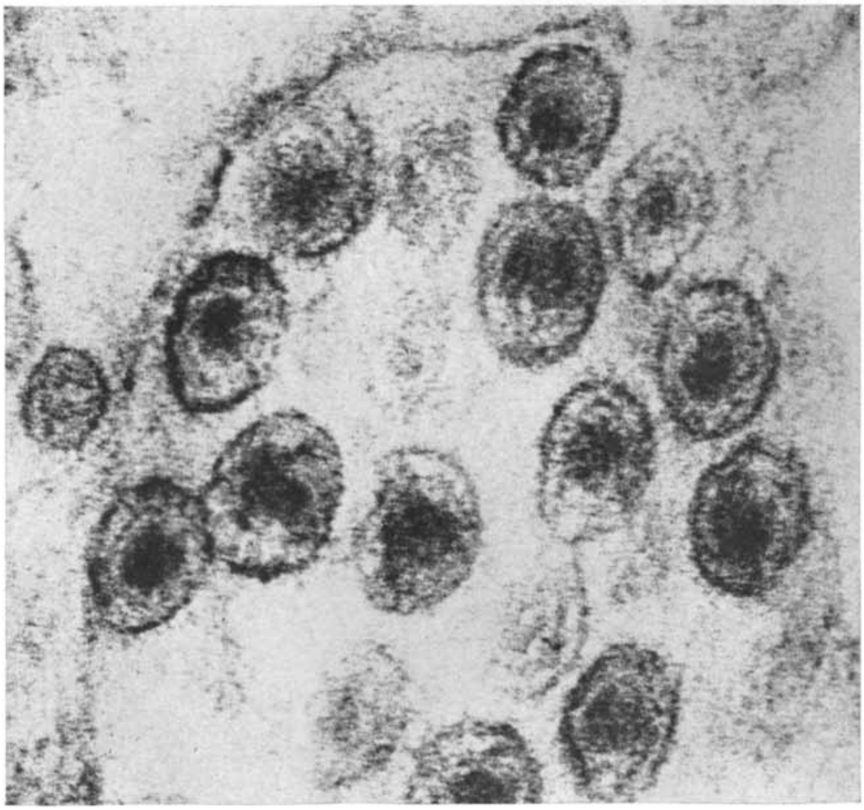
SARCOMA CELLS form a "focus" in a culture of chicken-embryo fibroblasts, or connective-tissue precursors. The rounded, denser cancer cells have been transformed by Rous sarcoma virus (RSV); they proliferate and pile up, in contrast to the elongated normal cells that form a monolayer on the dish around them. The cells are enlarged 65 diameters in this micrograph made by the author.



VIRUS AND CELL are enlarged 9,400 diameters in this electron micrograph of the edge of a cell infected five days before with RSV and "Rous-associated virus" (RAV). The gray area (*top right*) is the cell. Immediately adjacent to it are large masses of virus particles; no distinction can be made between RSV and RAV. The fibrous network (*left*) is cytoplasm that adhered to the surface when the cell was transformed by RSV. The micrograph was made by Peter K. Vogt of the University of Colorado School of Medicine.



AVIAN LEUKOSIS VIRUS is enlarged 50,000 diameters in this electron micrograph made by Robert A. Bonar of the Duke University Medical Center. The virus particles were fixed and dried and covered with a layer of collodion; the resulting replica of the particles was shadowed with chromium. The leukosis viruses are structurally indistinguishable from RSV.



ULTRASTRUCTURE of RSV and RAV thin sections is enlarged 250,000 diameters in this electron micrograph made by W. Bernhard of the Institut de Recherches sur le Cancer. Each particle has a central region, containing ribonucleic acid, and two membranes.

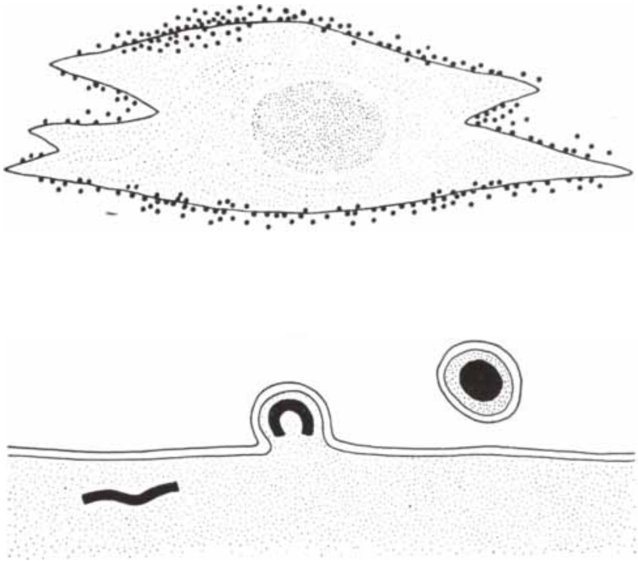
to offspring for many generations without producing any disease. There are marked differences also between RSV and another group of tumor viruses found in mammals: the small DNA-containing viruses that include the polyoma viruses of mice, the papilloma virus of rabbits and the SV-40 virus of monkeys, which was recently discovered growing in cultures of monkey kidney tissue along with the poliomyelitis virus. The polyoma virus, for instance, will produce tumors in mice only if it is inoculated at a very early age, and the tumors appear months later in some part of the body far from the site of inoculation.

The difference between RSV and the other tumor viruses shows up most clearly in tissue cultures. When normal animal cells are grown on a glass or plastic dish, they multiply only until they have covered the dish with a single-layered sheet of cells. This restriction is the result of a phenomenon called "contact inhibition": each cell is inhibited from moving over another cell when their membranes come into contact. Now, when cells planted on a dish are infected with RSV, they escape from contact inhibition. Instead of stopping their division when they come into contact with one another, they form little heaps of cells. These are actually microtumors; inoculated into a young chick, their cells will proliferate into a metastasizing sarcoma.

None of the other tumor viruses show this effect with the directness and rapidity of RSV. Inoculated into a tissue culture, they usually produce no visible change in the cells or else kill the cells. In the case of polyoma virus there is a very low probability of malignant transformation in tissue culture, but this usually occurs in several stages and over a long period of time.

RSV, in short, is unique in its power to transform cells: it brings about a malignant transformation in most if not all of the cells it infects, whereas the other viruses transform only a small proportion, if any. The tissue-culture transformation by RSV therefore gives us a convenient means for further exploration of the nature of the virus-cell interaction that leads to cancer.

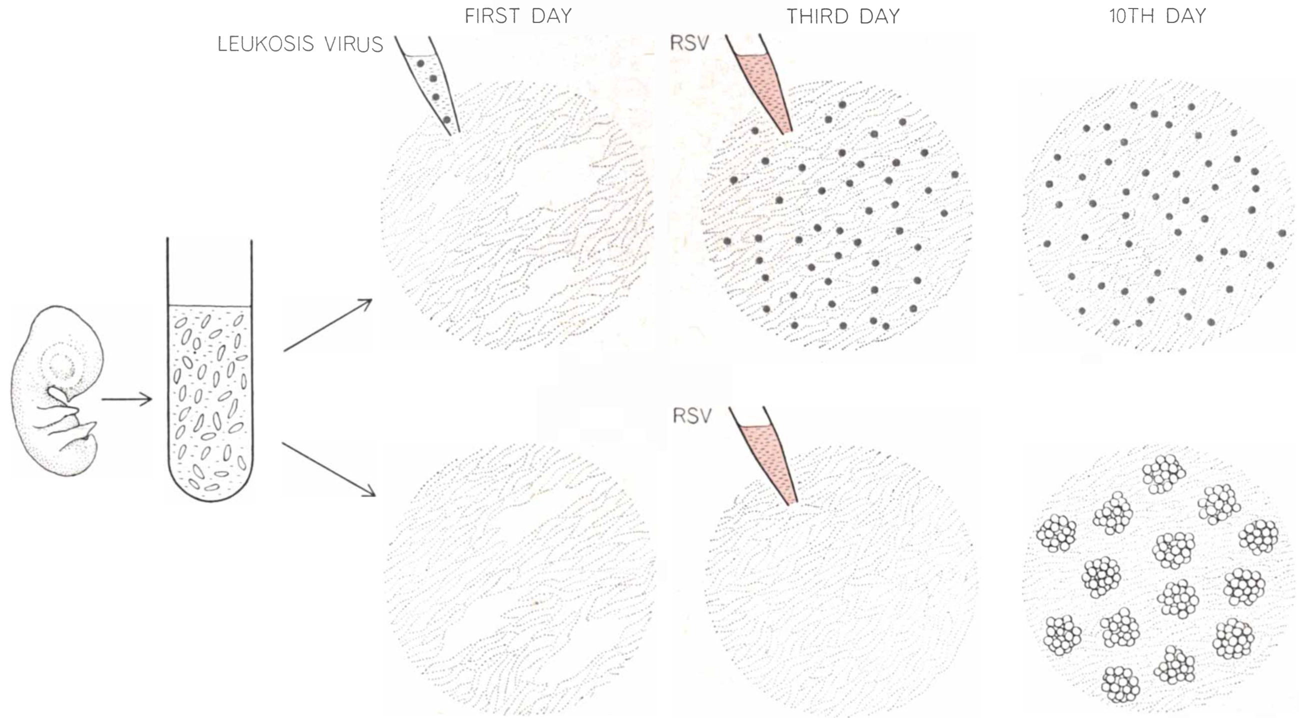
A standard procedure has been developed to provide a precise assay of the virus and the amount of its growth. The tissue culture is prepared by mincing 10-day-old chick embryos and treating the fragments with the enzyme trypsin to separate the cells from one another. The cells are then



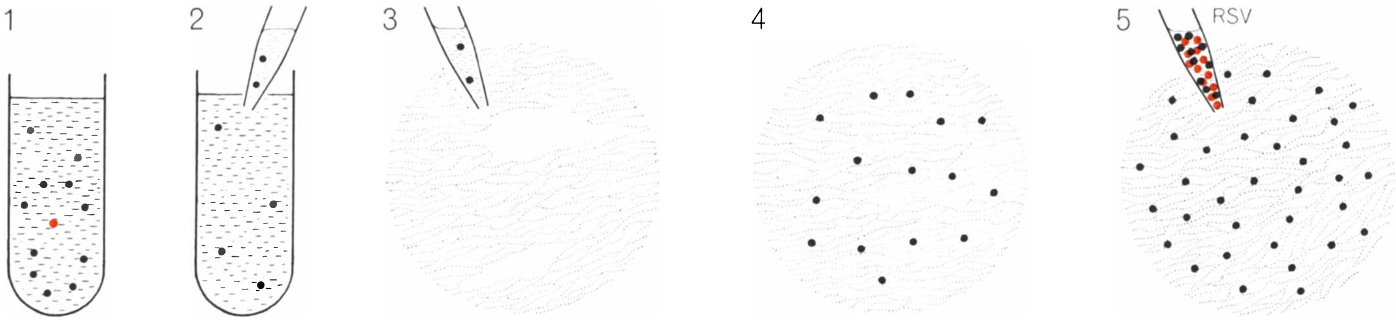
NEW VIRUS PARTICLES seem to mature only at the surface of an infected cell, as demonstrated in the photomicrograph (*left*), made by Vogt. The virus, stained by fluorescent antibody to RSV, shows as bright patches that outline and cover the cell 24 hours after infection. The enlargement is 800 diameters. The diagram shows how virus particles are concentrated at the edge of a cell (*top*), apparently because that is where they get their protein outer coats (*bottom*): the virus ribonucleic acid (*black*) gets its coat by a process of "budding," or evagination, of the cell's double membrane, and it incorporates some elements of the membrane.

placed on a dish to grow. While they are attaching themselves to the dish, a measured concentration of RSV is added to the growth medium. Within a few days the cells form foci of transformed cells that will grow into sarcomas when inoculated into chicks. It is easy to count the number of foci that develop in the tissue culture. This number, it turns out, is always proportional to the concentration of RSV originally placed in the culture; from this we can conclude that infection by a single virus particle is enough to initiate the transformation of a cell and its offspring into sarcoma cells.

In the Virus Laboratory of the University of California at Berkeley we began to study the growth of RSV in tissue cultures to see if it gave any clue to the carcinogenic potency of the virus.



INTERFERENCE TEST demonstrates the effect of prior infection with one of the avian leukosis viruses on subsequent attempts to infect cells with RSV. Two cultures are prepared from a single chick embryo (*left*). One is inoculated with leukosis virus (*first day*). Later RSV is added to both cultures. By the 10th day the RSV has infected the cells of the control culture (*bottom*), which have grown into foci, or heaps of transformed cells. But the leukosis virus has made the cells it infected immune to RSV (*top*).



HELPER VIRUS associated with RSV and able to block its effects was detected by this experiment. Assuming that RSV stock (*1*) contained more particles of an unknown associated virus (*black dots*) than of RSV itself (*color*), investigators diluted the stock greatly (*2*), inoculated it into a culture (*3*) and let the virus multiply (*4*). When they challenged the culture with standard RSV

We would add to a culture of, say, a million chick-embryo cells a high enough concentration of RSV to infect every cell. After about 12 hours new virus particles began to appear and the rate of virus production increased until the third day, when it reached a constant level that was maintained indefinitely. In cultures of most ordinary viruses, unless the supply of cells is replenished, the reproduction of the viruses eventually drops off sharply and then ceases altogether as the viruses kill off the cells and run out of hosts in which they can reproduce. In the case of RSV (and of the leukosis viruses as well) the virus does not kill the host cell; the offspring viruses are merely released from the cell surface without destroying the cell.

Because the leukosis viruses multiply in the same way as RSV, we could find no hint in the RSV growth curve of an explanation for the unusual carcinogenic property of the virus. We did, however, run into a frustrating obstacle. Occasionally one of our cultures would resist infection by RSV. In spite of heavy inoculations with the virus, the cells simply refused to transform or to reproduce the virus in any substantial amount. After several such annoying occurrences, which caused us to throw away the cultures as useless, we decided that the cause of the resistance had to be investigated. Ironically, as often happens in such cases, once we began to look deliberately for RSV-resistant chicken cells they failed to show up for a long time. Finally they did appear in some of our chick embryos, and we nursed these cultures along as we explored them for the resistance-inducing factor.

We eventually identified the factor as another virus that made the cells largely immune to RSV. This other virus occurs naturally and commonly in chickens, and it is frequently passed on from the hen to its eggs. We were able to identify it as a member in good standing of the leukosis group of viruses. When it appeared in a chick embryo used to prepare a tissue culture, the culture resisted RSV infection. Moreover, when we added the medium from these cells to the cells of an embryo that did not contain the natural virus, it infected them also and made them resistant to RSV. We named this virus RIF (for "resistance-inducing factor"). Like the other leukosis viruses, it produced no visible changes in the cells it infected.

The discovery of RIF soon led to a more surprising discovery. Some years earlier Alfred Prince of Yale University had noted that isolated cell colonies produced by chick-embryo cells heavily infected with RSV looked normal and produced only small amounts of RSV. Moreover, they resisted further infection ("superinfection") by RSV. It now occurred to us that RIF or some similar resistance-conferring virus might account for these puzzling facts. Repeating Prince's experiments, we found that the colonies of cells infected with RSV did indeed produce substantial amounts of a virus that induced resistance to superinfection by RSV.

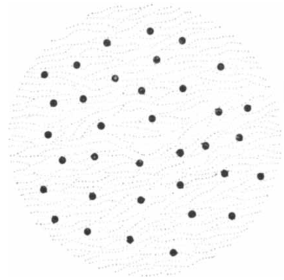
What was this virus and where did it come from? It could not be found in cells that had not been infected with RSV. The most plausible explanation, therefore, was that it invaded cells as a companion or passenger along with RSV. Detecting this virus, however, presented us with quite a problem. The only conceivable test for demonstrating its presence was to infect cells with it and then challenge the cells later with RSV to see if they resisted RSV infection. But how could such an experiment be performed if the unknown virus could not be inoculated separately but only in a mixture with RSV? Our one hope was that the resistance-conferring virus was present in larger amounts than RSV itself. In that case, if we diluted the virus stock to the point where RSV was no longer detectable, there might still be enough of the other virus left to infect all the cells and make the culture resistant to a new dose of RSV.

The experiment was tried and it worked. There *was* a resistance-inducing virus in the material, and its concentration was about 10 times higher than that of RSV. On first examination this virus appeared to be none other than RIF. It looked the same in the electron microscope, invaded the same part of the cell, behaved like a leukosis virus in producing diseases in chicks (as RIF does), was sensitive to the same inactivating agents and was neutralized by some of the antibodies that attacked RIF. There was, however, one slight but crucial difference that proved this virus was not identical with RIF: most of the antibodies that neutralized the virus did not neutralize RIF. This showed that the two viruses must differ in the protein of their coats.

The next step was to compare the new virus with RSV. It proved to be virtually an exact twin; indeed, in most characteristics it was suspiciously like RSV itself! Immunologically it was indistinguishable from RSV: it was neutralized by precisely the same antibodies. In all other properties it was remarkably similar to RSV, with one crucial exception: it did not transform normal cells into sarcoma cells, either in chickens or in tissue culture. Rather, it produced leukemia in chickens, as RIF does. Nonetheless, because it was so closely related to RSV in every other way, it was named the Rous-associated virus, or RAV.

Plainly the relation between RSV and RAV must be more than casual. We therefore set out to investigate it more intensively. The first goal was to try to isolate the two viruses from each other. By the dilution procedure we had used to show the existence of RAV we were able to obtain pure stocks of that virus.

6



stock (*5*), it failed to infect and transform the cells (*6*). The unknown virus was thereupon named RAV for Rous-associated virus.

Obtaining RSV free of contamination by RAV, however, proved to be a far more difficult matter.

All our early attempts to separate RSV failed. In 1961 Hidesaburo Hanafusa, who had come to our laboratory as a research fellow, made a new try. He began by diluting the virus stock so that it produced only two or three RSV foci in a tissue culture. At this dilution about 20 RAV particles (10 times the number of RSV particles) were expected to be present in the culture. The problem now was to prevent these and their offspring from invading the RSV foci. Hanafusa resorted to the stratagem of covering the culture with agar containing an antiserum that inactivated RAV. This opposed the spread of RAV in two ways: when the agar hardened, it restricted any movement of cells containing RAV, and the antiserum inactivated any RAV released from the cells.

After seven days, when the RSV-infected foci had developed fully, Hanafusa removed these foci, dispersed their cells with trypsin and planted them in a new culture of uninfected chicken cells. There the RSV-transformed cells proceeded to grow faster than the normal cells. This transfer was repeated twice a week, so that the transformed cells went through many transfers and multiplications.

At each transfer the foci and the culture were assayed for the presence of virus. In most cases they contained no RAV. But to our great surprise the foci contained no RSV either! In every way their transformed cells were typical Rous sarcoma cells: inoculated into chick embryos or young chicks, they produced typical sarcomas. Yet these tumors were completely devoid of the virus. The cells simply did not produce any RSV.

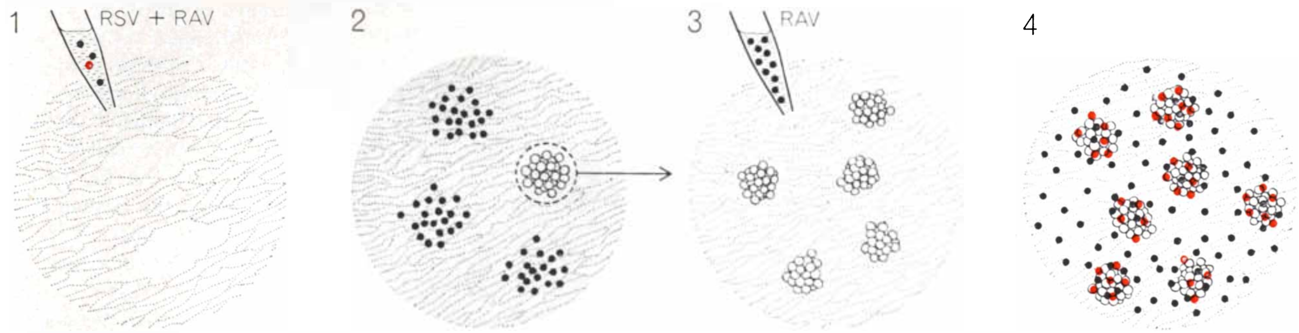
Occasionally a focus of sarcoma cells in the tissue culture did generate RSV, and in all these cases the cells also produced RAV. It therefore looked as if RAV was in some way essential for the production of RSV. To test this surmise RAV was deliberately added to sarcoma cells that were not producing virus (which we named NP—nonproducing—cells). The surmise was correct: invariably the addition of RAV caused NP cells to start making infectious RSV in the normal way. Further, we found that other viruses akin to RAV, such as RIF and other leukosis viruses, could elicit the production of RSV from NP cells.

What could this mean? RSV, without help from RAV, had readily succeeded in transforming normal cells into cancer cells. Alone, however, it was unable to reproduce itself in these cells. Apparently RSV was a defective virus, lacking the genetic information necessary for the production of complete offspring. It needed the help of a complementary virus (RAV or a kindred substitute) to provide a cell with full instructions for producing RSV.

What is missing in RSV? We have found evidence of one specific defect: RSV is unable to reproduce the protein required for its outer coat without the assistance of the helper virus. This could account for its inability to produce infectious progeny without help. Yet it retains a basic blueprint: its RNA. Its RNA genome (set of genes) is passed on from one generation of infected cells to the next. This is evident from the fact that even after more than 50 generations an NP cell descendant can produce RSV if the helper virus is added.

Our main concern, of course, is finding the factor (or factors) responsible for RSV's extraordinary power to transform cells. Although the viral genome it injects into a cell is incapable of synthesizing the full virus without help, it makes the cell fully malignant. There are two possible ways to account for this outcome. On the one hand, some property or function of the incomplete virus may of itself produce malignancy as a positive effect. In that case the fact that we are dealing with only part of the virus should help to narrow the search for the malignancy-triggering mechanism. On the other hand, RSV's malignant effect may lie in the *absence* of some property—a property that would regulate or control its behavior. For example, RSV may lack a control over the synthesis of materials that the virus uses for early functions before it is fully developed, with the result that RSV causes a runaway synthesis of these materials by the cell.

Whatever the control functions may be, this hypothesis assumes that they are provided by a helper virus. Such a theory would account for the paradoxical fact that the helper viruses are the very ones that can make cells resistant to RSV if they infect the cell before RSV does. As we have seen, RAV can prevent infection of a cell by RSV and it can also cause a cell that already con-



RSV NEEDS RAV to help it produce new infectious particles. This is shown by an experiment in which a culture is inoculated with RSV stock dilute enough to contain only a few "infectious units" of either virus (*1*). A resulting focus of Rous cells (*2*) is isolated from RAV by an overlay of agar (*gray*) containing antiserum to RAV and is allowed to grow. Then the cells of the focus are dispersed and transferred to a new culture, starting new foci (*3*). But no virus is produced by these "nonproducing" (NP) cells. When RAV is added to NP cells, it remedies a defect in the RSV, and the foci of transformed cells begin to produce RSV particles (*4*).

tains the RSV genome to start producing RSV. The explanation would be that in the first case RAV, if already present in a cell, inhibits the establishment of the RSV genome in the cell by virtue of its control functions; in the second case RAV, developing in the cell along with an already established RSV genome, helps the genome to mature to a full-fledged virus by supplying late functions responsible both for regulating the virus's growth and for supplying its outer coat. Indeed, it is conceivable that the very act of coating the virus is in itself a regulatory process that operates by withdrawing RSV genomes from a multiplying pool.

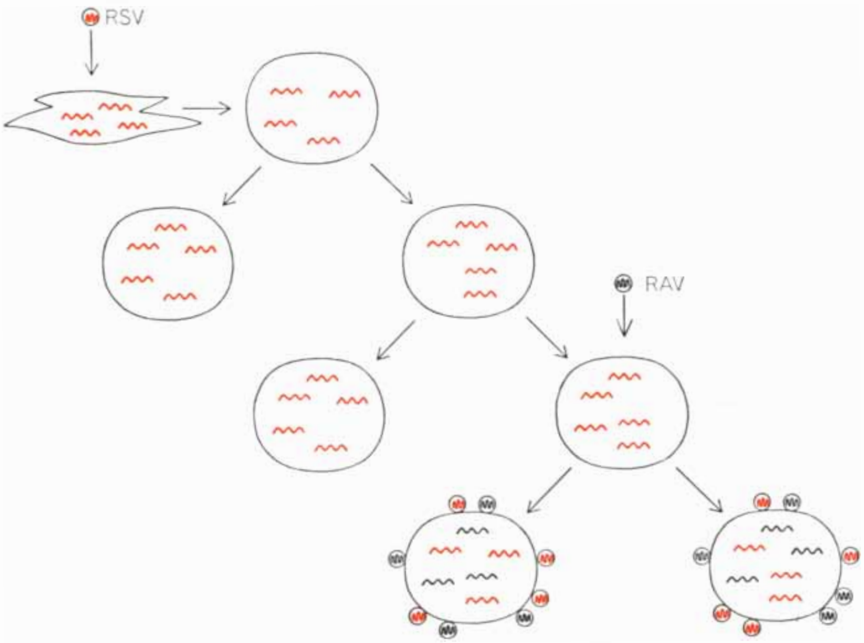
Quite recently new evidence has accumulated that the production of virus coat material does account for the ability of RAV to inhibit RSV infection. For one thing, there is the fact that the inhibition is nonreciprocal, that cells infected with RSV alone and producing no virus coat protein—the NP cells—are fully susceptible to infection by RAV. In the absence of coat-protein production, in other words, no interference is established.

Then too we have found that RSV can, under certain conditions, completely escape interference by RAV. Hanafusa discovered a second RAV with a completely different coat from the first one. When an RSV particle has a coat derived from this second RAV, it can freely invade a cell infected by the first RAV. Since the susceptibility of RSV to interference is apparently determined strictly by the coat it wears and not by its internal genome, we conclude that the interference reaction operates on some early step of infection—perhaps preventing penetration of the cell by RSV. Possibly specific sites on the cell membrane destined for the attachment of virus with a certain coat are blocked because they are occupied by material from a similar virus coat.

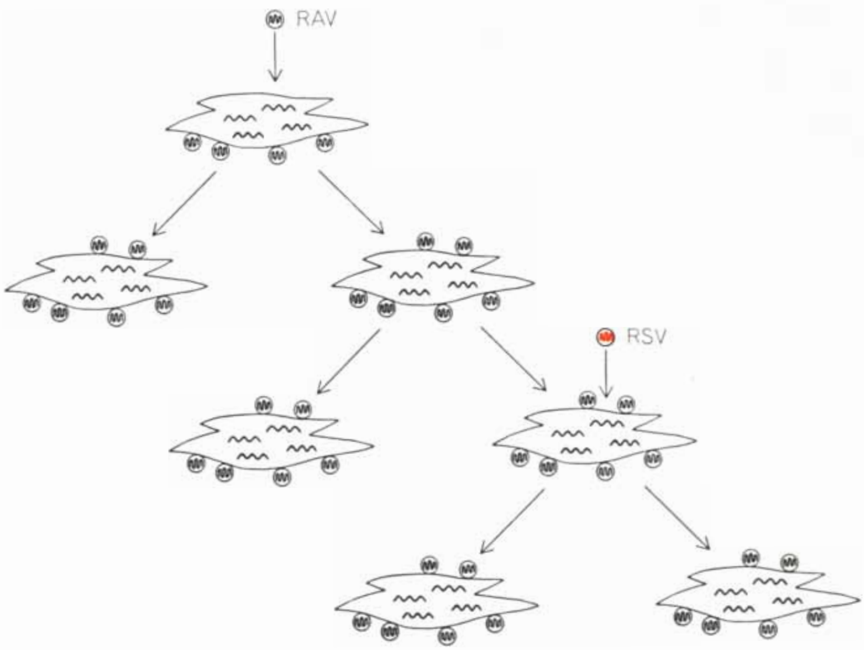
These new findings provide an explanation for the natural resistance some chickens display to infection with RSV—a resistance that has nothing to do with the presence of leukosis virus, being determined by a single gene on one of the chicken chromosomes. By merely changing the coat on RSV we can cause it to infect chicken cells that display this genetic resistance to the original RSV. This indicates that natural resistance too is due to the failure of the virus to gain entrance to the cell—not to some intrinsic failure of the virus genome to multiply after it is inside the cell.

Certain strains of RSV, it is now known, can cause cancer in mammals, including primates. Are these strains effective in such foreign hosts because they have a coat that somehow enables them to invade foreign cells? Such questions as this can also be investigated now by altering the coat of RSV without changing its genome.

To sum up, we have not found a clear-cut explanation for RSV's unusual ability to cause cancer, but we suspect that it is associated with the defectiveness of the virus. This defectiveness gives us a versatile tool for shaping the properties of RSV, which should be extremely valuable in further investigation of the mechanism of carcinogenesis.



SOLITARY INFECTION with RSV is conceived of as introducing RSV's ribonucleic acid, and thus its genetic information, into a normal cell. The cell is transformed and the RSV genome is replicated, but no RSV particles are produced. If RAV is added, RSV particles as well as RAV are produced; apparently the RAV helps RSV to make a protein coat.



INFECTION WITH RAV ALONE does not transform the cell, but the cell and its daughters produce RAV particles. If RSV is then added, it cannot become established in the cell. It may be that prior infection with RAV affects the cell membrane and so blocks the RSV.

A **Kodak** advertisement which recognizes that all are laymen, except in some small respect or other

For textile engineering with a modacrylic fiber that positively will shrink after it's piece-dyed or package-dyed

Though Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Co.) has to scramble mightily to keep up with the demand (at last, after all these years) for VEREL Modacrylic Fiber, it will supply development quantities of Type III VEREL Fiber that dyes and dries properly at relatively low temperatures, and therefore still provides 30 percent shrinkage afterwards.

For shoppers and husbands who wonder what's so good about that

Only a tiny minority of male readers can hope to grasp the relationship between women and color. The rest of them can just accept as fact that some colors are right and others are very, very wrong. The spectrophotometric difference between right and wrong can be pitifully slight. Fortunes are lost every business day on wrong colors. It takes too much out of a man to have to pick right colors way back at the stage before the fiber is extruded. Dyeing at the spun yarn stage (package-dyeing) lessens the commitment and tension while awaiting the ladies' verdict. The c. and t. are further reduced by postponing the dyeing to the woven or knitted stage (piece-dyeing). Package- and piece-dyeing have heretofore required temperatures high enough to shrink shrinkable fibers.

What you hadn't appreciated is that some man-made fibers are built to undergo a large, once-only shrinkage by a flash of heat. Various patented processes for applying the heat to clever combinations of shrinkable and non-shrinkable fibers lead to permanently fluffy, easy-care sweaters and soft, warm coats that today's honest, animal-loving girls can fondly stroke and proudly and defiantly call "fake." We now make it possible to dye coolly at convenience without using up all the precious shrinkage.

For background on how many milliroentgens film can distinguish from natural background

A new free pamphlet on personal monitoring films is available from Eastman Kodak Company, Special Sensitized Products Division, Rochester, N. Y. 14650. It contains a bibliography.

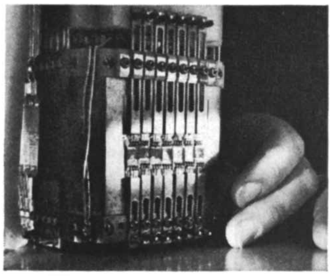
For background to the need for background on monitoring against background

Health physicists make a profession out of keeping the human race from being the worse off for having discovered radioactivity and x-rays. Apart from the healing arts, far more places make worthy use of radiation than engage health physicists. This results in wide reliance on agreed "safe" levels of personal exposure, as measured by commercial film-badge firms. The arrangement permits the customer to treat the whole thing as routine. Is there any obligation to reopen the subject merely because a newer KODAK film happens to make it just as easy to detect a much smaller increment over natural background than was possible when the conveniently safe levels were chosen?

For new highs in detectivity at the 4.3μ CO_2 band

Off-the-shelf KODAK EKTRON Detectors, Type E (which stands for our high-vacuum-resistant evaporated PbSe), now hit 1 to 2 x 10^{10} cm/watt-sec$^{1/2}$ in D^* at 1500 cycles, whether at –196°C, –78°C, or as warm as –45°C. This degree of temperature independence is news. Send for pamphlet on KODAK EKTRON Detectors to Eastman Kodak Company, Apparatus and Optical Division, Rochester, N. Y. 14650. Those willing to pay a bit more than the prices quoted therein can have D^*'s at 1500 cycles *higher* than 2 x 10^{10}. They might even reach 10^{11} if they will let us make them a sharp-cutting filter.

For an oversimplified explanation of "detectivity" and of what we're testing here:



By appropriate witchcraft entailing more than deposition of lead selenide on small rectangles of substrate, each rectangle becomes an EKTRON Detector if it passes a battery of tests. These measure how the PbSe changes electrical resistance in response to a change in radiant energy falling on it.

Of course, one doesn't just turn on the infrared the way one turns on the porch light. One thinks frequencies. One interrupts the infrared at a certain frequency and looks for this frequency of voltage fluctuation across the detector. Except that it generally has to be done up in the sky in some space vehicle, where one can't turn up the infrared source to make the signal plainer. One can't always be sure when the amplifier happens to hum at the right frequency that the infrared is doing it. There is always a certain amount of random electronic activity in the detector. The smaller the detector, the less this random activity gets averaged out and therefore the noisier it appears. On the other hand, the more power per unit area in the infrared signal, the better the signal stands out against the noise. The sharper the tuning to the frequency, the less noise will happen by chance to fall within the narrow frequency range.

This plodding line of thought leads to a definition of "detectivity" as "the signal-to-noise ratio at a given radiation wavelength and chopping frequency with an amplifier bandwidth of one cycle/sec for a photodetector of one square centimeter sensitive area when irradiated by one watt of flux." The brotherhood calls it D^*. Among the various photoconductive substances they have to juggle in their minds, lead selenide finds favor as the best compromise between high detectivity and relative independence of the interrupting frequency to rather high levels.

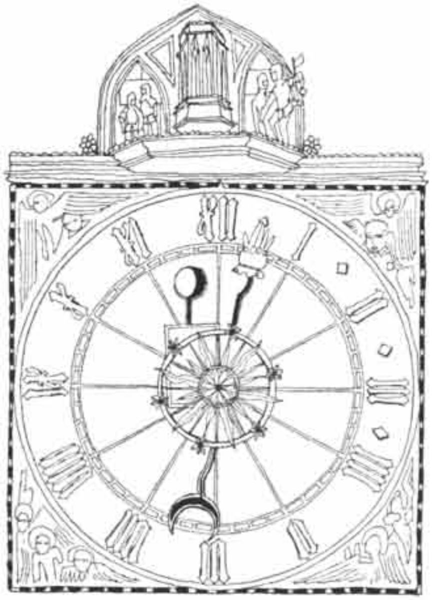
For fundamental studies of energy transfer in the living cell

To make the acetylpyridine analogs of DPN and TPN by enzymatic exchange reaction in pig-brain preparation, it is smart to order the 3-acetylpyridine from an EASTMAN Organic Chemicals distributor or from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). Though we insist on calling it *Methyl 3-Pyridyl Ketone* (EASTMAN 9172), ours comes fractionally distilled in vacuum to save time for the molecular biologist.

For idle curiosity about the self-image of molecular biologists

Despite days when a molecular biologist might prefer to keep busy setting up an attractive-looking vacuum pump to purify a reagent than to sit and think, it is best not to dwell on this.

A properly adjusted molecular biologist on a good day will aim his insights, for example, on the effects of replacing an $-NH_2$ group with a $-CH_3$ in diphosphopyridine nucleotide (DPN). Perhaps a glimmer of new light can be shed on how DPN or that other respiratory coenzyme, triphosphopyridine nucleotide (TPN), passes along electrons from one molecule to another at one of the long train of steps whereby a slice of apple pie and a chunk of porterhouse and some fresh air keep us alive to work another day.



SCIENCE AND

Cutback and Conversion

The cutback in the manufacture of fissionable materials by both the U.S. and the U.S.S.R., simultaneously announced in April by President Johnson and Premier Khrushchev, is a step toward the limitation of armaments but also provides an example of the problems that will attend the conversion of military production to civilian production. The U.S. cutback of 15 per cent in the production of enriched uranium, added to the cut of 25 per cent announced by the President in January, will bring the consumption of electricity by the Atomic Energy Commission's gaseous-diffusion plants down to 26.6 million megawatt-hours from a peak in 1957 of 53.7 million megawatt-hours. Although that will still represent about 3 per cent of the nation's electric-power consumption, the plants in 1957 accounted for 10 per cent. A.E.C. spending for this power will have dropped from $210.5 million to $107 million. Presumably the economic effects of the drop will be felt not only in the gaseous-diffusion plants and the organizations producing the electricity but also by the coal and oil industries, which supply fuel for the generation of electricity.

The cutback again focuses attention on efforts to predict and solve the problems of converting industry from armament manufacture. The Senate Committee on Labor and Public Welfare recently published a collection of papers on the subject under the title *Convertibility of Space and Defense Resources to Civilian Needs: A Search for New Employment Potentials.* John E. Ullmann and others at Hofstra University will publish during the summer a study of how much of the $8 billion spent annually by the Department of Defense in the electronics industry could be taken up by other customers. They conclude that no more than half of it could be, and that the gap could only be filled by the transfer of workers and resources to other occupations, such as the manufacture of machinery for underdeveloped nations, and by a greater investment in the life sciences, teaching and urban renewal.

Mental Health and Civil Rights

The State of New York has enacted pioneering legislation on the admission and retention of patients by psychiatric institutions, both public and private. The new law, which will take effect next year, is aimed principally at protecting the civil rights of the mentally ill. To that end it requires periodic court review of a patient's status. It also establishes a Mental Health Information Service to advise patients of their rights and to gather information for the courts.

The law grew out of a study entitled *Mental Illness and Due Process,* published two years ago by the Cornell Law School in cooperation with a committee of the Association of the Bar of the City of New York. The study found that under the present system of admission to psychiatric institutions by court order, few patients actually ask for the hearing to which they are entitled. Moreover, there is no automatic review of the patient's status, and once he is in a mental hospital he can be "forgotten." The new law makes the admission of a patient to a mental institution a medical rather than a judicial function but provides that the first court review of his status must be held within 60 days.

The Hunting of the Quark

The first search for a hypothetical subatomic particle called the "quark" has been conducted at the Brookhaven National Laboratory and the results suggest that it does not exist. This tentatively refutes an attractive speculation by Murray Gell-Mann of the California Institute of Technology, who proposed that the most elementary of elementary particles might be a triad of related particles—quarks. Two of the particles would have an electric charge a third as large as the electron's and one a charge two-thirds as large. The Brookhaven results indicate that no particles exist with a charge of one-third and a mass comparable to that of the other elementary particles. It is still possible, however, that quarks exist but have very large masses.

Gell-Mann postulated the existence of quarks as an extension of the successful theory, called SU(3) symmetry or "the eightfold way," developed independently by him and Yuval Ne'eman, an Israeli physicist. On the basis of this theory the particles that take part in strong, or nuclear, interactions can be classified into supermultiplets, or superfamilies (see "Strongly Interacting Particles," by Geoffrey F. Chew, Murray Gell-Mann and Arthur H. Rosenfeld; SCIENTIFIC AMERICAN, February). The eightfold way was recently successful in predicting the existence of the omega-minus particle, which was found at Brookhaven in February.

One set of particles that would satisfy SU(3) symmetry, Gell-Mann calculated, was a set of three particles, each with an electric charge less than that of the electron, which had previously been assumed to carry the basic unit of charge. He called these hypothetical particles quarks—a name he took from a line (significantly on page 383) in James Joyce's *Finnegans Wake:* "Three quarks for Muster Mark."

Robert K. Adair of Yale University and Lawrence B. Leipuner, William T. Chu and Richard C. Larsen of Brookhaven undertook to find some quarks. They bombarded a beryllium target with protons accelerated to 28 billion electron volts in Brookhaven's alternating-gradient synchrotron and analyzed the resulting beam of particles with scintillation counters. A quark with a charge of one-third should emit one-ninth as much light as particles with a charge of one. The investigators could find no such particles, although they calculated that—if quarks exist—at least 100 or so should have been produced in the course of their experiment. Their conclusion that there is no such thing as a quark could be wrong, they point out, if quarks have a mass two or three times greater than that of a proton. Particles of such a mass could only be created by a machine that accelerates particles to higher energies than the Brookhaven synchrotron does.

DNA Made to Specification

Substantial progress has been reported in the effort to synthesize precisely ordered chains of deoxyribonucleic acid (DNA), the molecule that carries the genetic information of living organisms. As found in the living cell, the DNA molecule contains thousands or tens of thousands of the four different subunits called bases: adenine (A), thymine (T), guanine (G) and cytosine (C). The sequence of these bases provides the genetic code the cell uses in manufacturing proteins.

It has proved difficult to synthesize DNA chains by purely chemical methods and particularly difficult to link the bases in a known sequence. At the University of Wisconsin, H. Gobind Khorana and his colleagues have been working on this problem for some 10 years. At the April meeting of the Federation of American Societies for Experimental Biology one of Khorana's associates, T. Mathai Jacob, described their progress to date.

In one method short DNA chains are built up by directly coupling one base to another. (The bases are actually in the form of nucleotides, structures in which a base has been linked to a sugar molecule and a phosphate group.) Using this stepwise method, the Wisconsin workers have synthesized DNA molecules nine to 12 bases long. The practical limit for this method appears to be about 20 bases. In an alternative method preformed base doublets (for example TC, TG and AC) have been coupled into sequences containing six doublets. The extension of this method to triplets is under study.

To create still longer DNA molecules of known sequence it has been found necessary to use a biological catalyst: the enzyme DNA polymerase. This enzyme was originally discovered by Arthur Kornberg of the Stanford University School of Medicine, who has been collaborating with the Wisconsin group. With the help of DNA polymerase a synthetic chain containing six doublets was used to make a chain of doublets thousands of pairs long. In this case the original doublet was AT, whereas the much longer molecule contained strings of the complementary doublet TA. Efforts to use these synthetic DNA chains in biologically active systems to produce synthetic proteins are still in an early stage but appear promising.

Fertility and Economic Growth

The way to curb India's rate of population increase is to concentrate on raising the economic level of the country's poorest villagers, argues the Indian demographer P. B. Gupta. In a series of papers published by the Indian Statistical Institute, Gupta points out that the decrease in mortality rates in India and other developing countries today has been brought about by public health measures, not by economic development, and it is therefore unlikely to be followed quickly—as such a decrease was in many Western countries some years ago—by a reduction in the birthrate. Gupta finds, moreover, that India's rural population, which accounts for 83 per cent of the total population, is not practicing birth control and is not likely to do so until there are changes in education and social structure that require major economic growth.

Gupta studied the relation between the marital fertility rate and the level of living of Indian villagers as revealed in national statistics for 1953 and 1954. He found that fertility is low among people living at a bare subsistence level and tends to rise with some improvement in the level of living. At what he calls a "critical level" of living, fertility reaches a maximum value, and only thereafter does it begin to drop with increasing economic status; the curve of fertility plotted against level of living rises to a peak and then falls. Gupta adapted this curve, a cross section of the rural fertility situation 10 years ago, to construct a curve predicting the relation of fertility to economic growth over the years.

A uniform increase of even as much as 20 per cent in the standard of living of all income groups, without a relative improvement in the condition of the lowest-income group, would cut the birthrate hardly at all, he concluded. He suggests, therefore, that special efforts should be made to improve the status of the poorest villagers in order to transfer as many people as possible from the "rising" portion of the fertility curve to the "falling" portion; that is, "to cause the people at the lower levels of living to cross the critical level." Such a transfer, he says, would not require a very great overall economic advance. Yet it should "automatically" reverse the fertility trend in the poorest segment of the population, paving the way for the greater reduction in fertility that should come with significant economic development.

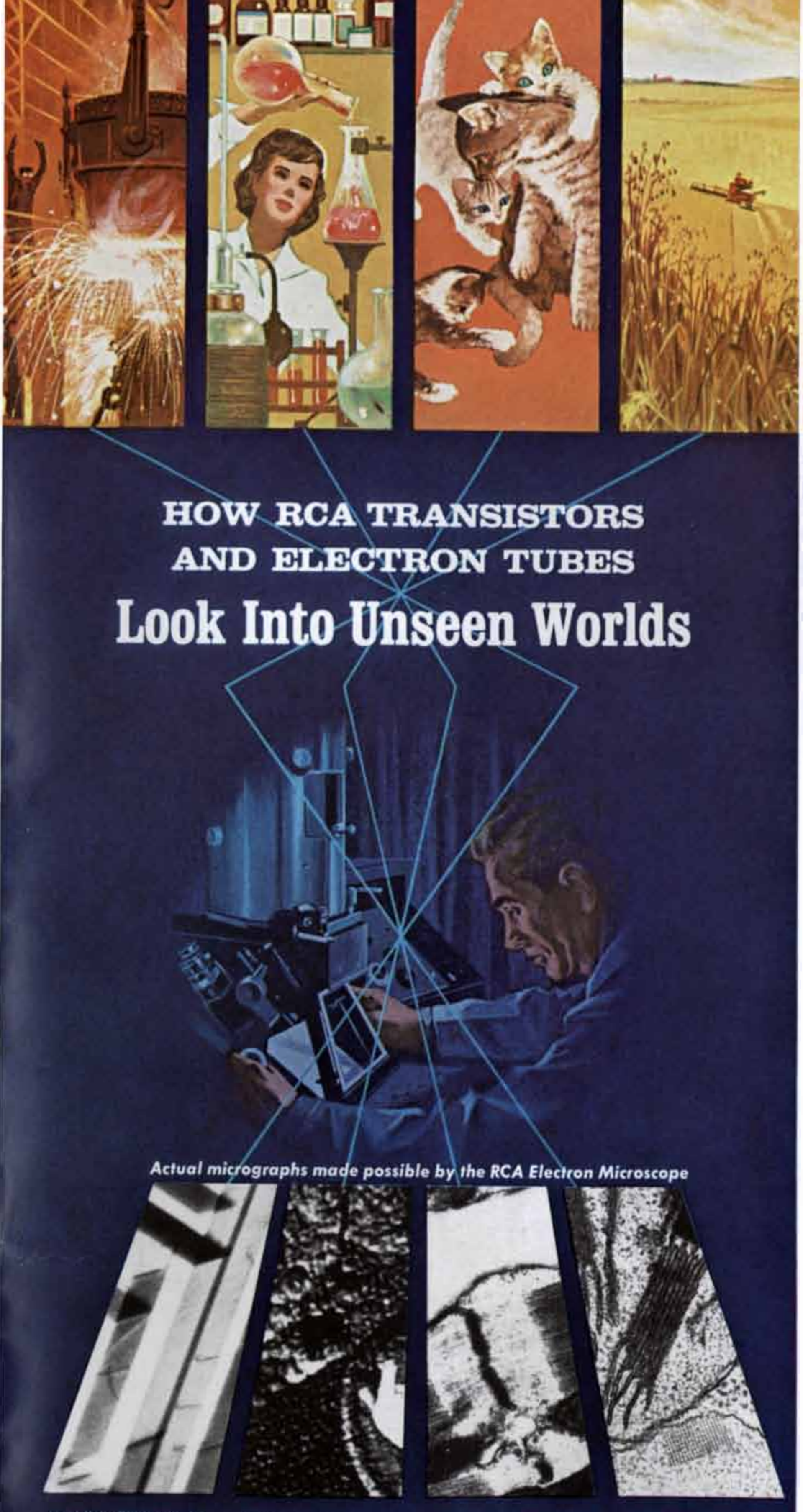
Superconducting Semiconductors

The phenomenon of superconductivity—the complete disappearance of electrical resistance at temperatures near absolute zero—has been observed in semiconductors, a class of materials heretofore thought to contain too few free electrons to be superconducting. The observations were made by experimenters at the Naval Research Laboratory, the Westinghouse Research Laboratories and the National Bureau of Standards. The findings confirm a prediction made more than a year ago by Marvin L. Cohen, then a graduate student at the University of Chicago; Cohen now works at the Bell Telephone Laboratories.

