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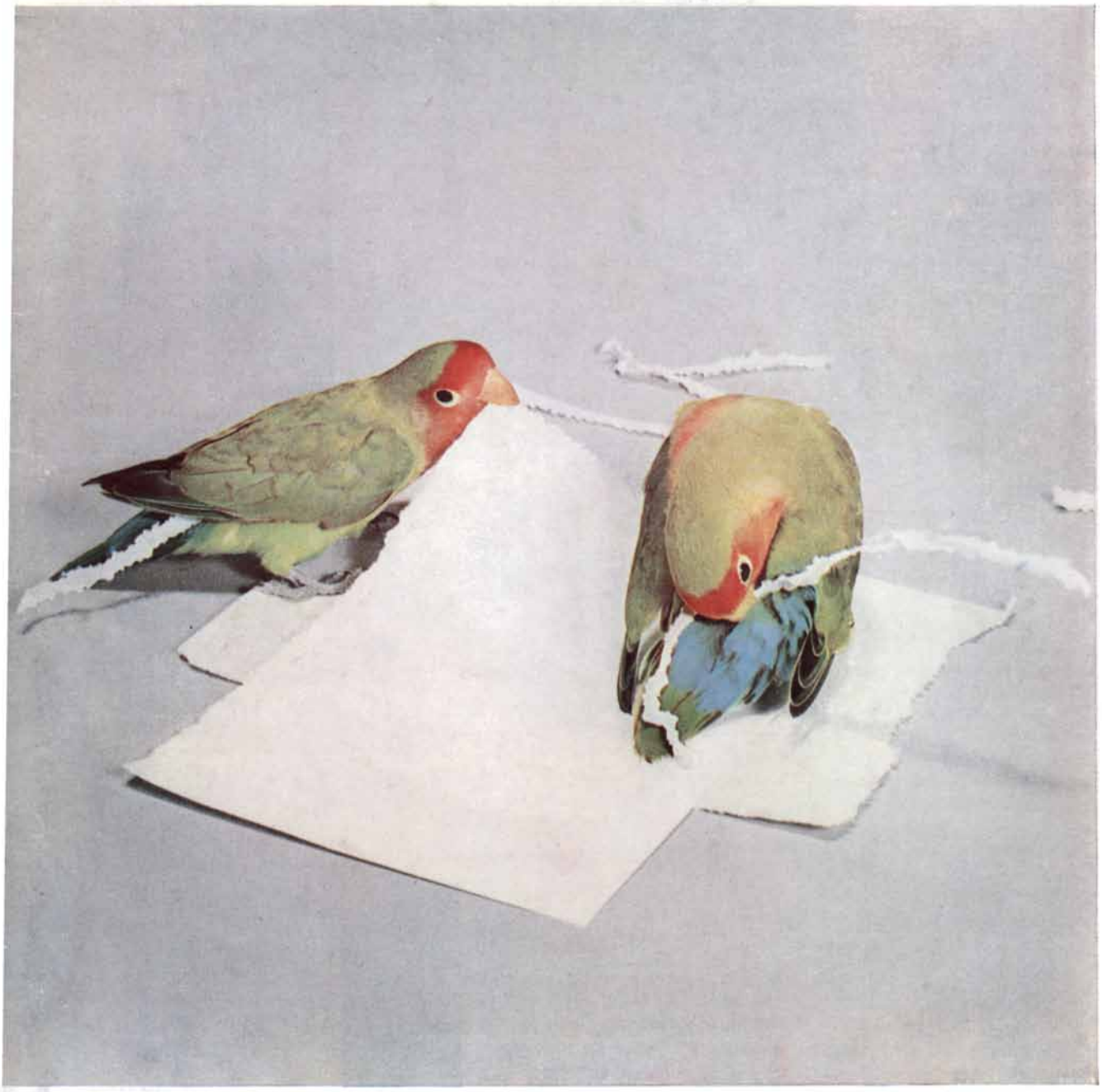
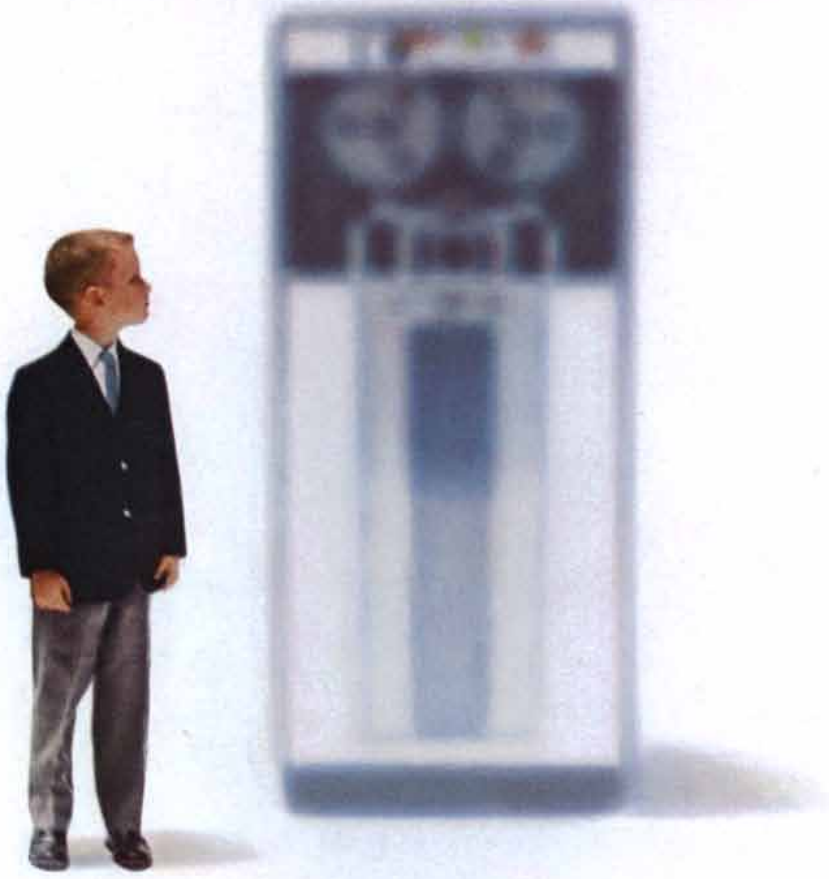