The electrical conductivity of a substance depends on the number of free electrons in the outermost shells of its atoms; metals have many free electrons and are good conductors, whereas insulators have tightly bound electrons and are poor conductors. The concentration of free electrons and hence the electrical conductivity of a semiconductor is somewhere between that of a metal and that of an insulator. According to one theory, only metals and metallic compounds with three, five or seven electrons in the outermost shells of their atoms make good superconductors. Cohen's suggestion that semiconductors might also be good superconductors was based on a model of superconductivity proposed in 1957 by John Bardeen, Leon N. Cooper and J. Robert Schreiffer of the University of Illinois.

The first confirmation of Cohen's prediction came early this year with the discovery of superconductivity in the semiconducting material germanium telluride; the discoverers, Robert A. Hein and John W. Gibson of the Naval Research Laboratory and Robert Mazelsky, Robert C. Miller and John K. Hulm of the Westinghouse Research Laboratories, report their work in *Physical Review Letters.* In a more recent issue of *Physical Review Letters* James F. Schooley and William R. Hosler of the National Bureau of Standards announced the observation of superconductivity in crystals of strontium titanate, also a semiconductor.

Since more is known about the properties of semiconductors than about those of metals, the new findings can be expected to have a considerable bearing on future studies of superconductivity.

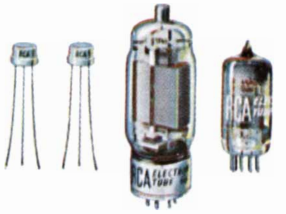


Lamellar Structure in an Austenitic Fe-30 Ni-6 Alloy, magnified 32,000 times. U.S. Steel Corporation Research Center.

Meningopneumonitis virus, magnified 126,000 times. University of North Carolina.

Cat papillary heart muscle, magnified 28,000 times. College of Physicians and Surgeons of Columbia University.

Chloroplasts, mitochondria, and crystal-containing body in a mesophyll cell of an oat leaf, magnified 67,000 times. Harvard University.



RCA transistors and electron tubes used in the high-power electron microscope.

Deep in the infinitesimal world of matter—solids, liquids, gases—there are structures as complex as those in outer space.

Now, new views of the mysterious world of solids—of living and non-living matter—are being revealed through the super-magnifying capability of the electron microscope.

In this remarkable device, RCA transistors and electron tubes play the major role. They make it possible to use electron beams instead of light rays, and magnetic fields in place of glass lens optics—*to produce the highest magnifications ever achieved.*

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Exploring the micro-structures of matter is another service performed by RCA transistors and electron tubes to help man acquire more knowledge about himself and the natural forces around him.

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Such studies may eventually make it possible to predict whether or not any substance will be a superconductor and to estimate the temperature at which the substance becomes superconducting.

Discriminating Cats

Past investigations by animal psychologists have suggested that cats are color-blind, even though they are physiologically equipped for color discrimination. Now two experimenters at the University of Pennsylvania School of Medicine report an ingenious test that demonstrates the cat's ability to distinguish colors.

Jeri A. Sechzer and John Lott Brown offered two pairs of experimental animals food rewards for correctly selecting either a red or a green exit from a test tunnel. The exit doors were actually colorless translucent plastic, illuminated from the rear by beams of light projected through color filters and also through a variety of neutral-density filters. The latter were changed in random order to produce five different levels of brightness for each color, or 25 color-brightness combinations in all. Two sequences of these combinations, for a total of 50 trials, made up each cat's daily exposure to learning.

The experimenters had provided for the variations in brightness in order to make intensity of illumination irrelevant as a test cue. They discovered, however, that the cats at first disregarded color and consistently selected a comparatively light or dark exit door for a number of trials or even for a whole day's session. In these first days a cat that selected one brightness variation, either light or dark, would choose the opposite in the next series of trials. As the cats' responses to color cues gradually improved, their reactions to levels of brightness diminished. Nevertheless, 27 days of training—a total of 1,350 trials—were required before the first cat achieved a three-day sequence of 90 per cent correct color choices.

After all four cats had attained the 90 per cent level, the experimenters reduced color saturation by projecting alternate flashes of white and colored light, at the rate of 80 flashes per second, on the exit doors. When the amount of colored light in the mix was cut to half the original value, the cats could still perform with 90 per cent correctness, although additional training was required. When the colored light was reduced to 10 per cent of the total illumination, however, the animals could no longer discriminate, even after 2,000 trials. The experimenters, who describe their work in *Science*, believe this breakdown in performance as the color cue diminished confirms that the cats were indeed responding to color in their correct choice of exit doors and not to some unrecognized factor.

Chromosomes and Miscarriage

Abnormalities in the cell's complement of chromosomes are apparently responsible for a large proportion of early spontaneous abortions, or miscarriages, A. E. Szulman of the Harvard Medical School has reported. A normal human body cell contains 46 chromosomes, 23 of which are descended from each parent. Occasionally an accident occurs during the formation of an egg or sperm from a precursor germ cell, as the result of which the fertilized egg receives an abnormal number of chromosomes. Such chromosomal accidents have recently been associated with a variety of congenital abnormalities in man.

Chromosomes can be identified and counted only at metaphase, the stage of cell division at which they are most clearly visible, and they are generally studied in white blood cells. Szulman, who described his work at the April meeting of the Federation of American Societies for Experimental Biology, had to use bits of embryonal membrane recovered from embryos that had died within the first 12 weeks of pregnancy. He cultured the material until enough cells were dividing, then arrested their division at metaphase and dispersed the chromosomes. In 15 out of 25 cases his chromosome counts showed gross defects in the chromosomal apparatus of the aborted embryo. Some of the anomalies were among those seen in live infants and adults. These included trisomy, or the presence of an extra chromosome, including one associated with mongolism, and the lack of one of the two chromosomes that determine sex. Other chromosomal conditions, however, have not been observed in live mammals and are apparently lethal. One such anomaly, which Szulman found in four cases, was triploidy, or the presence of three full sets of chromosomes (69) instead of two. The abnormal chromosome counts are apparently not an artifact of the procedure of tissue culture, Szulman said, because when he cultured tissue from healthy embryos that had been removed in therapeutic abortions, the cells invariably had the correct complement of 46 chromosomes.

Chemical Stimulation of the Brain

When certain substances are injected into localized regions in the brain of an experimental animal, they specifically release drives such as hunger and thirst

by Alan E. Fisher

It was once customary to think of the brain as an intricate switchboard and decoding system, operating by essentially electrical means. As neurophysiologists learned more about the central nervous system, however, they came to recognize that chemical mediators play an important role in brain activity. To examine this role more closely it is now possible with new techniques to apply chemical substances directly to local areas deep within the brain.

As usually happens in pioneering a new technique, there have been disappointments, puzzles, surprises and, most fruitful of all, findings that seem to contradict previous understanding. But the operation of the brain is so complex that it is only by piecing together knowledge gained in many different ways, and by reconciling conflicting data, that we can hope to penetrate its secrets.

The tracing of specific behavior to stimulation of particular areas in the brain was pioneered by Walter Rudolph Hess of the University of Zurich. In a series of illuminating experiments for which he received the Nobel prize in physiology and medicine in 1949, Hess found that by gentle electrical stimulation of certain areas in the hypothalamus of cats he could evoke fear, anger and reactions connected with digestion and other body functions. These discoveries started a train of highly fruitful experiments in electrical stimulation by many investigators, culminating in the discovery of nerve circuits that appear to control pleasure and punishment [see "Pleasure Centers in the Brain," by James Olds; Scientific American, October, 1956].

Nevertheless, electrical stimulation of the brain has definite limitations. The effects are often blurred or mixed, and the method has generally failed to elicit some of the basic forms of behavior, such as those prompted by the maternal and sexual drives. Two factors may account for these limitations. Electrical stimulation is not selective as far as nerve cells are concerned; it will fire any nerve cell indiscriminately. And the indications are that the neurons responsible for a particular form of behavior are not usually clumped in one place but are dispersed widely in the brain, overlapping with other functional fields or systems of neurons.

These facts prompted some neurophysiologists to search for a more specific type of stimulator: something that would selectively stimulate only the system of cells controlling a particular behavior. With the growing appreciation of the role of chemistry in brain function it seemed that carefully chosen chemical substances might exhibit the discrimination desired.

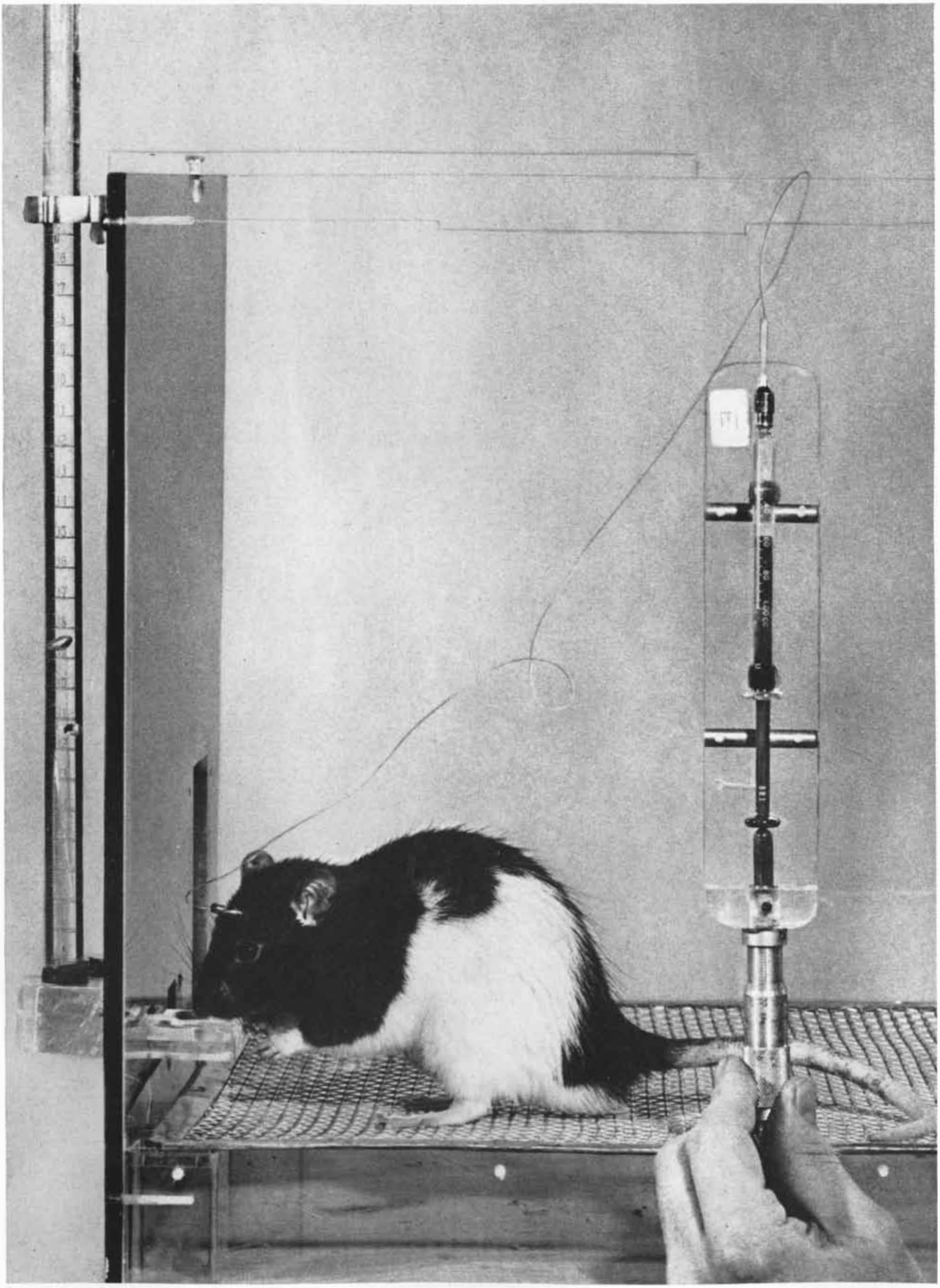
It was known, for example, that chemical messengers, or hormones, are deeply involved in the brain's activities and that other chemical substances control the basic process of transmission of nerve impulses. Acetylcholine, noradrenalin and probably other substances are released at the ends of the nerve cells and carry impulses across the synaptic gap from one neuron to the next. Other chemicals mimic or interfere with the action of these transmitters. Chemical "modulators" have also been found that alter the threshold for the cell's firing of an impulse.

The Case of the Mixed-up Rat

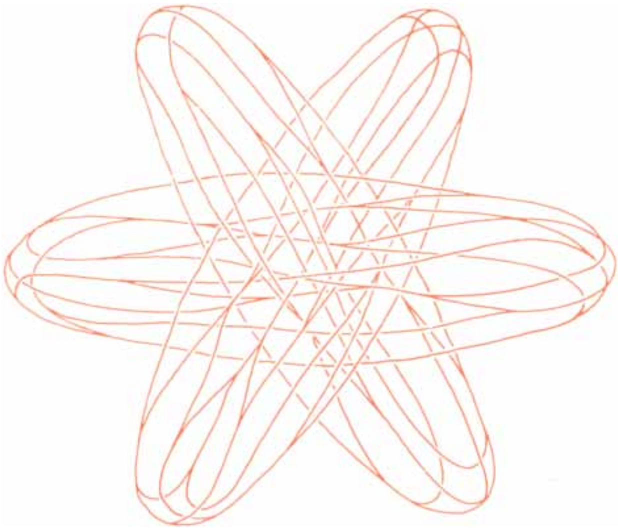
Was it possible that neurons or chains of neurons might be sensitive to specific substances to which they would respond selectively? Experimenters began to test this intriguing idea. The first results were not encouraging, but in 1953 Bengt Andersson in Sweden reported a significant success. Experimenting with goats, he injected a 5 per cent solution of salt into a precisely defined area in the middle of the hypothalamus, the governing center of the autonomic nervous system. The goats immediately began to drink large quantities of water. Evidently they had been induced to drink by some effect on the brain cells caused by the rise in osmotic pressure produced by the salt.

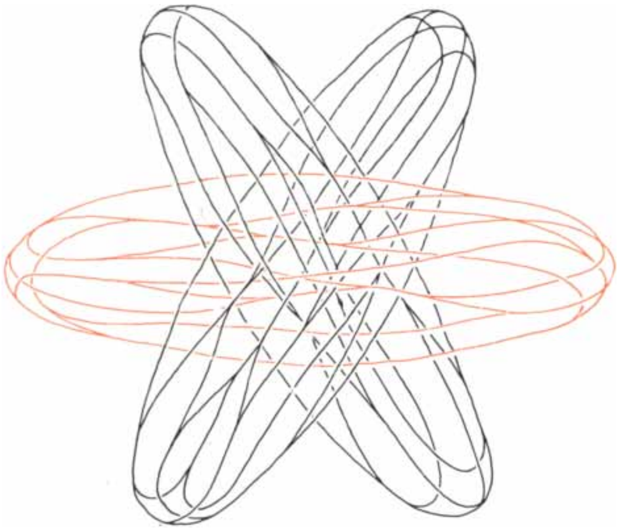
Late in 1954, while working in D. O. Hebb's laboratory at McGill University, I began to experiment with substances I hoped would produce direct chemical stimulation of specific brain cells. I started with the male sex hormone, testosterone, and injected it into specific sites in the hypothalamus of male rats. These particular regions seemed the most likely ones for action by the hormone because it was already known that they are involved in the primary drives of rats, such as courtship, care of the young, eating and drinking. I had expected, of course, that injection of the male sex hormone into the rat's brain would trigger male sex behavior.

By one of those ironic twists that are so typical of scientific research, the behavioral change produced in my first "successful" subject was a completely unexpected one. Within seconds after the male hormone was injected into his brain he began to show signs of extreme restlessness. I then put in his cage a female rat that was not in the sexually receptive state. According to the script I had in mind, the brain injection of male hormone should have driven the male to make sexual advances, although normally he would not do so with a nonreceptive female. The rat, however, followed a script of his own. He grasped the female by the tail with his teeth



WATER-SATED RAT returns to trough to drink more within a few minutes after the brain circuit that controls the animal's thirst drive has been triggered by injection of acetylcholine. A single stimulus can make the rat drink a day's normal ration in an hour.





SELECTIVE STIMULATION is a primary advantage in the use of chemicals. When an electrical stimulus is applied (*left*) to a group of neurons belonging to three separate circuits, all circuits operate (*color*) and no integrated response occurs. When a chemical stimulus is applied (*right*), only one circuit, for which the chemical is specific, operates. The other two remain inactive.

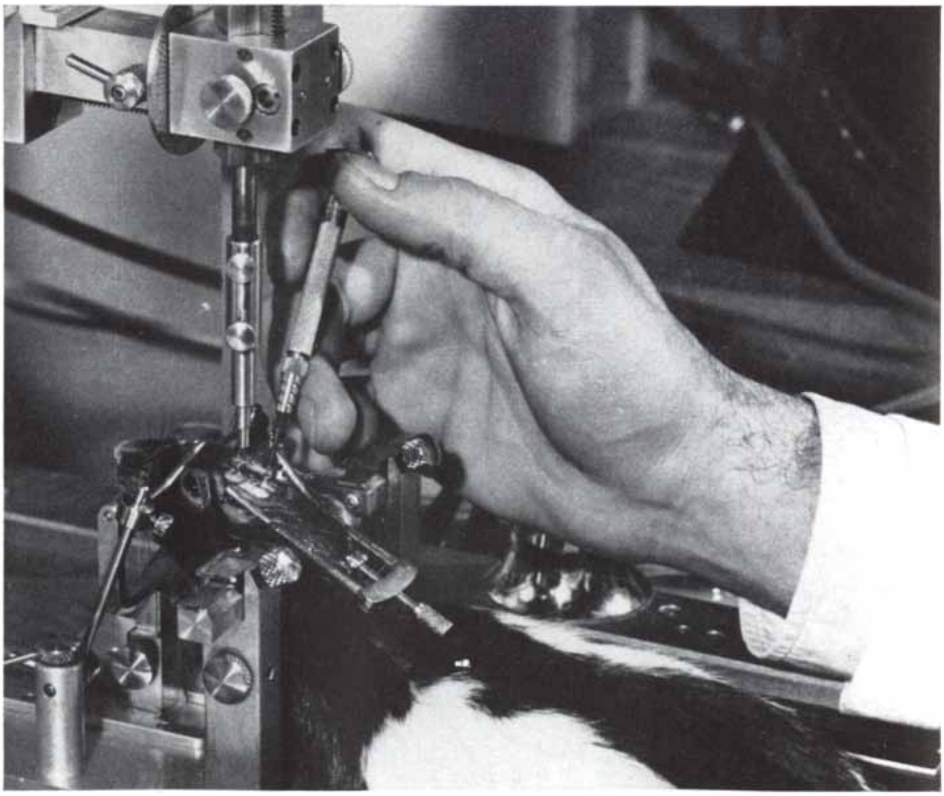
and dragged her across the cage to a corner. She scurried away as soon as he let go, whereupon he dragged her back again. After several such experiences the male picked her up by the loose skin on her back, carried her to the corner and dropped her there.

I was utterly perplexed and so, no doubt, was the female rat. I finally guessed that the male was carrying on a bizarre form of maternal behavior. To test this surmise I deposited some newborn rat pups and strips of paper in the middle of the cage. The male promptly used the paper to build a nest in a corner and then carried the pups to the nest. I picked up the paper and pups and scattered them around the cage; the male responded by rebuilding the nest and retrieving the young.

After about 30 minutes the rat stopped behaving like a new mother; apparently the effect of the injected hormone had worn off. Given a new injection, he immediately returned to his adopted family. With successive lapses and reinjections, his behavior became disorganized; he engaged in all the same maternal activities, but in a haphazard, meaningless order. After an overnight rest, however, a new injection the next day elicited the well-patterned motherly behavior.

The case of the mixed-up male rat was a most auspicious one. Although the rat had not followed the experimenter's script, the result of this first experiment was highly exciting. It was an encouraging indication that the control of behavior by specific neural systems in the brain could indeed be investigated by chemical means. We proceeded next to a long series of experiments to verify that the behavior in each case was actually attributable to a specific chemical implanted at a specific site in the brain rather than to some more general factor such as mechanical stimulation, general excitation of the brain cells, or changes in acidity or osmotic pressure.

We have now administered many different chemicals to the brains of hundreds of animals, mostly rats. For this work we have had to develop simple surgical techniques for implanting tiny hollow guide shafts in the animals' brains so that chemicals can be delivered to selected points. The location of each shaft is carefully established with



TRACING THE ROUTE OF A BRAIN CIRCUIT, one undertaking made possible by the selectivity of chemical stimuli, requires delicate techniques. At left a vernier-adjusted stereotactic machine is used in conjunction with a sectional atlas of the brain to implant the help of a three-dimensional brain map and a stereotactic instrument, which holds the head of the anesthetized animal and guides the surgical instruments. After a tiny hole has been made in the brain the shaft is inserted and antiseptically fastened to the skull with jewelers' screws and an adhesive. Each animal can be equipped with several guide shafts at different locations. In a rat four or five shafts may be inserted; in a monkey, as many as 100. The animal recovers quickly and resumes its normal laboratory existence. Through these permanent shafts we can deliver as little as one microgram of a chemical in crystalline form or as little as a ten-thousandth of a milliliter of a solution [*see illustration below*].

Arousing Male Behavior

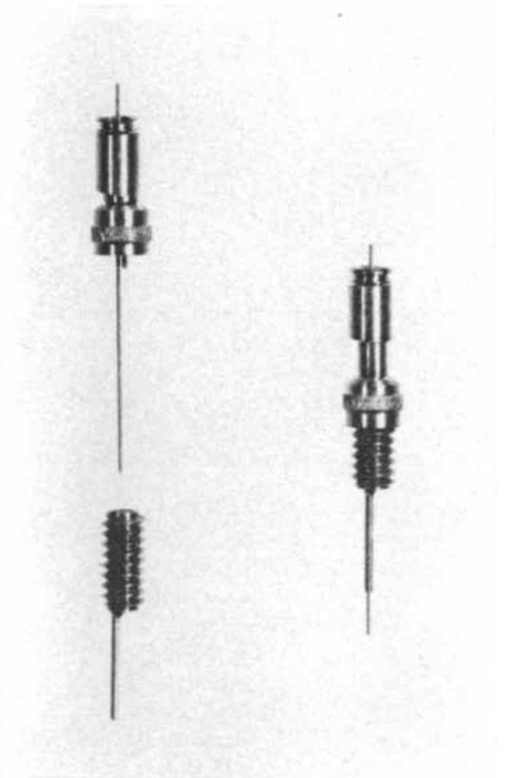
Our extended program of tests confirmed, first of all, the elicitation of maternal behavior by an injection of a testosterone solution at a specific location in the brain. When we placed the hormone in a site in the center of the brain just in front of the hypothalamus at the level of the optic tracts below it, many of the rats tested, male and female, responded with some form of maternal behavior.

An injection of the same hormone in the same general region but slightly to one side instead of in the center, brought forth a dramatically different response. Many of the animals now reacted as I had expected the original male to do—with male sexual activity. This was true even of female rats. Presented with a partner, whether male or female, the injected rat (male or female) soon tried to mount the partner. One heroic female persisted in this malelike behavior over a period of eight weeks in tests conducted every other day. The behavior was elicited only by testosterone; it did not appear when the same site was injected with other chemicals or stimulated by electricity.

When the male hormone injection was placed between the central and lateral sites in the hypothalamus, so that it impinged on both, some rats exhibited a curious combination of maternal and male behavior. They took care of the young and at the same time tried to copulate with any partner available. In several instances a male rat that had received such an injection tried to mount a nonreceptive female or male at the same time that it was carrying a rat pup in its mouth!

This was particularly puzzling because it seemed to deny the hypothesis that functionally related brain cells are selectively sensitive to specific substances. How could the neurons that mediate two different kinds of behavior respond to one and the same hormone? The question has not yet been fully answered, but we can offer a reasonable conjecture. Testosterone is known to act not only as a male hormone but also, under appropriate circumstances, as a weak substitute for the female hormone progesterone, which is linked to pregnancy and maternal behavior. (This versatility is generally true of the family of steroid hormones; most of them can mimic one another's actions.) Therefore a concentrated injection of testosterone into the brain cells may carry enough progestational potency to stimulate the cells that are sensitive to progesterone.

This hypothesis would explain how testosterone injected into the brain of a male rat can evoke maternal behavior. The male body contains little or no progesterone, and presumably its circulating testosterone, at normal levels, has no significant progestational potency. But when a concentration of testosterone is injected directly into cells that are susceptible to progestational stimulation, the hormone's secondary activity is strong enough to stimulate them.



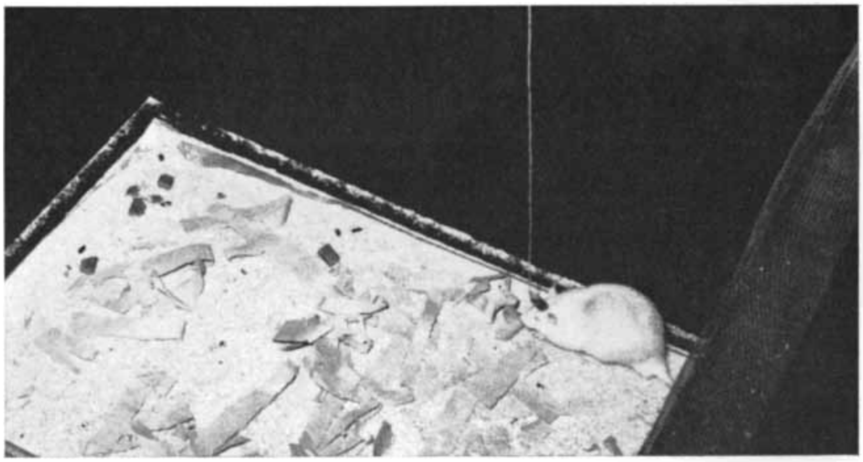
guide shafts leading to precisely calculated regions in the brain of an anesthetized rat. In the middle, unassembled and assembled, are the permanent guide shaft and the removable cannula that carries the chemical to the brain tissue. At right a rat with two guide shafts is about to receive a brain stimulus. The cannula in this instance contains the chemical agent in the form of a solid.

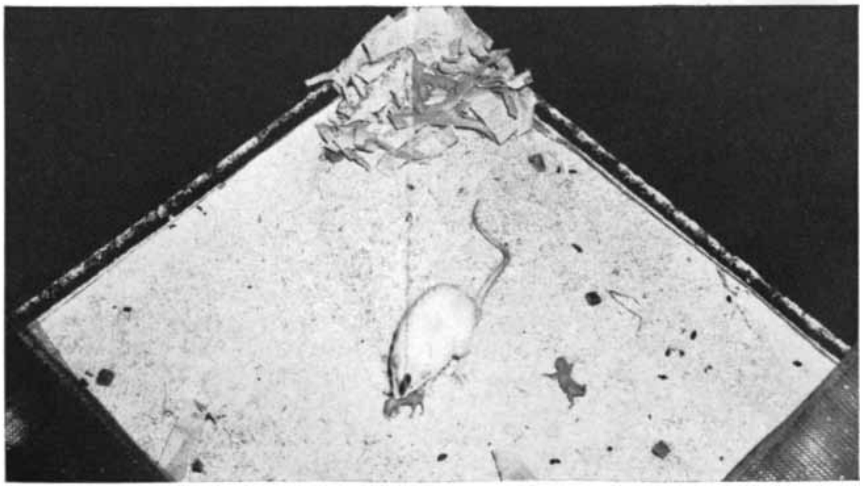
Whether or not this particular hypothesis is correct, the experiments in chemical stimulation seem to show that the male brain and the female brain are essentially identical in the character and organization of the neurons. In the rat, at least, both brains contain cells that can direct male behavior and other cells that can direct female behavior. Differences in sexual behavior can be attributed largely to differences in the kinds of sex hormone that enter the animal's circulatory system.

Yet even this concept is an oversimplification. Evidence obtained recently suggests that during early development sex hormones also play an organizational role, determining degrees of maleness or femaleness by permanently altering the response thresholds or growth within neural systems that will direct male and female behavior. Thus the presence or absence of a hormone during early life may determine the extent to which a nerve circuit develops the capacity for effective function. This may explain why many of our rats are unaffected by brain hormone stimulation, and why, under ordinary conditions, some males and females of every species display the behavior of the opposite sex.

The Puzzle of Steroid Action

Investigators at several other laboratories have now confirmed our finding that steroid hormones act selectively on nerve cells at specific sites in the brain. They have found, for example, that implants of estrogen in selected sites in the hypothalamus can produce sexual receptivity in a cat whose ovaries (the main natural source of estrogen) have been removed. Tracer experiments with radioactively labeled estrogen have shown further that the estrogen tends to concentrate around certain cells of the hypothalamus. A puzzling aspect of the experiment is that the radioactivity (and presumably the hormone itself) has disappeared from the brain by the time the cats become sexually receptive, which is not until five days or more after implantation.





INJECTION of testosterone (*upper photograph*) induces maternal behavior in this male rat. The male gathers scattered paper strips to make a nest (*lower photograph*), ignores food pellets and carries rat pups (which males normally would eat) to shelter in the nest.

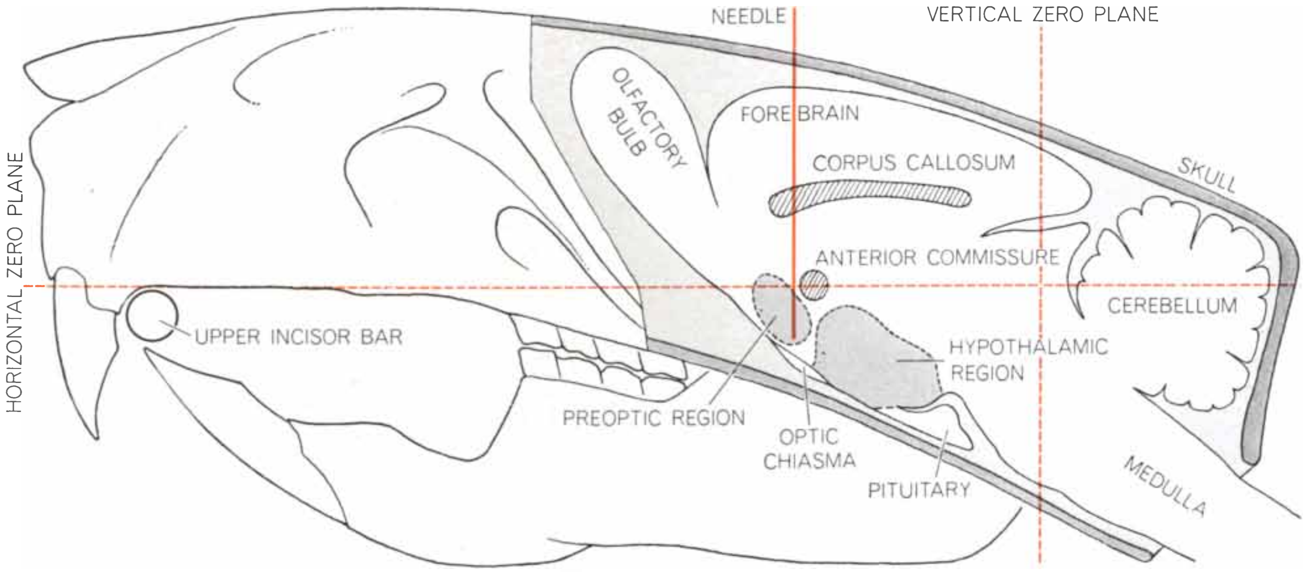
Other puzzling findings have emerged from related studies, and there are many questions to be answered before any comprehensive or confident conclusions can be presented. One of the chief questions has to do with the speed of action of the hormones I have injected into the brain. When a steroid hormone is injected into the muscle tissue or the bloodstream of a male rat, it does not take effect until 24 to 48 hours later. Our injections into the brain, on the other hand, usually produce changes in the rat's behavior within seconds or minutes. Part of the explanation may lie in the form of the injection. Normally steroids are soluble only in oils, and it is in such a solution that they are injected into the blood or peripheral tissues. For the injections into the brain we have generally used a rare steroid that is soluble in water. Possibly an oil-soluble hormone can act rapidly only after it has been converted to a water-soluble form.

R. D. Lisk of Princeton University has recently demonstrated, however, that even an oil-soluble steroid will take effect quickly under certain conditions. He experimented with injections of progesterone to stimulate sexual receptivity in the female rat. He found that when he injected progesterone into the veins of a female that had been primed with injections of estrogen for several days, she became sexually receptive in less than 10 minutes. It takes six hours for such a female to respond fully when the progesterone is injected into muscle tissue rather than the bloodstream.

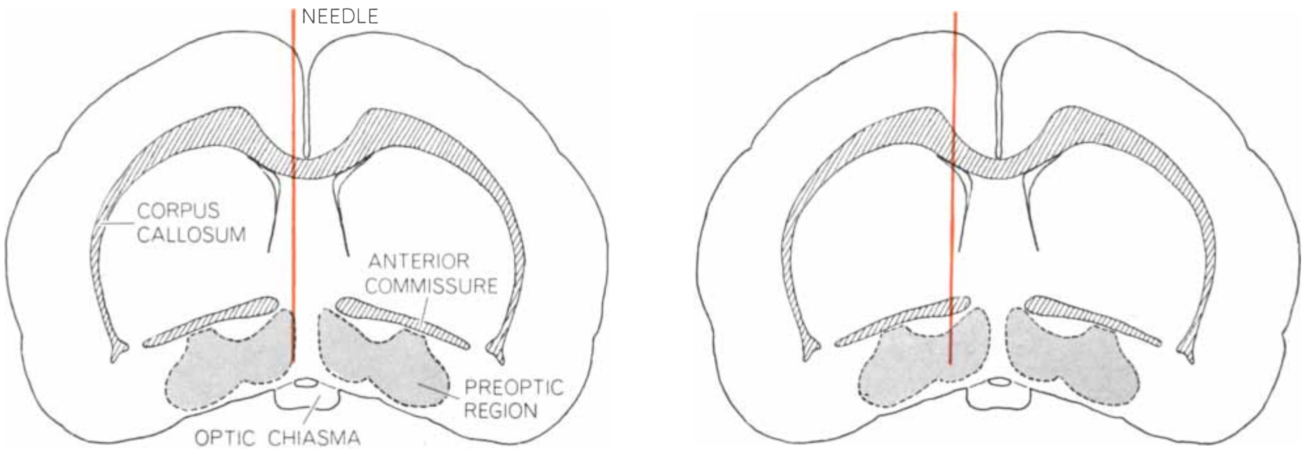
Control of Hunger and Thirst

With the chemical technique we have gone on to explore the rat brain for the location of the neural systems responsible for the control of other drives besides the sexual. Foremost among these drives, of course, are hunger and thirst. Several regions in the brain that help to control eating and the hunger drive are located in the hypothalamus and are well known. One center acts as an "appestat" (by analogy with the thermostat), and its setting can be raised or lowered. Electrical stimulation of this center will cause even a sated animal to increase its food intake sharply, whereas injury to the same center will drastically reduce an animal's appetite. The other center, in the lower middle region of the hypothalamus, acts as a satiation center, or "brake," for eating.

Some investigators have proposed that the main factor regulating the ac-



RAT'S HEAD is positioned by hooking the upper incisors over a bar on the stereotactic machine. The brain, in sagittal section (*right*), is labeled to show major anatomical features. The broken lines (*color*) show the zero coordinates for implant measurements.



TRANSVERSE SECTIONS of rat brain were taken about eight millimeters forward of the vertical zero coordinate. The needles, or cannulas, touch points in preoptic region where testosterone induced maternal behavior (*left*) and male sexual behavior (*right*).

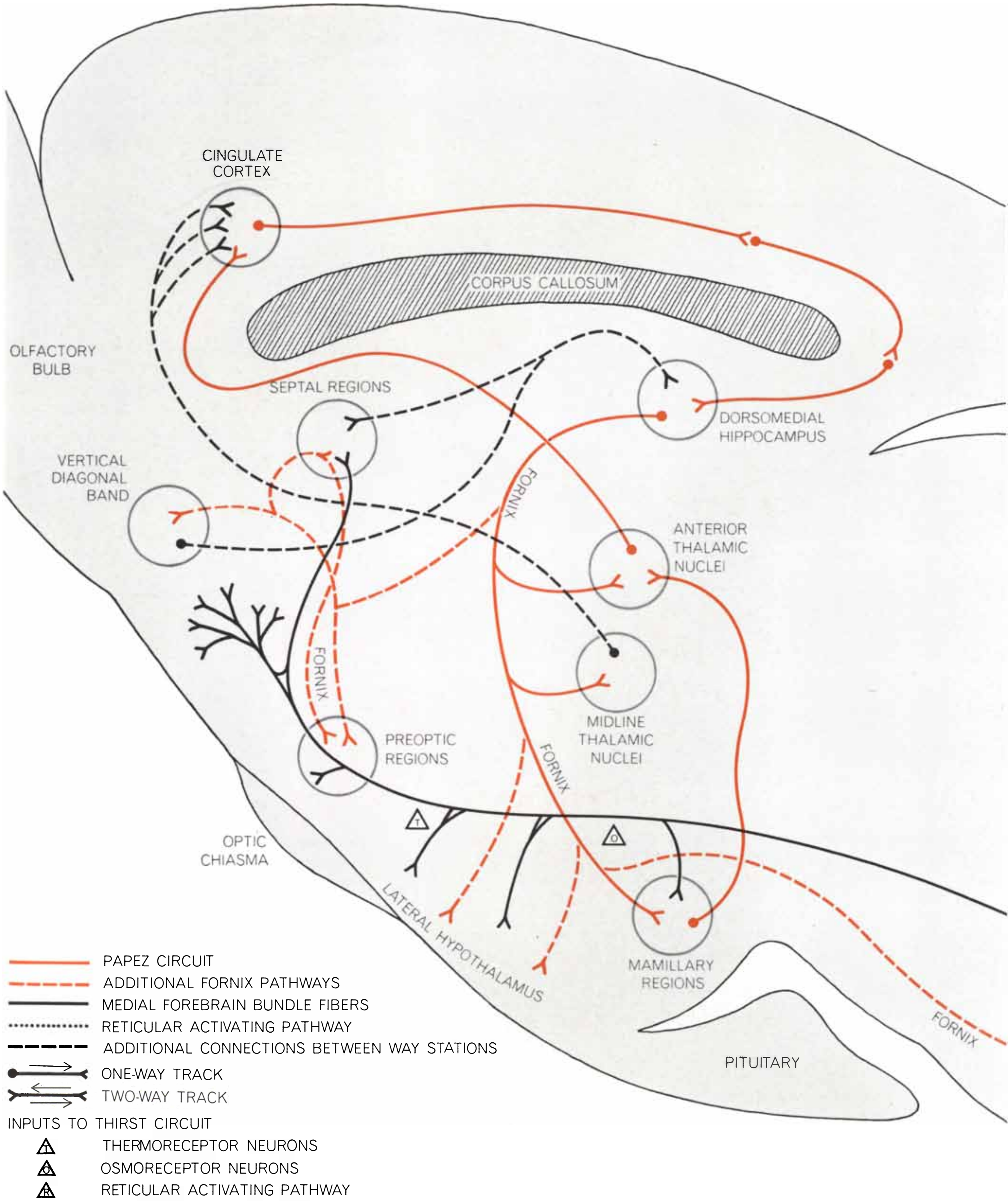
tivity of the appestat is the sugar level in the blood [see "Appetite and Obesity," by Jean Mayer; SCIENTIFIC AMERICAN, November, 1956]. Our first conjecture, therefore, was that the two oppositely working hormones of the pancreas that regulate the blood-sugar level—insulin and glucagon—might be the primary chemical modulators for the hunger drive, determining the settings or thresholds of the brain centers by acting directly on them. In an extensive series of attempts to stimulate these centers with the two hormones, however, we found no evidence that insulin or glucagon had any effect on them. (Indeed, it has not been conclusively proved that the blood-sugar level itself is a major factor in the regulation of appetite.)

Subsequently a Yale University graduate student, Sebastian P. Grossman, discovered that eating and drinking could be elicited in rats by brain injections of two other chemicals. They were none other than noradrenalin and acetylcholine, the substances that have long been known as transmitters of nerve impulses. Noradrenalin, injected into a site in the brain just above the hypothalamus, would cause even a well-fed rat to start eating again. Acetylcholine, injected into the same site, would drive the rat to drink. Grossman also found that these stimulating effects could be blocked by injection of chemicals that were known to block the transmitting action of noradrenalin and acetylcholine at nerve synapses.

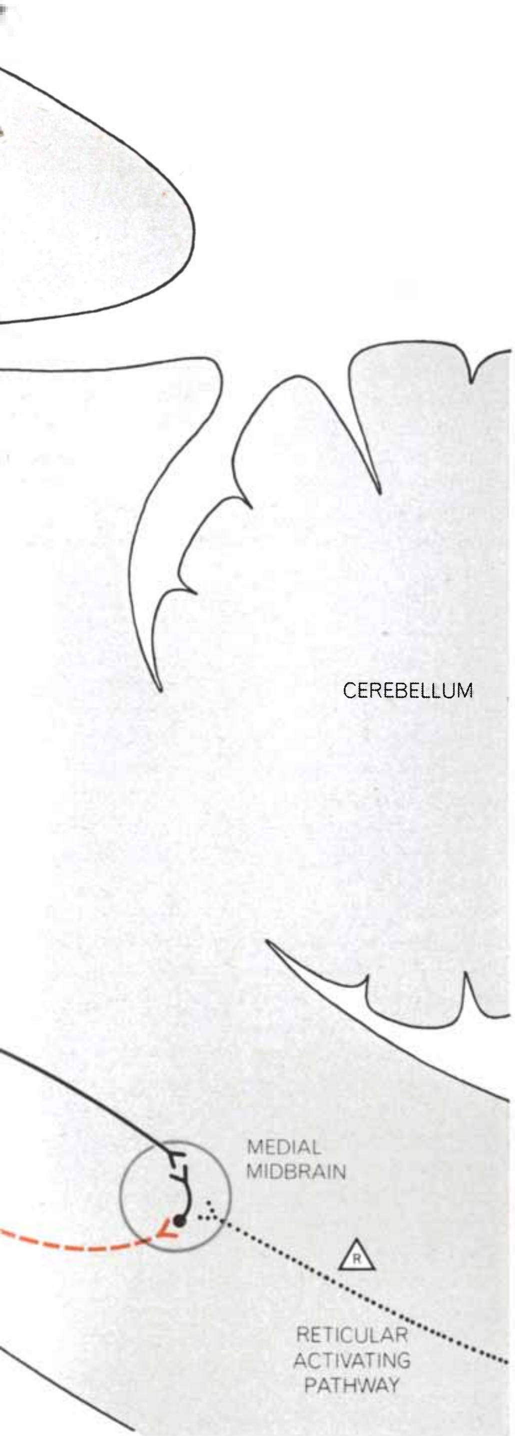
A Circuit Theory of Drives

I was naturally interested to learn that these two nerve-impulse transmitting chemicals can do their work within the tissue of the brain itself. But even more intriguing, Grossman had shown that different chemicals released different inherent drives even though injected at exactly the same site in the brain. This immediately suggested that the neurons composing each of these major drive circuits were chemically selective and would respond only to the appropriate chemical stimulus. If such a theory were correct, a specific chemical could be released almost at random in the midst of several quite separate circuits but would selectively excite only one of them. In this way it would be possible to probe various parts of the brain with a specific chemical and actually chart the circuit responsive to that particular stimulus.

In our laboratory at the University of Pittsburgh John N. Coury and I set



SCHEMATIC CIRCUITRY of the thirst drive is superimposed on a simplified outline of a rat's brain. Although all structures appear to lie on a single plane, they are actually distributed at varying depths in each brain hemisphere. The central figure eight (*solid color*) is a limbic circuit that links the hippocampal, the hypothalamic and the thalamic regions with the cingulate cortex of the forebrain. First postulated by James W. Papez in the 1930's, this circuit proves to be part of the thirst-drive system. Chemical exploration has identified other pathways (*broken colored lines*) extending the Papez circuit; in general, all involve the brain structure called the fornix. The second major component of the thirst-drive system (*solid black*) connects many forward limbic regions with the medial midbrain; the structures involved are the descending and ascending fibers of the medial forebrain bundle. Additional circuit elements (*broken black lines*) have been found to provide alternate connections between various system



way stations. Three brain regions (*triangles*), although not sensitive to cholinergic stimuli, can trigger the thirst-drive system. These are (*left to right*) neurons that respond to an increase in blood temperature, neurons that respond to an increase in the blood's salt concentration, and the reticular activating pathway leading to the midbrain.

out to try to chart the circuit that mediates drinking. Our design was to stimulate various sites in the rat brain by injections of the thirst-inducing substance acetylcholine or a chemical that mimics its transmitter action, such as muscarine. Tests were conducted at hourly intervals. As controls for the experiment some rats received no injections and some got injections of chemicals that have no impulse-transmitting action, but which can excite or depress nerve-cell activity. All the rats were given free access to as much water and food as they wanted, and an exact record was kept of their water consumption.

Normally rats drink 25 to 35 milliliters of water a day. Some rats we stimulated with brain injections of acetylcholine or muscarine quickly developed a colossal thirst. Within 10 minutes after the injection they began to consume large quantities of water, and within an hour some rats drank as much as twice a whole day's normal intake.

We found that this behavior could be evoked by injection of the drug at any one of many sites distributed widely in the brain [*see illustration on next page*]. Almost all the sites lie within what is known as the brain's limbic system, or the primitive "smell brain." It turned out that our initial map of the thirst circuit virtually coincided with one that James W. Papez, a Cornell University Medical College neuroanatomist, had described in 1937 as a closed-loop system that seemed to be responsible for emotion-directed behavior.

Our tests have shown that all the structures Papez outlined are implicated in thirst, but there are also a few thirst-inducing regions outside his circuit [*see illustration at left*]. We are exploring the entire brain to trace the full extent of the thirst system. We are now convinced that it involves a fiber trunk in the forebrain that connects limbic structures in the front of the brain with the hypothalamus and midbrain. Presumably suitable chemical stimulation of any of these regions alerts the entire thirst-drive system. We believe that the whole circuit normally utilizes acetylcholine, or a similar cholinergic chemical, as a neurotransmitter, and that when a cholinergic chemical is injected locally into the brain it initiates the chain release of cholinergic substances at nerve-fiber terminals throughout the system. It seems significant that Olds has found the same system to be involved in the mediation of "pleasure," or reward.

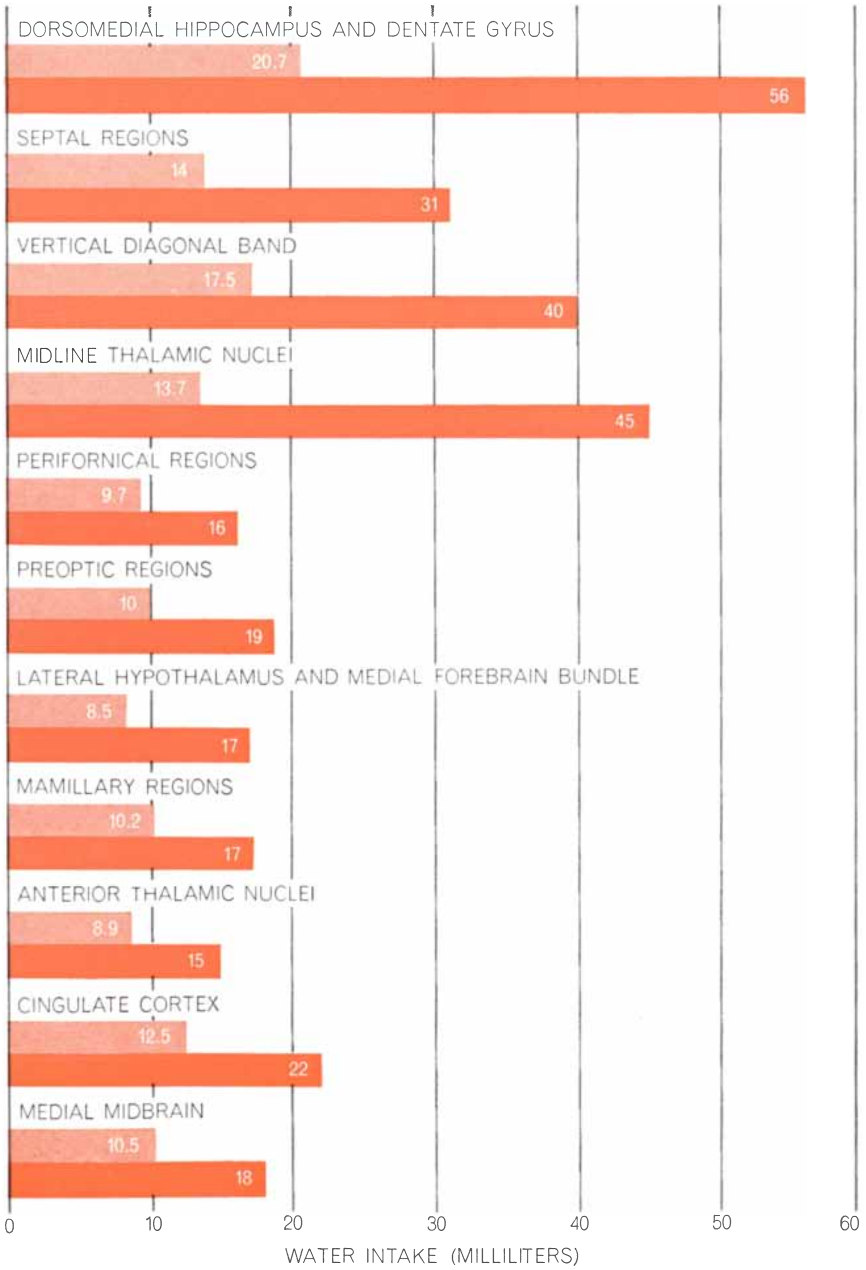
Our present model of the thirst-drive circuit in the brain, based on experiments, is a highly complex affair, and its very complexity strongly supports the model's plausibility. One obvious requirement for a basic drive system is stability; that is, it should not be easily knocked out or blocked by a simple disorder or injury to the animal. The complexity of the thirst system, as traced by our experiments, provides such protection, because the circuit contains many alternate pathways that can serve to maintain its integrity if some of the pathways are blocked.

This model of the thirst-drive system has some interesting parallels to Hebb's model of the memory system in the brain. Hebb believes that even the simplest perceptual learning involves hundreds of neurons widely dispersed in the brain and is established only gradually by the development of neuronal interconnections. The perception of a given event activates a certain pattern of sensory, associational and motor neurons. At first the pattern is a comparatively simple one and its durability is precarious. But as the perception is repeated and the neurons involved become more practiced in firing as a team, their functional interconnections become more firmly established. In time additional neurons are recruited, alternate pathways develop and the system becomes less and less vulnerable to disruption.

Hebb's model helps to explain the well-known fact that long-established memories are much less subject to obliteration by brain damage or stress than are the memories of recent events. Extending the analogy to the thirst-drive system, we can say that this system resists disruption because it is solidly established with a wealth of alternate pathways. It differs from a memory pattern, however, in that most of the neuronal interconnections are present at birth, having been established by genetic inheritance rather than by perception and learning.

The complexity of the thirst-drive circuit also helps to explain how a drive is maintained over a period of time. Obviously a nerve circuit that mediates a primary drive must be able to dominate brain activity long enough to permit the organism to search for environmental stimuli that will satisfy the drive. The thirst-drive circuit shown in the illustration at the left exhibits both closed-loop and reciprocal pathways. Such a system is ideally designed to continue functioning over a period of time, even after the cessation of the input that triggered the activity. Messages can continue to circulate, or "reverberate," through such a system until an inhibitory brake is applied.

Another set of experimental facts emphasizes the complexity of the thirst-drive system. It is clear that thirst can be triggered by several different means. For example, Andersson in Sweden has found two types of specialized neurons in the hypothalamus that increase thirst. One type responds to increased osmotic pressure, the other is sensitive to a rise in temperature. There is also other evidence suggesting that thirst-triggering inputs come from other parts of the brain, including the amygdala and the reticular activating system. Our map of the thirst-drive system, picturing it as a complex circuit with many way stations, helps to explain how these various inputs may be fed into the system.



EXCESSIVE WATER INTAKE during the hour after stimulus is related to the area of the brain that was stimulated. The light bars show the mean amount of water consumed in the course of multiple tests with a series of rats. The dark bars show the maximum water intake by a single animal. Normally a rat will drink about 1.5 milliliters per hour. A greater intake is evidence that the stimulated structure is part of the brain's thirst-drive system.

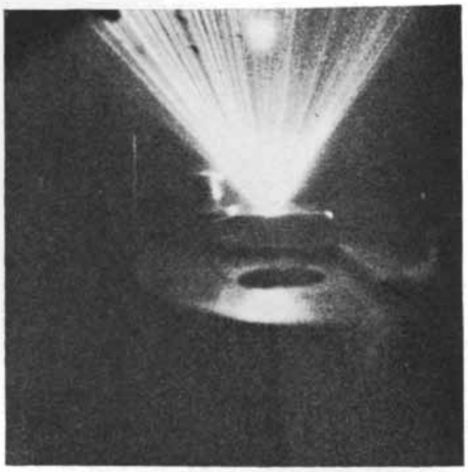
So far we have little information about the chemical substances and brain circuits that control the primary drives other than thirst. Evidence from electrical-stimulation experiments, however, suggests that the same structures and pathways are involved in these other drives. It looks more and more as if the primary-drive circuits all follow a roughly parallel course in the brain. Thus in our laboratory we are seeking to determine whether each is stimulated and modulated by specific chemicals. We recently tested a male rat by injecting three different chemicals, on separate occasions, into the same site in the brain. An injection of acetylcholine into this site stimulated the animal to drink, noradrenalin prompted him to eat and testosterone caused him to build nests! Coury and I are now trying to trace a hunger circuit through the brain. Curiously enough we had very little success until a mixture of chemicals was tried that both suppresses acetylcholine action and enhances the action of noradrenalin.

The Cat Is Not a Rat

I must point out that so far the only animal in which we have succeeded in tracing a brain circuit for a primary drive is the rat. The brain of the cat, for example, does not respond the same way when we inject acetylcholine into regions anatomically similar to those that stimulate thirst in the rat. Instead of stimulating cats to drink, these injections elicit anger, fear or a sleeplike trance. Independently, Raúl Hernández-Peón in Mexico City has reported tracing in the cat's brain a sleep circuit that follows much the same course as the thirst circuit in the rat. The chemical that induces sleep is acetylcholine. We interpret this to mean that there are species differences in the relations between specific chemicals and nerve circuits, but that the general principle of chemical specificity of separate functional systems still applies.

Whether or not our present theories are correct, chemical explorations of the brain have established at least two significant facts: first, that certain brain cells are stimulated selectively by specific chemicals and, second, that drive-oriented behavior can be triggered and sustained by chemical means. It seems safe to predict that chemical stimulation of the brain will become an increasingly important tool in the investigation of the neurophysiological bases of behavior.

MATERIALS EVALUATION BY IRRADIATION



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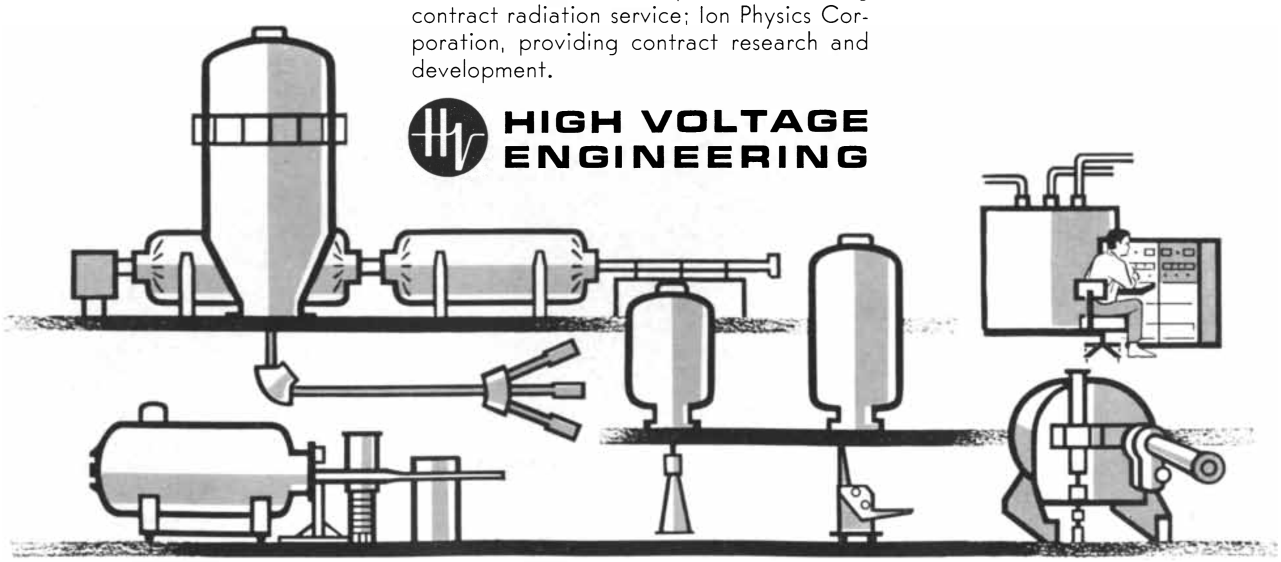

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Magnetothermoelectricity

By passing an electric current through semimetals in the presence of a magnetic field it is possible to build solid-state refrigerators that are highly effective. They offer the basis for a new technology

by Raymond Wolfe

The burgeoning of solid-state physics in the past two decades is testimony to the subtle and remarkable things that can happen when solid materials interact with various forms of energy. In this period the fruitful interplay between solid-state theory on the one hand and experimental discoveries on the other has provided the basis for a host of technological advances, ranging from pocket-sized radios to worldwide satellite communication systems. Many of these advances exploit the fact that solid-state devices can generate, detect, convert, divert and amplify electromagnetic energy. Another important family of solid-state devices can transform light or heat or sound or motion into electricity and vice versa.

As the somewhat forbidding title of this article suggests, I shall describe how the flow of heat and electricity in certain crystalline solids—the semimetals—is influenced by the presence of a magnetic field. It has been found, in brief, that a magnetic field can increase the efficiency with which heat can be pumped "uphill" electronically to provide refrigeration [see "The Revival of Thermoelectricity," by Abram F. Joffe; SCIENTIFIC AMERICAN, November, 1958]. Within the past few years thermoelectric refrigeration has found increasing use for the spot-cooling of electronic devices and is beginning to compete with mechanical refrigeration in consumer products, such as kitchen refrigerators and ice-cube makers (although this competition so far is based more on novelty than on economics).

The presence of a magnetic field can also enhance the inverse of electronic refrigeration: it can enhance the conversion of heat to electricity. Conventional thermoelectric generators are finding important but limited use for generating small amounts of electricity from heat derived from fossil fuels or radioactive isotopes. These generators also compete with solar cells, which are widely employed for supplying electricity from sunlight in space vehicles.

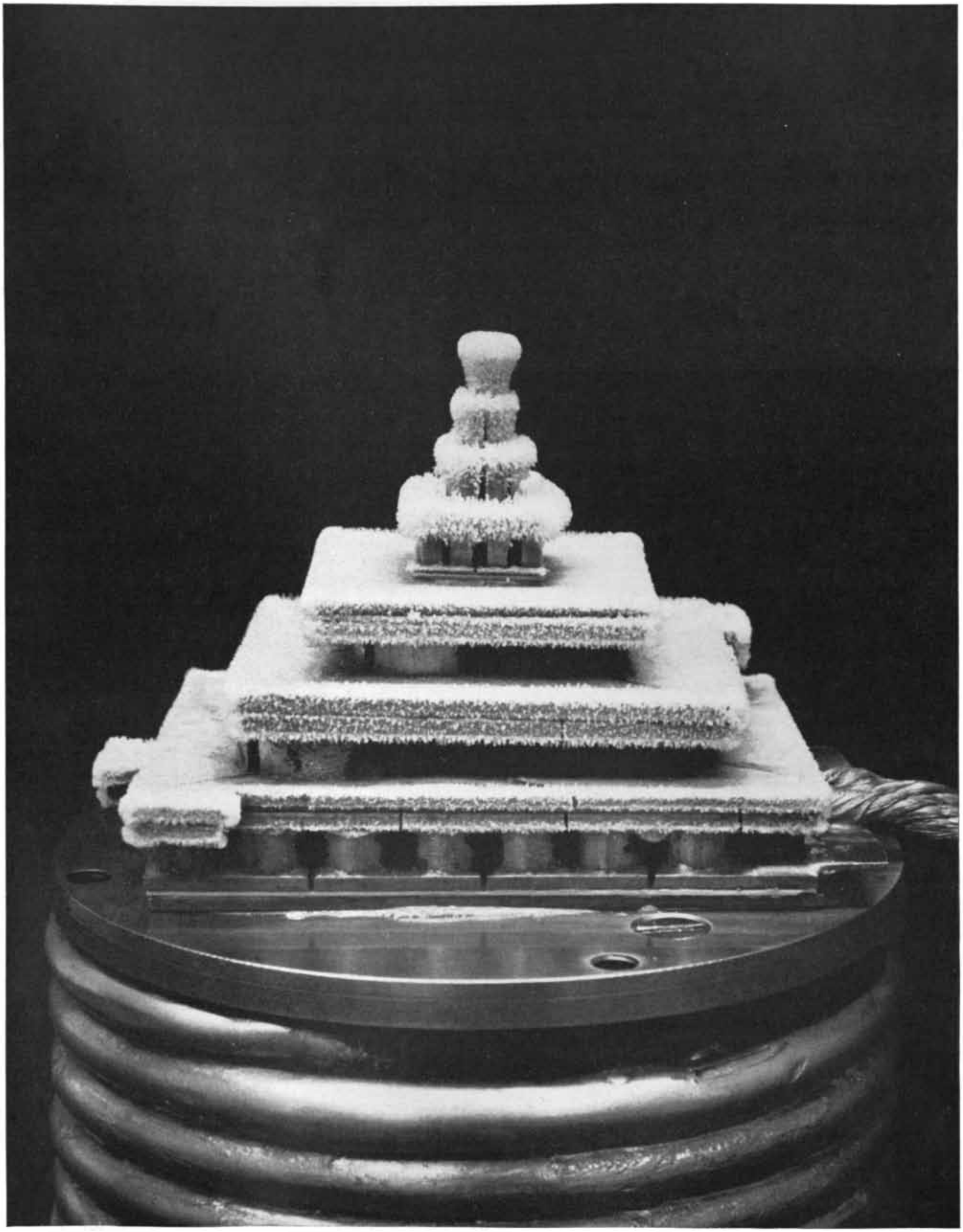
In the discussion that follows I shall concentrate chiefly on the magnetic enhancement of thermoelectric cooling and the related thermomagnetic cooling devices. The reason is that the magnetic effects to be discussed are most important at temperatures well below zero centigrade. Although there are frequent requirements for refrigeration at subzero temperatures, there are few opportunities to generate electricity from sources that can sustain a heat flow at low temperatures. Thus the first applications of magnetothermoelectricity will probably be for refrigeration.

The discussion will require a definition of the class of materials known as semimetals. As the name implies, semimetals have properties that are intermediate between those of metals, such as copper, and those of semiconductors, such as germanium. Metals are good conductors of electricity because they contain many free electrons, typically one for each atom in the crystal. Each electron, of course, carries one negative unit of electric charge. Equally important in semiconductors and semimetals are the carriers of positive charge known as holes. A hole arises when an electron is missing from the electronic configuration of certain crystalline structures. Such a missing electron behaves very much like a particle with one positive unit of electric charge.

Semiconductors are poor conductors of electric current because they contain far fewer electrons (or their effective equivalent, holes) than metals do. Semimetals are intermediate in conductivity because they have equal numbers of electrons and holes. These can coexist in semimetals because of a unique arrangement of the electron "energy bands" in these materials.

To explain energy bands I must discuss briefly a few quantum-mechanical concepts. In a single atom the electrons surrounding the nucleus are restricted to a set of discrete energy levels: the lower ones are normally occupied and the upper ones correspond to excited states of the atom. When atoms are bound together in a regular crystalline arrangement, however, the discrete energy levels of the individual atoms broaden into energy bands that the electrons are allowed to occupy. Between these bands are forbidden energy regions, or energy gaps [*see illustration on page 73*].

In a typical metal the highest occupied energy band (the conduction band) is only half-filled and the electrons in this band are free to move under the influence of an electric field. In nonmetallic perfect crystals there are just enough electrons available to fill all the energy states up to the top of a certain band (the valence band), leaving no electrons to occupy the conduction band. If the energy gap between these two bands is large, the crystal is an insulator; it contains no free electrons in the conduction band, and the electrons in the valence band, which is completely full, can carry no electric current. If the energy gap is small, as it is in a semiconductor, thermal energy in the crystal is sufficient to promote some electrons up into the conduction band, leaving an equal number of holes free to move at the top of the valence band. In most semiconductors a minute amount of impurity (say one part per billion) is enough to supply extra electrons to fill all the holes in the valence band, leaving only free electrons (an *n*-type semicon-



SEVEN-STAGE THERMOELECTRIC REFRIGERATOR is built up from semiconducting couples, or arms, arranged electrically in series. The couples consist of two kinds of bismuth telluride alloy: "*p*-type" and "*n*-type." (The significance of these types is explained on page 73.) When current flows through the refrigerator, heat is "pumped" from the top down and is removed by water flowing in coils at the base. When the water is at 27 degrees centigrade, the top plate of the refrigerator drops to —118 degrees C., for a difference of 145 degrees. The device, about 1½ inches high, normally runs in a vacuum. When operated in air, it frosts as shown here. It was built by John R. Madigan, George F. Boesen and others at the research center of the Borg-Warner Corporation.

ductor), or to soak up the conduction electrons, leaving only free holes (a p-type semiconductor).

In a semimetal, instead of an energy gap there is a slight overlap between the two bands. Again there are just enough electrons available to fill the valence band, but now electrons from the top of the valence band spill over into the bottom of the conduction band. This leaves free holes in the valence band and an equal number of free electrons in the conduction band even at absolute zero, when the thermal energy vanishes. In a pure semimetal, such as bismuth, there is one electron and one hole for approximately every million atoms. What makes these electrons and holes in bismuth and related semimetals particularly interesting is their very high mobility, which gives rise to fairly high conductivity and great sensitivity to a magnetic field. Bismuth has only a millionth as many electrons as copper, yet its resistivity is only 100 times higher.

Next to bismuth, the semimetal that has been most extensively investigated is antimony. These two elements are similar in many ways. They are in the same column of the periodic table; the atoms of each have five outer electrons, with the result that they form the same chemical compounds, and they crystallize in the same form. The atoms in the crystal occupy essentially a cubic array except that one of the diagonals of the cube is slightly stretched. This stretch direction establishes an axis of threefold symmetry just as a simple cube has threefold symmetry if it is viewed along a diagonal. The slight distortion from cubic symmetry gives rise to a surprisingly large anisotropy, with the result that most properties are strongly influenced by the orientation of the crystal. Bismuth and antimony can be mixed in any proportion and the alloys also crystallize in this same structure.

In 1958 A. L. Jain, a graduate student at the University of Chicago, was investigating the electrical properties of these alloys when he observed an interesting phenomenon, which had been theoretically predicted two years earlier by V. Heine of the University of Cambridge. When a little antimony is added to bismuth, the alloys behave much like pure bismuth. When more than 5 per cent of antimony is added, however, the alloys no longer have the energy-band overlap characteristic of semimetals. Instead they appear to have a small energy gap, too small to be detected at room temperature but apparent in the electrical properties at very low temperatures (below –220 degrees C.). In alloys containing more than 40 per cent antimony the gap disappears again, the bands overlap and the alloys resemble pure antimony [*see top illustration on page 74*].

A great deal of quantitative information is available about the nature of the holes and electrons in bismuth and antimony. As the two are mixed together and the energy bands shift, what happens to the properties of the electrons and holes in these bands? This question has not been fully answered, but it was during the search for such information that the interesting thermoelectric properties of these materials were fortuitously revealed.

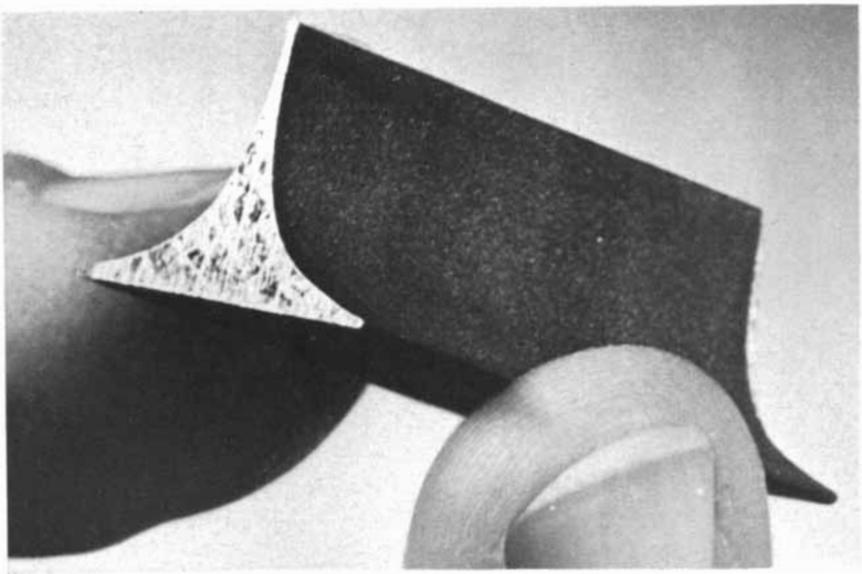
At the Bell Telephone Laboratories in 1960 George E. Smith was preparing to determine the properties of the electrons and holes in some of these alloys. He began by checking the electrical resistance at low temperatures to see if his alloys behaved like Jain's. During these preliminary measurements he observed some troublesome variations in voltage, which he soon identified as thermoelectric effects. The current flowing through his specimen gave rise to heating at one junction with the copper wire of the circuit and cooling at the other junction. This is the Peltier effect, discovered 130 years ago, which is used in thermoelectric refrigeration [*see bottom illustrations on pages 74 and 75*].

Now, the inverse of the Peltier effect is the Seebeck effect, which is the basis of the thermoelectric generation of electricity from heat. In Smith's sample the heat produced by the Peltier effect gave rise, in turn, to an extra voltage by the Seebeck effect.

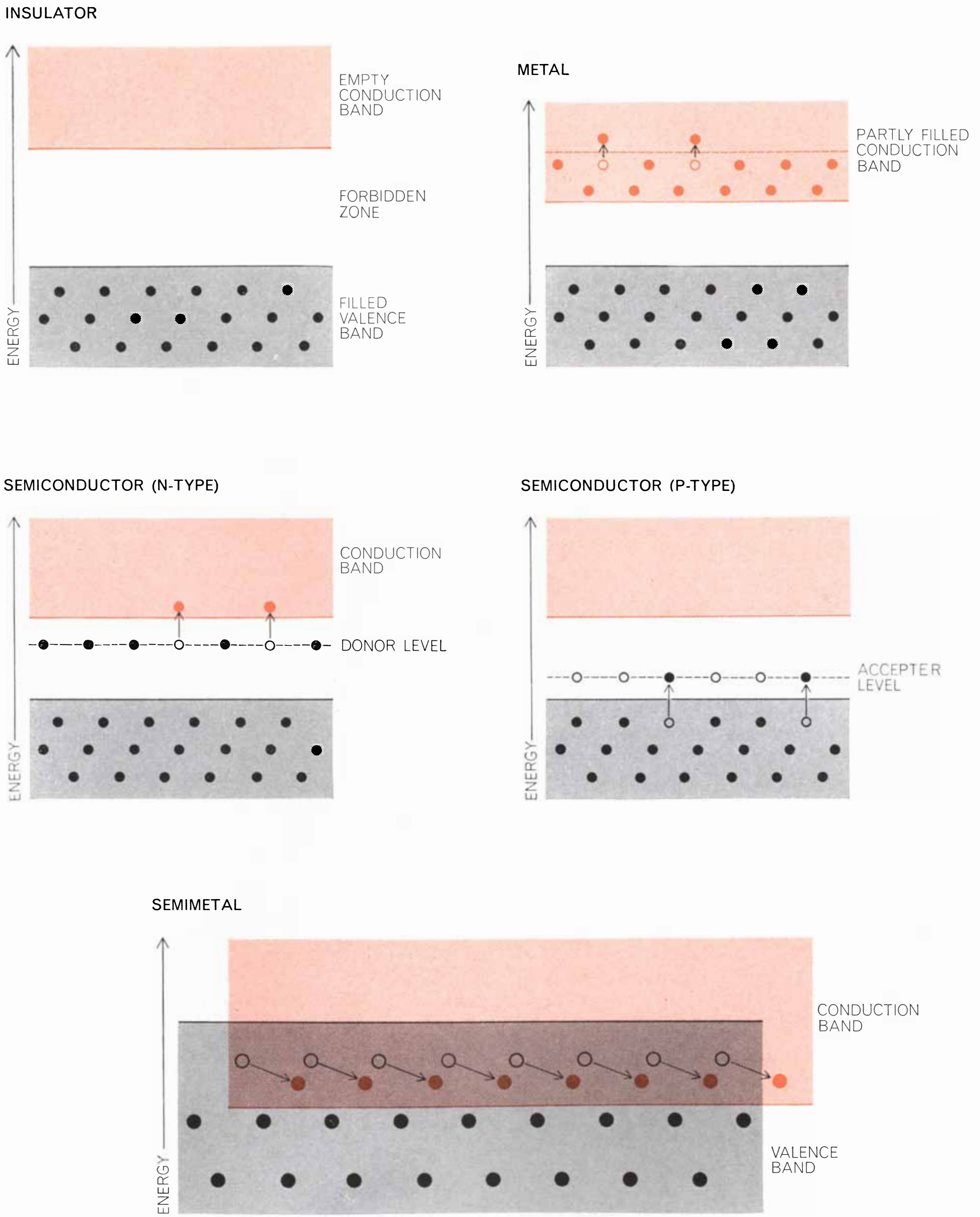
Instead of bypassing these annoying complications and proceeding with his planned experiments (which concerned the motions of electrons in a magnetic field), Smith decided to investigate what he recognized as surprisingly large thermoelectric effects. He soon found that these bismuth-antimony alloys had higher values of the thermoelectric "figure of merit" than had ever been observed before.

What is this figure of merit? It is a combination of physical properties that determines how much cooling can be achieved in a thermoelectric refrigerator using the Peltier effect. This same figure of merit also determines how efficiently heat can be converted into electricity by the Seebeck effect [*see top illustration on page 76*].

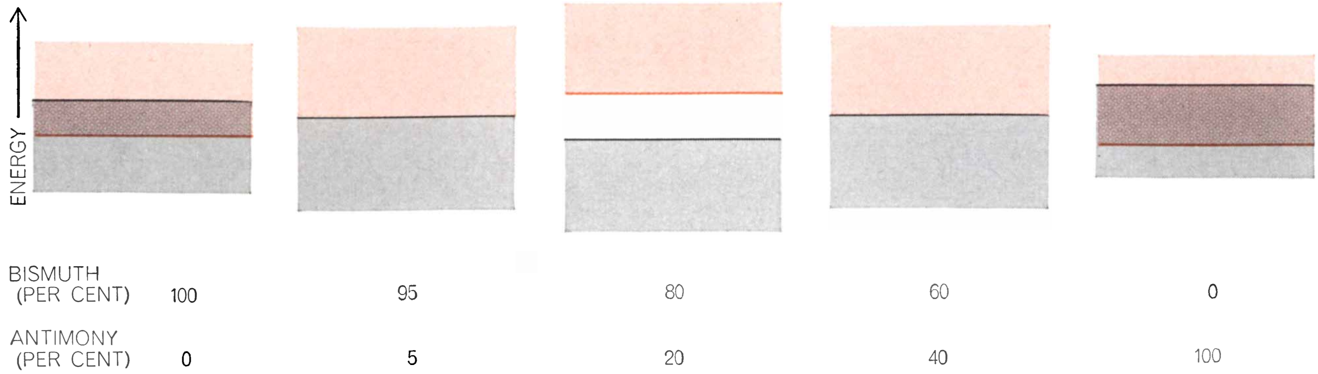
If one considers the properties that make a material useful for thermoelectric refrigeration, one finds that three quantities are important. The first obvious requirement is that the thermoelectric effect must be large to achieve a large amount of cooling. Second, to minimize the heating associated with the flow of electric current the elec-



"INFINITE CASCADE" REFRIGERATOR, shaped from a single crystal of pure bismuth, is a remarkable new thermomagnetic device. A similar unit became 101 degrees C. colder at the thin top edge than at the base when subjected to the flow of current in a transverse magnetic field of 110,000 gauss. (Heat was removed from the base by a "heat sink" of running water near room temperature.) The device was built by T. C. Harman, J. M. Honig and others at the Lincoln Laboratory of the Massachusetts Institute of Technology.



ELECTRON ENERGY LEVELS determine the electrical properties of solid materials. Only the electrons (*solid dots*) in a partially filled band can carry electric current. An insulator has a wide forbidden zone, or gap, between an empty conduction band and a completely full valence band. In a metal the conduction band is about half full of electrons. In an *n*-type (for "negative type") semiconductor trace impurities provide electrons in a "donor level" that can jump to the conduction band. In a *p*-type (for "positive type") semiconductor trace impurities provide an "accepter level," which accepts electrons from the valence band, leaving behind positive "holes" (*open circles*). A hole acts like a particle with one unit of positive charge. In a semimetal the conduction and valence bands overlap slightly, and electrons from the top of the valence band spill over into the bottom of the conduction band.



BISMUTH-ANTIMONY ALLOYS have conduction bands and valence bands that overlap or are separated by a small forbidden zone, depending on composition. When bands overlap, the alloy behaves as a semimetal and reacts strongly to a magnetic field.

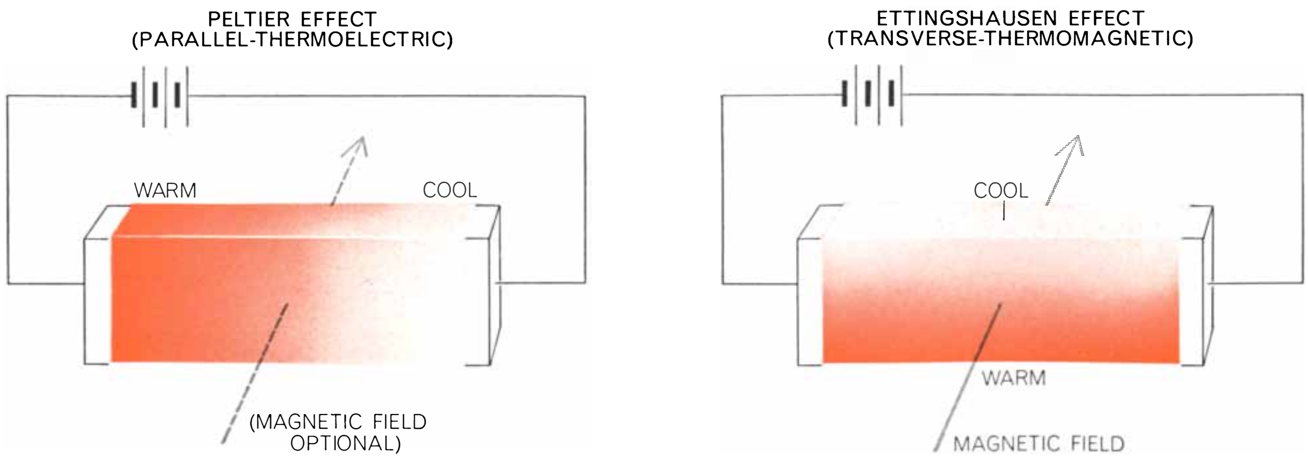
trical resistance must be low. Finally, in order to build up a large temperature difference the material must have a low thermal conductivity. These three properties are combined in the figure of merit, which is defined as the square of the thermoelectric power divided by the electrical resistivity times the thermal conductivity.

What Smith observed was that certain bismuth-antimony alloys, which had only modest figures of merit at room temperature, exhibited greatly improved properties at temperatures around 100 degrees Kelvin (degrees centigrade above absolute zero). This was an unexpected comeback for materials that had been the best thermoelectric materials known until 1954 but that had then been displaced from favor. (As early as 1838 bismuth and antimony were used to freeze a drop of water in the first primitive thermoelectric refrigerator.) The materials that supplanted bismuth and antimony in 1954, and that still exhibit the highest figures of merit at room temperature and above, are semiconductors such as lead telluride or bismuth telluride.

When a current flows in a bar of *n*-type semiconductor, the negative electrons carry both kinetic and potential energy from the negative to the positive end of the material. In a *p*-type semiconductor the positive holes carry the two forms of energy in the opposite direction. If the two kinds of semiconductor are joined in a single device, a simple thermoelectric refrigerator results. If current flows through the device so that electrons in the *n*-type material and holes in the *p*-type material both flow away from the junction, energy is carried away from the junction in both materials and it is cooled.

One might think that no net flow of thermal energy could be produced in a semimetal such as bismuth or antimony because it contains equal numbers of electrons and holes, which would carry energy equally in opposite directions. The electrons and holes, however, do not have identical properties. In bismuth and the bismuth-rich alloys the electrons are much more mobile than the holes in certain crystalline directions; they predominate over the holes, giving these materials *n*-type properties. In antimony and the antimony-rich alloys the holes predominate, so that these materials have *p*-type properties. Nevertheless, this electron-hole competition takes its toll, and these materials have lower figures of merit than the best single-carrier semiconductors at room temperature.

At lower temperatures the picture changes. The best available thermoelectric semiconductors have figures of merit near three per 1,000 degrees C. (or three units, for short) at room temperature, but this value drops at both lower and higher temperatures. The alloy Smith first investigated (an alloy containing 5 per cent antimony) had a figure of merit of only 1.8 units at room temperature when measured parallel to the direction of threefold symmetry, and only half this value in perpendicular directions. But when the temperature was lowered to that of



TEMPERATURE DIFFERENCE is produced by the Peltier and the Ettingshausen effects when a current is passed through certain semiconductors or semimetals. The Ettingshausen effect requires a magnetic field; the Peltier effect can be increased by one.

liquid nitrogen (−196 degrees C.), the figure of merit rose until it was about five times higher than that of the best semiconductors. In subsequent experiments Smith and I found that none of these bismuth-antimony alloys had a higher figure of merit at room temperature, but the alloy containing 12 per cent antimony reached a value of six units at −185 degrees C.

The three quantities that combine in the figure of merit all change with temperature. The resultant change in the figure of merit is downward with temperature for both *n*-type and *p*-type semiconductors. In the bismuth-antimony alloys the electrons and holes cooperate to resist the forces that make semiconductors less *n*-type or less *p*-type at low temperatures. We were able to show by certain theoretical arguments that the figure of merit must actually rise to a maximum near the temperature of liquid nitrogen. Below −50 degrees C. the cooperation between the electrons and holes in a semimetal becomes more important than the competition, with the result that these bismuth-antimony alloys in properly oriented single-crystal form are the best *n*-type thermoelectric materials known today [*see top illustration on page 80*].

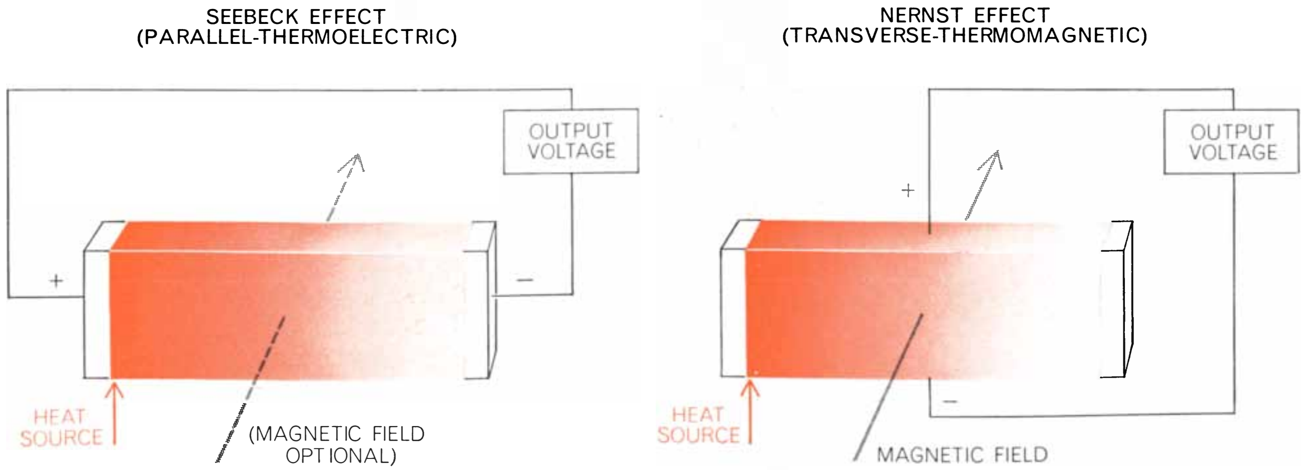
What happens to the thermoelectric figure of merit in a magnetic field? The thermoelectric power, resistivity and thermal conductivity of semiconductors are all affected by a magnetic field, but the changes are small in the best thermoelectric semiconductors. In the semimetals the changes are much greater. For instance, in bismuth at liquid-nitrogen temperature the resistance increases by as much as 500 times in a magnetic field of 15,000 gauss, which is readily produced by a standard laboratory electromagnet. This large magnetoresistance effect tends to decrease the thermoelectric figure of merit because a given amount of current produces more heating when the resistance is increased, but a part of the effect is offset by a reduction in thermal conductivity. Thermal conductivity is made up of two components: one is the heat carried by the electrons and holes, the other is the heat carried by the vibrating atoms of the crystal. In these alloys in the absence of a magnetic field the two components each carry about the same amount of heat. When a magnetic field is present, the amount carried by crystal vibrations is hardly affected, but the amount carried by the electrons and holes is greatly reduced. The crucial question then is: How does the thermoelectric power, the third variable in the thermoelectric figure of merit, change in a magnetic field?

To answer this question Smith and I measured the properties of the same material (88 per cent bismuth and 12 per cent antimony) that we had found to give the maximum figure of merit at low temperatures in the absence of a magnetic field. This first experiment turned out to be a fortunate choice. We found that the thermoelectric power increased in a properly oriented field by a factor of two or more. These increases were much larger than those usually observed in semiconductors, but in strong magnetic fields they were more than offset by still larger increases in electrical resistance. It was obvious that in a very strong field the increase in resistance would result in a greatly reduced figure of merit.

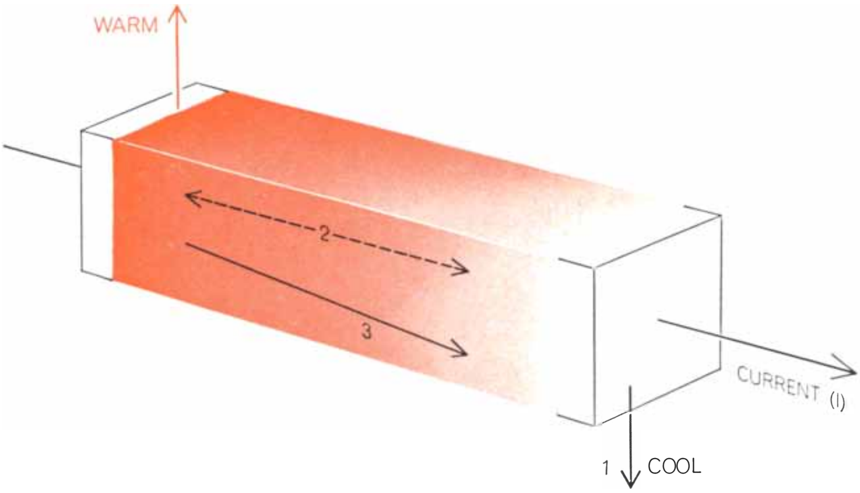
As our measurements soon verified, however, when the magnetoresistance effect is reduced by lowering the magnetic field, the increase in the thermoelectric power predominates and there is a corresponding increase in the figure of merit. In other words, the figure of merit rises to a maximum at some intermediate field strength and then falls, as expected, in stronger fields [*see illustration on page 82*]. The field required to reach this maximum rises rapidly with temperature. It is only 400 gauss at liquid-nitrogen temperature but rises to something higher than 17,000 gauss at room temperature [*see bottom illustration on page 80*].

The increases in the figure of merit were very substantial. At room temperature we achieved in our maximum field a value of three units, comparable to the best commercially available semiconductors. At lower temperatures smaller fields were required to give almost a threefold increase in the figure of merit. The highest value recorded on that first specimen (and this remains the record in spite of many further experiments) was 8.6 units measured at 100 degrees K. (−173 degrees C.) in a field of only 1,000 gauss. A field of this strength can be provided easily by a small permanent magnet.

Our results on the magnetic enhancement of the thermoelectric figure of merit were first announced at a meeting of the American Physical Society in March, 1962. At that same meeting in a postdeadline paper a group from the Lockheed Research Laboratories (C. F. Kooi, K. F. Cuff and others) also reported on their measurements of the flow of heat and electricity in the presence of a magnetic field in bismuth-antimony alloys. They had also observed high values of the figure of merit near liquid-nitrogen temperature, but there was



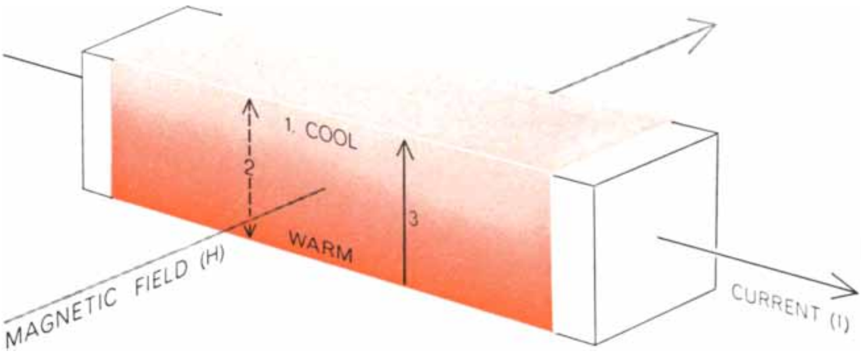
POTENTIAL DIFFERENCE is generated by the Seebeck and the Nernst effects when heat is applied to certain crystalline solids, notably semimetals. The Nernst effect requires the presence of a magnetic field, whereas the Seebeck effect can be enhanced by one.