LOVEBIRDS IN THE LABORATORY

FIFTY CENTS

January 1962

What kind of computers will be needed tomorrow?



As man reaches further for knowledge, the problems he meets become more complex. IBM is developing new computers to help solve them.

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Charles Sanders Peirce...on the passion to learn

"If we endeavor to form our conceptions upon history and life, we remark three classes of men. The first consists of those for whom the chief thing is the qualities of feelings. These men create art. The second consists of the practical men, who carry on the business of the world. They respect nothing but power, and respect power only so far as it (is) exercized. The third class consists of men to whom nothing seems great but reason. If force interests them, it is not in its exertion, but in that it has a reason and a law. For men of the first class, nature is a picture; for men of the second class, it is an opportunity; for men of the third class, it is a cosmos, so admirable, that to penetrate to its ways seems to them the only thing that makes life worth living. These are the men whom we see possessed by a passion to learn, just as other men have a passion to teach and to disseminate their influence. If they do not give themselves over completely to their passion to learn, it is because they exercise self-control. Those are the natural scientific men; and they are the only men that have any real success in scientific research."

—Principles of Philosophy, Vol. I
Collected Papers of Charles Sanders Peirce, 1931

For five years The RAND Corporation, with its own funds, has presented this series to acquaint scientists and scholars with the Corporation and its mission. With this purpose accomplished, we now suspend the series. We have been gratified by the number of readers who have written in appreciation of our advertisements. In response, we made reprints which will be available until the supply is exhausted.

THE RAND CORPORATION, SANTA MONICA, CALIFORNIA

Established 1845 **SCIENTIFIC AMERICAN** January 1962 Volume 206 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows two female lovebirds of the species *Agapornis roseicollis* (peach-faced lovebird) in the Laboratory of Ornithology at Cornell University. Presented with a piece of paper, each bird begins a ritual of preparing its nest materials: it cuts out a strip of paper with its bill and tucks the strip into its feathers. Differences in such behavior among the various forms of lovebird are a clue to their evolution and shed light on the role of heredity in animal behavior (*see page* 88).