	EFFECT	REQUIREMENTS FOR COOLING
1	THERMOELECTRIC COOLING (PELTIER EFFECT)	LARGE THERMOELECTRIC POWER (S)
2	JOULE HEATING	LOW RESISTIVITY (ρ)
3	HEAT CONDUCTION	LOW THERMAL CONDUCTIVITY (κ)

THERMOELECTRIC FIGURE OF MERIT $= Z_{TE} = S^2/\kappa\rho$

THERMOELECTRIC FIGURE OF MERIT involves the three effects that play a role in thermoelectric cooling. Peltier cooling (*1*) occurs where the wire of the electric circuit forms a junction with the thermoelectric material. The electrical resistivity of the material produces heat (Joule heating, *2*), half of which flows to the cool end. Finally (*3*) heat flows from the warm to the cool end of the material, which also reduces cooling effectiveness.



	EFFECT	REQUIREMENTS FOR COOLING
1	THERMOMAGNETIC COOLING (ETTINGSHAUSEN EFFECT)	LARGE THERMOMAGNETIC COEFFICIENT (N); LARGE MAGNETIC FIELD (H)
2	JOULE HEATING	LOW LONGITUDINAL RESISTIVITY (ρ_L)
3	HEAT CONDUCTION	LOW TRANSVERSE THERMAL CONDUCTIVITY (κ_T)

THERMOMAGNETIC FIGURE OF MERIT $= Z_{TM} = N^2H^2/\kappa_T\rho_L$

THERMOMAGNETIC FIGURE OF MERIT involves the three effects that underlie thermomagnetic cooling. Ettingshausen effect (*1*) is proportional to the magnetic field and produces a heat flow perpendicular to both the electric current and the field. As in thermoelectric cooling, Joule heating (*2*) and heat conduction (*3*) reduce temperature difference.

one important difference between the two papers. Instead of the thermoelectric figure of merit, the Lockheed group was concerned with the "thermomagnetic" equivalent.

In our measurements, as heat flowed down a bar placed in a transverse magnetic field, we observed an increased voltage differential between the ends of the bar; this was due to the magnetic enhancement of the Seebeck effect. In their case in a very similar experiment they observed a voltage *across* the bar, perpendicular to both the heat flow and the magnetic field. This is the Nernst effect, which can be used to convert heat into electricity in a thermomagnetic generator [see "Galvanomagnetic and Thermomagnetic Effects," by Stanley W. Angrist; SCIENTIFIC AMERICAN, December, 1961].

Just as there is a relation between the two thermoelectric effects (Seebeck and Peltier), so there is a relation between the Nernst effect and the thermomagnetic cooling phenomenon known as the Ettingshausen effect. Once the Lockheed workers had shown the Nernst effect in bismuth-antimony alloys, it was clear that these alloys would also be useful in an Ettingshausen refrigerator. (The bottom illustrations on the preceding two pages show the relation of the various effects.)

The first published suggestion that the Ettingshausen effect could be used for thermomagnetic refrigeration had been made four years earlier, in 1958, by two physicists at the University of Sydney, B. J. O'Brien and C. S. Wallace. They defined a figure of merit for thermomagnetic devices analogous to the one previously discussed, and they succeeded in achieving a tiny amount of cooling below room temperature: a maximum temperature drop of a quarter of a degree C. Five years later, by using a properly oriented and shaped crystal of a bismuth-antimony alloy, the Lockheed group was able to achieve a temperature drop of 54 degrees C. in a field of 15,000 gauss. This was achieved not at room temperature, however, but below a "heat sink" temperature of −117 degrees C. (The heat sink removes heat from the warm end or surface of a refrigerating device.) The cooling achieved by the Lockheed thermomagnetic device far exceeds what has been achieved with thermoelectric refrigeration at this temperature.

Working independently during the past two years, other groups have also contributed to the theory and practice of thermomagnetic devices, both in this

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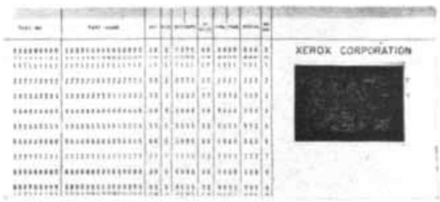

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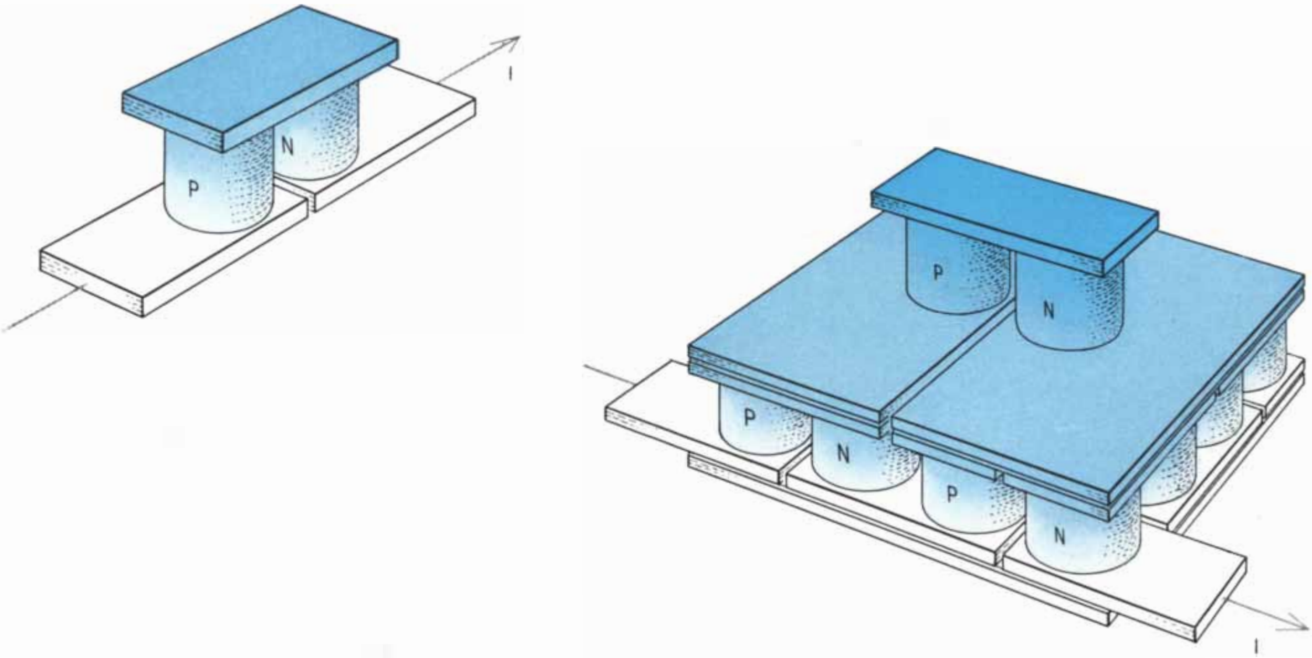
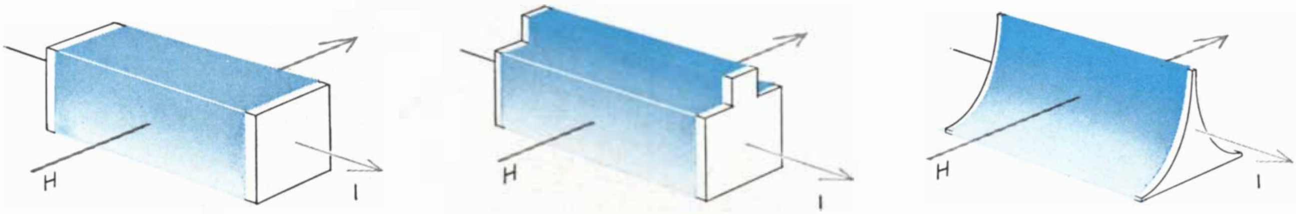
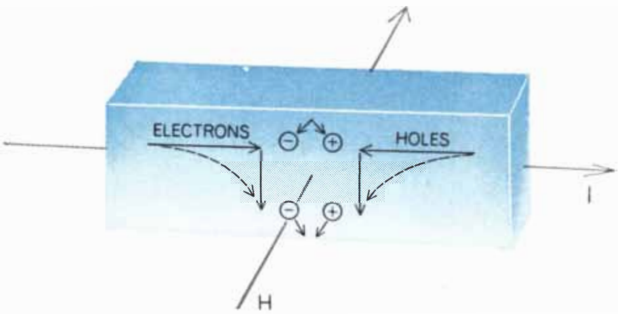


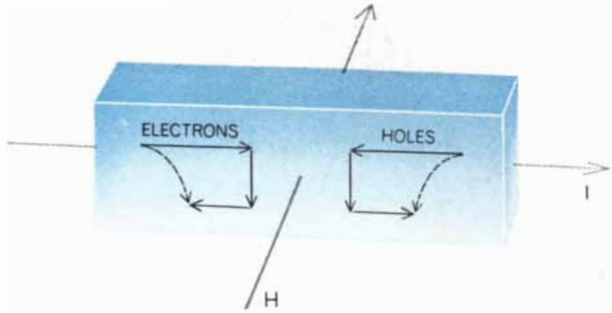
THERMOELECTRIC REFRIGERATORS can provide lower temperatures if a large stage is used to cool a smaller stage; this is called cascading. The thermoelectric materials in these units are *n*-type and *p*-type semiconductors. A single-stage device (*left*) can give a maximum temperature drop of about 75 degrees C. A two-stage device (*right*) can produce a drop of about 105 degrees. The semiconducting elements in these devices are electrically in series. A photograph of a seven-stage refrigerator appears on page 71.



THERMOMAGNETIC REFRIGERATORS can be built in stages also. A single-stage device is shown at left, a two-stage device is in the middle. But the greatest cooling is achieved by tapering a single block to form an infinite cascade, as shown at the right. A single crystal of pure bismuth shaped in this way (*see photograph on page 72*) has yielded a temperature drop of 101 degrees C.



MECHANISM OF THERMOMAGNETIC EFFECT involves the magnetic deflection of electrons and holes flowing in an electric field. Excess electrons and holes pile up at the bottom of the bar and annihilate, releasing heat. At the top of the bar the creation of electron-hole pairs absorbs heat, cooling the top surface.



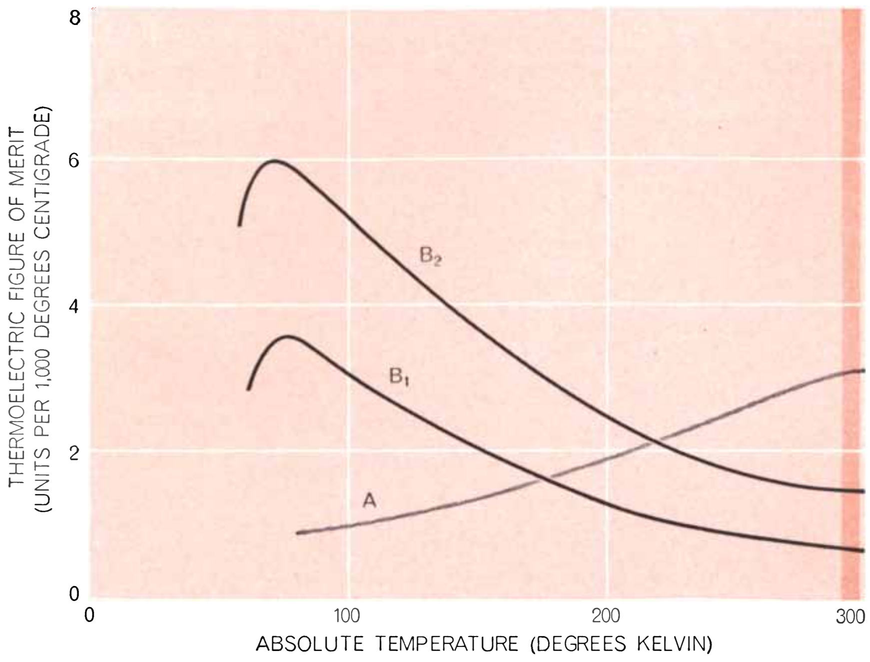
MECHANISM OF MAGNETORESISTANCE helps to explain why intensification of a magnetic field ultimately reduces the thermoelectric figure of merit. As the highly mobile electrons and holes in a semimetal are increasingly deflected by a magnetic field, their forward motion declines. This raises electrical resistance.

country and in Britain. Most notable is the work of T. C. Harman and J. M. Honig and their associates at the Lincoln Laboratory of the Massachusetts Institute of Technology. This group has recently achieved a remarkable result. They have used a heat sink near room temperature (running water), a magnetic field of 110,000 gauss (supplied by a huge electromagnet at the National Magnet Laboratory) and a specimen current of 55 amperes. Under these conditions they have measured a temperature drop of 101 degrees C. across a single crystal of pure bismuth in the optimum Ettingshausen configuration.

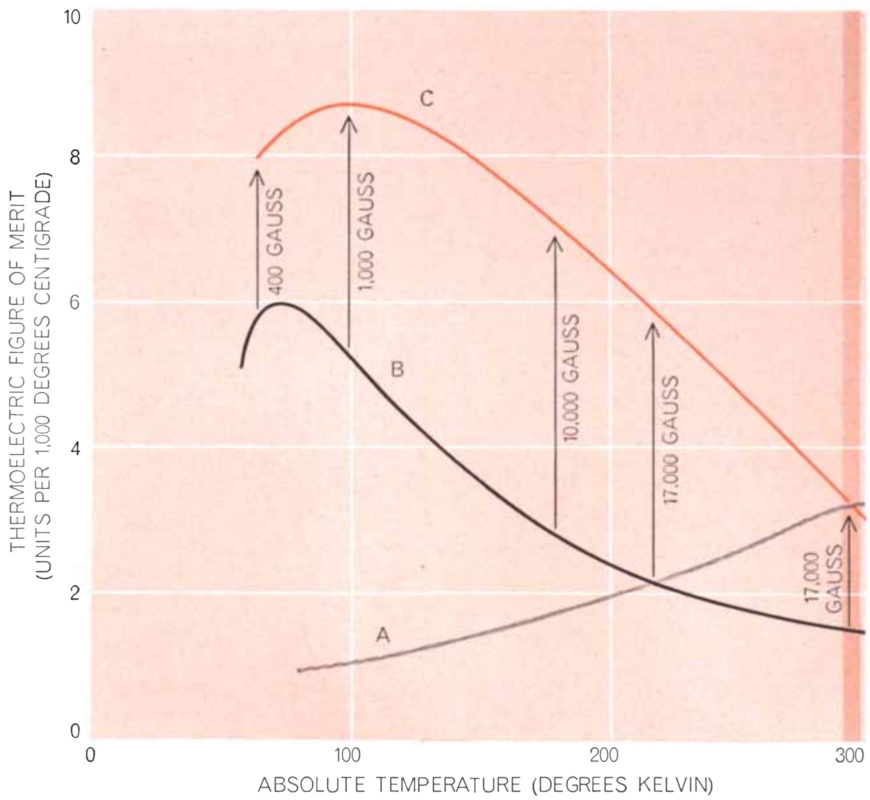
To achieve these large amounts of cooling, the Lockheed and Lincoln Laboratory groups used another suggestion made in the original paper by O'Brien and Wallace. This is a special type of "cascading" that is unique to thermomagnetic devices. A conventional cascade provides a way to increase temperature differences by using a large refrigerator as a heat sink for a small refrigerator. This type of cascading is commonly used in multistage thermoelectric refrigerators. For example, a seven-stage thermoelectric refrigerator built by John R. Madigan, George F. Boesen and others of the Borg-Warner Corporation, using conventional semiconductor materials, has achieved a temperature drop of 145 degrees C. below room temperature [*see illustration on page 71*]. This could be further improved by using the *n*-type bismuth-antimony alloys in a magnetic field as described above. A single-stage thermoelectric cooler, by comparison, gives a maximum temperature drop of about 75 degrees C.

In a thermomagnetic refrigerator a cascade could be achieved by stacking small bars on top of larger bars, but O'Brien and Wallace suggested that this same effect could be achieved by tapering a single block. The exponential shaping shown in the photograph on page 72 is equivalent to infinite cascading and gives considerably greater cooling than a rectangular block.

This simple trick gives thermomagnetic devices an important advantage over thermoelectric devices, which can be cascaded only by building up a complex pyramid of many segments. Another important advantage is that only a single type of material is required instead of the *n*-type and *p*-type couples used in thermoelectric devices. Certain theoretical arguments have been advanced to show that the ultimate refrigeration attainable with *n-p* pairs of thermoelectric materials is less by a fac-



THERMOELECTRIC PERFORMANCE of the best conventional thermoelectric material, such as bismuth telluride (A), is compared with the performance of a bismuth-antimony single crystal. Curve B_1 is for current flowing perpendicularly to the crystal's threefold axis of symmetry; curve B_2 is for current flowing parallel to that axis. The two curves reach their maximum near the temperature of liquid nitrogen. The dark-colored band at right indicates room temperature, where the conventional materials are still superior.



MAGNETIC ENHANCEMENT of the thermoelectric effect raises the figure of merit for a bismuth-antimony alloy from B to C. Curve A is again the performance of the best conventional material. The magnetic-field strength required for maximum enhancement is least at the lowest temperature. A field of 17,000 gauss was the maximum available from a standard laboratory electromagnet. These studies were conducted at the Bell Telephone Laboratories.

tor of two or four than that attainable with thermomagnetic materials. These theories are admittedly oversimplified and they do not consider the magnetic enhancement of thermoelectric materials described above. Thermoelectricity is still very much in the running because no magnetic field is required at room temperature, and significant magnetic enhancement can be achieved with small fields at low temperatures.

Let us take a closer look at the movement of the holes and electrons in a semimetal when it is used for thermomagnetic cooling. Consider an electric current flowing along a horizontal bar of semimetal in a transverse (horizontal) magnetic field [*see bottom illustration at left on page 78*]. If the left end of the bar is at a negative potential, the electrons travel from left to right and the holes travel from right to left. In the magnetic field both types of carrier are deflected by the so-called Lorentz force, which acts in a direction perpendicular to both the particle motion and the field. If the field is such that the negative electrons are deflected in a clockwise direction, they acquire a downward velocity. The holes, with their positive charge, are deflected in a counterclockwise direction in this same field and are therefore deflected downward as well.

Thus both electrons and holes move toward the bottom of the bar. (They carry no net current in this direction because they have equal and opposite charges.) They tend to pile up above their normal concentration at the bottom, while their numbers are depleted at the top. The excess electrons and holes recombine at the bottom, giving up energy in the form of heat. At the top the deficiency is made up by creating electron-hole pairs at the expense of energy, which is extracted from the crystal in the form of heat. This extraction of heat is the mechanism of Ettingshausen cooling.

If there is only one type of carrier (say electrons as in an *n*-type semiconductor), the average deflection of the moving electrons in the magnetic field is canceled by the buildup of a transverse electric field (known as the Hall effect), so that the resultant current flows straight along the bar. However, the electrons move with different velocities and there is a tendency for the fast ("hot") electrons to be deflected in one direction and the slow ("cold") ones in the opposite direction. This gives rise to an Ettingshausen temperature difference but one that is much smaller than

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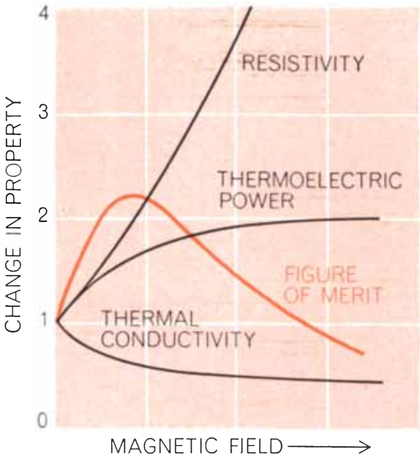
the two-carrier effect that takes place in semimetals.

Carrying this picture somewhat further, one can see why application of a magnetic field leads to large increases in the electrical resistivity of a semimetal. This magnetoresistance, as it is called, ultimately harms both the thermoelectric and the thermomagnetic figures of merit. In a semimetal the downward velocity of electrons and holes is proportional to the magnetic field [*see bottom illustration at right on page 78*]. Now consider the same field acting on this downward motion. The electrons are again deflected clockwise and the holes counterclockwise, so that each type is deflected along the bar, back in the direction from which it came. Since this second deflection is again proportional to the field, the original forward velocities of both electrons and holes are reduced by an amount proportional to the square of the magnetic field. Since the electrons and holes in semimetals are highly mobile, the magnetic deflections are large, and the resultant forward motion is only a small fraction of that achieved when the magnetic field is absent. Thus one can account for the large magnetoresistance effect in semimetals. In semiconductors, which have only one type of carrier, the magnetoresistance effect is usually much smaller for a given field.

Can this simple model be extended to explain the effects of a magnetic field on the thermoelectric power of a semimetal? If the electrons and holes had identical properties but opposite charge, the resultant thermoelectric power would be zero (the *n*-type and *p*-type effects would cancel each other) and this would not be changed by the magnetic field. The difference between the two mobilities must be considered, but even this is not sufficient. The complexity of this problem is illustrated by some of our experiments on pure bismuth crystals. In certain orientations as the field is increased the thermoelectric power increases, as described above. In other orientations the thermoelectric power decreases with increasing field and even changes sign from *n*-type to *p*-type.

No simple model of deflected electrons and holes can explain all these effects. One can only say intuitively that the large deflections due to the cooperation of high-mobility electrons and holes will result in changes much larger than those usually observed in semiconductors. These changes can be understood in detail by extending the theory of the transport of heat and electricity in semimetals to the case of highly anisotropic

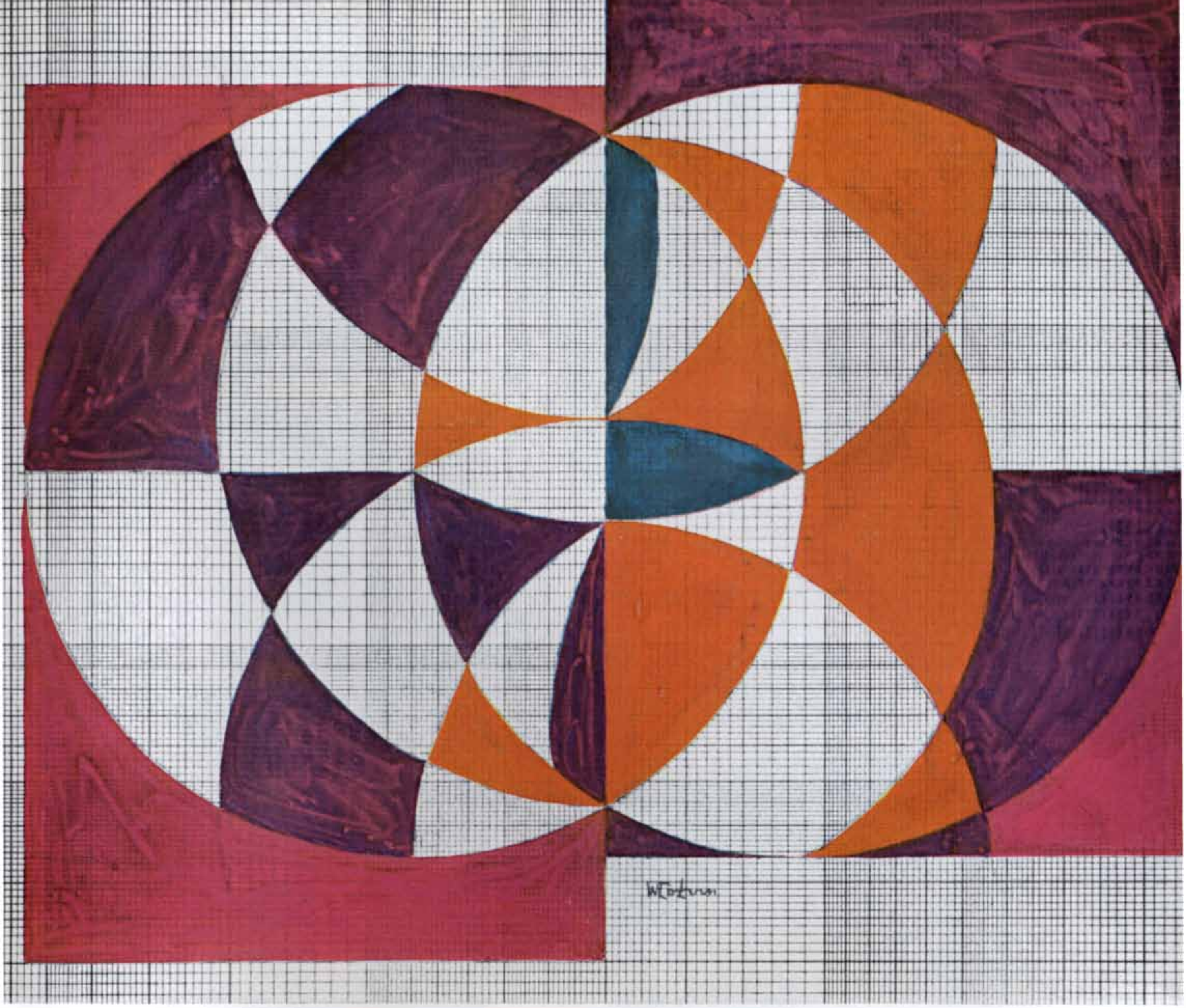


EFFECT OF MAGNETIC FIELD is to shift the three factors that enter into the thermoelectric figure of merit. Enhancement occurs until the sharp rise in electrical resistance offsets the gains in the other two factors.

electrons and holes in a magnetic field. As this theory develops, one should be able to predict new magnetothermoelectric effects and to optimize the desirable properties of semimetals.

What are the prospects for practical applications of thermomagnetic cooling or magnetically enhanced thermoelectric devices? As noted earlier, small-scale uses have been developing for conventional thermoelectric generators and thermoelectric refrigerators. Magnetothermoelectric devices will have little immediate impact on these existing applications, but they may extend the range of electronic cooling to lower temperatures, even below that of liquid air. They could also be used to generate electricity from the flow of heat at low temperatures.

The problem here is to allow heat to flow through the device from some source near room temperature to a heat sink at a much lower temperature. Such a sink could be provided by a quantity of liquefied gas, such as the liquid oxygen used in rocketry or the liquid methane that is transported by the shipload as a commercial fuel in certain parts of the world. The source of heat might be the atmosphere or a body of water. For example, as heat flows from river water into a ship's hold to vaporize the cargo of liquid methane, a fraction of this heat could be converted into electricity by a magnetothermoelectric generator. (This can be considered the production of electricity from a "source" of cold.) There is little doubt that the new knowledge of semimetals will ultimately lead to improved methods of controlling and converting energy.



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EIGHT GENOTYPES of the flower *Impatiens balsamina* are portrayed here with the symbols of the genes that determine their pigmentation. Uppercase letters signify dominant genes, lowercase letters recessive genes. Gene designated by *L* (or *l*) governs the production of purple pigment and that designated by *H* (or *h*) governs the production of red pigment. *P* (or *p*) denotes a gene that regulates the amount of pigment produced. A table of the pigments present in the four flowers at right appears on page 86.

Flower Pigments

A few closely related pigments produce the full range and gradation of flower colors from bright blue to rosy red. Recent investigations have shed light on their molecular structures and genetic origins

by Sarah Clevenger

The rich variety of colors displayed by flowers has presented a challenge to both the chemist and the biologist. It has proved no easy matter to answer all the questions that may be asked. Why do the brilliant colors of the plant tend to be concentrated in the flower? Are many pigments involved or only a few, modified in various ways? How are the pigments synthesized in the plant? What function do they serve? Questions such as these have provided new insights into the intricacies as well as the beauties of nature.

Current studies of flower pigments and their control by genes can be traced to two seemingly unrelated researches of about 100 years ago. One was the experiments of Gregor Mendel, who worked out the basic laws of inheritance in his classic studies of the garden pea. The other was the synthesis by a young English chemist, William Henry Perkin, of the first coal-tar dye, mauveine. Perkin's success inspired an intensive investigation of pigments, both natural and synthetic. In the late 19th century and the early years of the 20th chemists such as Richard Willstätter and Stanislaus von Kostanecki in Germany and Robert and Gertrude Robinson in Britain identified many flower pigments and worked out their molecular structure.

The rediscovery of Mendel's work in 1900 stimulated research on the inheritance of flower color. A group of geneticists at the John Innes Horticultural Institution near London were early leaders in this field. Although many plant geneticists had examined the inheritance of flower color, Muriel Wheldale Onslow of the University of Cambridge was the first to realize that here might be a way to investigate the chemical events controlled by Mendelian factors. She reasoned that the presence of a simple biochemical substance—such as a pigment—might be correlated with a change in a single gene. Working in association with H. L. Bassett, she showed that this correlation did indeed exist in snapdragons, in spite of the fact that the identification of the pigments was incomplete. This work initiated the biochemical-genetic approach to the problem of plant pigments. It was also the first clear-cut demonstration of a link between a single gene and a biochemical entity.

Later in the 1930's Rose Scott-Moncrieff, a student of Muriel Onslow's, noted certain basic patterns of inheritance in the course of working with genetic varieties of many different plant species. Building on these classic studies, with the advantage of new analytic techniques such as paper chromatography, plant biochemists and geneticists have in recent years learned much more about the nature of the pigments and their production by the living cell.

Flower pigments are easily divided into two groups: the water-soluble flavonoids found in the cell vacuole, which give rise to red, blue and yellow colors, and the fat-soluble carotenoids located in the plastid bodies of the cell, which are red, orange or yellow. Although the carotenoids make a substantial contribution to the coloring of flowers, this article will deal only with the flavonoids. These pigments have a basic chemical structure consisting of two six-carbon-atom benzene rings linked together by a chain of three carbon atoms. This basic molecular structure of 15 carbon atoms is sometimes written $C_6—C_3—C_6$.

The various groups of flavonoid pigments are differentiated by the level of oxidation of the three-carbon chain. Two of the more common flavonoids are the anthocyanins (from the Greek for "blue flowers"), which come in shades of blue, purple or red, and the flavonols (from the Latin for "yellow"), which are yellow or ivory. The anthocyanins have fewer chemical variations than the flavonols.

In the cells of the flower the pigment is usually bound to one or more units of sugar, which make the molecule more soluble in water. When the sugar is attached, the pigment is known as an anthocyanin; the pigment without the sugar is called an anthocyanidin.

Six common and seven rare anthocyanidins have been isolated from flowers. The illustration on page 87 shows the chemical structure of the common ones. It will be seen that they differ in the number and arrangement of chemical groups attached to the "*B*" ring of the molecule. This ring may carry one, two or three hydroxyl groups (OH). Occasionally a methyl group (CH_3) replaces the hydrogen atom of a hydroxyl group.

Cyanidin, the most common anthocyanidin, was first isolated from *Centaurea cyanus,* the blue cornflower, which gave the pigment its name. Other anthocyanidins were similarly named. The red pigment pelargonidin was originally found in a bright red geranium of the genus *Pelargonium.* The deep purple pigment delphinidin was isolated from a member of the genus *Delphinium.* These three pigments differ from one another by the number of hydroxyl groups found on the *B* ring.

Another related group of pigments differ in the number of methyl subunits on the *B* ring. This group includes the purple pigment petunidin (isolated from petunias), the rosy red pigment peonidin (found in peonies) and the mauve pigment malvidin (discovered in a member of the mallow family, *Malvaceae*).

An increase in the number of hydroxyl groups on the *B* ring makes the pigment bluer, whereas an increase in methyl groups makes the pigment redder.

The wide variety of flower colors is due not only to the different pigment molecules but also to the different cellular environments in which the pigments are found. Anthocyanins, for example, change color when they accept or release hydrogen ions, depending on the environmental conditions. In a slightly acid environment, which contains an excess of hydrogen ions, the pigment is reddish. As the hydrogen-ion concentration falls, the pigment becomes bluish, then colorless and finally decomposes in a basic solution. The color may also change when the anthocyanins form complexes with tannins and other pigments. Metallic ions, such as iron or aluminum, can also form complexes with the pigment to produce different colors. Thus a few pigments under a variety of environmental conditions are able to produce a wide spectrum of flower colors.

Often associated with the anthocyanidin pigments are the colorless compounds known as leucoanthocyanins. Only leucopelargonidin, leucocyanidin and leucodelphinidin occur frequently, and these are more often found in the woody portion of the plant than in the more highly colored portions.

Since flower color is determined not only by the pigments present but also to some extent by the cellular environment, it is possible for different pigments to produce the same color. Although some pigments produce characteristic colors, the only sure way to identify the pigments present is by extraction and separation. Pigments can be extracted from flowers with alcohol that has been slightly acidified to keep the pigment from decolorizing. The sugar groups are removed by boiling the pigment with dilute acid. To this solution is then added a small amount of isoamyl alcohol, which rises to the top, carrying the pigment with it.

The mixture of pigments can then be separated by paper chromatography. In this technique pigments of different chemical compositions migrate at different speeds when placed on absorbent paper and exposed to the action of solvents [*see illustration on page 91*]. During the first run of a chromatogram the pigments are spread out along one line and may be overlapping, which makes identification difficult. After the chromatogram has dried it is run in the second direction with the line of pigments along the bottom of the sheet. The resulting pattern of spots is spread over two dimensions and is usually quite faint, but it can be intensified by the use of appropriate sprays. Several pigments fluoresce characteristically under ultraviolet radiation, and this also aids in the identification. A certain amount of information can be derived about an unknown anthocyanidin by comparing its performance in a two-dimensional chromatogram with that of pigments of known configuration. Thus the isolation, separation and identification of flower pigments can be achieved with a high degree of accuracy.

To determine the forms of the pigments as they occur naturally in the cell, a simple alcohol extract of the pigments is applied to chromatography paper. A two-dimensional chromatogram of such an extract is shown on the cover of this issue of *Scientific American*.

Although it is not easy to isolate and identify the various plant pigments, it is a far more difficult problem to discover how the plant produces them. Green plants can synthesize all organic compounds—both simple and complex—from a few inorganic substances. The metabolic pathway of any one compound is very hard to follow. Some success in elucidating the synthesis of the flavonoid pigments has, however, been gained by two methods, one biochemical, the other genetic.

In the first method the metabolic pathway is followed with the help of molecules labeled with radioactive carbon atoms. Using this technique J. E. Watkin, E. W. Underhill and A. C. Neish of the National Research Council of Canada and others have established the broad outline of the biosynthetic pathway of the flavonoids. The Canadian group studied the formation of the flavonol quercetin in buckwheat. They found that the *A* and *B* rings of the molecule are synthesized by different pathways. Ring *B* and the three-carbon chain are formed by the condensation of a seven-carbon sugar with a three-carbon molecule of pyruvic acid. After several changes, in which one carbon atom is lost, the resulting product is phenylpyruvic acid, a C_6–C_3 molecule. This molecule then condenses with three molecules of acetic acid, which are the precursors of ring *A*, to yield the C_6–C_3–C_6 backbone of the flavonoid pigments.

It is not clear at what point in the synthesis the hydroxyl and methyl groups are introduced into the structure. Judging from the relative distribution in nature, the more primitive, or basic, structure carries two hydroxyl groups on the *B* ring. This form or its precursor is modified by the addition or removal of a hydroxyl group. Probably one of the late steps is the addition of methyl groups to form the methoxyl groups. Often delphinidin, petunidin and malvidin are present together in a flower; this would be expected if malvidin is formed by the stepwise methylation of delphinidin or its precursor.

The second—the genetic—approach to studying pigment biosynthesis is a method that has been successful in elucidating biosynthetic processes in microorganisms. The method involves the use

GENOTYPE	PIGMENTS		FLOWER COLOR
	ANTHOCYANIDINS	FLAVONOLS	
IlhhPp	PELARGONIDIN	KAMPFEROL	PINK
IlHhPp	PELARGONIDIN LEUCOPELARGONIDIN	KAMPFEROL	RED
LlhhPp	MALVIDIN	KAMPFEROL MYRICETIN	PURPLE
LlHhPp	MALVIDIN PELARGONIDIN LEUCOPELARGONIDIN	KAMPFEROL MYRICETIN	MAGENTA

FLAVONOID PIGMENTS found in the petals of four genotypes of the flower *Impatiens balsamina* include anthocyanidins (from the Greek for "blue flowers") and flavonols (from the Latin for "yellow"). Anthocyanidins can color petals blue, purple or red depending on their chemical environment. Flavonols contribute yellow or ivory shades.

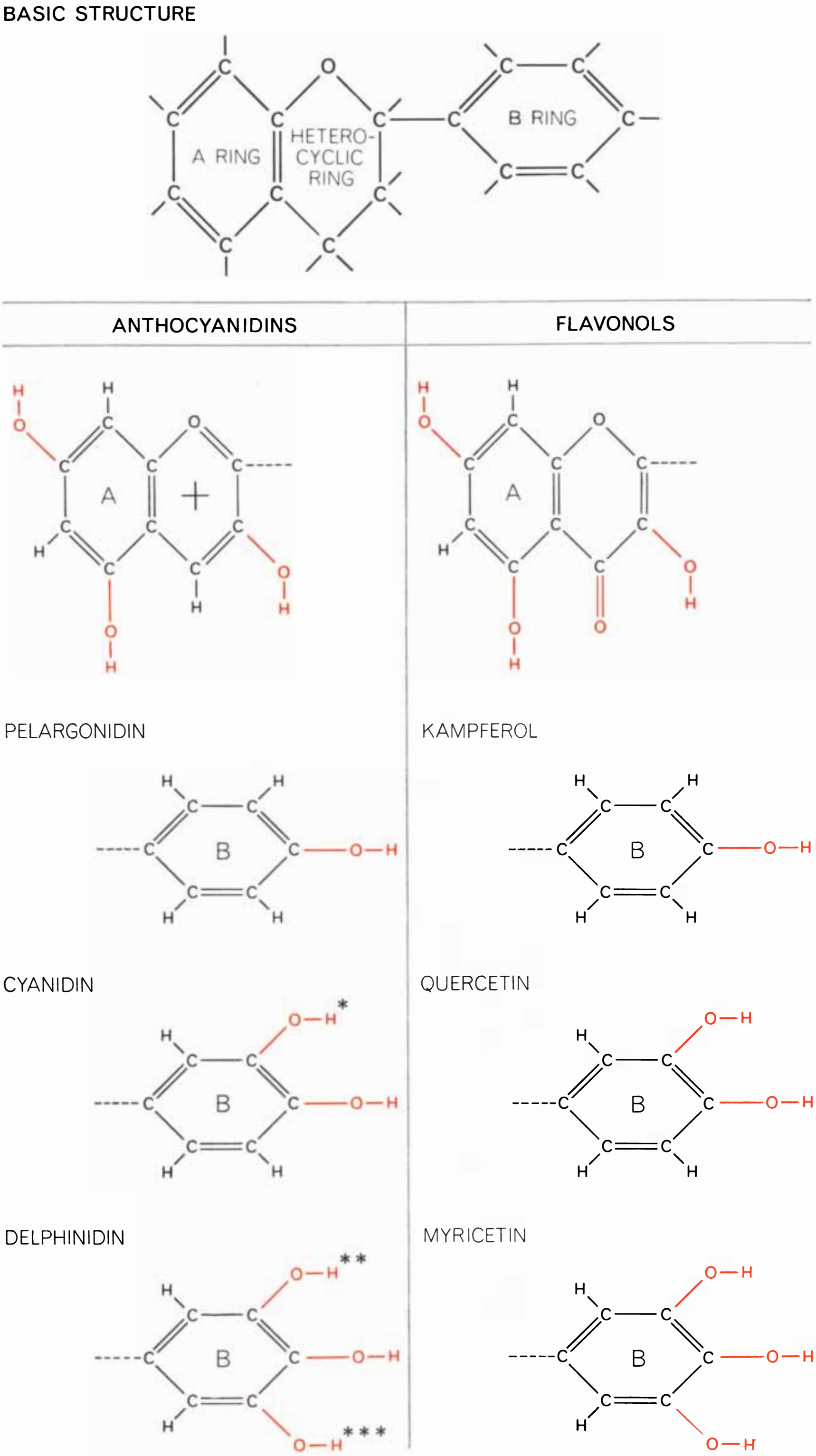
of mutant forms and is therefore more difficult to apply to higher plants, which have longer generation times and a more varied metabolism. Nevertheless, the method has contributed significantly to the knowledge of pigment synthesis.

A genetic study of this type has been carried out with members of the genus *Impatiens*. The generic name of these plants is derived from the characteristic fruit, which opens violently when mature and in the process projects the seeds some distance. Because this can happen if the capsule is merely touched, the plant is known as touch-me-not in many lands and in many languages. Among the members of the genus are the jewelweeds of eastern North America and the popular house plant often called sultana after the Sultan of Zanzibar, in whose country the plant was collected.

A group of plant physiologists at Indiana University headed by Charles W. Hagen, Jr., has been studying the genetic control of the flower pigments of *Impatiens balsamina*, the common garden balsam. Its flowers vary in color from white and pastel shades to deep purple or bright red. The mode of inheritance of these flower colors was determined several years ago by D. W. Davis and his co-workers at the College of William and Mary. The identification of the anthocyanidin pigments present in the different hereditary strains was made recently by Ralph Alston and Hagen and the flavonols were identified by me.

The formation of flower color in balsams is controlled by three separate sets of genes. Two genes, *L* and *H*, determine the kinds of pigment produced; the third gene, *P*, determines the amount. One form of this third gene suppresses pigment production and the flowers are very pale. Another form of the gene acts as an intensifier and the flowers are brightly colored.

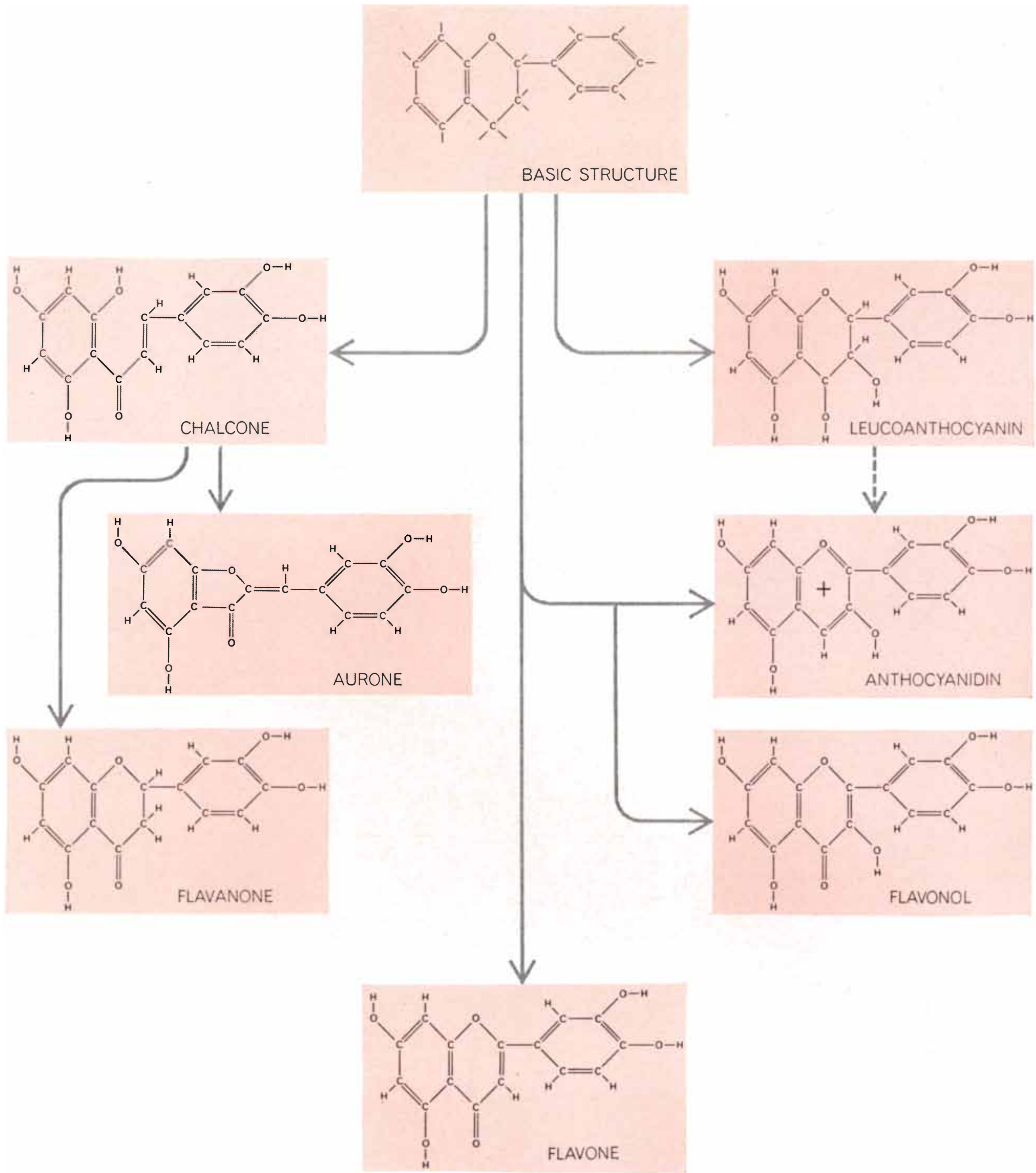
Analysis of the petal pigments present in the various strains has provided some interesting correlations [*see illustration on opposite page*]. When the gene *L* is present, the flower contains malvidin and myricetin, a flavonol resembling delphinidin. Since both pigments carry three groups on the *B* ring, it seems that *L* is associated with the addition of the third hydroxyl group. A similar correlation between the gene *H* and the presence of pelargonidin and leucopelargonidin suggests that *H* is associated with the formation of a single hydroxyl group on the *B* ring. Inasmuch



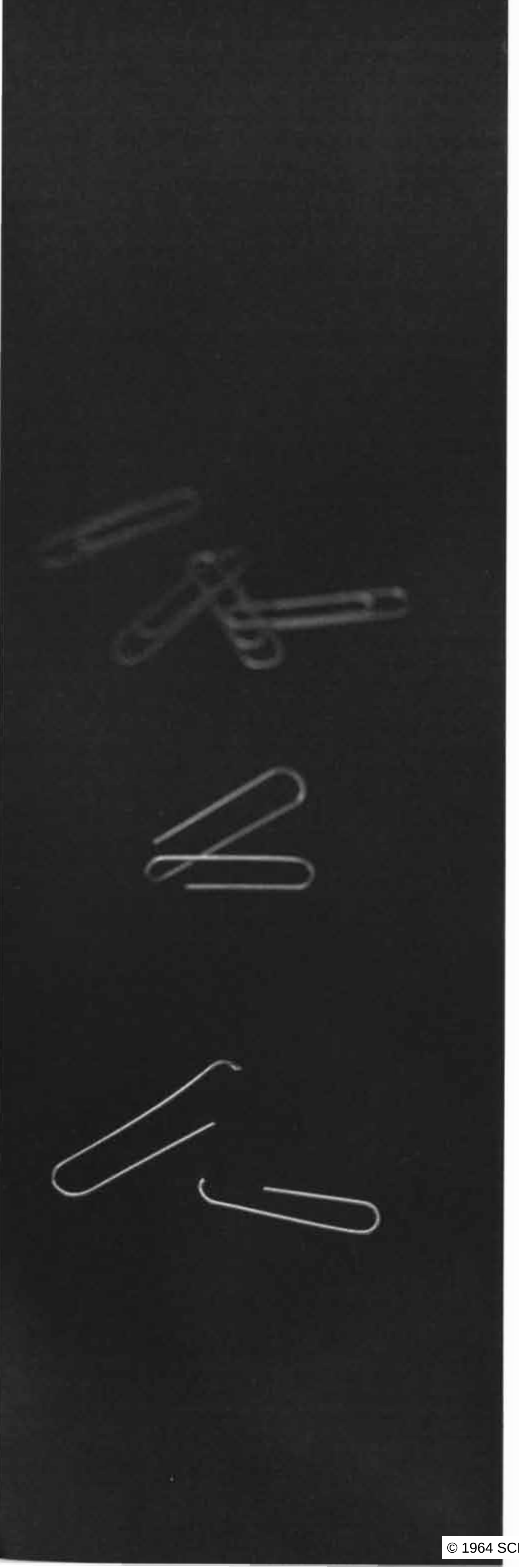
CHEMICAL STRUCTURES of the common anthocyanidin and flavonol pigments are variations of a basic configuration (*top*), in which two six-carbon-atom benzene rings (*A and B*) are linked by a smaller three-carbon-atom structure known as a heterocyclic ring. What distinguishes the anthocyanidins from the flavonols is the level of oxidation of the heterocyclic ring; the flavonols have a doubly bonded oxygen atom there. Differences in hues within each family depend mainly on groups of atoms attached to the *B* ring. The pigments produced by the addition of one, two and three hydroxyl groups (OH) to certain positions on the *B* ring are shown at bottom. If a methyl group (CH_3) were substituted for the hydrogen atom in the hydroxyl group indicated by an asterisk, the result would be a rosy red pigment called peonidin. A similar methyl substitution at the double asterisk would produce petunidin and at the double and triple asterisks malvidin.

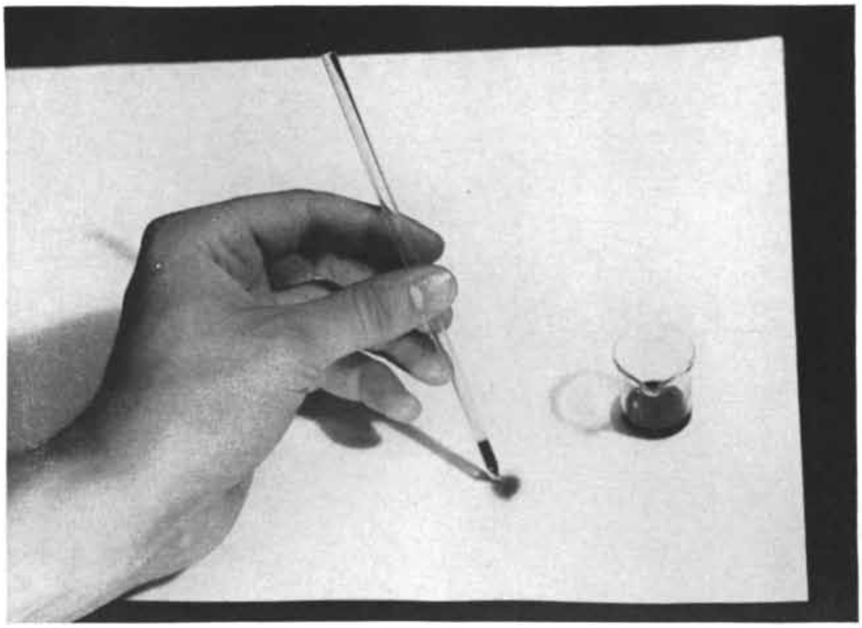
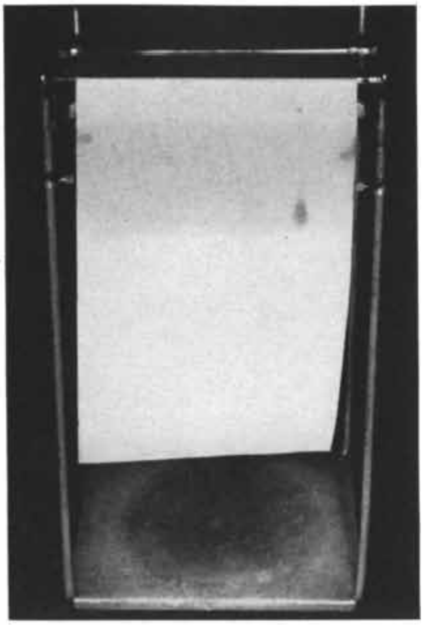
as the synthesis of anthocyanidins, flavonols and leucoanthocyanins are all affected by the two genes, it is probable that these compounds are synthesized along similar pathways. The pigmented sepals contain a different complement of pigments from that found in the petals.

In order to study pigment development under more uniform conditions than those found in the greenhouse, Attila O. Klein of the Indiana group developed a method of growing detached petals in a nutrient culture solution. Light is needed both for the production of the anthocyanins and the expansion of the petals. One unexpected result of this work revealed that the petals in culture are able to synthesize certain pigments (cyanidin, peonidin and quercetin) that are normally found in the colored sepals of these strains but



PIGMENTS MAY BE SYNTHESIZED in the flower at different stages along a multibranched, metabolic pathway as successive variations are introduced to the basic flavonoid molecule (*top*). One branch leads to the formation of the anthocyanidins, possibly by way of the colorless leucoanthocyanins (*broken arrow*). Other branches lead to the flavonols and other flavonoids. Slight chemical variations among the flavonoid pigments contribute to the full spectrum of colors displayed by the world of flowers.



PIGMENTS ARE ANALYZED by a technique known as paper chromatography. A solution of alcohol and dilute mineral acid containing several pigments from one flower is spotted on the corner of a sheet of paper (*left*). The paper is then hung from a trough that contains a solvent (*right*). As the solvent travels down the paper (*darker area at top*) different pigments will be deposited at different distances from the point of origin, depending on their chemical structure. The pigments can be further separated by rehanging the paper from its edge and using a different solvent. The solution can also be made to ascend the paper from a trough of solvent at the bottom; the chromatogram on the cover was made by a combination of the two methods.

not usually in the petals. This is further evidence that the action of a gene depends on the chemical, physical and genetic environment in which it acts. The cells of the cultured petals are able to produce substances that intact petals normally do not synthesize.

By pooling such information from various laboratories, one can speculate concerning the possible pathway for the synthesis of the flavonoid pigments—a multibranched pathway leading to many variations of the basic C_6—C_3—C_6 skeleton. One branch leads to the formation of the anthocyanidins, perhaps by way of the colorless leucoanthocyanins. Other branches lead to other flavonoids, such as the chalcones, the flavonols and the aurones. The differences between these various groups are slight; they involve the level of oxidation of the three-carbon chain and the number, kind and position of additional groups. Yet these slight variations contribute to the full spectrum of colors displayed by the plant world.

The comparison of the pigment complement present in different species of the same genus gives valuable information concerning the evolution of species within the genus as well as about the genetic control of pigment synthesis. Within any genus the differences between species have evolved gradually over the years through mutation and selection of genes. Undoubtedly some of these genetic changes have affected the synthesis of pigments. Consequently a comparison of the pigments in closely related species should shed light on the fine-scale evolution of pigment synthesis.

The genus *Impatiens* is well suited to such a study because it contains a great many species with a wide variety of flower colors. The greatest number of species are found in the tropical areas of the Eastern Hemisphere. Two somewhat similar plants I have investigated provide an excellent illustration of the possibilities offered by the comparative study of pigments. Both plants are native to Indonesia. *Impatiens platypetala,* found in Java and Sumatra, has large, showy magenta flowers. On the nearby island of Celebes grows an *Impatiens* with bright yellow-orange flowers. Because the two plants are so similar some taxonomists consider the second to be a variety of the first and call it *I. platypetala* var. *aurantiaca.* Others maintain that the second is a separate species and should be recognized as *I. aurantiaca.*

An analysis of the flower pigments strengthens the second viewpoint. The magenta petals of *I. platypetala* contain mainly malvidin, but the orange flowers of *I. aurantiaca* contain an apparently unrelated anthocyanidin not previously found in nature. The structure of the new pigment, called aurantinidin, is now being worked out by J. B. Harborne of the John Innes Institute. The pigment seems to resemble another rare anthocyanidin called luteolinidin. Since the two groups of plants synthesize such widely differing pigments, it seems unlikely that they are closely related, and so one can conclude that their resemblance is superficial rather than fundamental. A mixture of pigments from the flowers of these two species was used to make the chromatogram shown on the cover.

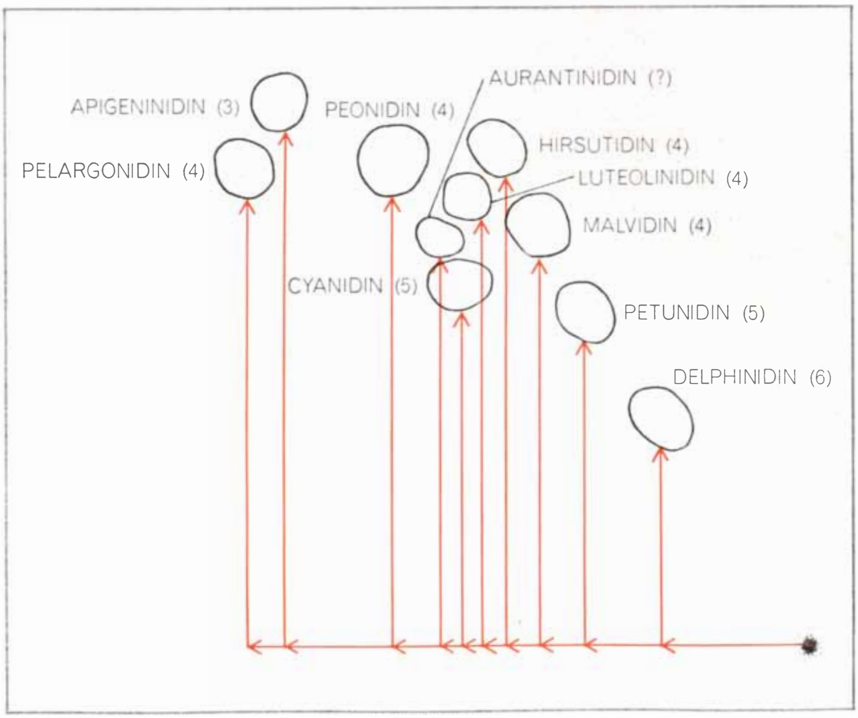
So far only a small percentage of the known species of the genus *Impatiens* has been analyzed. Cyanidin and malvidin are the most common pigments in the petals; cyanidin is the most common in the sepals and stems. From a morphological point of view one would expect the petal to be more highly evolved than the sepal, and sepals, in turn, to be more complex than the stem. It appears that this ordering may also be true for the pigments if one assumes that the nonmethylated pigments are the more primitive and the methylated pigments the more elaborate.

This suggests that the biosynthetic sequence leading to the production of anthocyanidins, at least as far as the *B* ring is concerned, proceeds as follows: first, two hydroxyl groups are added as in cyanidin, then a third as in delphinidin; finally stepwise methylation produces first petunidin, then malvidin. At times methylated pigments appear with small amounts of their unmethylated counterparts, indicating that such a stepwise procedure is plausible. These separate steps appear to be under the control of different genes; the pigment produced in any given cell depends on whether a particular gene functions or is prevented from functioning.

In spite of the abundance of the flavonoids in nature, they represent an unresolved area of plant metabolism. One of the more important unanswered questions about anthocyanins in particular and flavonoids in general concerns their function in the living plant. Many roles in metabolism have been postulated but none has actually been shown to obtain in the plant. These substances may be end products of metabolism that gradually build up in the cell; they may act as agents of oxidation and reduction; they may be waste products that serve little or no use, or perhaps they act as antifungal agents.

Undoubtedly one of the functions of the pigments in the flowers is to attract the pollinating agents. Although it is quite clear that flower pigments do perform this function, it is probably a function that developed only secondarily; anthocyanins are found in plants that are not dependent on attracting pollinating agents. Bright red and red-orange flowers, particularly prevalent in the Tropics, attract birds. Bees favor yellow and blue flowers. Day-flying butterflies pollinate brightly colored flowers, whereas their night-flying counterparts, the moths, choose the white or pale flowers, which are more noticeable during the poorly lighted hours. In addition to attracting pollinators by the conspicuousness of their coloring, most flowers have streaks, dots or lines known as pollen guides to help orient the alighting visitor in search of nectar.

Since flower pigments are so widely distributed, one feels that they must have other important functional roles. With the wide appeal that this subject has for plant physiologists, geneticists, biochemists and taxonomists, it is certain that a great deal of new information on the subject of flower pigments will be produced in the next few years. However one looks at these pigments, they are a most attractive subject for investigation.



TWO-DIMENSIONAL PAPER CHROMATOGRAM, similar to the one on the cover, is made by first hanging the spotted paper and allowing the solution containing the pigments to descend; an edge is then placed in a different solvent and the solution ascends. In this schematic drawing the general areas in which the various anthocyanidin pigments are deposited are indicated. The number in parentheses after the name of each pigment denotes the number of free hydroxyl groups on a molecule of that pigment.

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VISUAL SEARCH

The cognitive operations involved in looking for a face in a crowd or a word in a list can be studied by timing the scanning process. Apparently many such operations can be carried out simultaneously

by Ulric Neisser

One of the faces in the crowd at the top of the opposite page is that of John F. Kennedy, watching a football game shortly before his inauguration. Most people find it easy to single him out by scanning the photograph quickly, with scarcely a glance at the other faces. We perform such searching and scanning operations many times a day, for example in looking up the telephone number of a Mr. Smith who lives on Fifteenth Street. There are a lot of Smiths, but it does not take long to skim down the column to the correct address; the irrelevant addresses are passed over so quickly that they seem blurred. In a sense they are not seen at all. In much the same way one sees, but does not see, dozens of hurrying figures when trying to locate a friend in a busy air terminal. And yet the context—the unfamiliar travelers, the wrong addresses, the crowd of faces surrounding Mr. Kennedy—must surely be examined if the search is to succeed. The scanner must extract enough information from the elements of the context to make sure, or at least to suggest, that they lack the properties that define the object of his search. So in a sense the context *is* seen. There are evidently intermediate stages of perception; it is not a case of "now you see it" or "now you don't" but of something in between.

The complexity of the cognitive processes operating at these stages depends on the nature of the target and the field. In one extreme case the field is empty except for the target; elementary visual mechanisms for distinguishing contrast and contour suffice to locate the parachutist against a cloudy sky in the illustration at the bottom of the opposite page. The column of numbers on this page, however, represents a very different task: the search is for the one number in the list that is a multiple of 7, and in this case the analysis required is far more than visual. It does begin with elementary discriminations of lines and curves that form a pattern, but it goes on to interpret those patterns as numbers and then to subject the numbers to a rather advanced symbolic process. The search for Mr. Smith's telephone number is at an intermediate level of complexity, somewhere between "seeing" and "reading." The information in the wrong addresses need not be processed fully; the visual pattern of the street names penetrates the nervous system only far enough so that some subsystem sensitive to "Fifteenth Street" can have an opportunity to react.

Perceptual analysis, then, has many levels. It seems to be carried out by a multitude of separate mechanisms arranged in a hierarchy, the more complex mechanisms receiving as their input the information that has been assimilated and predigested by more elementary ones.

My associates and I have been interested in visual search as a tool with which to investigate this hierarchy of information-processing operations. We have studied processes at the level of telephone-directory search: at the boundary between perception and thought. (Our experiments have been conducted at the Lincoln Laboratory of the Massachusetts Institute of Technology, at Brandeis University and at Harvard University's Center for Cognitive Studies, with support from the National Science Foundation.) By timing people as they scan lists of letters or words in search of specified targets, we hope to learn something about the various visual and cognitive processes involved and about how they are organized and interrelated. To the extent that these processes are a form of thinking, what we measure is perhaps an approximation of "the speed of thought."

We ask a person to scan a list, usually consisting of 50 items, to find a specified "critical item," or target. The lists are generated by a computer; each item is a group of letters, a group of letters and digits or a word, all drawn at random from a pool of items with the desired characteristics. In the simplest condition the critical item is a letter, for example *K* in the list at the left in the illustration on page 96. The subject peers through a window into a box within which the experimenter positions a list. When the subject is ready to begin scanning, he turns a switch to illuminate the list and start an electric timer. He scans the list until he

104
493
762
288
844
126
925
417
338
500
675
313

SEARCH TASK here is to find the one three-digit number that is a multiple of 7.

A FAMOUS SPECTATOR at the Orange Bowl football game on January 2, 1961, was President-elect John F. Kennedy. The reader should have little trouble finding him but will be hard put to explain how that one face can be identified among so many.

LONE PARACHUTIST can be discovered very quickly against a cloudy but featureless sky in this photograph. Elementary visual mechanisms are all that are required in searching for any target, even a small one, that is in strong contrast to its background.

EHYP	ZVMLBQ
SWIQ	HSQJMF
UFCJ	ZTJVQR
WBYH	RDQTFM
OGTX	TQVRSX
GWVX	MSVRQX
TWLN	ZHQBTL
XJBU	ZJTQXL
UDXI	LHQVXM
HSFP	FVQHMS
XSCQ	MTSDQL
SDJU	TZDFQB
PODC	QLHBMZ
ZVBP	QMXBJD
PEVZ	RVZHSQ
SLRA	STFMQZ
JCEN	RVXSQM
ZLRD	MQBJFT
XBOD	MVZXLQ
PHMU	RTBXQH
ZHFK	BLQSZX
PNJW	QSVFDJ
CQXT	FLDVZT
GHNR	BQHMDX
IXYD	BMFDQH
QSVB	QHLJZT
GUCH	TQSHRL
OWBN	BMQHZJ
BVQN	RTBJZQ
FOAS	FQDLXH
ITZN	XJHSVQ
VYLD	MZRJDQ
LRYZ	XVQRMB
IJXE	QMXLSD
RBOE	DSZHQR
DVUS	FJQSMV
BIAJ	RSBMDQ
ESGF	LBMQFX
QGZI	FDMVQJ
ZWNE	HQZTXB
QBVC	VBQSRF
VARP	QHSVDZ
LRPA	HVQBFL
SGHL	HSRQZV
MVRJ	DQVXFB
GADB	RXJQSM
PCME	MQZFVD
ZODW	ZJLRTQ
HDBR	SHMVTQ
BVDZ	QXFBRJ

THE LETTER *K* is the target in the list at left, and the "critical item" is the one that includes it. A more difficult task is a search for an item that does *not* include a specified letter. In the list at right, for example, there is only one item that does not include a *Q*.

finds the target, then turns the switch again to stop the clock, and the experimenter records the total time required for the search.

Not all this time, to be sure, is needed for perceptual analysis of the items through which a person is searching. He may need some time to get started, and he certainly needs time to execute the response that stops the clock. This complication is dealt with by having him scan a number of lists, in each of which the *K* is in an unpredictably different place. The additional time needed to find a *K* that is in the 31st line rather than in the 21st can be ascribed entirely to the visual analysis of the intervening 10 lines.

Now, if some fixed amount of time is needed for the analysis of each line, the overall duration of the search will vary as a linear function of the number of lines involved, that is, of the actual position of the target in the list. And in fact, when position is plotted against time, the points are almost invariably fitted well by a straight line. The graph at the top of the opposite page is typical of thousands we have obtained. The most important information to be read from such a line is its slope, which indicates the increase in search time required for each additional line scanned. This time per item, then, measures decision time uncontaminated by reaction time; it seems to represent a relatively direct measure of the time used in perceptual analysis.

The speed with which a person scans tends to decrease dramatically during the course of a long experiment. On the first day his graph may indicate that he is using more than a second to process each line, but after two weeks of practice his time per item may well be only a tenth as long. Most subjects stabilize at about 10 lines per second with targets such as *K* and a list such as the one illustrated. This suggests, plausibly enough, that most people do not enter the experiment with ready-made perceptual hierarchies for finding *K*'s efficiently. They acquire—or perhaps one should say that they "construct"—a recognition system in the course of practice.

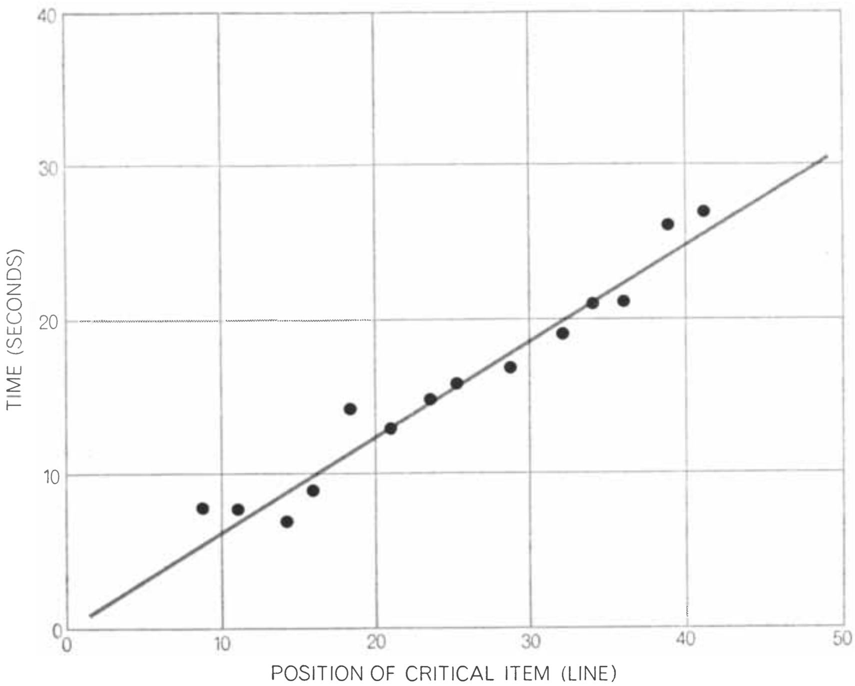
With repeated scans they discover the perceptual operations that seem to be minimally sufficient for the problem. For example, some may find techniques that enable them to examine several lines at once, whereas at first they had fixated each item separately and successively. For some perhaps a rechecking procedure, involving frequent regressions to preceding lines, seems indispensable at first and is dispensed with later. Certainly the operations on which a subject eventually settles, and the manner in which he comes to adopt them, depend on many variables.

Although this kind of perceptual learning is of great theoretical interest, its course seems to be somewhat different in each subject and we have so far found no satisfactory way to study it. Our chief interest, therefore, has been in the kind of pattern analysis established after long practice. The first question to be asked about the modes of analysis used by experienced subjects concerns their thoroughness. Does the subject "identify" each letter to determine if it is a *K*? The answer is almost certainly that he does not. Our conviction on this point arises partly from our volunteers' reports that the letters are "not seen" or are "only a blur," but even more from theoretical considerations and a further experiment.

The fact is that letter identification is not necessary for finding a *K*. The analysis of each line need go only far enough to detect some of the distinctive features that, in various overlapping and probabilistic combinations, determine particular letters. These features must be characteristics of the given visual configuration: things like particular angles, open spaces, parallel lines, locations of the geometric center of gravity and so on. Rudimentary visual processes that precede the identification of letters suffice to detect such features. (The relation of the target's configuration to that of the context plays an important role [*see illustration at right*]. Operations that suffice to distinguish a Z from a set of rounded letters cannot be relied on in a context of angular letters. The more extensive operations needed in the latter case take more time.)

Some combination of feature-detectors is presumably sufficient to penetrate the nervous system far enough to stimulate activity in some subsystem sensitive to the letter that is sought. Other combinations can activate other letters, but in a one-letter search only one system need be allowed to proceed; activity can be suppressed for all other characters, so that throughout the scan nothing takes place at the level of letter identification until the target letter appears.

Such an interpretation of the scanning process suggested that a search that actually required the subject to identify letters in each line would be



DURATION OF SEARCH varies directly with the position of the critical item in the list, as shown by this graph in which position is plotted against time. The data used here were for a search by an inexperienced subject whose time per item was .62 second.

ODUGQR	IVMXEW
QCDUGO	EWVMIX
CQOGRD	EXWMVI
QUGCDR	IXEMWV
URDGQO	VXWEMI
GRUQDO	MXVEWI
DUZGRO	XVWMEI
UCGROD	MWXVIE
DQRCGU	VIMEXW
QDOCGU	EXVWIM
CGUROQ	VWMIEX
OCDURQ	VMWIEX
UOCGQD	XVWMEI
RGQCOU	WXVEMI
GRUDQO	XMEWIV
GODUCQ	MXIVEW
QCURDO	VEWMIX
DUCOQG	EMVXWI
CGRDQU	IVWMEX
UDRCOQ	IEVMWX
GQCORU	WVZMXE
GOQUCD	XEMIWV
GDQUOC	WXIMEV
URDCGO	EMWIVX
GODRQC	IVEMXW

CONTEXT affects the speed of a search. The letter *Z* is seen more easily against a background of generally round letters (*left*) than in a context of straight lines (*right*). Subjects found the *Z* twice as quickly in the "round" contexts as in the "angular" ones.

QG17NI	JEWELS
Y6C1SR	ACTUAL
JSITO6	OWN
6GJX5R	TUNICS
1JCNSY	CLUES
IVCYSJ	WILES
TRYSJ1	PORTS
OSQR5V	RAGED
S5JWV6	SOON
5TVCWX	PHOTOS
Q17J5Y	GATES
TXCI5J	SOURED
6OV1WT	PORTLY
RJ1CO5	AERIAL
VYCJIX	QUITS
IY5WVX	UNDUE
WV51JT	COMA
7WOYGJ	DRAWL
NQC3R1	NASTY
I7W6J3	DOPE
5TJ73C	CREEPS
71ITQ3	SODA
CXTSO7	SNEEZE
TX5V73	LAMB
YBV6OJ	PUTS
SBONJI	MIMIC
CJ7WRT	SURETY
17WRJ6	FIGS
YGT1VJ	SANG
IGVTQO	CHERUB
3SJTO5	ENTRY
OXG3W5	VEERED
YGT315	RIFLED
PO3SJT	THE
BSTYGO	SAND
X1NRWB	LISTEN
WSCQXY	TREAD
V71IGB	SIZES
RSWX17	SCION
SO65IR	TUG
3GORIV	DAMPLY
NY17RQ	YORE
YG1S3B	OFFICE
S17NYB	ALLOWS
OVBQI5	JUICY
V5WG3B	GAVEL
T5NYW6	ELATED
R7GBJY	CHANGE
5RSTQG	MOLDY
B36QIN	NIPPY

TEN-TARGET SEARCH involved lists such as the one at left, in which the subject must find *A, F, K, U, 9, H, M, P, Z* or *4*. (The target happens to be *P*.) The critical item in the list at right is defined in terms of its meaning: the task is to find the name of an animal.

much slower than the search for a given letter. Such a task is exemplified at the right in the illustration on page 96, where the problem is to find a line that does *not* contain a *Q*. Indeed, even with extensive practice our volunteers never attain speeds greater than four to five lines per second in such "inverted searches." This finding confirms the view that there are distinguishable levels of pattern analysis, and that more thorough analyses require more time.

One of the questions we have been most anxious to investigate is the manner in which the several operations that must go on at a single level of the hierarchy are conducted—for example detection of the various distinctive features contributing to letter identification. Are these rudimentary operations carried out simultaneously or one at a time? The question can be put to the test by requiring the subject to look for several targets at once.

For instance, he can be presented with a list and asked to find either a *Q* or a *K* without being told which of these the list actually contains. Whatever pattern analysis the subject may employ during such a scan, it must surely be more complex than the minimal system needed for *K* alone. A simple assumption would be that the search for *K* and the search for *Q* proceed independently, in which case hunting for both *Q* and *K* would involve all the features needed for finding *Q* in addition to all those for *K*. Probably this is too simple and one should think of the joint task as requiring only a few more components than either problem alone.

In any case, the question is whether or not searching for two targets takes more time than searching for only one. An increase in time would be consistent with a hypothesis that the operations are carried out in sequence, each awaiting the outcome of earlier ones. On the other hand, if more operations can be performed without an increase in time, the system is at least partially parallel; at some level a number of "decisions" can be made at once.

We began our experiments on this point rather timidly, with only two alternative targets. We were surprised to find that from the very beginning of practice our subjects searched as rapidly for either of two targets as for one alone. Thus encouraged, we decided to try four targets: *H, M, Q* and *Z*. Our subjects were first trained to search for one or another of these letters individually. Then they were introduced to several problems involving two letters, such as *H* and *M*. For a day or two the subjects scanned more slowly in the double searches than in the well-practiced single ones, but soon the difference disappeared. At that point we introduced lists that might contain any one of the four target letters. To our surprise the fourfold search was soon going about as rapidly as the others!

The information processes that detect these four letters cannot be entirely identical, so the multiple search must involve at least some additional operations that are not necessary in looking for, say, the single letter Z. Our results seemed to show that these extra processes take no extra time and so must be simultaneous with some of the Z operations. It is true that the multiple scan is basically different from the single one and not simply an addition to it. Even from this point of view, however, the difference is one of complexity, and one would expect the more complex multiple analysis to take more time. If it does not take more time, the extra information in it must be flowing in parallel rather than in increased depth.

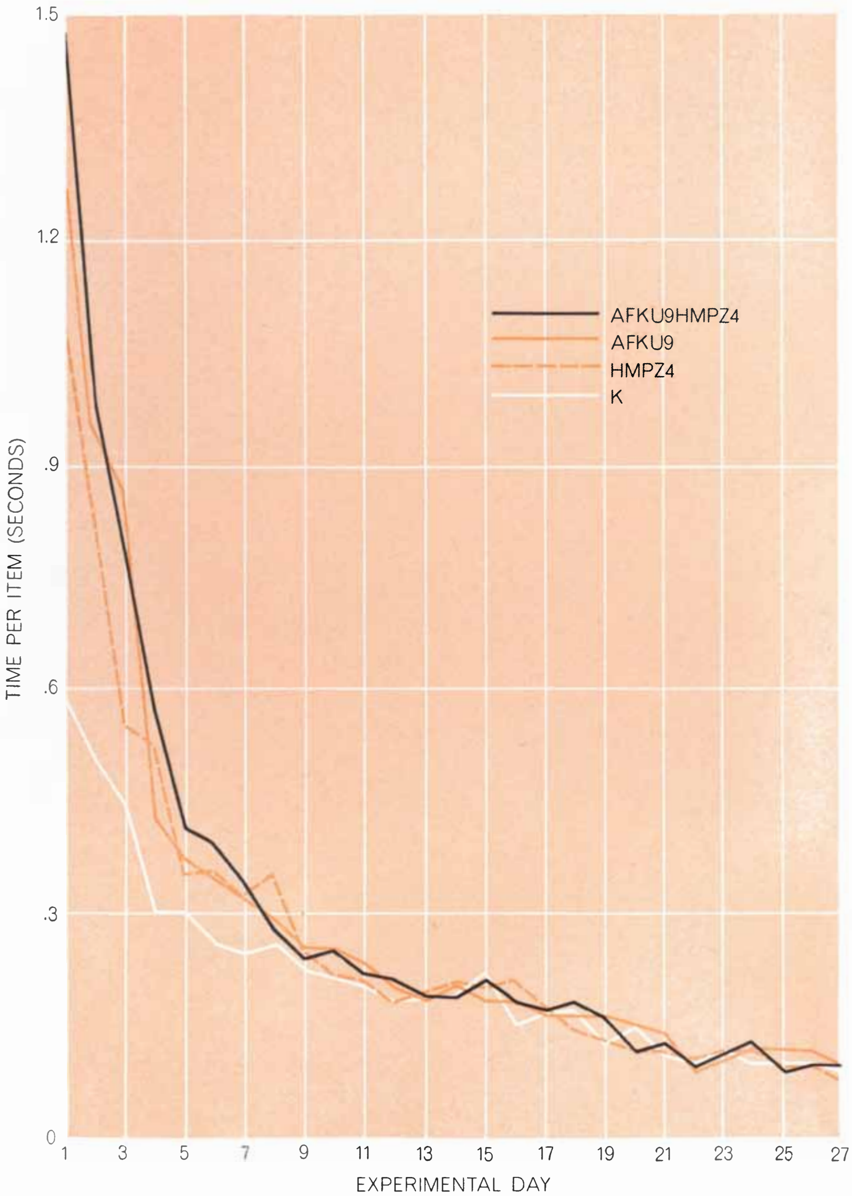
There was still a possibility, of course, that the fourfold scan is indeed slower than the single ones, but only by an amount too small for detection by our methods. One way to investigate this possibility was to add more targets to the search. We therefore decided to find out if our subjects could look for 10 targets as quickly as for one. We had an additional theoretical reason for studying such a broad search. It is well known that most people cannot hold more than about seven items in their immediate memory, and also that they usually fail at certain tasks involving judgment if there are more than about seven categories [see "Information and Memory," by George A. Miller; Scientific American, August, 1956]. These tasks are all rather complex, however, and we wanted to see whether or not a similar limitation would apply to scanning.

In the 10-target experiment we did not delay the introduction of the complex conditions until the subjects had mastered the simple ones. From the outset they worked on four kinds of search. Although only one kind of search was conducted on a given list, all four kinds had to be done during every experimental session. The four tasks were to search for a *K;* to search for one of the five characters *A, F, K, U* or *9;* to search for *H, M, P, Z* or *4;* to search for any one of the 10 letters and numbers defined in the other conditions. To find out what unpracticed subjects are up against in the 10-target condition, the reader can scan the list at the left in the illustration on the opposite page.

Understandably the subjects began by scanning much more quickly in the single-target condition than in the others. Practice, however, brought particularly rapid improvement in the ability to search for multiple targets. After about two weeks our volunteers were scanning with equal speed under all conditions, and they continued to do so until the end of the experiment. The convergence of their performance records is shown in the illustration below. At the end of the experiment everyone was scanning lists at the rate of about 10 lines a second.

On the last two days the set of irrelevant letters from which the lists were generated was changed somewhat: three new letters sometimes appeared in the context. The change was not even noticed by the subjects and it made no difference in their scanning efficiency. This provides additional evidence that a searcher does not identify the irrelevant letters as he scans a list.

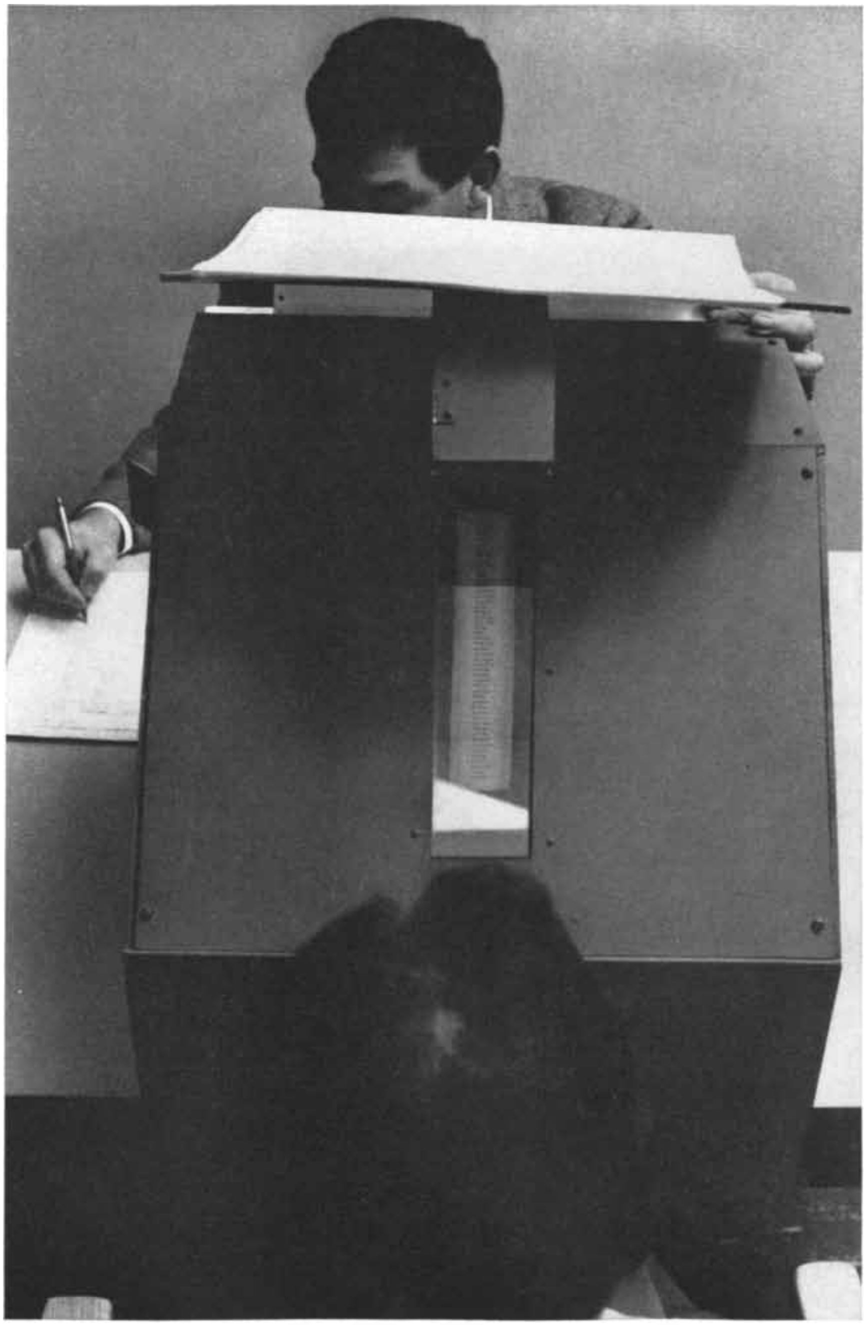
These data leave little doubt that visual search can involve a multiplicity of processes carried out together. At first thought such a finding seems surpris-



MULTIPLE TARGETS could, with practice, be found just as quickly as a single target. The experiment charted here had four conditions, requiring searches for one, five or 10 targets at once. Each point plotted here is the mean time per item for six volunteers.

ing. Everyone is familiar with the confusion that results from trying to think about two things at the same time or from following two conversations. Indeed, a well-established body of research confirms the everyday experience that several tasks cannot be carried out at the same time without loss of efficiency. The apparent contradiction between these results and our own can be resolved by considering the relatively low level of the cognitive analysis involved in scanning; restrictions that apply to complex decision processes may not be effective for elementary visual operations.

From another point of view the simultaneity of simple visual processes is not at all surprising. Work with electronic information-handling systems has already suggested that parallel systems are preferable to serial ones for a wide class of problems. Investigation of mechanical pattern recognition, and especially the programing of computers to identify printed or handwritten letters, has shown that parallel organization is particularly effective in tasks in which the defining criteria are initially vague and must be "learned" [see "Pattern Recognition by Machine," by Oliver G. Selfridge and Ulric Neisser; SCIENTIFIC AMERICAN, August, 1960].



SUBJECT (*foreground*) sits at a viewing box in which the experimenter inserts lists. The subject turns a switch to illuminate a list and at the same time start a timer. On finding the target the subject stops the clock and the experimenter records the duration of search.

Our experiments have not been confined to searches for isolated letters. A much more interesting task confronts a subject who must search through lists of words. As long as the target is a single word, however, he can treat his task almost like a letter search. He need only look at the initial letters or at some other clearly distinguishing features of each word to see if they match those of the target; only when they do is further processing necessary. Indeed, scanning is extremely rapid in such situations. Even when the target is any member of some familiar set of words (for example all the states in the U.S. that have six or fewer letters), subjects can scan very quickly, employing what seem to be letter-searching techniques.

To ensure that the items on the list were dealt with as words, we found that we had to define the target in terms of meaning. For instance, we would ask a subject to search through lists such as the one at the right in the illustration on page 98 to find "an animal" or "a man's or woman's first name." Such a search has many targets indeed. There are hundreds of animal names and first names, even if word length is restricted to six letters or fewer. In the case of word-hunting we still do not understand the processes involved well enough to characterize them as "simultaneous" or "successive"; our research was directed toward answering some preliminary empirical questions. We wondered how fast such a scan can be carried out, whether or not the speed depends on the number of potential targets and to what extent the subjects must "read" the irrelevant words through which they search.

The irrelevant words in our lists were randomly generated from a pool of about 8,000 English words three to six letters long, checked to eliminate animal names, proper names and rare words. In these lists we embedded either animal target names selected from a pool of about 115 animal names or proper names chosen from among 514 fairly common first names. (None of our subjects, of course, would be likely to "know" precisely these pools of possible targets, but they were drawn from the well-established Thorndike-Lorge

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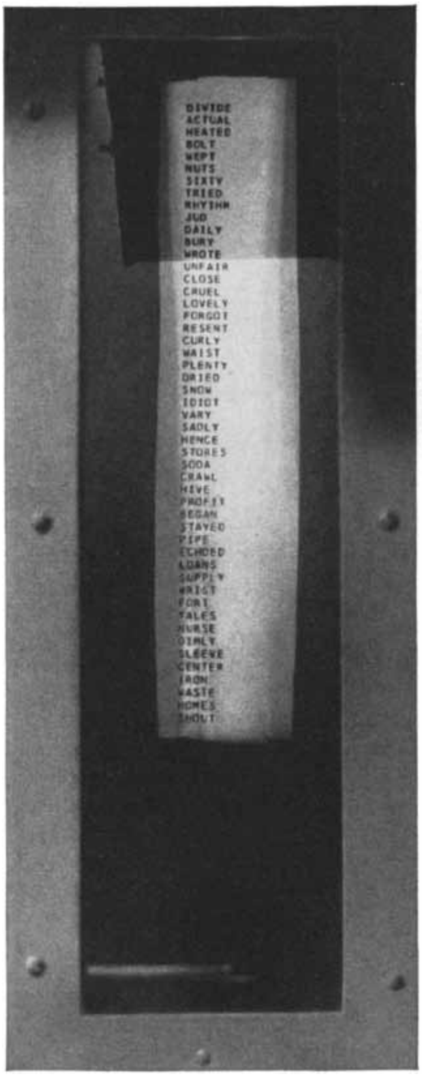
An inexperienced person can scan through a word list containing animal names more rapidly than he can scan a letter list in search of *K*, but the name-directed search does not benefit as much from sustained practice as the letter search does. By about the 15th session most people are able to scan for first names or animal names at a rate of five or six words per second; thereafter they seem to improve very little. They search as rapidly for first names as for animal names even though there are many more of the former. We also studied a condition in which the target might be, unpredictably, either a first name or an animal name; a few people are as quick at looking for either a first name or an animal name as for one of these alone; the others perform somewhat more slowly in the combined search.



FIRST NAME OR ANIMAL is the target in this list. "Jud" is found in the 10th line.

How shall we conceptualize an information-processing system that decides in a fifth of a second whether or not a given string of letters stands for an animal? Does the subject make decisions about the meanings of the irrelevant words he scans? Can we assume that he "reads" each word? Note that the scanning task is both more and less demanding than ordinary reading: more because the scanner must examine every individual word, less because he need not establish connections between words. The scanning rate of five words per second, or 300 words per minute, is not particularly rapid compared with the reading speed of many college students.

The words are certainly not being read subvocally; the same subjects go only half as fast when they are asked to read the lists aloud as quickly as possible. Most of them maintain that they do not "read" the individual words at all, even to themselves, as they scan. And the words are not examined closely enough to be remembered. When tested immediately after a scan, subjects usually cannot distinguish words that appeared on the list from words that did not.

It seems, then, that the word "read" is as ambiguous as "see" is; reading too may occur in varying degrees of depth. This conclusion is not a novel one, since everyone is familiar with the differences among skimming, rapid reading, intensive study and so on. Our results suggest, however, that varying degrees of comprehension are possible even for individual words. The subjects do not "skim" the lists by reading only some of the words. Rather, they process each word—but only lightly. Just as one can decide that there is no *K* in a given line without actually identifying the letters, so too one can determine that a given word is not an animal name without firmly deciding what it does mean. Whatever may be the processes by which this is done, our data indicate that they do not involve seriatim comparison of the word with all possible animals; if they did, first-name searches would be much slower than animal-name searches. On the other hand, the processes are slower, and presumably more complex, than those needed for finding individual letters.