THE ILLUSTRATIONS

Cover photograph
by William Vandivert

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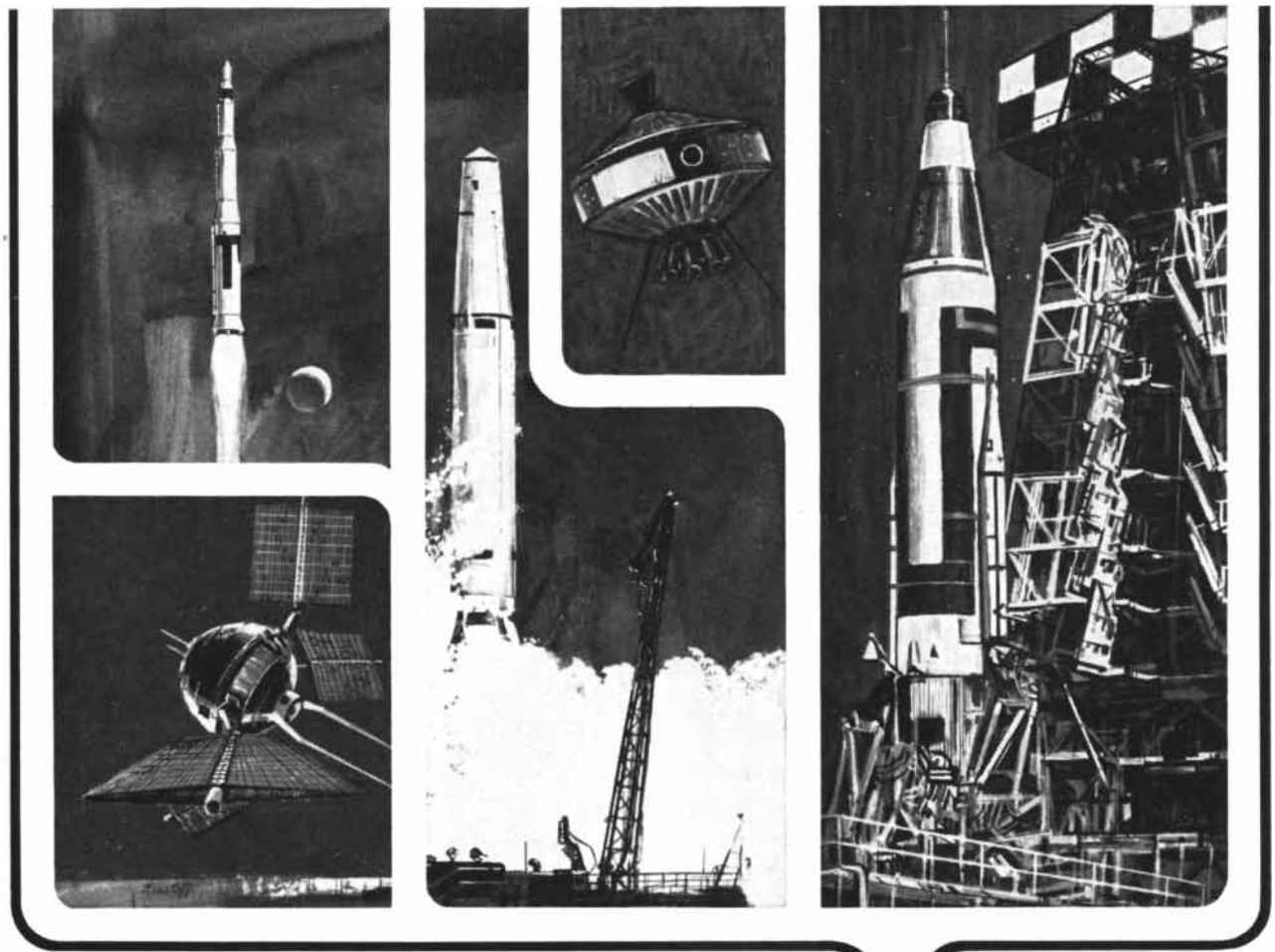
CAREERS IN SPACE TECHNOLOGY LEADERSHIP