By laboratory standards our subjects are well trained and have acquired an unusual skill. It is quite certain, however, that we have not approached the limits of human capacity for rapid, complex, multiple searching. The achievements of our subjects are modest indeed compared with the daily work of people who are accustomed to looking for several thousand targets at once: the readers in any newspaper-clipping agency. Such a firm may have hundreds of clients, each of whom wants a clipping of at least any newspaper story in which he or his firm is mentioned; beyond this, many clients will be interested in an appreciable number of different trade names and titles and others will specify their clipping needs in a more general way. For example, a peace group may ask for every reference to disarmament, arms control and the like, whereas a manufacturer of burglar alarms may want to have the name of every local victim of theft or robbery. Moreover, the agency's client list is not fixed; 10 or 20 new clients may engage its services every week and a comparable number may discontinue. It takes a year or more to train a clipping reader to scan newspaper type at well over 1,000 words a minute, keeping watch for all the agency's targets. Error rates are said to be in the neighborhood of 10 per cent for the best readers, and neither the error rate nor the speed seems to change as an agency gradually acquires more clients.

The achievements of clipping readers suggest that our own basic finding is no artifact: the speed of a search is independent of the number of different targets that can terminate it successfully. This conclusion applies equally to the simple search for particular letters and the more difficult, slower search for particular kinds of words. In all likelihood it applies to other searches also. The rate at which one scans a crowd for a familiar face probably does not depend on the number of people with whom one is familiar.

In a simple task such as the search for any one of 10 letters, these results are fully compatible with the concept of a multilevel perceptual system. They suggest, moreover, that a number of operations at a given level are carried out simultaneously. We do not yet understand the search for specific classes of words well enough to make a model of the processes involved. It is already clear, however, that the cognitive operations involved add up to something more than simply a search for component letters and something less than a full appreciation of the meaning of each word encountered.

THE TUNNEL OF EUPALINUS

Some 2,500 years ago the Greek tyrant Polycrates had the engineer Eupalinus plan a 3,400-foot tunnel to supply his fortified capital with water. The tunnelers dug from both ends and met in the middle

by June Goodfield

Technology reflects the practical demands of any given society. This truism is equally applicable to earlier ages as to our own. When, 2,500 years ago, the Greek tyrant Polycrates initiated a great program of engineering and construction work on the island of Samos, he did so with the urgency of a dictator wanting to keep a firm grip on his possessions. His capital city, also named Samos, lay up on the slopes of Mount Castro, dominating the natural harbor below and the mile-wide strip of sea between Samos and the mainland of Ionia (now Turkey). Through the bottleneck of the strait all the coastal trade passed, and Polycrates had a stranglehold on it. By 525 B.C. he was master of the eastern Aegean.

He made his position well-nigh impregnable. He surrounded the city with a ring of fortifications that rose over the top of the 900-foot Mount Castro. He built a stout breakwater more than 300 yards long to protect his ships from the southeast wind—the only wind that troubled them. He ensured protection in the life hereafter by completing a magnificent temple to Hera. And for the more mundane, but equally essential, problem of providing his city with a protected supply of water he drove a tunnel 3,400 feet long, six feet wide and six feet high straight through the heart of Mount Castro. In honor of the engineer responsible for the tunnel it became known as the tunnel of Eupalinus.

For a century after Polycrates' death the fortress of Samos apparently remained invulnerable. When Pericles laid siege to the city in 439 B.C., he finally offered in exasperation to call off his campaign if the Samians would give him a hostage for their good behavior. Somewhat unwisely the Samians sent a crotchety old man whom they were glad to be rid of, and he took his revenge by revealing the secret of the underground tunnel. The water supply was cut and the fortress obliged to surrender.

During Polycrates' lifetime, however, the city prospered, a thriving community where technology flowered along with a school of natural philosophy founded by Pythagoras. Today the city is in ruins, deserted and unexcavated. The temple consists of a single column and a capital; the breakwater is concealed beneath the mole of the modern harbor. Yet everywhere in the village around the ancient harbor, once known as Tigani but recently renamed Pythagorion, traces of the golden age of Samos appear. One still walks on the ancient paving stones; children play games on the fallen capitals of the temple; broken columns serve as posts for tying up fishing boats, and the fishermen are continually hauling up ancient amphoras. Of all the monuments of Polycrates only the tunnel is well preserved, still testifying to the ingenuity and skill of the ancient Greeks. When Herodotus described the tunnel of Eupalinus as one of the greatest works of the Hellenes, he spoke with good reason. It is, in fact, one of the most striking works of all antiquity, in many respects rivaling even the Egyptian pyramids.

Basically Polycrates' problem was simple enough. He wished to bring a supply of water from a copious spring in a valley to the northwest of the city, on the far side of Mount Castro. The water could have been brought all the way around the mountain by a surface conduit or, as the Romans were to do much later, by an aqueduct across the valley. In either case the water supply would have been exposed to an enemy for the greater part of its length, and would have entered the fortifications of the city on an undefended flank. Polycrates was grandiose in all his schemes, and it is characteristic that he conceived an aqueduct that was to be subterranean all the way from its source to its emergence, half a mile from the city and well within the city's fortifications. The system that Eupalinus designed to meet Polycrates' requirements is amazing. Not only did he construct a tunnel two-thirds of a mile long, almost dead straight through the heart of the mountain, but he also brought the water from its source to the tunnel proper in an underground conduit that followed a 2,800-foot curving course along the contours of the valley, passing under three creek beds en route.

For centuries the tunnel kept its secret; its existence was known but its whereabouts were undiscovered. The earliest direct reference to it appears in the works of Herodotus, who wrote his description a full century after the tunnel was dug. The Polycratic works around Samos were also mentioned in general terms by Aristotle, who, with inimitable sarcasm, described them as typical of the large-scale constructions undertaken by dictators to keep their people out of mischief. We have evidence from within the tunnel itself that it was used by the Romans, and was still known in Byzantine times, but that is all.

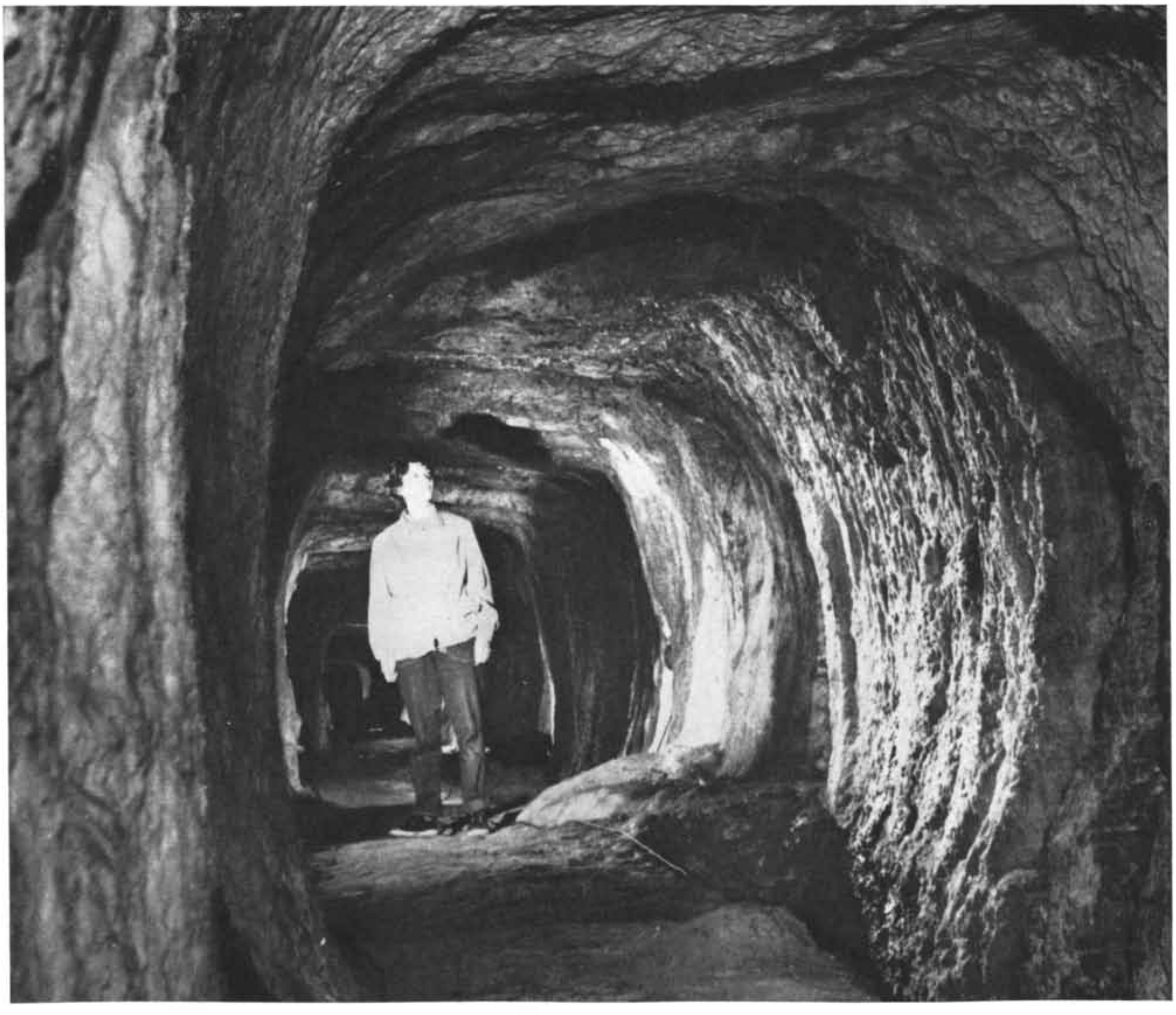
During the 19th century a number of efforts were made to find the location of the tunnel. The source of the water, a spring in the hamlet of Agiades, was well known. In 1853 a man named Guérin uncovered the upper end of the subterranean conduit and excavated part of it, but he stopped before he reached the tunnel. Abbot Kirillos of a nearby monastery later discovered the north entrance of the tunnel and persuaded Prince Constantinos, the hereditary lord of the island, to excavate it.

Fifty men went to work in May, 1882. They cleared and restored about half of the tunnel, the whole of the conduit at the north end and a portion of a similar conduit at the south end. They also built a small house on the foundations of an ancient structure at the south entrance to the tunnel. In 1883 the German archaeologist Ernst Fabricius undertook a survey of the tunnel on behalf of the German archaeological institute in Athens. He left an excellent description. Then once again the tunnel was neglected.

When I visited Greece in 1958, I heard reports in Athens that an American professor had just returned from Samos declaring that the north end of the tunnel was inaccessible. That summer, with a Greek colleague, I went to Agiades. We found the north entrance and went inside. In 1959 the German archaeologist Wolfgang Kastenbein made a new survey with a view to checking and correcting the work of Fabricius. In 1961 I returned with my husband, Stephen Toulmin, and our film unit and spent 10 days on the island, surveying the terrain, filming the tunnel and checking Fabricius' description with the hope of throwing some light on how the tunnel was built.

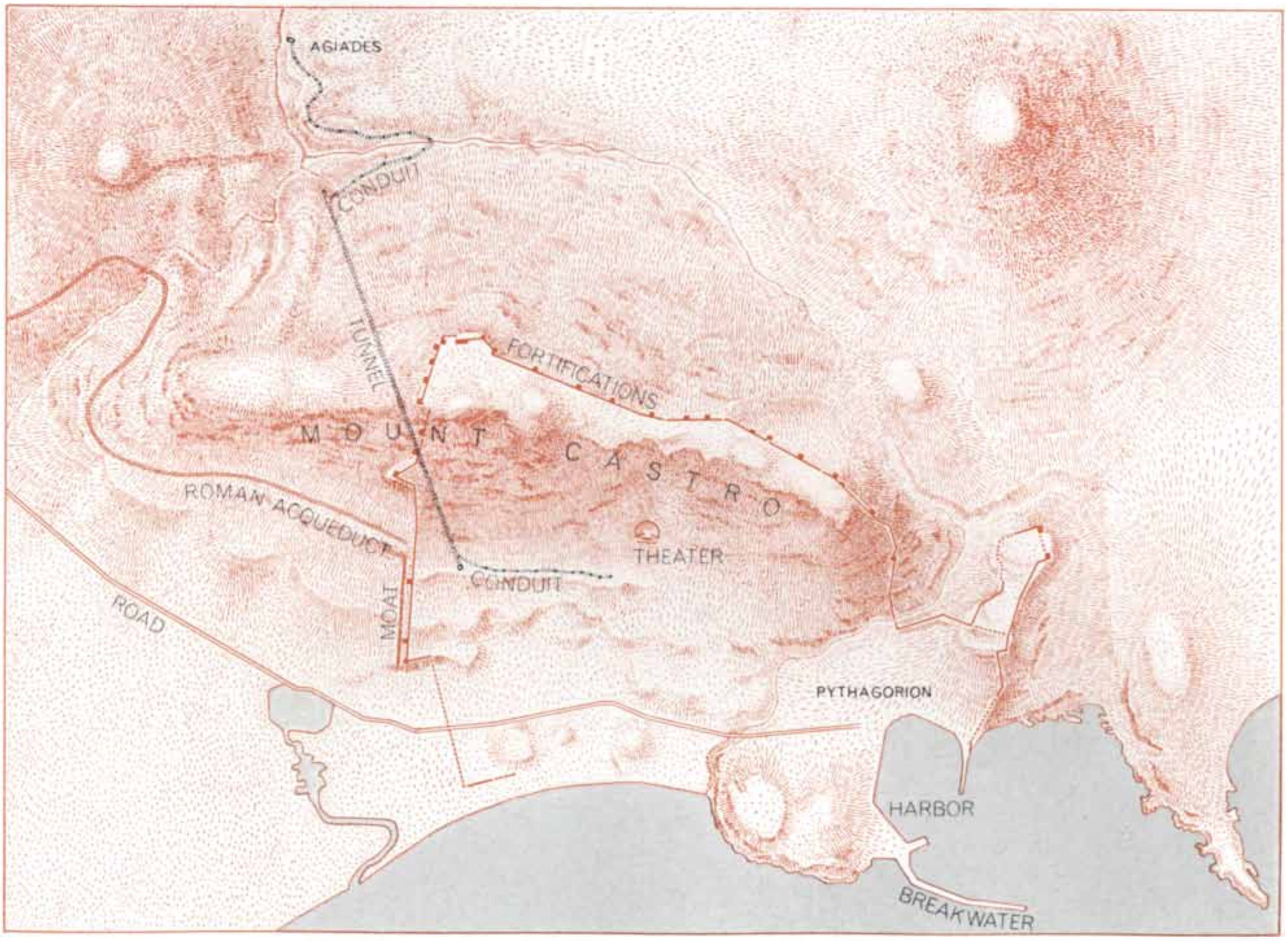
As Fabricius pointed out, the topography dictated much of the design. The old city stretched up the slopes of Mount Castro for a considerable distance. From the city one can clamber over the rocks to the top of the mountain in only a few places. The western side of the mountain is even more rocky and precipitous. Normally one goes from Pythagorion to Agiades through a narrow, rocky gorge that is a stream bed in the wet season. It lies between Mount Castro and Mount Cataruga to the northwest.

The community of Agiades consists of a few houses and three chapels dedicated to St. John the Baptist, all clustered around the generous spring. In the sere landscape of the Samian summer this fertile valley is startlingly green because the water flows all the time. The ancients, probably Eupalinus, built a reservoir that is now covered by one of the chapels. The visitor who wants to examine it must apply at Pythagorion; although the town no longer obtains its water from this source, the officials still retain the key to the reservoir. Fabricius



TUNNEL OF EUPALINUS, 3,400 feet long, was hewn out of solid limestone about 525 B.C. It carried water to the Greek city of Samos from a source outside the fortifications. The author is seen in the tunnel. The water channel is at lower right. The photograph shows clearly the square shape of the tunnel and gives an impression of its great length and remarkable straightness.

ISLAND OF SAMOS, the site of the tunnel of Eupalinus, is in the eastern Aegean Sea. The fishing village of Pythagorion has grown up around the harbor of the ancient, ruined city of Samos, capital of the tyrant Polycrates, who built the tunnel. In his time, 2,500 years ago, all the rich coastal trade passed through the narrow strait between Samos and the mainland, now Turkey.



POSITION OF THE TUNNEL within Mount Castro is shown on this map, based on a map published in 1884 by the German archaeologist Ernst Fabricius. The conduits that brought water to the tunnel at the north end and took water into the city at the south are underground. Dots along their courses represent access shafts. The Romans repaired the tunnel but also built an aqueduct.

was more fortunate than we were: the abbot opened the drain at the bottom of the reservoir and allowed half the water to flow out so that he could see details of the construction. He found that the water entered from two man-made apertures in the rock near the north corner. The ultimate source of the water was not visible, but presumably it is the natural water table in the rock.

The reservoir is in a roughly triangular room. Fabricius noted 14 four-sided pillars made of large chalk blocks. When it was roofed over and covered with earth, the reservoir must have been completely camouflaged. Probably in ancient times its exact location was known only to those entrusted with the maintenance of the water supply. Today the water flows out of the reservoir through a hole in the south wall of the chapel. It is still the only water supply for the people of Agiades.

The underground conduit to the tunnel begins about 10 yards from the chapel, its course marked by the many ancient inspection shafts opening to the surface. They were restored in the 1880's. The passage itself, just high enough and wide enough for a man to walk through, had round clay pipes in the floor, some of which are still in place. From its upper end it travels south for 425 feet, until it passes under the bed of a stream that flows only after a rain. It then curves east and parallels a larger stream for about 1,050 feet. At 1,830 feet from the source it turns sharply west, passes under this stream and then runs along the northern slope of Mount Castro. Farther on it turns to the southwest and passes the entrance to the tunnel of Eupalinus after going once more under a small and usually dry creek bed. Finally it enters the east side of the tunnel [*see bottom illustration on opposite page*]. The lower third of the conduit has fallen into decay since Fabricius visited it, but the inspection shafts still show its course.

Why did Eupalinus choose to bring the conduit nearly 2,800 feet along this crooked route under three streams instead of taking a straight and much shorter path from the source? The direct route, moreover, would have crossed only one stream bed. Fabricius suggests that by selecting the circuitous route Eupalinus found it easier to dispose of material excavated from the conduit. The access shafts would not have to be deep and the rubble could be brought up through them and thrown over the slope. Fabricius fancied that here and there he could detect the ancient debris, but there is so much vegetation that one cannot be sure.

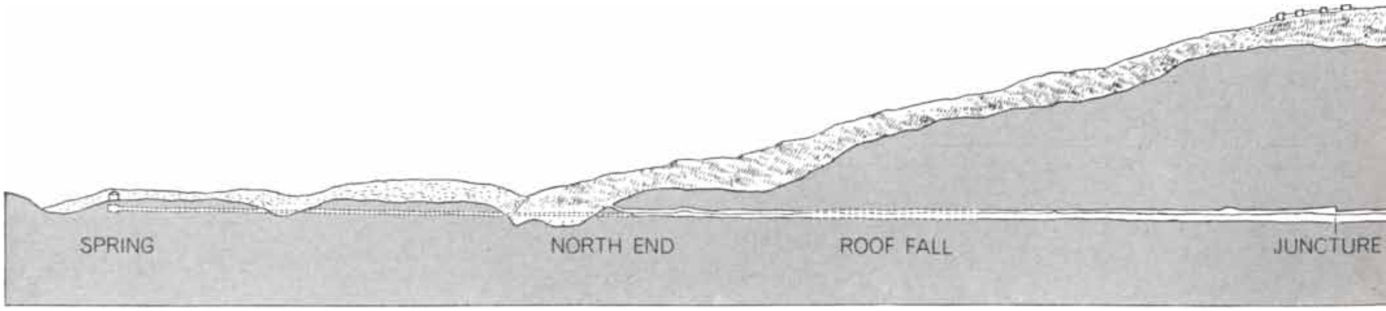
Fabricius mentions a modern staircase of 18 steps leading down into the tunnel proper from the north entrance, which is on a rather steep hillside. Today brambles and other vegetation have grown so thick over the entrance that it is hard to find. The staircase is concealed under rubble; in order to enter one must lie flat and proceed feet first down a rough scree. With portable lights the tunnel itself is easy to study.

Apparently for the first 210 feet Eupalinus did not wall or shore up the tunnel and it collapsed. Starting about 45 feet from the entrance there is a long stretch of wall that appears to be of Roman construction. At many places in this section the tunnel has partly collapsed and one must climb over rubble until finally, 520 feet from the entrance, a roof fall completely blocks the way. Because of all the debris it is difficult to judge the quality of the workmanship. The conduit from the spring enters through the east wall of the tunnel some 45 feet from the north entrance. Instead of flowing along the floor of the tunnel, the water ran through a channel, which starts where the north conduit enters the tunnel. At this point it is below the tunnel floor and has its own arched roof—in effect it is a second tunnel under the first. Farther on the channel is found along the east wall, roofed in places and open in others; it becomes deeper toward the south end of the tunnel.

The south portion of the tunnel is in a nearly perfect state of preservation and is far more revealing. The underground conduit into the city leaves the east side of the tunnel about 100 feet from the south entrance. Its route can be traced for some distance by the access shafts, which are much deeper than those of the north conduit. A road now being built up to the south entrance follows the line of shafts and in some places bulldozers are damaging the conduit. The terminal point of the conduit in the city seems never to have been found. Possibly the conduit branched out to supply a number of points; it may even have reached as far as the harbor. An ancient inscription at Pythagorion describes two ornamented water clocks in the stoa, or covered walk, near the harbor. It seems highly probable that the clocks were operated by water from the conduit, since it provided the only steady supply.

The main part of the south portion of the tunnel is spectacular. Immediately inside the little house at the entrance a short flight of steps leads down into a walled stretch about 40 feet long. Although Fabricius drew this section straight in his diagram, it is in fact curved slightly. The sides are built of

MODERN VILLAGE OF PYTHAGORION surrounds the harbor of ancient Samos. Stumps of two marble columns can be seen in this view. Mount Castro is in the background.



SECTION THROUGH MOUNT CASTRO in the plane of the tunnel shows the position of the tunnel in the heart of the mountain. Fortifications are visible on top of Mount Castro. The underground conduits at the ends of the tunnel are shown by broken lines

large blocks joined without mortar, and two huge blocks leaning against each other at an angle form a gabled roof. This wall was almost certainly erected by the original builders of the tunnel. At the inner end of the passage there was once a door, as can be seen from a notch for the hinge chiseled into the corner of the wall on the right side; the other side has a cavity for a bolt. Just in front of this doorway a large shaft, not mentioned by Fabricius, rises to the surface, providing light that can be seen for nearly 1,400 feet within the tunnel.

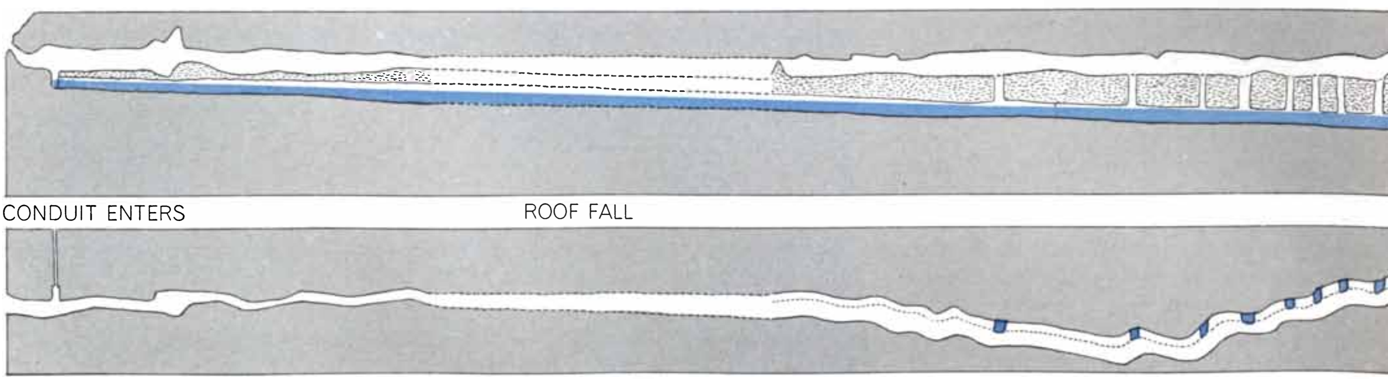
Past the doorway the full magnificence of the tunnel is revealed. With some irregularities, it is remarkably straight. Its six-foot height and width allowed workers carrying rubble out to pass those returning for more. From here on the tunnel was hewn with hammer and chisel in the solid limestone. Wherever calcium carbonate, the substance of stalactites and stalagmites, has not yet formed a coating over the walls, chisel marks can still be seen. The smooth ceiling of the tunnel consists of naked rock all the way and corresponds to the natural strata, which were simply peeled off. Because the strata sloped, most of the ceiling is higher on the west side than on the east. Pieces have fallen out of it in only a few places. The walls and floor are not everywhere even, but in a construction such as this absolute accuracy was not necessary. There are niches hewn in the rock all along the walls, presumably where the workmen set up their oil lamps.

These days it is hazardous to walk through the tunnel. In many places the footpath is only 18 to 24 inches wide and, worse still, it is extremely wet. The farther one goes into the tunnel from the south end, the wetter it becomes. The path grows narrower and the footing becomes slimier. Extreme caution is necessary because the channel on the east side is as much as 25 feet deep. Even though parts of the channel are covered, it is difficult to know how much weight the covering will hold.

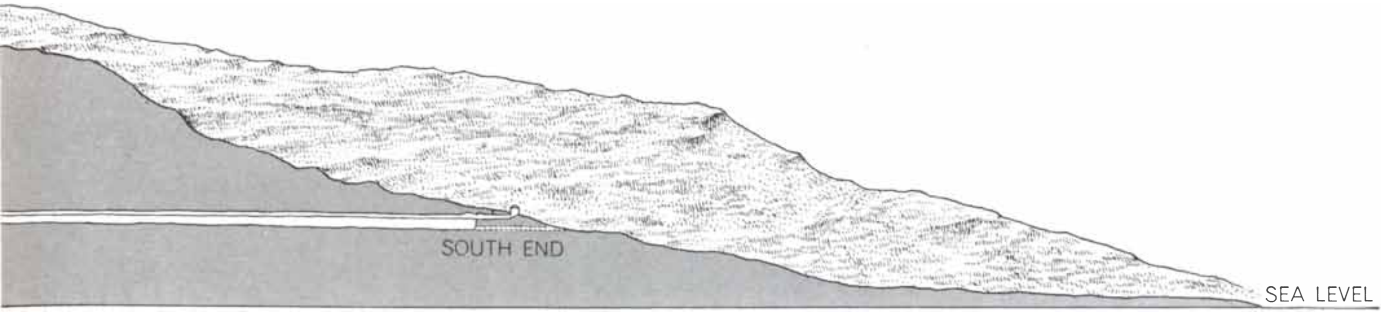
The walls of the channel were hewn with much more care than those of the tunnel itself. Fabricius noted one place above the channel where three strong nails had been hammered into cracks in the rocks. He suggested that a plumb line had been hung from the nails to ensure that the walls were vertical and at the right distance from each other. He also noted that at varying intervals there were large square holes opposite each other, one in the east edge of the floor of the tunnel, the other in the wall of the channel. Presumably beams that fitted into these holes served as joists for the removal of rubble.

It is clear that the builders of the tunnel wanted to avoid the trouble of carting out all the rubble from the channel, because they covered parts of the channel with stone slabs and piled the rubble on these slabs up to the level of the tunnel floor. Under the slabs they left a generous passage as much as 10 feet high. At the bottom of the channel are fragments of the clay tile through which the water flowed—rectangular gutters open at the top.

The channel may well be evidence of an important mistake made by the builders. There seems to be no reason why the tunnel itself could not have been built with the same slope as the channel, thereby obviating the need for the channel. Yet for some reason Eupalinus designed the tunnel with only a gentle slope between the north and the south end. From careful measurements Kastenbein has calculated that



TWO SCHEMATIC DIAGRAMS of the tunnel, a longitudinal section (*top*) and a plan view (*bottom*), reveal construction details. The north end is at the left. The height of the tunnel in the top diagram and its width in the bottom diagram are drawn to a scale five times larger than that used for the length. Thus irregularities are greatly magnified. Water (*color*) flowed in



because they are not in the same plane as the tunnel. The water was actually carried in a channel, or trench, cut into the floor of the tunnel. Lowest line in the tunnel marks the bottom of this channel. Line in middle of tunnel represents tunnel floor.

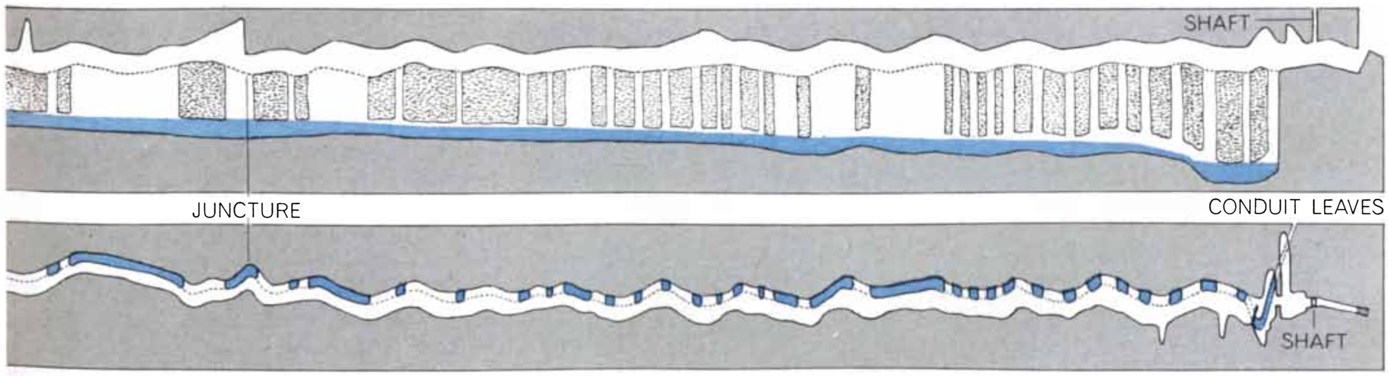
the floor of the gallery at the north end of the tunnel is only about six feet higher than it is at the south end. He also found that the floor in the middle of the tunnel is slightly lower than it is at the south end. Perhaps the south end had to be located where it was, rather than lower down, for reasons unknown to us. The builders may simply have wanted to bring the tunnel out at the highest possible point above the city. Or it may be that the tunnel was already under construction when it was decided to have an underground reservoir, which lowered the height of the source and gave the water less force as it flowed down.

There is always the possibility, of course, that the channel was part of the original plan. By restricting the water to a channel it would be easier to inspect and maintain the tunnel proper. As Fabricius points out, however, we cannot exclude the possibility that Eupalinus, skilled though he was, miscalculated. Certainly it would have been difficult for him to establish with a high degree of accuracy the relative heights of the two ends of the tunnel before the start of construction. In any case, it is clear that the tunnel did not slope enough for an adequate flow of water and that the channel had to be dug to carry the water. If the mistake was not discovered until the water pipes were laid, the final depth of the channel at the south end could have been as much a result of trial and error as of calculation.

About 1,330 feet from the south entrance of the tunnel one finds remains from the early Christian period. In winter water seeping through the roof here causes extensive flooding, making this part of the tunnel impassable. In summer the water at the worst spot is only knee-deep. Here there are a number of thin white marble slabs and columns of different thicknesses and shapes, all thickly covered with calcium carbonate. When Fabricius made his survey, the deposit was removed from the corner of one slab, revealing ornamentation much like the reliefs found in Byzantine churches. It is possible that the slabs were brought in to make a small shrine incorporating a water basin, supplied by the water that runs down the walls of the tunnel. Possibly the water was credited with miraculous properties, like that at another shrine in an ancient quarry behind a little monastery on the southern slopes of Mount Castro. The water basin there is decorated with similar ancient pillars.

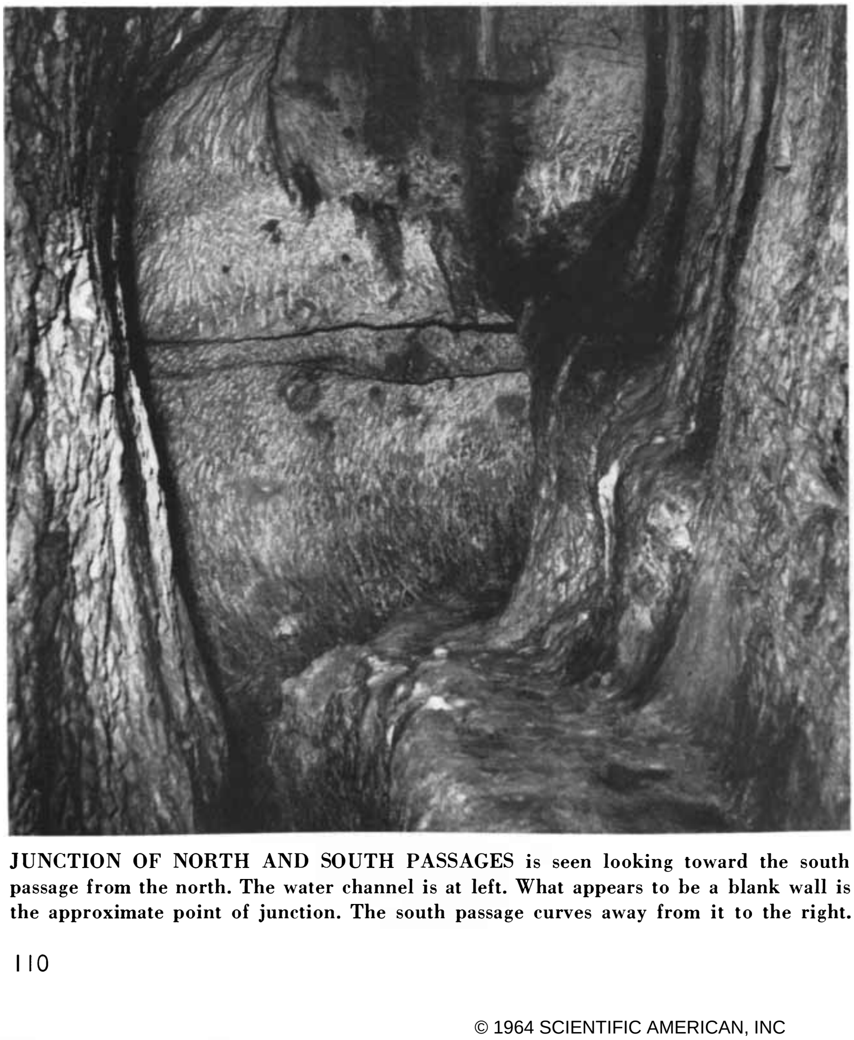
At a distance of nearly 1,400 feet from the south entrance of the tunnel the passage cut from the south comes to a sudden end. The abandoned working face is clearly visible. The passage that had been driven from the north comes into the west wall almost at right angles. This is obviously the point at which the two independently driven tunnels were joined. The odd angle of the junction is accounted for by a curve in the northern portion of the tunnel just before it joins the southern portion [*see bottom illustration on next page*].

Further evidence that the tunneling proceeded from both ends can be seen in an abrupt change in elevation of the tunnel at this sharply angled junction. Here the floor of the northern part of the passage is as much as three feet higher than the ceiling of the southern part. In fact, the passage overshoots the south passage for a short distance. Perhaps the work crews had been hearing each other for some distance and those in the north tunnel changed direction as a result. In this last stretch the north



the channel along the east wall. Much of the material removed to make the channel was placed on stone slabs above it. Such rubble is indicated by rough stippling. Section marked "Roof fall" includes 130 feet of open tunnel to which access is blocked by a stalactite wall. The diagrams are based on diagrams made in 1959 by Wolfgang Kastenbein, archaeologist of Bochum, Germany.

MARBLE SLAB with carving in Byzantine style leans against the wall near the middle of the tunnel. A thick deposit of calcium carbonate has been removed from a portion of it.



JUNCTION OF NORTH AND SOUTH PASSAGES is seen looking toward the south passage from the north. The water channel is at left. What appears to be a blank wall is the approximate point of junction. The south passage curves away from it to the right.

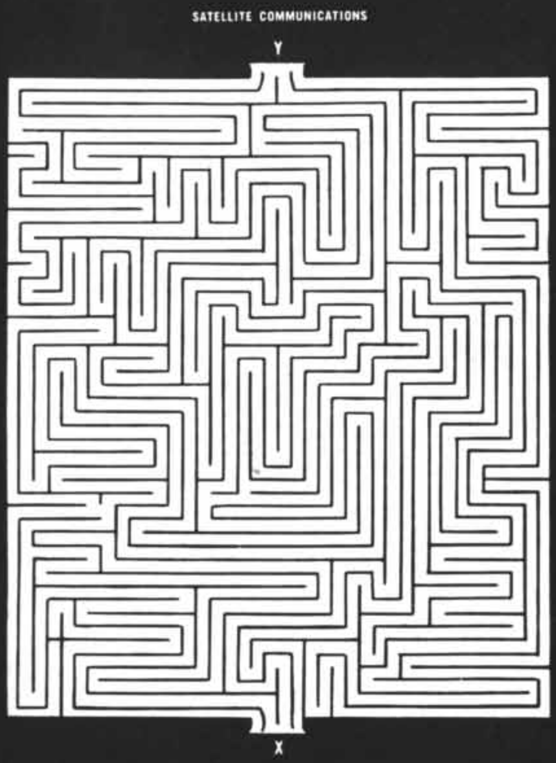
passage, which had been surprisingly straight, makes several curves. Kastenbein believes that had both passages continued on their original straight courses, they would have made a nearly perfect juncture.

Continuing north through the north passage, one finally reaches a stalactite-stalagmite wall that blocks further progress. With the help of a bright light it is possible to see another 130 feet through a crack in this obstacle. Therefore only about 300 feet of the whole tunnel, less than 10 per cent of it, cannot be inspected today.

Given enough light, working and studying in the tunnel is an awesome experience. One is constantly astonished by the precision and general high quality of the craftsmanship. With a powerful electric generator we were able to light the tunnel for about 100 yards at a time and to see it in a way that perhaps no one else, even its builders, has ever seen it. It stretches on and on, a gallery carved in wonderful white limestone—a superb square-sectioned profile, the walls covered with a gleaming translucent deposit. One cannot help wondering just how it was accomplished: how many men were used to dig it, how many died, how long it took. On these points even Herodotus is silent.

Throughout the entire length of the tunnel we found only the one ventilation shaft near the south entrance. Nonetheless, even though we stayed in the tunnel with our generators and lights for eight hours at a time there seemed to be no lack of fresh air. It reminded us of the cool fresh air in the limestone caves of France. Perhaps the rock is sufficiently porous to allow air to penetrate. It also seems probable that the water conduits provide a through draft. In fact, we discovered the juncture of the water conduit on the north side by lighting a fire inside the tunnel and noting where the smoke billowed out.

As this description makes clear, the tunnel of Eupalinus was an engineering feat of the first magnitude. How was it laid out and cut with such extraordinary accuracy? It is necessary to distinguish between the problem of laying out the direction and slope in the first place and the problem of maintaining the direction and slope once inside the tunnel. Around the first question a myth has grown up that has little more foundation than most myths in the history of science. Because Pythagoras was born in Samos and set up a school there, the legend associates the tun-



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The problem is one of getting from X to Y without entering a blind alley at any time. Look well ahead! (From *Mazes and Labyrinths, a Book of Puzzles*, by Walter Shepherd; Dover Publications, Inc., New York 14, N.Y.)

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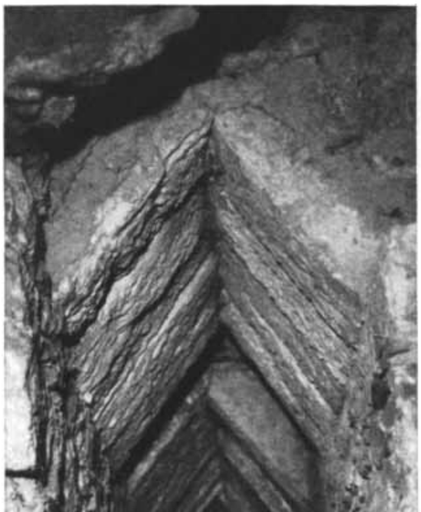
nel with his name. He left Samos, however, before the tunnel was contemplated. It has been suggested that his theory of similar triangles was applied to the building of the tunnel. The only evidence for this comes from Hero of Alexandria, who lived 600 years later. Hero was noted for thinking up charming theoretical solutions to difficult practical problems, and he gives as a theoretical exercise a method for aligning a tunnel.

Basically Hero's proposal calls for making a series of right-angle sightings, or traverses, around the mountain, beginning at one entrance of the proposed tunnel and ending at the other. By keeping careful track of all measurements one could establish the relative positions of the two ends and plot an imaginary line connecting them. This line would make a certain angle with an initially chosen base line and thereby indicate at what angle the tunnel should be drilled from each side to meet in the middle of the mountain.

Anyone who has actually visited the site would be forced to reject Hero's proposal. The terrain is so rough that to make the required sightings while maintaining a constant elevation is all but impossible. Even with modern instruments, surveying along the west side of Mount Castro must be an extremely tricky business because of the extensive overhangs and ravines. Finally, as far as we know the Greeks of those days had no instrument capable of performing the horizontal leveling with the necessary degree of accuracy. The diopter, the first accurate leveling instrument, came into use only a century after the tunnel was dug.



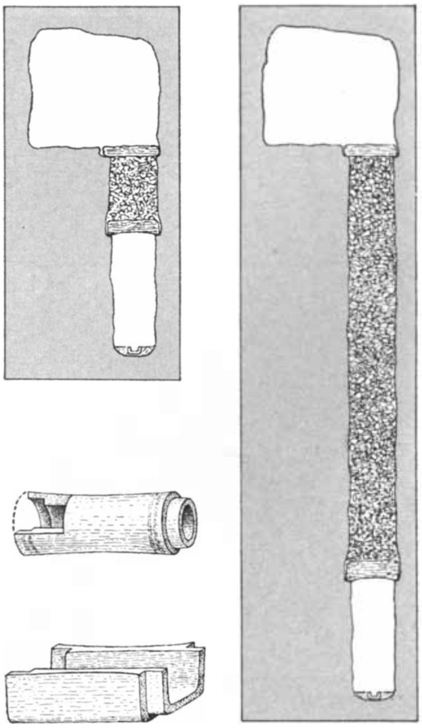
GABLED ROOF at the south end of the tunnel is characteristic of ancient Greek construction. The roof is made of pairs of large, flat stones leaning against each other.

The site of the tunnel may provide an important clue to the method used in aligning its north and south entrances. In principle Eupalinus could have located the tunnel wherever he wished and brought the water directly to the heart of the city. Instead the south exit of the tunnel is near the very western limit of the fortifications on the southern side of Mount Castro. Why was the exit so far from the ancient city?

The answer, I believe, is that this was the only location where it was possible to plant a row of poles as a surveying guide up and over the mountain and keep them in sight all the time. With the aid of such poles Eupalinus could have established a line connecting the north and south ends of the tunnel and the route under which the tunnel was to pass.

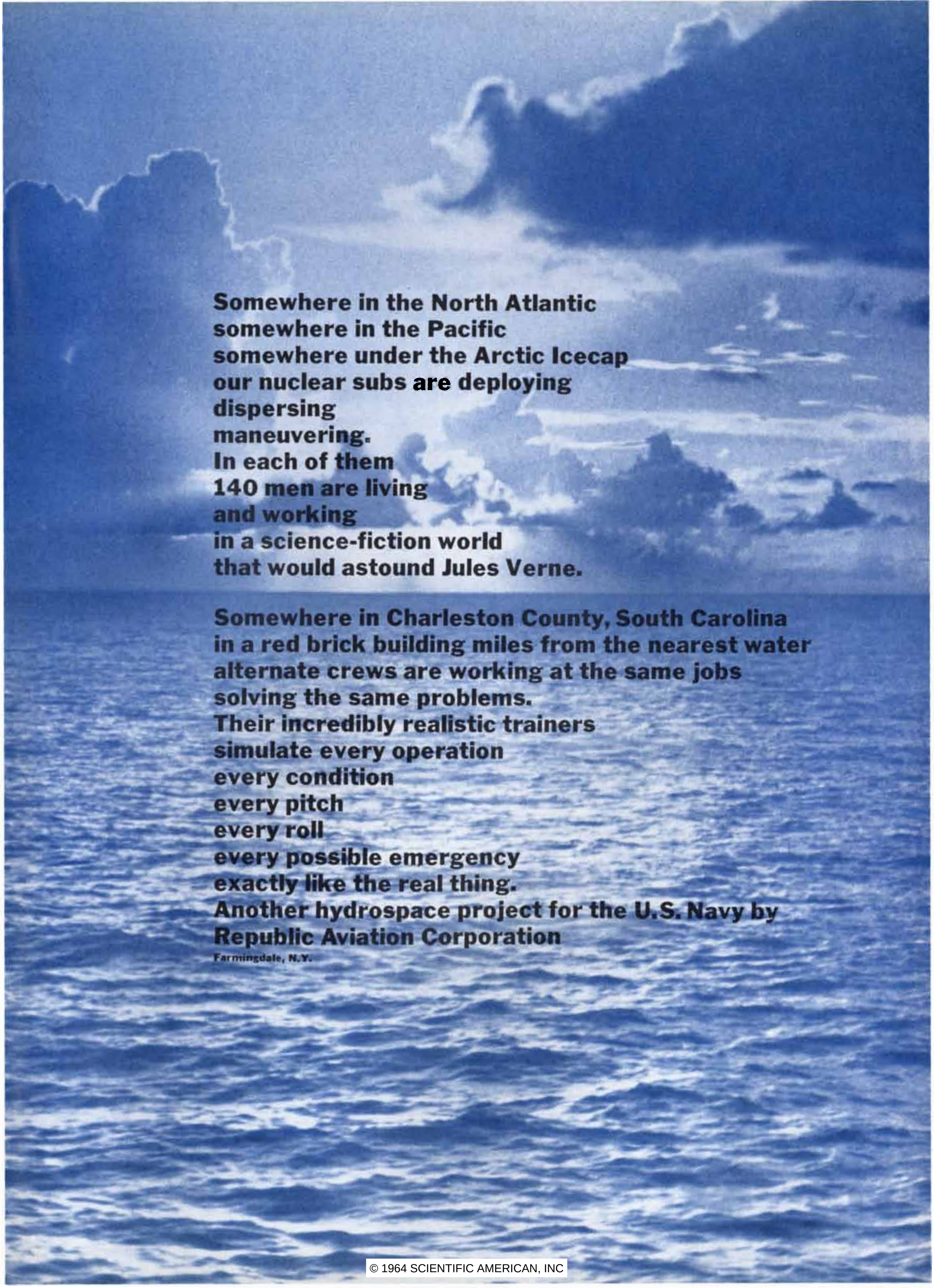
This still leaves unanswered the harder question: How did Eupalinus know the difference in height between the two ends? There is no place one can stand and see them both; moreover, the north end is hidden from the sea, which could have provided a natural horizon for the purpose of measuring elevation. Conceivably Eupalinus or his assistants sighted from one pole to the next with the help of some form of water level, which we know was used by the Greeks at about this time. In this way he could have measured quite accurately the vertical rise from the south portal of the tunnel to the top of the mountain and from there the drop to the north portal. Alternatively, he could have performed a triangulation over greater vertical distances, but this almost certainly would have afforded less accuracy.