Of particular interest to engineers and scientists is the continuing growth and diversification of Space Technology Laboratories, Inc. What is now STL was founded as the Guided Missile Research Division of the Ramo-Wooldridge Corporation in 1954, when the Ballistic Missile Program was given highest national priority. ■ Assigned contractual responsibility for the program's systems engineering and technical direction, STL has grown from a small group of engineers, scientists and administrators to an industrial organization with a professional staff numbering more than 2,000 with over 2,500 supporting personnel—from its initial headquarters in a suburban Los Angeles schoolhouse to the ultra-modern STL Space Technology Center nearing completion on a 110-acre site at One Space Park, Redondo Beach, California. ■ STL has contributed importantly to the management of a program that has given this nation the Thor, Atlas, Titan and Minuteman ballistic missile systems. At the same time, STL has been called upon to design, fabricate, instrument and successfully launch Pioneer I, Explorer VI and Pioneer V—and to contribute to the management of Transit 1B, Transit 2A, Transit 3B, Courier 1B and Tiros programs. ■ Today, STL in addition to its continuing role in the USAF Atlas, Titan and Minuteman programs, is performing research, development, design and construction for three Orbiting Geophysical Observatories (OGO), and project coordination and systems planning for Project Relay, both for NASA; and performing design, fabrication and test of the spacecraft for the Air Force-ARPA Vela Hotel Program to detect nuclear explosions in space, as well as conducting studies for the Air Force-ARPA BAMBI Project, a multi-satellite system which can identify and destroy enemy ICBM's shortly after launch. STL's continuing program of original and applied research covers a broad spectrum of technical disciplines including particle physics, solid state theory, guidance space physics, communication theory, propulsion and power, and electromagnetic systems in the infrared, ultraviolet and microwave regions. ■ The expanding activities of STL create immediate career opportunities in Southern California and at Cape Canaveral. Engineers and scientists are invited to communicate with Dr. R. C. Potter, Manager of Professional Placement and Development. STL is an equal opportunity employer.

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Two other highly important discoveries were made. FIRST, that contrary to a general belief, the slow reader is not a "sure" reader. People who read fast almost invariably *retain far more of what they read* than the plodding slow reader. SECOND, that slow reading is as common among those with high IQs as among the lesser brows.

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How many "fixations" do your eyes make on each line? Unconsciously, as you read across each line, your eyes actually move in little jumps. The momentary pauses between these jumps are called "eye fixations." Read part of the material on the left hand page. You should get across each line with not more than three eye fixations. If you are not aware of the number, have someone watch your eyes and count the fixations. Even if there are three—and certainly if there are more—your eye span can be widened by the exercises provided; that is, there will be fewer fixations and you will read faster because of this improvement alone.

Do you find yourself reading word by word, instead of in groups of words or phrases and **do you regress continually,** looking back every line or so to check up on a word or words you either missed or misunderstood? In most cases these habits can be almost totally eliminated.

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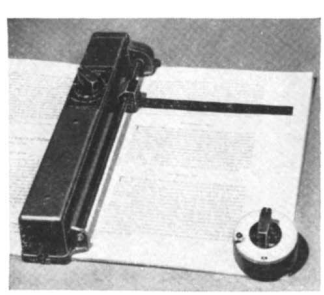

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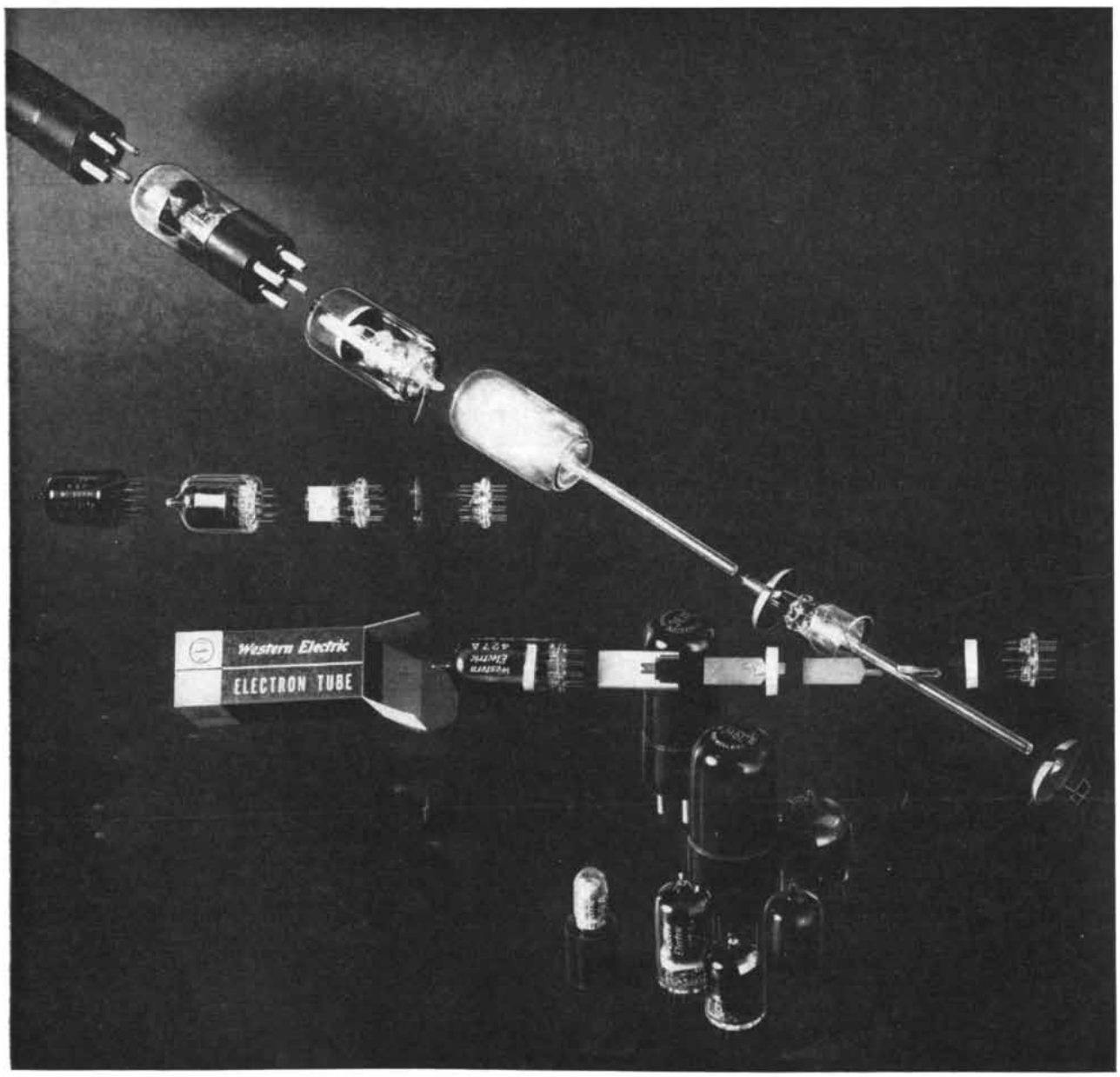

HOW MUCH ROOM DOES IT TAKE TO THINK ?

FOR Archimedes of Syracuse (287-212 B.C.), knowledge came within the confines of a bathtub. It was here the father of experimental science postulated his famous principle of hydrostatics.

Archimedes' kinsman, King Hieron, had a new gold crown, but like most kings, he distrusted his goldsmith. Though it weighed correctly on the family scales, Uncle Hieron thought the wily goldsmith had substituted silver for gold inside the crown. So he gave his nephew the neat task of solving the mystery without disturbing so much as a bauble on the crown.

One day on his way to the public baths, Archimedes kept thinking about the fact that stones or bodies immersed in water are easier to lift. Although this observation had been made by others, it was not known just how much lighter the stone was in water. Still meditating on the problem, Archimedes hopped into the brimful bath and water flowed over the top of the tub. Suddenly, as the attendant was rubbing, soaping, and perfuming the mathematician, the moment of learning came. The weight he lost on submerging was equal to that of the water which brimmed over. Joyfully, Archimedes jumped out of the tub and, completely in the buff, ran down the path happily shouting, *"Eureka! Eureka!"*

Fortunately, our absent minded philosopher made it home without arrest where he tested his hypothesis, determined that the King's crown was 108 grams light, and discovered the fundamental principle named in his honor.

Those who choose to grow in serving the demands of today's technology must carry an inventory of brainpower with the same kind of problem solving perception so ably evidenced by Archimedes. Even in long ago 1954 A.D., Systron-Donner exhibited this rare ability to synthesize dissimilar sets of information to achieve problem solution.

Such was the case of the unstable helicopter. Early in 1954, Harold Morris, now Donner division technical director, was asked to provide a device which would automatically control the

helicopter through the autopilot and hold the machine at any given position in space. If you've ever watched a helicopter pilot, you know he never takes his hands off the stick. So you can readily imagine that the device which controls helicopter position within inches must be very sensitive. But more than that, the helicopter people wanted a compact, grossly reliable device, able to withstand plenty of salt water.