As for maintaining the direction once inside the tunnel, Eupalinus would have had to dig the first few yards with extreme care, guided from outside. From then on the light from the ventilation shaft near the south end acted like a leading light in a harbor. The workmen only had to keep it always in sight by looking back as they dug deeper and deeper into the mountain. The same method could have been used at the north end, although there is no trace there of a similar shaft. Of course, since that end was outside the fortifications, all signs of the tunnel would have been blocked or camouflaged the moment it was completed.



CROSS SECTIONS of the tunnel and the water channel in the north gallery (*top left*) and south gallery (*right*) show the square shape of the tunnel, the change in depth of the channel and also how rubble was carefully piled above the channel. The beautifully designed round clay pipe found in the underground conduits outside the tunnel and the open rectangular gutter from the water channel are shown at lower left.

So well was the tunnel constructed that it has withstood many centuries of neglect, and it can probably endure many more. When Prince Constantinos began the restoration late in the 19th century, he meant to clear it completely and to get the water flowing once again. This could still be done very easily, because the tunnel is the best preserved of all ancient Greek works. It is incredible that this unique example of Greek science and technology stands ignored and neglected while vast sums are spent to preserve and display the fragmentary ruins of a hundred temples. After all, we owe a great deal more to the Greeks than statuary, sculpture and temples: they gave us the development of abstract thought and with it the beginnings of Western science.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somewhere in the Pacific
somewhere under the Arctic Icecap
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dispersing
maneuvering.
In each of them
140 men are living
and working
in a science-fiction world
that would astound Jules Verne.
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MATHEMATICAL GAMES

A collection of short problems and more talk of prime numbers

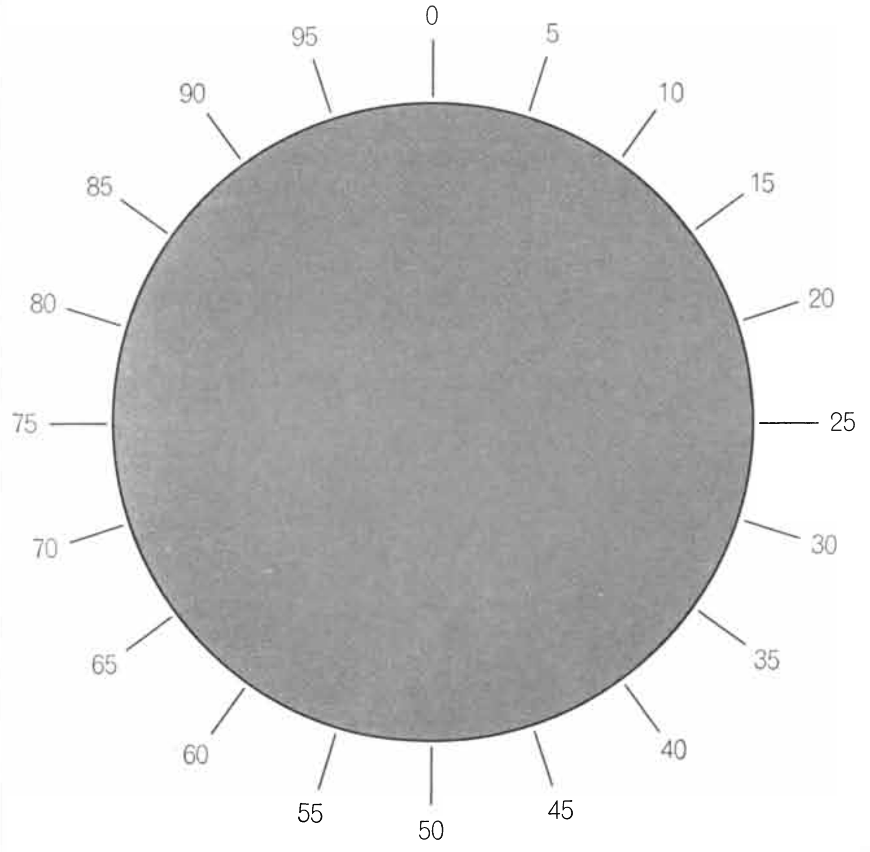
by Martin Gardner

This month's department continues a traditional practice of offering, once or twice a year, a selection of short problems, none of which calls for advanced mathematical skill. The solutions will be given next month.

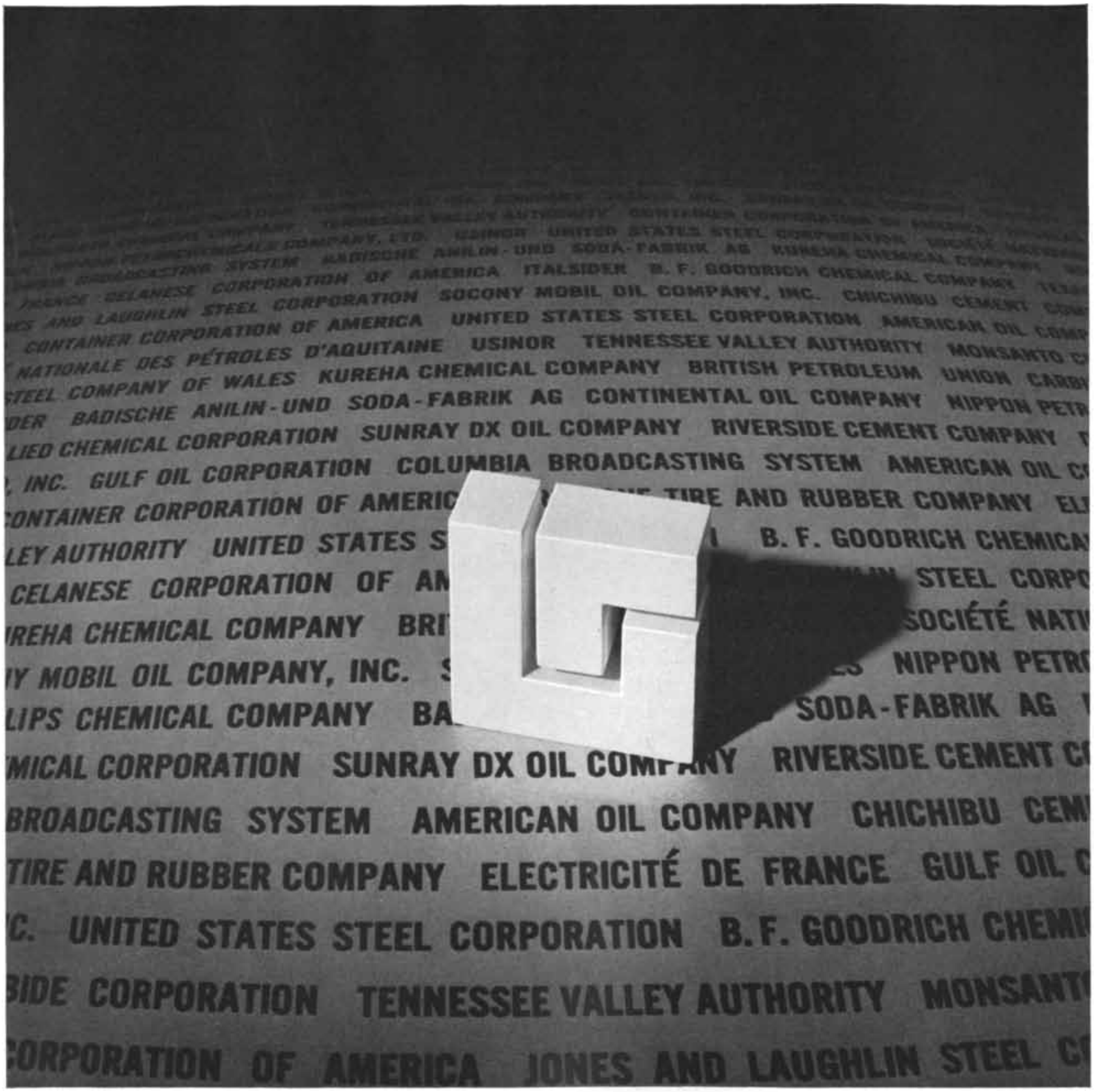
1.

The year is 1984. A moon base has been established and an astronaut is to make an exploratory trip around the moon. Starting at the base, he is to follow a great circle and return to the base from the other side. The trip is to be made in a car that is designed to travel over the satellite's surface and has a fuel tank that holds just enough fuel to take the car a fifth of the way around the moon. In addition the car can carry one sealed container that holds the same amount of fuel as the tank. This may be opened and used to fill the tank or it may be deposited, unopened, on the moon's surface. No fraction of the container's contents may be so deposited.

The problem is to devise a way of making the round trip with a minimum consumption of fuel. As many preliminary trips as desired may be made, in either direction, to leave containers at strategic spots where they can be picked



A tour-of-the-moon problem



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Dunning's 10-word square

up and used later, but eventually a complete circuit must be made all the way around in one direction. Assume that there is an unlimited supply of containers at the base. The car can always be refueled at the base.

To work on the problem, it is convenient to draw a circle and divide it into twentieths as shown on page 114. Fuel used in preliminary trips must of course be counted as part of the total amount consumed. For example, if the car carried a container to point 90, left it there and returned to base, the operation would consume one tank of fuel. A straightforward procedure would be first to transport 41 containers to point 10, then carry a 42nd container to point 15 and return to point 10. This would consume 42 tankloads of fuel and bring 42 containers into play, a total of 84 tanks all together. No more fuel is needed to complete the trip if proper back-and-forth trips are made, but the total consumption of 84 tanks can be more than cut in half by better planning.

This operations-research problem is similar in some respects to the well-known problem of crossing a desert in a truck (see this department for May, 1959), but it demands a quite different analysis. I have no proof that the best solution I know is indeed the minimum; perhaps readers will improve on next month's answer.

2.

An oil well being drilled in flat prairie country struck pay sand at an underground spot exactly 21,000 feet from one corner of a rectangular plot of farmland, 18,000 feet from the opposite corner and 6,000 feet from a third corner. How far is the underground spot from the fourth corner? Readers who solve the problem will discover a useful formula of great generality and delightful simplicity.

3.

A. K. Austin of Hull, England, has written to suggest a wild variation of ticktacktoe. It is the same as the standard game except that each player, at each turn, may mark either a naught or a cross. The first player to complete a row of three (either three naughts or three crosses) wins the game.

Standard ticktacktoe is a draw if both sides play rationally. This is not true of the unusual variant just described. Assuming that both players adopt their best strategy, who is sure to win: the first or the second player?

4.

In this country at least eight coins are required to make the sum of 99 cents: a half-dollar, a quarter, two dimes and four pennies. Imagine yourself the leader of a small, newly independent nation. You have the task of setting up a system of coinage based on the cent as the smallest unit. Your objective is to issue the smallest number of different coins that will enable any value from one to 100 cents (inclusive) to be made with no more than two coins.

For example, the objective is easily met with 18 coins of the following values: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90. Can the reader do better? Every value must be obtainable either by one coin or as the sum of two coins. The two coins need not, of course, have different values.

5.

"No," said the mathematician to his 14-year-old son, "I do *not* feel inclined to increase your allowance this week by ten dollars. But if you'll take a risk, I'll make you a sporting proposition."

The boy groaned. "What is it this time, Dad?"

"I happen to have," said his father, "ten crisp new ten-dollar bills and ten crisp new one-dollar bills. You may divide them any way you please into two sets. We'll put one set into hat *A*, the other set into hat *B*. Then I'll blindfold you. I'll mix the contents of each hat and put one hat on the right and one on the left side of the mantel. You pick either hat at random, then reach into that hat and take out one bill. If it's a ten, you may keep it."

"And if it isn't?"

"You'll mow the lawn for a month, with no complaints."

The boy agreed. How should he divide the 20 bills between the two hats in order to maximize the probability of his drawing a $10 bill, and what will that probability be?

6.

Charles Dunning, Jr., of Baltimore, Md., recently set himself the curious task of placing letters in the nine cells of a three-by-three matrix so as to form the largest possible number of three-letter words. The words may be read from left to right or right to left, up or down and in either direction along each of the two main diagonals. Dunning's best result, shown at the left, gives 10 words: tea, urn, bay, tub, but, era, are, any, try, bra.

No one knows how close it is possible to come in English to the theoretical maximum of 16 words. A letter may be used more than once, but words must be different in order to count. They should be dictionary words. I have on hand a specimen from an old puzzle book that raises the number of words to 12 and will provide next month's answer. A failure to reply personally to all readers who may find better squares will not mean that such letters are not welcome; I shall report on all significant results in a later column.

7.

So many readers were intrigued by the 12-coin problem in last month's department that I follow it here with a less familiar, and not so difficult, balance-scale puzzle.

Five objects, no two the same weight, are to be ranked in order of increasing weight. You have available a balance scale but no weights. How can you rank the objects correctly in no more than seven separate weighings?

For two objects, of course, only one weighing is required. Three objects call for three weighings. The first determines that *A* is heavier than *B*. We then weigh *B* against *C*. If *B* is heavier, we have solved the problem in two weighings, but if *C* is heavier, a third weighing is required to compare *C* with *A*. Four objects can be ranked easily with no more than five weighings.

With five objects the problem ceases to be trivial, and beyond five it increases rapidly in difficulty. As far as I know, no general method for ranking *n* objects with a minimum number of weighings has yet been established.

8.

Hundreds of entertaining puzzles, known as "chess tours," involve the movements of single chess pieces over the board. This department for April included a brief discussion of knight's tours and their connection with graph theory. Here is a choice selection of five queen's-tour problems. The reader does not have to be a chess player to work them out; he need only know that the queen moves an unlimited distance horizontally, vertically or diagonally. The problems are roughly in order of increasing difficulty.

1. Place the queen on square *A* [*see illustration on this page*]. In four continuous moves traverse all nine of the gray-shaded squares.
2. Place the queen on cell *D* (the white queen's starting square) and make the longest trip possible in five moves. The queen must not visit the same cell twice, and she is not allowed to cross her own path. Assume the path to be through the center points of all cells.
3. Place the queen on cell *B*. In 15 moves pass through every square once and only once, ending the tour on cell *C*.
4. Place the queen on a corner square. In 14 moves traverse every cell of the board, returning to the starting square on the 14th move. Individual cells may be visited more than once. This "reentrant queen's tour" was first published in 1867 by Sam Loyd, who always considered it one of his finer achievements. The tour, whether reentrant or open at the ends, cannot be made in fewer than 14 moves.
5. Find a similar reentrant tour in 12 moves on a seven-by-seven board. That is, the queen must start and end on the same cell and pass through every cell at least once. As before, cells may be entered more than once.

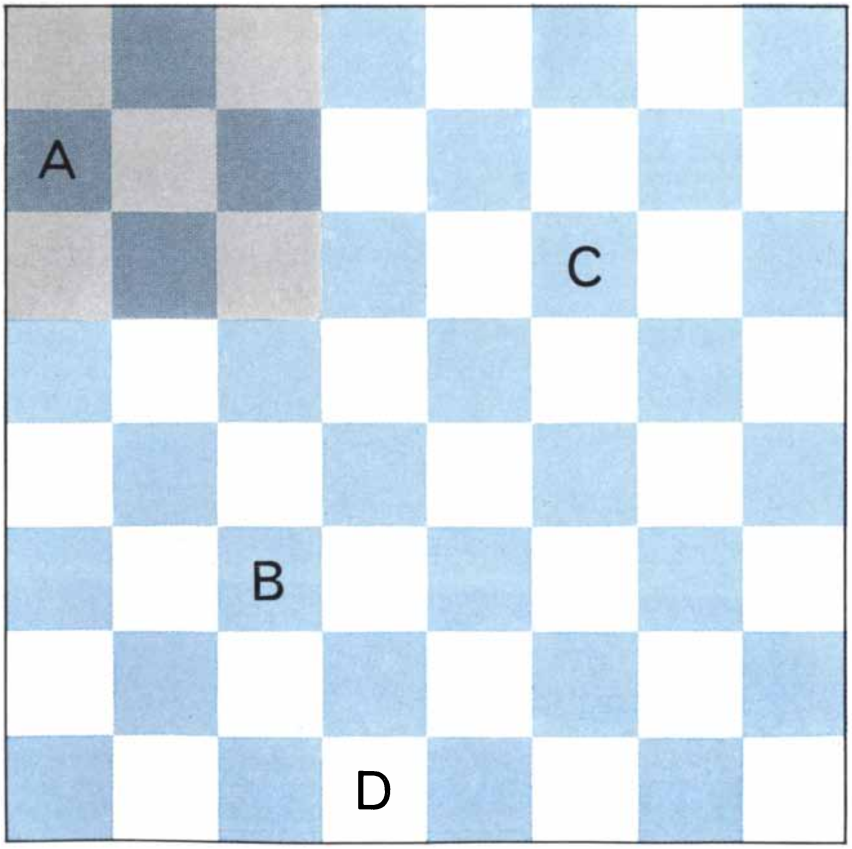
The discussion of prime numbers in this department in March brought such a wealth of enlightening letters that I cannot do them justice without devoting another column to the topic, which I hope to do eventually. I should like now, however, to correct a few errors in the March article and update some of its information.

Many readers noticed that the photograph of the computer grid at the left on page 122 of the March issue, within a border of about one centimeter from the outside edges, did not match the corresponding portion of the photograph at the right on that page. The computer's scope had failed to function properly within this border. A corrected photograph is shown on the next page.

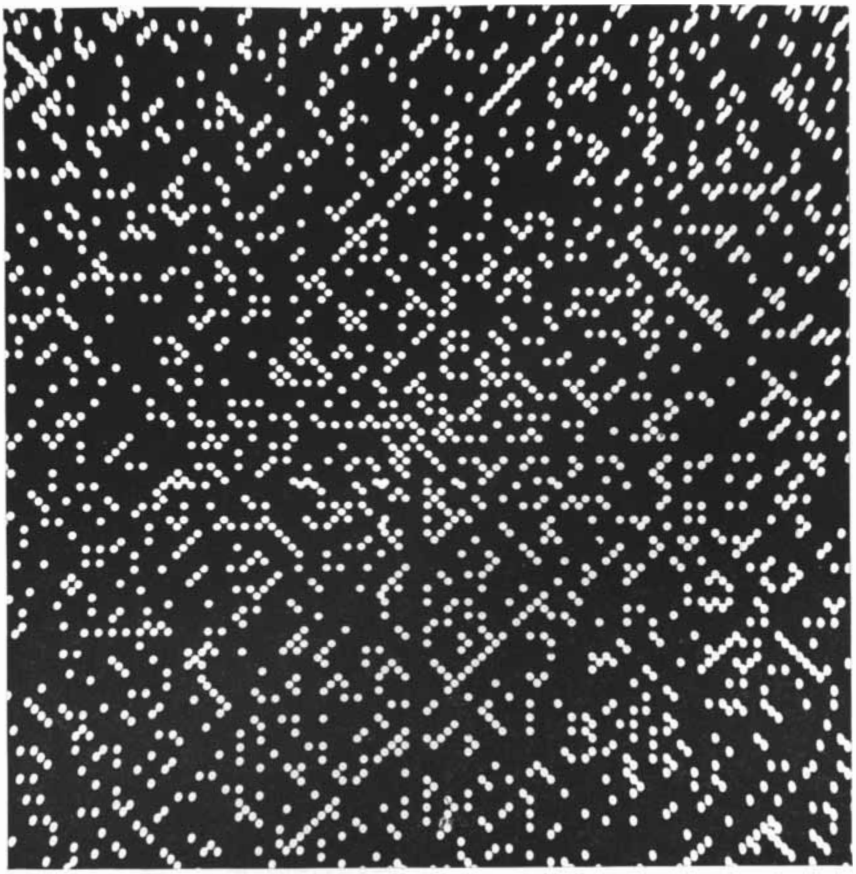
A number of readers experimented with triangular arrays of integers and found that the primes cluster along straight lines in the same manner as in Stanislaw Ulam's spiral grids. Laurence M. Klauber of San Diego, Calif., sent me a copy of a paper he had read to a meeting of the Mathematical Association of America in 1932, discussing his search for prime-rich polynomial formulas in such an array. Ulam has also used the Los Alamos computer for investigating a variety of other types of grid, including the triangular, and in every case he found that significant departures from random distributions of primes were at once apparent. This is hardly surprising, because any orderly arrangement of consecutive integers in a grid will have straight lines that are generated by polynomial expressions. If the expression is factorable, the line cannot contain primes; this fact alone can account for a concentration of primes along certain other lines.

All diagonals of even numbers are obviously prime-empty, and other lines are empty because they are factorable by other numbers. Many readers noticed that the diagonal line extending down and to the right from 1 on Ulam's spiral grid contains in sequence the squares of odd integers, and the diagonal line extending up and to the left from 4 gives the squares of even integers. Both diagonals are, of course, prime-empty. Conversely, other lines are prime-rich because they are generated by formulas that act as sieves, removing numbers that are multiples of low primes. The significance of Ulam's spiral grids lies not in the discovery that primes are nonrandomly distributed, which is to be expected in any orderly arrangement of integers, but in the use of a computer and scope to extend such grids quickly so that photographs provide, so to speak, a bird's-eye view of the pattern from which hints can be obtained that may lead to new theorems.

I should have qualified my statement that no formulas are known that express a function of n in such a way that they give a different prime for every integral value of n. It has been proved that no *polynomial* expression of this sort is



Board for queen's-tour problems



Corrected photograph of computer grid showing spiral of primes

possible, and it is also true that no nonpolynomial expression has yet been found that is useful in generating primes.

There are, however, some formulas of queer sorts that can be said to produce primes. Many readers called my attention to W. H. Mills's formula (*Bulletin of the American Mathematical Society*, Vol. 53, page 604, June, 1947), which contains an irrational number between 1 and 2. When positive integers are substituted for *n* in the formula, the expression gives prime values; but since the irrational number is not known, the formula is of no value in computing primes. In fact, it is easy to write irrational numbers that generate every prime in sequence, for example .20305070110130170190230.... To be sure, one has to know the sequence of primes before computing the number. There are many ways of writing complicated functions of *n* so that integral values of *n* produce distinct primes, but the catch is that the function itself requires the introduction of the prime-number sequence, making the formula valueless for finding primes. Readers interested in formulas of this type will find a nontechnical discussion of them in Oystein Ore's excellent book *Number Theory and Its History*.

It was stated that the only known "repunit" primes (primes consisting of the digit 1 repeated a prime number of times) are those with 2, 19 and 23 units. This is true, but some very recent work on repunit primes has now eliminated all possible numbers up to and including the repunit number of 137 units. John Brillhart's paper "Some Miscellaneous Factorizations" (*Mathematics of Computation*, Vol. 17, pages 447–450, October, 1963) carried the testing of repunits through repunit 109. Two readers, Hugh Thompson and James R. McCullough, hit on the same method of testing repunits of a certain type, finding factors of 227, 2,467, 907, 347, 359, 773 and 797 respectively for repunits of 113, 137, 151, 173, 179, 193 and 199. McCullough, working with the University of Connecticut's 7040 computer, later found factors of 18,797, 80,173, 12,517, 12,671 and 52,009 for repunits 127, 131, 149, 181 and 197. This leaves, as the only untested repunits with fewer than 200 units: 139, 157, 163, 167 and 191. I would be pleased to hear of factors for any of these numbers.

George O. Anderson, André Blanchard, Paul Carnahan, Martin J. Cohen, David Erbach, Daniel Jaffe, Ellis E. Johansen and Stuart Mayper were the first of many readers to suggest a better solution to the problem of finding a million consecutive composite numbers. Let k be the product of all primes from 2 to 1,000,001. The sequence $k-2$, $k-3$, $k-4$, $\ldots$, $k-1{,}000{,}001$ will contain only composites. This procedure gives a prime-free sequence much lower than the one obtained by the factorial procedure explained in the April issue in answer to this problem. As several readers made clear, it by no means rules out the possibility of still lower sequences of the same length.

Readers were asked last month for the minimum number of weights needed to weigh 27 boxes with integral weights of from one through 27 pounds, assuming that weights may be placed on either side of a balance scale. Three weights—two, six and 18 pounds—will do it. (They represent doublings of successive powers of 3.) These weights will achieve an exact balance for every even number of pounds from one through 27. The odd weights are determined by checking the even weights directly above and below; for example, a box of 17 pounds is identified by the fact that it weighs less than 18 and more than 16 pounds. (Mitchell Weiss of Downey, Calif., sent this pleasant twist on an old problem.)

The task of alphabetizing the letters of REPUBLICAN by dealing letter cards into three piles can be solved in two operations. First, write down the letters in alphabetical order: ABCEILNPRU. *A* is the first letter, so we place a *0* above the letter *A* in the word REPUBLICAN. We move *right* along the word in search of *B*, the second letter, but we do not find it. Because we are forced to move *left* to reach *B*, we put *1* above it. We continue to move right in search of *C*. This time we find it on the right, so we label it with *1* also. The next letter, *E*, forces us to move left again, therefore we label it *2*. *I* is to the right of *E*, so it gets *2* also, but *L* carries us left again, so it gets *3*. In short, we raise the number only when we have to move left to find the letter. This is how the final result appears:

5	2	4	5	1	3	2	1	0	3
R	E	P	U	B	L	I	C	A	N

On each letter card write the ternary equivalent of the decimal number assigned to that letter. The cards are held in a face-down packet, spelling REPUBLICAN from the top down. Imagine that the three piles are numbered, left to right, 0, 1, 2. Turn over the top card, *R*. Its ternary number is 12. The *last* digit, 2, tells you to deal the card to pile 2 (the end pile on the right). The next card, *E*, has a ternary number of 02; it also goes on the right end pile. Continue in this way, dealing each card to the pile indicated by the final digit. The piles are always assembled from right to left by putting the last pile (2) on the center pile (1), then all those cards on the first pile (0). Turn the packet face down and deal once more, this time dealing as indicated by the *first* digits of each ternary number. Assemble as before. The cards are now alphabetized.

To put the cards back in their original order a new analysis of the letters must be made, assigning them a new set of numbers:

5	2	4	1	3	2	5	1	0	1
A	B	C	E	I	L	N	P	R	U

Two operations will return the cards to their initial order, but the sorting procedure is not the same as before. If the decimal numbers assigned to the letters go above 8, then a ternary number for a letter will require more than two digits, and the number of required operations will be more than two. It is easy to see that the minimum number of operations is given by the number of digits in the highest ternary number. To alphabetize SCIENTIFIC AMERICAN the letters are numbered:

6	1	4	2	5	6	4	3	3	1
S	C	I	E	N	T	I	F	I	C

0	4	2	5	3	1	0	4
A	M	E	R	I	C	A	N

Because the highest number, 6, has only two digits in its ternary form, only two operations are called for. However, to reverse the procedure, changing the alphabetized order back to SCIENTIFIC AMERICAN, the highest number is 10. This has three ternary digits, therefore three operations are necessary. If the reader will test the system on longer phrases or sentences, he will be astonished at how few operations are required for what seems to be an enormously difficult sorting job. One can generalize the method to any number of piles, *n*, simply by writing numbers in a system based on *n*.

THE AMATEUR SCIENTIST

How to make a series interferometer to observe various subtle phenomena

Conducted by C. L. Stong

For the precise determination of length, or of small changes in the density, pressure or temperature of transparent substances, amateur experimenters will find no yardstick more accurate than a simple beam of light as used in a homemade interferometer. All interferometers are based on the principle that light waves that take different paths from a common source can fall out of phase and either cancel or reinforce each other when they reunite. If the source consists of white light, which is a blend of many wavelengths, the interfering waves produce colorful patterns as seen in such natural interferometers as soap bubbles, opals and all colored bird feathers except a few with yellow pigmentation. Interferometers that are commonly used for measuring length split a beam of monochromatic light into two rays that take separate paths until they recombine to interfere. The resulting pattern appears in a monochrome of varying intensity, as discussed in this department some time ago [November, 1956]. Instruments of the type used for measuring the density of fluids or gases, as well as the local distribution of temperature and stress or pressure, also split the beam into two rays, but the rays take essentially the same path. These instruments, known as series interferometers, cause one ray to traverse part of the path more than once; interference occurs at the end of the transit.

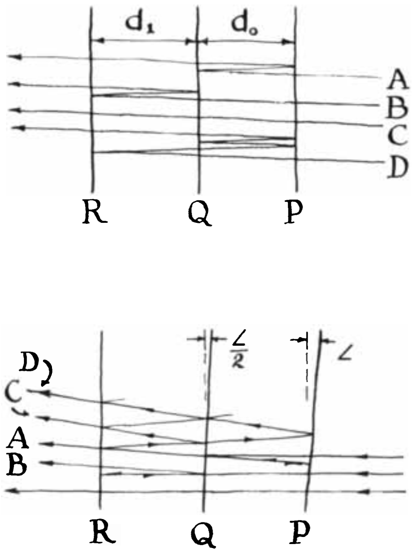
The construction of most series interferometers requires the use of machine tools not ordinarily available to amateurs. However, a series interferometer that can be made with ordinary hand tools has now been designed by G. F. Pearce, professor of mechanical engineering at the University of Waterloo in Canada. "The essential part of this instrument," writes Pearce, "consists of a series of three partially transparent mirrors. A beam of light, when passing through the mirrors, may take many paths of differing length. A given ray, for example, may pass through the first mirror, be reflected from the second back to the first and then back again through both the second and the third mirror. A second ray that substantially coincides with the first may traverse both the first and the second mirror and be reflected from the third back to the second for a final reflection to and through the third. Still another ray may traverse the first two mirrors, be reflected from the third back to the first, oscillate for a time between the first and the second mirror and finally complete its transit through the third, as shown in the upper part of the accompanying illustration [*this page*].

"When the mirrors are about equally spaced and are approximately parallel, the rays that traverse paths *A* and *B*, as depicted in the illustration, will interfere to form a pattern of alternate light and dark areas. Other parts of the beam that traverse a variety of path lengths, such as those shown at *C* and *D*, form an interference pattern that is superimposed on the interference pattern caused by *A* and *B*. This superimposed pattern can be eliminated by inclining the mirrors as shown in the lower part of the illustration. If mirrors *P* and *Q* are inclined as indicated, the rays that traverse different paths become separated and emerge in different directions.

"The interference pattern can be observed by simply inserting a collimator lens between the source and the mirror system so that the light passes through the mirrors as a bundle of parallel rays that are focused on a screen by a field lens between the third mirror and the screen [*see top illustration on opposite page*].

"The mechanism I contrived for supporting the mirrors in any relative position was constructed of aluminum plates. Any other substantial material, such as plastic panels or even plywood, may be substituted, however. The partial mirrors can be made by the familiar techniques used by amateurs for silvering the mirrors of reflecting telescopes or can be obtained from suppliers such as the Edmund Scientific Co. in Barrington, N.J., or Henry Prescott in Northfield, Mass. The mirrors I use reflect approximately 40 per cent of the incident light and transmit 60 per cent. They measure about two inches wide by three inches long, but the size is not critical. Homemade instruments of the same type have been operated with partially silvered microscope slides that measure one by three inches.

"The base of the interferometer should be constructed of material at least three-quarters of an inch thick to provide a solid support for two equally sturdy end brackets [*see middle illustration on opposite page*]. Apertures that are just a fraction of an inch smaller than the mirrors are cut in the end brackets. One mirror is mounted over the aperture of the bracket that faces the screen. The glass can be attached to the metal by light clips of spring brass or by a few dabs of epoxy cement. The reflecting surface should face away from the screen. The re-

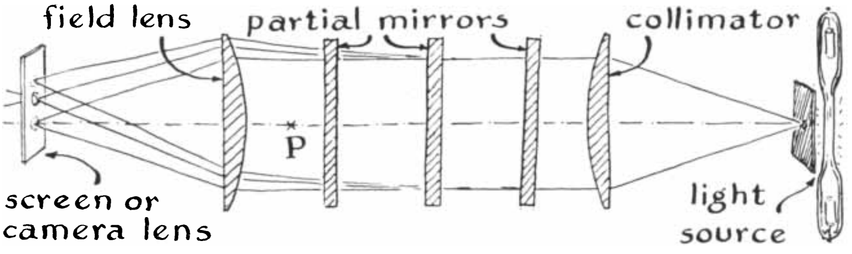


Paths of rays through partial mirrors

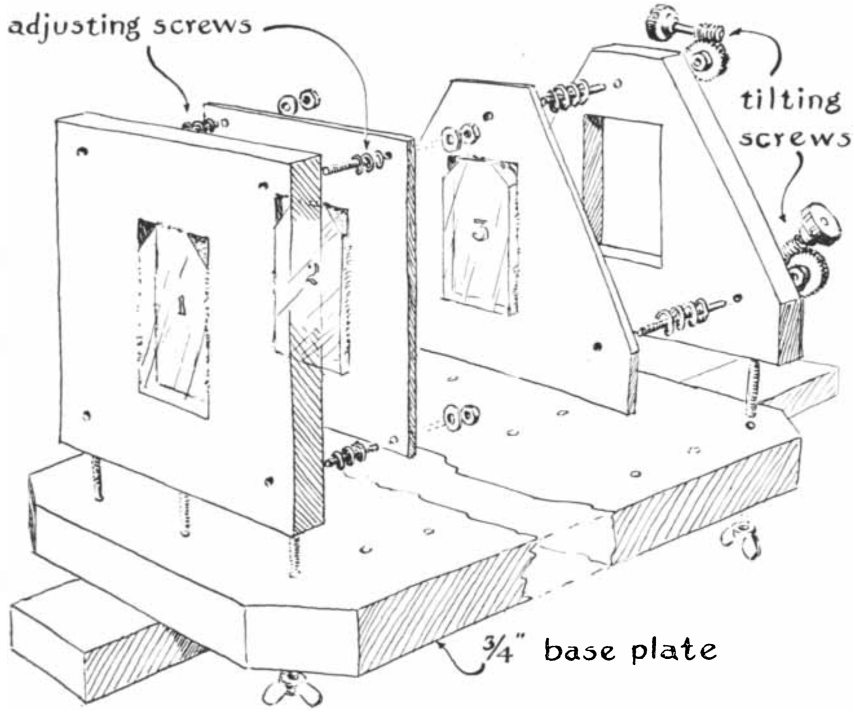
maining two mirrors are similarly attached over the apertures of two intermediate supporting plates, which can be made of thinner material. One of the intermediate plates is attached to the bracket nearest the screen by a suspension system that consists of four adjusting screws, together with a set of four helical compression springs that space the plate from the bracket. The bracket is drilled and tapped in its four corners for the screws, but the plate is merely drilled with oversize holes that slide easily over the screws when the retaining nuts are turned. These nuts are normally used only for tilting the middle mirror in relation to the mirror closest to the screen. The middle mirror can be attached to its supporting plate by the same technique used for mounting the first mirror; the coated side should face away from the screen.

"The system used for supporting the third mirror is similar. In this case, however, the supporting plate is suspended from the second bracket by only three screws. In my instrument these screws are equipped with heads in the form of worm gears taken from surplus apparatus. Worm gears are not essential, but they are exceptionally convenient for making fine adjustments. Oversize holes were made for the screws in the end bracket; the plate that carries the mirror was drilled and tapped. The threads make a loose fit, so the screws do not bind when the plate is tilted a few degrees. As shown in the accompanying illustration [*bottom of this page*], compression springs maintain the desired spacing between the end bracket and the plate. The coated surface of the third mirror should face toward the screen. The completed interferometer can be supported on any substantial surface, such as the top of a solid bench or table.

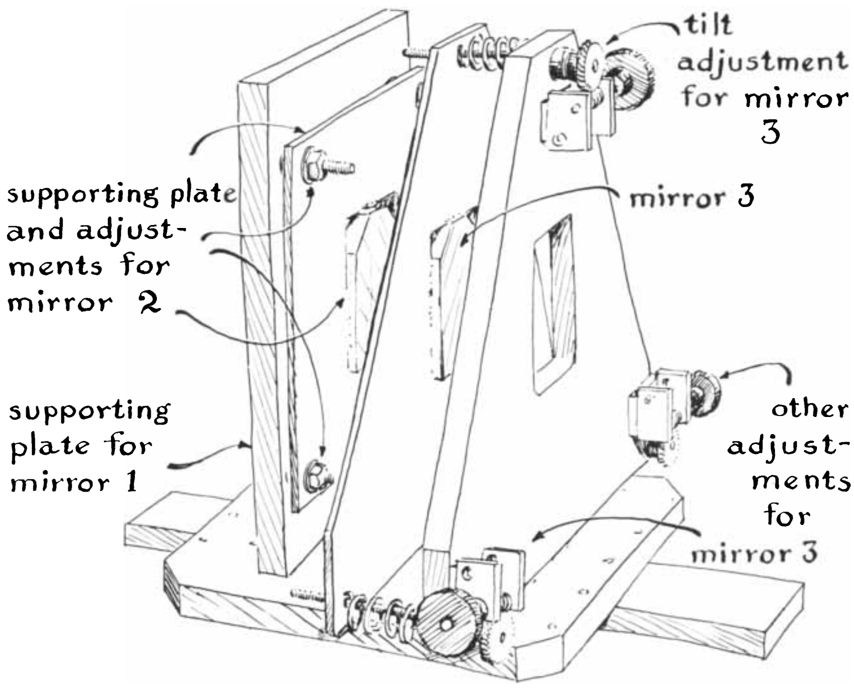
"The lenses used for bending the light into a bundle of parallel rays that traverse the mirrors and for focusing it on the screen are of the simple planoconvex type. They need be no larger in diameter than the mirrors. Neither do they have to be achromatic, because the light is monochromatic. My lenses were obtained from the Edmund Scientific Co. A bracket for supporting the collimating lens was improvised from a piece of plywood that in turn is held in position by an apparatus stand. The position of the lens is adjusted simply by moving the clamp and stand. A comparable arrangement supports the field lens between the mirror system and the screen. Although the interference pattern can be projected onto a screen, I



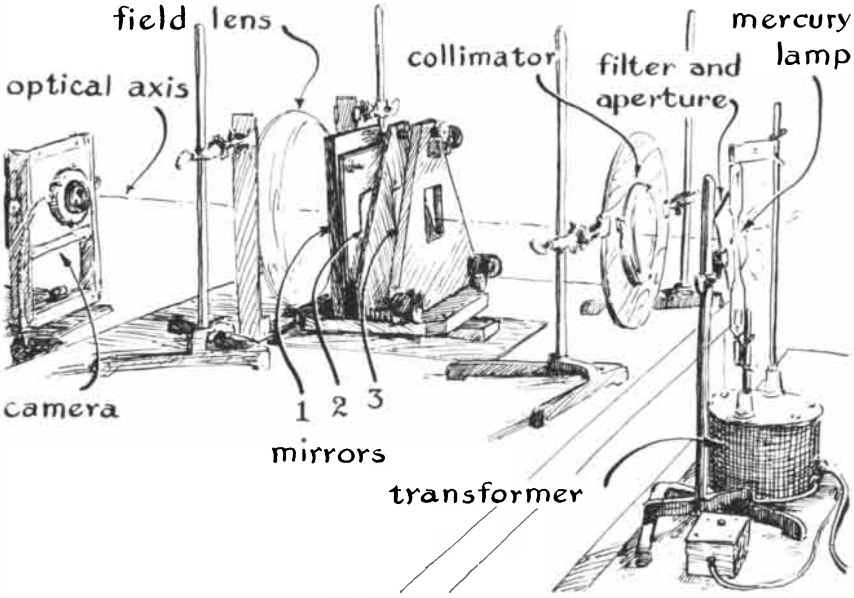
Optical scheme of a series interferometer



Arrangement of mirrors and brackets



Details of the mirror-suspension system



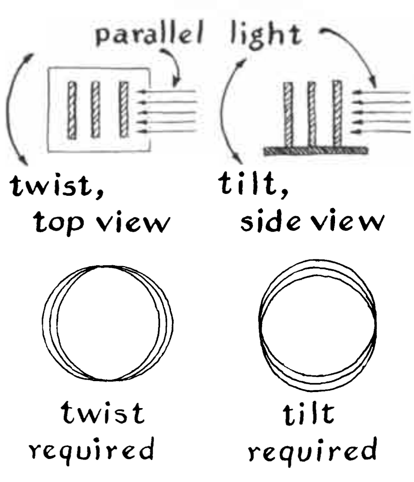
A series interferometer designed for construction by an amateur

prefer to examine it on the ground glass of a camera so that photographs of interesting patterns can be made conveniently. I use a view camera equipped with an extension bellows. Cameras of this type, incidentally, provide many desirable features not found in miniature cameras of more recent design. Often an older model made of wood can be bought for less than $10, complete with a set of plateholders.

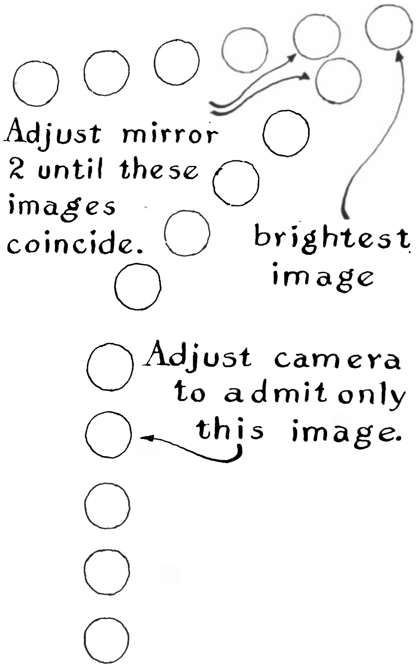
"As the source of monochromatic light I use a tubular mercury lamp together with a green filter similar to the Corning Type 4-64 that blocks the transmission of all rays except those emitted by the 5,460-angstrom line of mercury. Rays from the lamp are restricted by an aperture three-sixteenths of an inch in diameter located at the focus of the collimating lens. An alternate source, somewhat less intense, could be provided by a mercury lamp of the General Electric Type H-100-A38-4, which must be operated in conjunction with a current-limiting ballast, such as a Type 9T64Y3518. Doubtless an adequate source could be improvised by placing a sheet of dark green plastic, of the kind used for candy wrappers, over the mercury bulb of an ordinary sunlamp, but the precise color of plastic and the number of thicknesses to use for optimum results would have to be determined experimentally.

"The fully assembled interferometer occupies a space about two feet wide and four feet long. Usually I mount the lamp on a small stand on one side of the table that supports the mirror assembly and lenses. The camera rests on a tripod just beyond the opposite side of the table [*see illustration above*]. With the apparatus so positioned, I first adjust the mirrors for approximately equal spacing; in a typical experiment that might be five-eighths of an inch. Next I check to ensure that the mirror facing the camera (mirror *1* in the illustration) is perpendicular to the base plate. The second mirror is then tilted away from the camera approximately one degree and the third mirror approximately two degrees.

"Next, the system of mirrors is aligned to prevent multiple images from reaching the ground glass when the image of the source is focused by the lens of the camera. Normally this will require both twisting and tilting the



Initial adjustment of images



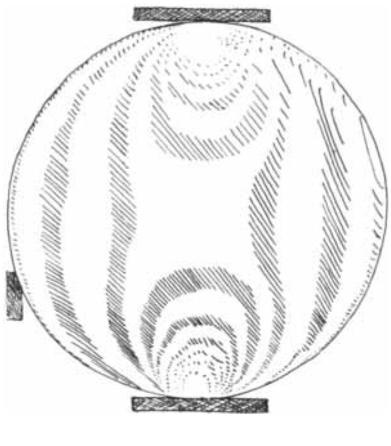
Final adjustment of images

interferometer [*see bottom illustration on page 124*]. As an aid in making the adjustment I insert a disk of transparent plastic about an inch in diameter and three-sixteenths of an inch thick between the two mirrors closest to the light source. The adjustments are made simply by slipping wedges of appropriate thickness between the base and the table top either to incline the assembly toward the camera slightly or to rotate it about its longitudinal axis. If overlapping disks of light in vertical array are observed on the ground glass, the instrument must be tilted; if the disks overlap horizontally, twist is required. When the position of the base has been altered so that the images merge, the orientation of the interferometer is correct.

"During the next procedure—adjusting the mirror spacing—it is convenient to view the image of the light source from a position about midway between the field lens and the first mirror, that is, from position *P* in the accompanying illustration [*top of page 123*]. To view the image, the rays can be deflected to the side by inserting a small hand mirror between the field lens and the interferometer mirror, or by removing the field lens temporarily. The image will appear as a series of bright spots in echelon formation that diminish in intensity as shown in the upper part of the accompanying illustration [*left*]. Adjust the center mirror by the screws that suspend it from the end bracket until the two images closest to the apex of the V coincide. Fine lines of light and shade—the interference fringes—should now be seen. The reason for a solid supporting table will now become apparent: the slightest vibration will disturb the fringes and make them difficult to see. Replace the field lens. A vertical array of images should now be visible at its focal point, as shown in the lower part of the illustration.

"Position the camera so that its iris coincides with the focal point of the field lens. Then alter the position to exclude all images from the ground glass except the second from the top, as illustrated. When the camera is properly focused, an interference pattern of alternate dark and light lines will be seen on the ground glass. The spacing of the lines is determined by the thickness of the plastic disk, as shown by the accompanying illustration [*at left below*]. If the intensity of the image is uncomfortably low, the pattern can be examined directly by removing the ground glass and observing the lines by means of a small magnifying lens, such as a jewelers' loupe. The fringes can be al-

A typical fringe pattern

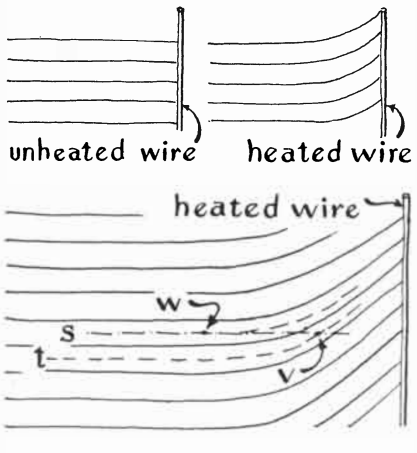


Plastic disk under stress

tered in inclination and spacing by adjusting the tilting mechanism of the bracket nearest the light source.

"When so adjusted, the interferometer is sensitive to the optical properties of any transparent substance placed between the mirrors closest to the light source. The transparent disk of plastic can be used for an initial test. If a mechanical load is applied across the diameter of the disk, for example, the resulting stress will reduce the diameter of the disk and increase its thickness. The distortion will not be uniform. Accordingly some of the transmitted light rays now traverse a path that is optically longer or shorter than other rays, as indicated by the altered interference pattern. To determine the nature of the distortion, first make a photographic negative of the interference pattern of the unstressed disk and a second negative with the disk loaded. Superimpose the negatives in register and make a photographic print through the pair. The print will show the kind of distortion pattern indicated in the accompanying illustration [*bottom right on opposite page*].

"The temperature distribution in air or other transparent media near a hot surface can be determined by observing changes in the density of the medium as reflected by the altered index of refraction. Heat lowers the density of most media and increases the velocity of light in the region of lower density, thus lowering the index of refraction. The effect can be demonstrated by placing a heated wire in front of the transparent plastic disk in the interferometer. Whereas the fringes appear to meet the image of a wire at room temperature at right angles, as depicted at the upper left in the accompanying illustration [*below*], they curve increasingly as they approach the image in the case of a



Various fringes from wire

$$\frac{n^2-1}{n^2+1} = C\rho$$

where: n = index of refraction

ρ = density

C = a constant

$$\frac{(n-1)(n+1)}{n^2+1} = C\rho$$

i.e., $(n-1) = C\rho$ very closely

$$n_1 - n_2 = C(\rho_1 - \rho_2)$$
$$= C\left(1 - \frac{\rho_2}{\rho_1}\right)$$
$$= (n_1 - 1)\left(1 - \frac{\rho_2}{\rho_1}\right) \ldots (1)$$

$$N_0 = \frac{l}{\lambda_0}$$

where: l = length of light path in heated air

λ_0 = wavelengh of light in vacuum

N_0 = number of wavelengths along l in a vacuum

$$n_1 = \frac{N_1}{N_0} \text{ and } n_2 = \frac{N_2}{N_0}$$

where: N_1 and N_2 are numbers of wavelengths under experimental conditions

substituting in equation 1:

$$\frac{N_1}{N_0} - \frac{N_2}{N_0} = (n_1 - 1)\left(1 - \frac{\rho_2}{\rho_1}\right)$$
$$N_1 - N_2 = (n_1 - 1) N_0 \left(1 - \frac{\rho_2}{\rho_1}\right)$$
$$N_1 - N_2 = (n_1 - 1)\frac{l}{\lambda_0}\left(1 - \frac{\rho_2}{\rho_1}\right)$$

relating temperature to density:

$$N_1 - N = \Delta N = (n_1 - 1)\frac{l}{\lambda_0}\frac{(T_2 - T_1)}{T_2}$$

solving for temperature:

$$T_2 - T_1 = T_1 \frac{\Delta N}{(n_1 - 1)\frac{l}{\lambda_0} - N}$$

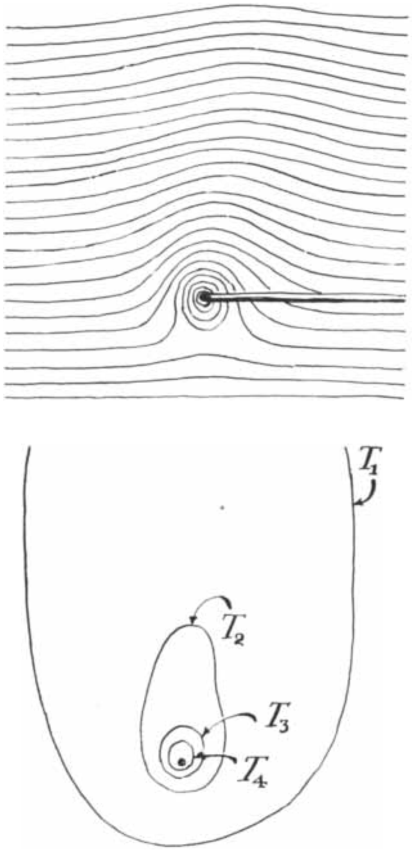
ΔN = fringe displacement measured in fringe widths

Formulas and equations for interferometer

heated wire, as shown at the upper right in the illustration.

"Such patterns can be analyzed in terms of the temperature distribution. Assume the pattern of fringes associated with a heated wire, such as the one in the lower part of the illustration. Select a pair of adjacent fringes, such as those at s and t. A line drawn parallel to the straight portion of the fringes and continued toward the wire will intersect fringes that depart from straightness as they approach the wire. At point v in the illustration, for example, the straight, broken line that has its origin in the straight portion of fringe has crossed the bent-up portion of fringe t. The heated wire has caused a shift of one whole fringe with respect to the center line of fringe s. This means that the light passing through point v has speeded up and is a full wavelength ahead of the light at point w. The amount of shift in terms of wavelength can be similarly determined at any point along the fringe. The index of refraction of a perfect vacuum has been accepted as 1, and that of air is about 1.0003. The density of normal room air can be measured by a barometer. With these data plus the number of wavelengths that the light shifts, as measured by the interferometer, the experimenter can determine the index of refraction of the heated medium and the local temperature by simple arithmetic, using formulas in the illustration [*left*].

"The first of the equations, on which the formulas are based, was derived independently during the past century by the physicists H. A. Lorentz of Holland and L. V. Lorenz of Denmark. It relates the index of refraction of a gas to its density. As indicated, the index of refraction, −1, is very closely equal to the product of the density of the medium multiplied by a constant. The constant is therefore equal to the quotient of the difference between the index of refraction and unity divided by the density, a quantity that can be measured by a thermometer and a barometer. If n_1 is the index of refraction of the room air and n_2 is the index of refraction of the heated air, and if p_1 and p_2 are the corresponding densities, then, as indicated in the second set of equations, it can be shown that the difference between the speed of light through the room air and through heated air is equal to the product of the difference in the speed of light through air at room temperature and vacuum multiplied by 1 minus the ratio of the density of the heated to the unheated air. Similarly, the third set of equations



Fringe (above) *and isothermals* (below)

relates the difference between the number of wavelengths that traverse air at room temperature and any selected point in the heated region, as measured by the interferometer, to the index of refraction of air at room temperature and the ratio of the density of hot to unheated air.

"Finally, by applying the law that relates the temperature of a gas to its density the formula is derived for computing the temperature of the heated air. To apply the formula the experimenter need only measure the temperature, T_1, of the room air and express the measurement in degrees Kelvin. Because the quantity ΔN is equal to the fringe displacement as measured in fringe widths by the interferometer, the formula can be used to calculate the temperature rise above room air at any point along the center line of the interference fringe. The fringe pattern in the vicinity of a horizontal wire takes the form of a series of concentric ovals, as shown in the upper part of the accompanying illustration [*above*]. This pattern can be analyzed by the same technique; the temperature data can then be used for making a graph of the isothermals as shown in the lower part of the illustration."

Classic Jobs of Measurement

Performed by Electro Instruments

A Foreword by
Dr. Walter East
President, Electro Instruments, Inc.

"You name it, we'll find a way to measure it," our brash engineers keep assuring me. I like their spirit, even if it has been costly to me in the way of expensive dinner bets!

It was with a measuring breakthrough that Electro Instruments was born. Our original Stepping Switch Digital Voltmeter was the first to substitute electronically driven switches for mechanical needle movement devices. It quickly proved itself an ideal instrument for speedier, more accurate, more reliable measurement—with useful applications in many industrial operations.

Since that time we have pioneered 19 other electronic "firsts."

These have led to ways of refining many older measuring systems. But, more important, they have extended the areas in which our instruments, and our systems, can serve industry.

The end result for which industry employs measurement is economy . . . be it in personnel . . . time . . . materials . . . investment. Looking through our "case histories," I ran across a number of outstanding examples of economies effected by use of Electro Instruments.

I thought we might usefully present these to industrial engineers, executives, superintendents, as ideas they might consider for their own operations.

Many readers, I appreciate, will have industrial measuring problems quite different from those cited in the examples. On this point, I think our engineers are worth re-quoting: "You name it, we'll find a way to measure it!"

Electro Instruments' *solid state* Digital Multimeters bring greater speed, higher reliability to many jobs of measurement, and at a lower investment.

Electro Instruments offers the world's most carefully designed X-Y Recorders.

Spectra performance recorded without need for photography

In many biochemical operations, recorded profiles are necessary for accurate identification of compounds, and for purposes of quantitative assay. Used in connection with newly developed instruments capable of exciting molecules to a state of phosphorescence, Electro Instruments X-Y Recorders have proved a means of producing visual display of spectra without need for photographic equipment or processes.

500 man hour job cut to 33 ½!

Telescoping a job that once required 500 man hours into a 33½-hour operation is no mean feat! Yet a system employing an Electro Instrument Digital Multimeter accomplished just that — for one of America's major spacecraft* companies.

What was involved was the testing of printed circuit cards. Each of 1000 cards produced daily by the company had to be given 32 separate tests for quality. It took an experienced electronics technician and inspector 15 to 45 minutes per card to perform the job.

In the interest of speeding up this tedious job, experiments with an automatic electronic testing machine were begun. The eventual solution proved to be a punched tape system — designed, incidentally, by one of the company's engineers — with an Electro Instruments Digital Multimeter employed as a key parameter.

Each of the 1000 cards are now given the 32 quality tests in *less than 2 minutes*—with results being displayed at the push of a button! (*Name on request)

Electro Instruments, Inc.
8611 Balboa Avenue, San Diego 12, California

ELECTRO INTERNATIONAL, INC., ANNAPOLIS, MARYLAND • TRANSFORMER ENGINEERS, SAN GABRIEL, CALIFORNIA

BOOKS

Has the concept of cybernetics lived up to its early promise?

by J. Bronowski

Brains, Machines, and Mathematics, by Michael A. Arbib. McGraw-Hill Book Company ($6.95).

From time to time a new branch of science catches the imagination of scientists and public together, so that it comes to express the spirit of a whole generation. The theory of evolution by natural selection did this 100 years ago; it was an idea that laymen as well as naturalists could seize, with the result that they could see its implications and feel themselves personally engaged in them. In our own century the theory of relativity took the same hold on the generation of World War I. For a time after World War II it seemed that cybernetics might become another such formative branch of science, which would bring together many different fields and impress on them the unity of a new conception that was both profound and understandable.

The recent death of Norbert Wiener provides an occasion to observe that that heroic dream is over. Cybernetics remains in the best sense a fundamental idea as well as a popular one, but it has turned out to be less embracing and, in an odd way, less interesting than we had hoped 20 years ago when it was conceived. This is an appropriate moment in history to take stock of the achievements of cybernetics and the lingering disappointments, and Arbib's neat and summary book serves as a fair text for both.

Wiener coined the word "cybernetics" from the Greek *kybernetes*, meaning steersman; what he had in mind was the sort of machine that, like a steersman, corrects its own deviations from a planned course of action. To us as human beings the most fascinating of all machines is the living mechanism of the body and the brain. We hoped above all that cybernetics would press the analogy between dead and living mechanisms so far that it would finally unravel the processes by which the brain (and the nervous system as a whole) controls and corrects the intricate functions of the body.

Two original ideas in cybernetics encouraged this hope. One was the realization, and the practical demonstration, that a machine can be made to follow a program that contains alternative paths among which it must choose. That is, we can write instructions for a machine that require it to use the results of some of its computations in order to decide along which of several paths it shall go next to carry out its program. This seems a simple idea today, and it had already been thought of by Charles Babbage when he designed his computing engines more than 100 years ago. Yet this principle of choice is the most radical change in the conception of a machine since Leibnitz built the first calculating machine nearly 300 years ago. Leibnitz held that animals are automatic machines; if he had conceived of automata with choice, he ought to have included human beings among them.

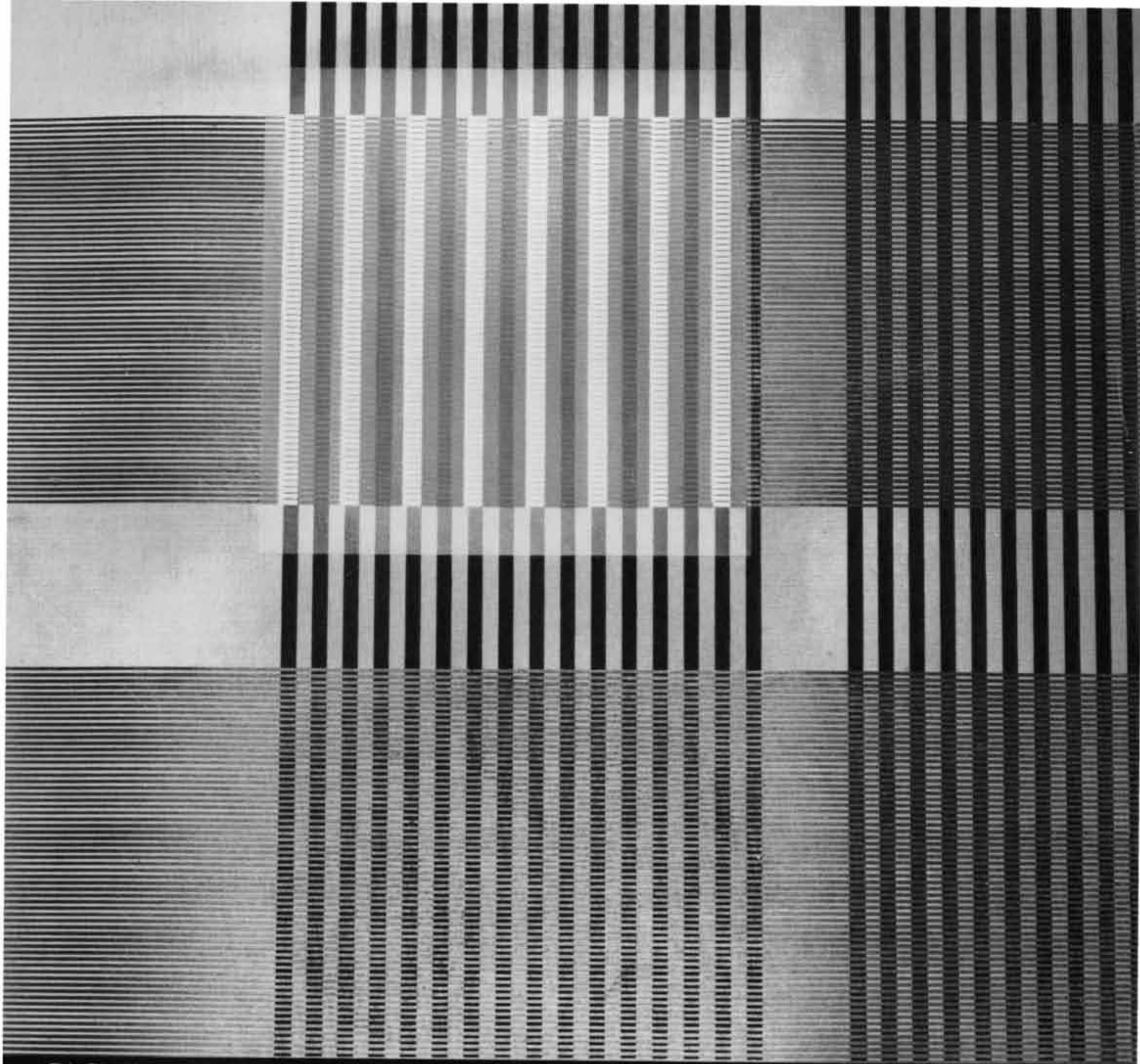
The second original idea that cybernetics made familiar is that of feedback. At one stroke this laid bare a simple means by which living things monitor and correct their own actions as they move through a changing environment. And of course a machine with feedback is also not a rigid machine of the old-fashioned sort. It senses its environment and, in particular, adjusts itself to the total configuration it forms with the environment.

The two principles of choice and feedback widened our conception of a machine enormously. They gave a new depth to the analogy between machines and living beings; they showed that the delicate adjustments of the body can be understood and imitated as practical everyday mechanisms. Indeed, it became clear—perhaps shockingly clear—that any subtle machine must have some of the characteristics we used to think were a monopoly of intelligent beings. For example, a computer cannot be asked to use its own findings in order to choose between alternatives unless it has a store for these findings; unless it has something like a memory. If its findings are to include appreciations of its own states, even its internal states, then it must also have something like sense organs.

In short, it was not unfair to call the new computers electronic brains, and they seemed well on the way to becoming electronic bodies also. This was the time when most of the internal balances and regulations of the body were mimicked by machines. W. Grey Walter made instructive toys that explored their environment here and there by chance and learned conditioned reflexes from it. W. Ross Ashby made a delightful assembly that recovered its inner stability even after it was injured.

There was a small explosive charge (an intellectual one) hidden in Ashby's innocent array of random circuits: his machine was one of several signs of a third preoccupation of cybernetics, as original and as important as the other two. If a machine is to adjust itself to its environment—its inner or its outer environment—it must treat the environment as an instruction, and it must then know how to interpret this awkward bundle of instruction. That is, it must decode the messages of the environment, and to do so it must sift the messages—accept some and reject some —and in general guess at and wrestle with its own errors. The third new idea in cybernetics is that of tolerance: to overcome the background of inherent uncertainties and act decisively in the face of error.

The cybernetic principle of tolerance has become best known in the form Claude E. Shannon gave it in his theory of information. Here the principle is expressed by saying that the uncertainties, or noise, in a channel of communication set an upper limit to the ratio between the information that is sent and that which is received. In order to approach this limit and minimize the errors, we have to send internal checks with the information; we have to code



Thin Film Memory Unit

Lincoln Laboratory, a research center of the Massachusetts Institute of Technology, conducts investigations in selected areas of advanced electronics, with emphasis on applications to national defense and space exploration. The *Information Processing research program* is directed toward enriching the technology of digital computers, developing improved techniques for automatic data processing systems, and increasing understanding of the interaction between computers and their users. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, M.I.T., Box 18, Lexington 73, Massachusetts

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A description of the Laboratory's work will be sent upon request it with a large amount of redundancy.

A machine also can, like a message, be safeguarded from error by splicing redundant parts into it. This elegant technique was first demonstrated mathematically and practically by that fountain of ideas John von Neumann. Its effect is to make possible what is succinctly described in the title of von Neumann's original paper as "the synthesis of reliable organisms from unreliable components."

The use of the word "organisms" here, where we expect the word "machines," shows that von Neumann was aware from the outset how important this kind of tolerance is to the stability of living things. It is a matter of convenience in an electronic computer that it can go on working when some of its parts fail; in a living brain it is a matter of life and death. The human brain is, surprisingly, more like a machine than the body is: when any cell in the brain dies, it is not replaced. During a lifetime perhaps 10 per cent of the cells in the brain may die off at random, and yet the brain is able to carry on its work—to observe, to record, to recall, to reason and to command.

Up to this point, then, cybernetics had found a powerful and fruitful analogy between the brain and the machines that use electrical circuits. The wiring diagrams for the large computers seemed every day to look more like the pathways in the nervous system, until we had the feeling that the designers gave them their mocking code names (ACE, MANIAC and so on) to ward off the fear that they might one day turn out to be human. There was, it seemed, no action of the brain that could not be pictured as carried out by a shuttle service of on-and-off signals.

Of course this happy belief has not been proved false. Nothing that has been discovered in the past 10 years, or that has resisted discovery, has made us despair of the basic tenet that biological processes have the same mechanisms as physical processes. No reputable investigator intends to abandon the search for such concrete mechanisms, or to fall back on some mystic vitalism to relieve him of the ardors of the search.

But it has become uncomfortably clear that we were too sanguine and thought ourselves nearer the end of the search than we are. Three kinds of obstacle have loomed up between what we understand and what we seek to explain, and it is well to survey them one by one.

The first obstacle lies in the mode in which the information the senses bring in from the outside world is presented to the brain. It was pleasant and convenient to think, until a few years ago, that the outside world impresses itself on the brain point by point by a simple mapping. Indeed, there are senses that carry their information to the brain in this direct way, as single events; the sense of smell does so. But we now know that the most important human sense, the sense of sight, works far more elaborately. This was shown by Jerome Y. Lettvin, Humberto R. Maturana, Warren S. McCulloch and W. H. Pitts in a painstaking and now classic analysis of the visual system of the frog. Arbib has been most influenced by the early cybernetic models of McCulloch and Pitts, but he gives a very fair account of this later work. He concludes:

"The function of the retina of the frog is not to transmit information about the point-to-point pattern of distribution of light and dark in the image formed on it. On the contrary, it is mainly to analyze this image at every point in terms of four qualitative contexts (boundaries, moving curvatures, changing contrasts, and local dimming) and a measure of illumination and to send this information to the colliculi, where these functions are separated in the four congruent layers of terminals.

"The retina transforms the visual image from a mosaic of luminous points to a system of overlapping qualitative contexts in which any point is described in terms of how it is related to what is around it."

The brain asks the eye for information not about points but about objects: their boundaries, their movements and their contrast against the background.

This is a much more recondite system of information than we, who are used to television pictures and graph paper, would expect. Moreover, in higher animals it is relayed to either two or three different parts of the brain, which have evolved at different times. In short, the brain (and the retina, which in origin is part of the brain) is concerned from the first moment with integrating the impressions it receives from the environment; it *begins* by discriminating. What it treats as units of information are far more complex assemblies and contrasts than we would think of feeding to a machine. We shall surely have to discover another new conception of the machine before we can enter into the working of the brain.

The second obstacle to our understanding is that we are still at a loss to know how the brain stores and then recalls its past activity. No acceptable model of human memory has yet been found, either in electrical or in molecular analogues. It may be that this is the place at which the next advance must come, and that once we know how to picture the memory we shall also understand the manner in which the brain integrates an experience before it stores it. Certainly we cannot understand learning or speech or the formation of concepts until we understand the working of memory.

The third obstacle is of another kind. It derives from a difficulty in logic, not in conception, and I list it here only because Arbib's book gives an inordinate amount of space to it. Since the time of Euclid (and Thomas Hobbes's conversion to philosophy by Euclid) we have been accustomed to present any connected system of propositions in mathematics and physics as deductions, step by step, from a compact set of explicit axioms. Almost 50 years ago David Hilbert asked, with the lucid and fatal innocence of genius, whether it is then self-evident that every proposition in the system can either be proved or disproved by logical deduction from the axioms. It turned out not to be self-evident, and in time Hilbert sadly asked if it is even true. Kurt Gödel in 1931 and A. M. Turing in 1936 showed that it is *not* true of any system that contains all the arithmetical numbers. There must be propositions, even in the simple arithmetic of numbers (although we do not know how to spot them), that can never be proved or disproved in a finite number of steps. Gödel and Turing both demonstrated this essentially by specifying the operations of a logical machine that will go on grinding away at some propositions forever.

It has therefore become a common topic in books about machines to ask whether the human brain can somehow recognize truths (whatever that may mean) that a machine cannot prove. This question was sensibly answered by Ernest Nagel and James R. Newman in their book *Gödel's Proof;* they pointed out that whatever machine the brain may be, it is certainly not one that is provided with a fixed set of axioms and forever reasons from them and them alone. Indeed, the process of scientific discovery does not consist of a search for axioms but of a search for empirical propositions from which new axioms may be induced; at any stage in the development of a science the axioms are temporary structures that must be added to as the science grows. This was seen well before Gödel by F. P. Ramsey when he proved that a scientific system that defines all its entities rigidly is not capable of finding new relations between them. Science progresses not by deductive but by inductive steps, and it is certainly an activity of the brain to make these inductive guesses (which will sometimes be false) from evidence that is not conclusive. This has nothing to do with Gödel's proof of the limitation of logical machines; we do not abdicate our belief that the brain is a mechanism because we deny that it is a Turing machine. But it does remind us that we have another threshold to cross before we understand its mechanism.

Arbib's book traverses all the cybernetic subjects (rather too many) in a compact manner and with more mathematical backing than is usual. He cannot be blamed for the sense of disappointment we feel at the end of the book: the sense that the cybernetic models already belong to the past, and begin to have as old-fashioned an air as the model that used to describe the brain as a telephone exchange. Perhaps we can go no further in elucidating the machinery of life by analogies drawn from engineering. If so, the time has come to learn a more radical approach from more modern sciences. At the beginning of this century physics was at a standstill until Max Planck and Albert Einstein broke away from the explanations of natural phenomena that would satisfy engineers. It is my belief that the mechanism of the brain will not be explained until a new generation of biologists invents new concepts as unexpected and as audacious as Planck's and Einstein's.

Short Reviews

THE TWO CULTURES: AND A SECOND LOOK, by C. P. Snow. Cambridge University Press ($1.95). This volume contains the celebrated 1959 Rede Lecture, which started all the fluttering and fussing and fuming, and a sequel. In this Sir Charles repeats his main argument. In advanced Western society "we have lost even the pretense of a common culture." The best-educated people often cannot communicate with one another "on the plane of their major intellectual concern." This breakdown is bad in every way. It causes us to misread the past, fumble the present, jeopardize the future. We must do our best to bridge the gap between the cultures and make possible, chiefly through education, concerted good action to which science and the humanities can contribute their full strength.

For reasons a little hard to explain the argument touched a nerve, although not the same nerve in both cultural camps. Snow made some men happy and gave others a pain—if not worse. F. R. Leavis was stirred to such paroxysms that one might have thought Snow had been personally responsible for the demise of D. H. Lawrence. Sir Charles had done no such thing. In truth, the Rede Lecture justified neither the wild cheering nor the abuse. The ideas were not new, as he readily admits; nor were they expressed with unusual clarity and cogency. Yet they took hold and in varying degrees and different ways influenced teachers, students, social critics, scientists, literary men, thoughtful persons of all kinds—although to what lasting or constructive effect it is impossible to say. Snow's explanation of the hubbub is unanswerable. The "time was right," the "ideas were in the air," they were suited to the "mysterious operation" of the *Zeitgeist*. Moreover, Snow says, the ideas must have merit or they would not have triggered off such a response.

Having reaffirmed his central position—all in an agreeably modest key—Snow turns to emendations and further thoughts. He takes notice of the criticism of the expression "two cultures." Does the word "culture" have the same meaning when used to describe Neanderthal or Trobriand Island ways of life? Snow suggests that it does; each group in its "common attitudes, common standards and patterns of behaviour, common approaches and assumptions" exists as a culture "within the anthropological scope." As for the objections to his limiting the cultures to two, he admits to having oversimplified; but he holds to his original count as being "a little more than a dashing metaphor, a good deal less than a cultural map" and "fairly sensible."

An important modification of Snow's original position relates to the sharpness of the cultural divide in the U.S. as compared with Britain. In the U.S. "the divide is nothing like so unbridgeable." For one thing, the effort is well under way in a number of our universities to both educate nonspecialists in the sciences and put science students on speaking terms with the humanities; for another, a kind of third culture has arisen that is concerned with "how human beings are living or have lived." This culture, which flourishes more vigorously here than in Britain, is fed by many different streams: social history, sociology, demography, political science, economics, psychology, medicine and "social arts such as architecture." The sources are neither as scientific as physics or chemistry nor as humanistic as literature or painting; yet they partake of both natures. The third culture uses facts, systematization, statistics, models, logical inference; yet it does not scorn insights not based on statistics, generalizations that go beyond observation, sympathies and social responsibilities. It is very much concerned with such problems as the human effects of the scientific revolution. It strives to gain understanding both of individual and collective behavior so as to make it possible to protect the innocent, make restitution to victims, rehabilitate the sinner and put out small fires before they become world conflagrations. The third culture sets an example to the other two; if it prospers, it may mediate their differences and conciliate their suspicions and their antagonisms.

The balance of the second essay rambles from demography to Dostoevski. The conjunction of these opinions is not obvious, except that they serve loosely to support Snow's main thesis; they exhibit the breadth and catholicity of his interests, but they are in no sense indispensable. Whatever else might be said, one cannot fail to take Snow seriously or to recognize his commitment to the cause of peace, intelligent action and human betterment.

THE FEYNMAN LECTURES ON PHYSICS, by Richard P. Feynman, Robert B. Leighton and Matthew Sands. Addison-Wesley Publishing Company, Inc. ($8.75). This volume, the first of two, consists of lectures given by Feynman in the first year of a two-year introductory physics course at the California Institute of Technology. The lectures were tape-recorded and then revised and reorganized by the three men named on the title page and by others. Designed for a fairly elite audience, even though beginning students, the text is not at all bashful about using mathematics and quickly introducing hard ideas. What makes this book stand out is its rather personal and informal tone (so characteristically Feynman's), its originality and independence of approach, its agreeable and helpful digressions on the history and philosophy of the subject. The average physics textbook at this level is not so venturesome (nor are its intellectual requirements so severe). By scrapping many conventional frames of reference, by being relatively indifferent to the usual nervous-Nellie curriculum requirements, the authors have produced an interesting book. One would like to know how well the students took to it. Many illustrations.

THE MUSHROOM HUNTER'S FIELD GUIDE, by Alexander H. Smith. The University of Michigan Press ($6.95). The safest place to hunt mushrooms (for those who intend to eat them and are not armed with a microscope, a hand lens, botanical tweezers and a wide knowledge of mycology) is the grocery. If this seems too restrictive, the best course is to venture forth armed with this authoritative field guide, now revised and enlarged. There are more than 3,000 kinds of mushroom in the U.S., of which some 200 are described here. For each kind the *Guide* gives identification marks, information on edibility, directions as to when and where to find it and large, clear photographs (of which 89 are in color). We are told that the poisonous and the edible species are the two extremes in mushrooms: not many kinds are deadly and not many taste good. Unfortunately the few poisonous species, such as the *Amanita* (which do not affect the victim for many hours, by which time "no first-aid methods are of help and there is not too much that a doctor can do"), produce great numbers of mushrooms, are frequently found by collectors and are close enough in appearance to nonpoisonous species—at least to the untrained eye—so that grievous mishaps occur. In sum, hunt and collect but restrain impulsive gluttony.

PROCEEDINGS OF THE INTERNATIONAL CONGRESS ON TECHNOLOGY AND BLINDNESS, edited by Leslie L. Clark. The American Foundation for the Blind ($12). These proceedings of a congress held in New York City in 1962 are of exceptional interest, and for the average reader they should prove a revelation as to the vigorous, many-fronted scientific and technical attack on blindness and the rehabilitation of the blind. Panels of specialists drawn from psychology, medicine, physics, engineering and education considered questions dealing with such topics as "mobility" and mobility devices (for example electronic-probe canes, senders and receivers of sound, light and radio waves); reading machines; indirect access to the printed page (for example machine translation, automatic braille reproduction); the mechanisms of seeing; the use of the remaining sensory channels to gather some of the information lost through blindness, and so on. To go through these pages is not only an absorbing intellectual experience but also a heartening one.

DIRECTORY OF SELECTED SCIENTIFIC INSTITUTIONS IN THE U.S.S.R. Charles E. Merrill Books, Inc. ($14.75). SOVIET MEN OF SCIENCE, by John Turkevich. D. Van Nostrand Company, Inc. ($12). These two reference volumes should prove useful to U.S. scientists, whose contacts with scientific communities in the U.S.S.R. have, in spite of the frigidity of international relations, steadily increased and become more fruitful over the past 10 years. The *Directory*, prepared by the Battelle Memorial Institute for the National Science Foundation under a Government contract, sketches the administration of science and technology in the U.S.S.R., lists the academies of sciences and their main facilities and furnishes a directory of selected scientific institutions. For each academy and institution information is provided as to the principal staff members and their major research and teaching programs. Turkevich' book consists of some 400 biographies of leading Soviet scientists. Each entry describes the subject's major interests and achievements and supplies data on his professional affiliations and honors. Like the *Directory*, this book has been made possible through a grant from the Federal Government.

ONE HUNDRED PROBLEMS IN ELEMENTARY MATHEMATICS, by Hugo Steinhaus. Basic Books, Inc., Publishers ($4.95). Problems in elementary mathematics are not necessarily elementary problems in mathematics. Steinhaus, known for his professional papers as well as for his entertaining popular book *Mathematical Snapshots*, has collected in this volume problems and puzzles of number theory, algebra, geometry, chess and other fields. Some are original, some comparatively new (at least in this country). All are ingenious, some are quite difficult, some are unsolved and perhaps unsolvable. One need not know higher mathematics to understand the statement of the problems, but even though fully worked-out solutions are given, a considerable aptitude for mathematical thinking is often indispensable to following the game.

OCEANIC SCULPTURE, by Carl A. Schmitz; photographs by F. L. Kenett. New York Graphic Society ($8.95). A superb collection of photographs of Melanesian wood carvings: male and female figures, masks, magical boards, drums, doorposts, prow ornaments, shields and so on. Although fashioned with the simplest tools, highly stylized and unmistakably primitive, the carvings are magnificent. Some are almost overpoweringly grotesque and terrifying, some subtly sinister, some brilliantly humorous, some abstract, some unaffectedly representational. An elegant book.

THE STRUCTURE OF LINE SPECTRA, by Linus Pauling and Samuel Goudsmit. McGraw-Hill Book Company ($2.75). A reissue of a well-known monograph first published in 1930, just at the time when the quantum mechanics of Heisenberg, Schrödinger, Dirac and others was transforming atomic physics. The authors, while referring to this invention, do not base their treatment on it; they deemed it desirable to interpret line spectra in the more easily visualizable terms of the vector model of the atom, which results in a notably lucid presentation. Paperback.

BREAKTHROUGHS IN MATHEMATICS, edited by Peter Wolff. Signet Books (75 cents). Selections from Euclid, Archimedes, Descartes, Lobachevski, Boole, Dedekind and others, with commentary by the editor on the meaning and importance to the growth of mathematics of each of the contributions. All these selections have been dished up before, some of them many times, and the editor's commentary adds no fresh insights, but this is a convenient and inexpensive little introduction for the student.

THE DAWN OF A NEW AGE, by Eugene Rabinowitch. The University of Chicago Press ($6.95). A collection of papers on science and human affairs that have been published over the past 20 years, most of them in the *Bulletin of the Atomic Scientists*. Rabinowitch is always to the point, mature in his social outlook, moderate in his counsel. One cannot help wishing that many more investigators spoke in his tone and that makers of political decisions listened attentively to what he has to say.

HISTORY OF PHARMACY, by Edward Kremers and George Urdang; revised by Glenn Sonnedecker. J. B. Lippincott Company ($9.50). A third and revised edition of a standard history. To make the book "more palatable to the student" considerable textual material from the preceding edition has been moved to the notes and references at the end, and other material, including certain illustrations, has been omitted. For reference purposes, therefore, the library shelf should carry both the second and the third editions.

FARADAY, MAXWELL, AND KELVIN, by D. K. C. MacDonald. Doubleday & Company, Inc. ($1.25). This charming little volume in the "Science Study Series" contains three biographical essays on a famous trio of 19th-century physicists. The late D. K. C. MacDonald was a gifted explainer of hard scientific ideas and had a lively sympathy for and understanding of the personalities of his subjects. A rewarding book.

ELEMENTS OF MATHEMATICAL LOGIC, by Jan Łukasiewicz. The Macmillan Company ($6.50). An English translation of Łukasiewicz' respected lectures on mathematical logic, first delivered at the University of Warsaw in 1928. His explanations of fundamental concepts, although dated in some respects, are exceptionally clear and open the subject invitingly to beginners.

SYMBOLS OF PREHISTORIC MESOPOTAMIA, by Beatrice Laura Goff. Yale University Press ($25). A comprehensive survey of symbols used by the prehistoric peoples of Mesopotamia in their pottery, figurines, temple architecture and other artifacts, the intention being to relate dominant forms to the history of religion and contemporary mythology. More than 700 illustrations: photographs, line drawings and plans.

Notes

THE ORIGIN OF ADAPTATIONS, by Verne Grant. Columbia University Press ($12.50). A large monograph that reviews and develops "the causal theory of organic evolution as applied to diploid sexual organisms." Illustrations.

HISTORY OF ENGLISH THOUGHT IN THE EIGHTEENTH CENTURY, by Sir Leslie Stephen. Harcourt, Brace & World, Inc. ($5.90). A soft-cover edition of a classic 19th-century survey of the deist controversy, of moral, philosophical and political theories and of the work of Locke, Pope, Wesley, Samuel Johnson, Hume, Adam Smith, Burke and many others.

COMBUSTION AND PROPULSION, edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz and S. S. Penner. The Macmillan Company ($20). The fifth AGARD colloquium, held in Braunschweig, Germany, in 1962, was concerned with high-temperature phenomena, which are the subject of the papers and discussions contained in this volume.

QUANTUM SCATTERING THEORY, edited by Marc Ross. Indiana University Press ($4.95). Selected papers on collision processes and the formal theory of scattering. Paperback.

THE SCIENCE OF GENETICS, by Charlotte Auerbach. Harper Torchbooks ($1.85). A soft-cover reprint of an authoritative, simple and exceptionally lucid introduction for the general reader. Many effective illustrations.

STRANGERS IN THE LAND, by John Higham. Atheneum ($1.95). A paperback edition, corrected and with a new preface, of the patterns of American nativism from the beginning of the Civil War to 1925.

BIOCHEMICAL FINDINGS IN THE DIFFERENTIAL DIAGNOSIS OF INTERNAL DISEASES, edited by R. Schoen and H. Südhof. American Elsevier Publishing Company, Inc. ($20). A translation of a cooperative German work that discusses the increasingly important and fruitful use of biochemical tests and analyses in the diagnosis of disease.

TRANSFER OF LEARNING, edited by Robert F. Grose and Robert C. Birney. D. Van Nostrand Company, Inc. ($1.75). A collection of selected readings on an "enduring problem in psychology," namely the extent to which special forms of training inspire the general capacities of the mind, or, to put it differently, how far the training of any mental function—reasoning power in arithmetic, accuracy of movement in finger exercises—improves other mental functions.

SLEEP AND WAKEFULNESS, by Nathaniel Kleitman. The University of Chicago Press ($12.50). A thoroughly revised and enlarged edition of a highly regarded reference work that presents a detailed picture of present knowledge about sleep and wakefulness. Included is an exhaustive bibliography consisting of more than 4,300 items.

A SOURCE BOOK IN PHYSICS, by William Francis Magie. Harvard University Press ($10). A reissue of a standard work that gives extracts from important contributions to physics over three centuries ending with the year 1900.

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BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

THE SUPERSONIC TRANSPORT

PROGRESS REPORT OF THE NASA SPECIAL COMMITTEE ON MATERIALS RESEARCH FOR SUPERSONIC TRANSPORTS. Richard H. Raring, J. W. Freeman, J. W. Schultz and H. R. Voorhees in *NASA Technical Note D-1798;* May, 1963.

SOME RADIATION PROBLEMS IN THE SUPERSONIC ENVIRONMENT. D. L. Dye and W. R. Sheldon in *SAE Paper 683C;* April, 1963.

THE SUPERSONIC TRANSPORT—A TECHNICAL SUMMARY. Staff of the Langley Research Center in *NASA Technical Note D-423;* June, 1960.

X-RAY ASTRONOMY

EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM. Riccardo Giacconi, Herbert Gursky, Frank R. Paolini and Bruno B. Rossi in *Physical Review Letters,* Vol. 9, No. 11, pages 439–443; December, 1962.

NEUTRON STAR MODELS. A. G. W. Cameron in *The Astrophysical Journal,* Vol. 130, No. 3, pages 884–894; November, 1959.

A DEFECTIVE CANCER VIRUS

ANALYSIS OF THE DEFECTIVENESS OF ROUS SARCOMA VIRUS. II: SPECIFICATION OF RSV ANTIGENICITY BY HELPER VIRUS. H. Hanafusa, T. Hanafusa and H. Rubin in *Proceedings of the National Academy of Sciences,* Vol. 51, No. 1, pages 41–48; January, 1964.

THE DEFECTIVENESS OF ROUS SARCOMA VIRUS. Hidesaburo Hanafusa, Teruko Hanafusa and Harry Rubin in *Proceedings of the National Academy of Sciences,* Vol. 49, No. 4, pages 572–580; April, 1963.

RESPONSE OF CELL AND ORGANISM TO INFECTION WITH AVIAN TUMOR VIRUSES. Harry Rubin in *Bacteriological Reviews,* Vol. 26, No. 1, pages 1–13; March, 1962.

CHEMICAL STIMULATION OF THE BRAIN

CHEMICAL TRACING OF NEURAL PATH-

WAYS MEDIATING THE THIRST DRIVE. Alan E. Fisher and John N. Coury in *Thirst: Proceedings of the First International Symposium on Thirst in the Regulation of Body Water,* edited by Matthew J. Wayner. Pergamon Press, 1964.

MATERNAL AND SEXUAL BEHAVIOR INDUCED BY INTRACRANIAL CHEMICAL STIMULATION. Alan E. Fisher in *Science,* Vol. 124, No. 3214, pages 228–229; August, 1956.

MAGNETOTHERMOELECTRICITY

ETTINGSHAUSEN EFFECT AND THERMOMAGNETIC COOLING. B. J. O'Brien and C. S. Wallace in *Journal of Applied Physics,* Vol. 29, No. 7, pages 1010–1012; July, 1958.

NEW WAYS IN THERMOELECTRICITY. D. A. Wright in *British Journal of Applied Physics,* Vol. 15, No. 3, pages 217–227; March, 1964.

ORIENTED SINGLE-CRYSTAL BISMUTH NERNST-ETTINGSHAUSEN REFRIGERATORS. T. C. Harman, J. M. Honig, S. Fischler, A. E. Paladino and M. Jane Button in *Applied Physics Letters,* Vol. 4, No. 4, pages 77–79; February, 1964.

THEORY OF THE LONGITUDINALLY ISOTHERMAL ETTINGSHAUSEN COOLER. C. F. Kooi, R. B. Horst, K. F. Cuff and S. R. Hawkins in *Journal of Applied Physics,* Vol. 34, No. 6, pages 1735–1742; June, 1963.

FLOWER PIGMENTS

THE CHEMISTRY OF FLAVONOID COMPOUNDS. Edited by T. A. Geissman. The Macmillan Company, 1962.

THE STORY OF POLLINATION. B. J. D. Meeuse. The Ronald Press Company, 1961.

VISUAL SEARCH

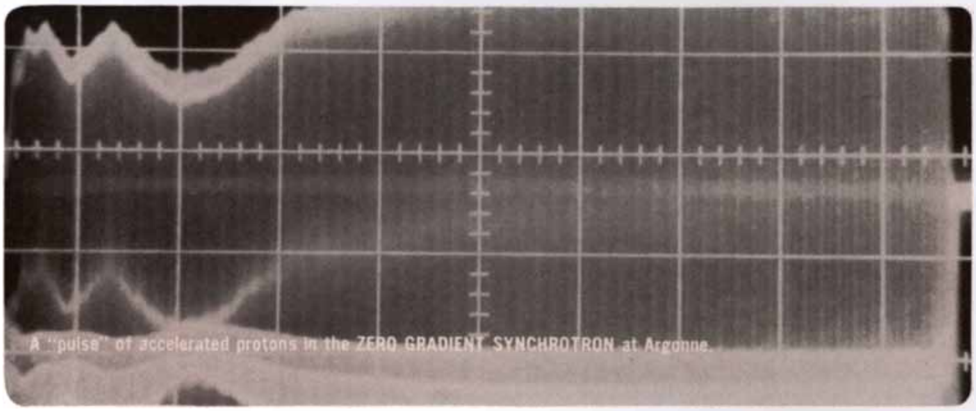
COLOR CODING AND VISUAL SEARCH. Sidney L. Smith in *Journal of Experimental Psychology,* Vol. 64, No. 5, pages 434–440; November, 1962.

DECISION-TIME WITHOUT REACTION-TIME: EXPERIMENTS IN VISUAL SCANNING. Ulric Neisser in *The American Journal of Psychology,* Vol. 76, No. 3, pages 376–385; September, 1963.

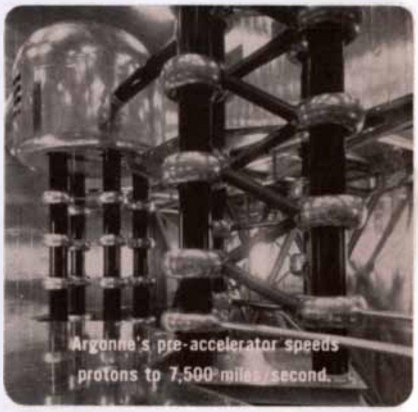
THE TUNNEL OF EUPALINUS

ALTERTHÜMER AUF DER INSEL SAMOS. Ernst Fabricius in *Mittheilungen des Deutschen Archäologischen Institutes in Athen,* Vol. 9, pages 163–197; 1884.

A CONTROL DATA 3600 used with the ZGS at Argonne.



A "pulse" of accelerated protons in the ZERO GRADIENT SYNCHROTRON at Argonne.



Argonne's pre-accelerator speeds protons to 7,500 miles/second.

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