At the time, Morris was working on two projects, accelerometers and analog computers. Two more dissimilar efforts, one could barely conceive.

His first solution to the helicopter control problem required four accelerometers, two to sense motion, and two to integrate their outputs. Integrating the output was a grand idea for it provided a velocity control signal which would anticipate the aberrations of the helicopter. But like so many great schemes, there was a hitch. Bearing friction in the integrating accelerometers critically modified the stability of the system.

Drawing on the work he was doing in computers, Morris decided to link the analog computer and the force balance accelerometer in one coherent electromechanical system. The result, a sealed box weighing 24 pounds containing a fixed purpose analog computer with the ability to control the helicopter's position in space within inches. Containing 41 tubes which consume less than 80 watts of power, the device uses microwatt techniques which are "state of the art" even today.

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LETTERS

Sirs:

We have read with interest the article "Air Pollution and Public Health" by Walsh McDermott in the October 1961 issue of *Scientific American*. It is certainly relevant in the face of our increasing population and growing cities. We believe, however, that there are misconceptions in this article that should be corrected. In addition, one of the most important sources of air pollution—cigarette smoking—was ignored except in relation to lung cancer. This results in only a partial presentation of the possible factors.

We disagree with Dr. McDermott's oversimplification that the final products of combustion are water and carbon dioxide. This will only be true for hydrocarbons. If there is sulfur or other elements, the oxides of sulfur or other compounds will also be formed. This occurs where coal is used as a fuel, for example, or if the fuel oil contains a large amount of sulfur.

Later he says that "the end result—the irritation of certain cells of the body—is probably much the same." This is a confusing sentence. If he means that many compounds are irritating, we agree. On the other hand, if he means that the end results, namely bronchitis, cancer or some other disease condition, are the same regardless of the source of irritation, the evidence for this is lacking. We are inclined to believe he has the latter interpretation in mind since he mentions the Donora and London smog incidents and states that these were probably due to sulfur compounds, then states that there is no reason to doubt that a hydrocarbon smog could have the same effect. There is no evidence for this. In fact, repeated studies in the Los Angeles area have failed to indicate that hydrocarbon or auto exhaust smog is a factor in chronic respiratory disease. It certainly does irritate the eyes.

Dr. McDermott also states that in the Donora and London smog episodes no single component was in a higher concentration than usual. This is incorrect. In Donora there were a number of components that were increased, and in London sulfur compounds and smoke have been consistently elevated when there has been a "smog." This has been greater than the usual concentrations. It is true that no single component reached concentrations that a toxicologist would consider sufficient to explain the symptoms that are observed in an average healthy population.

We do not wish to underestimate the potential hazard of continued and increased air pollution. This article, however, glosses over the effect of cigarette smoking and the possible synergistic effect of this with other pollutants such as are known to occur in urban areas or to individuals at work.

One of us has recently completed two studies, one on workers in a flax mill in Massachusetts and the other on a random sample of the population of a town in New Hampshire where there is some air pollution from a local mill. In both studies the relationship between present cigarette smoking habits and the prevalence of chronic nonspecific respiratory disease as determined by responses to a standard questionnaire and simple tests of pulmonary function was overwhelming. In the flax mill, for example, we were unable to demonstrate that the varying degrees of dustiness in the mill had any effect whatever on the prevalence of respiratory symptoms. In the New Hampshire town we found that there was a slight effect associated with place of residence and years of exposure to dusts and gases at work. Both of these effects were much less than the effect associated with the lifetime cigarette smoking history of the individual.

Because of these observations we believe that any study that attempts to assess the effect of an air pollutant must take into consideration the smoking his-

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tories of the individuals examined, and that the data should be standardized for smoking habits. Only by separating the various components and determining their relative effect can the necessary objective data be obtained so that a sound decision can be made. Dr. McDermott's article does not provide the reader with enough information to reach a fair decision.

BENJAMIN G. FERRIS, JR., M.D.

MARY O. AMDUR, PH.D.

School of Public Health
Harvard University
Boston, Mass.

Sirs:

Drs. Ferris and Amdur are quite right that I made two factual errors: (a) on the final products of a completed combustion and (b) on the values for individual pollutants in Donora and London. In both cases, however, the sense of the points I was trying to make was in no way impaired.

The recently completed studies they cite certainly sound interesting, and I will look forward to seeing their reports. Obviously I did not have that material available at the time the manuscript was prepared.

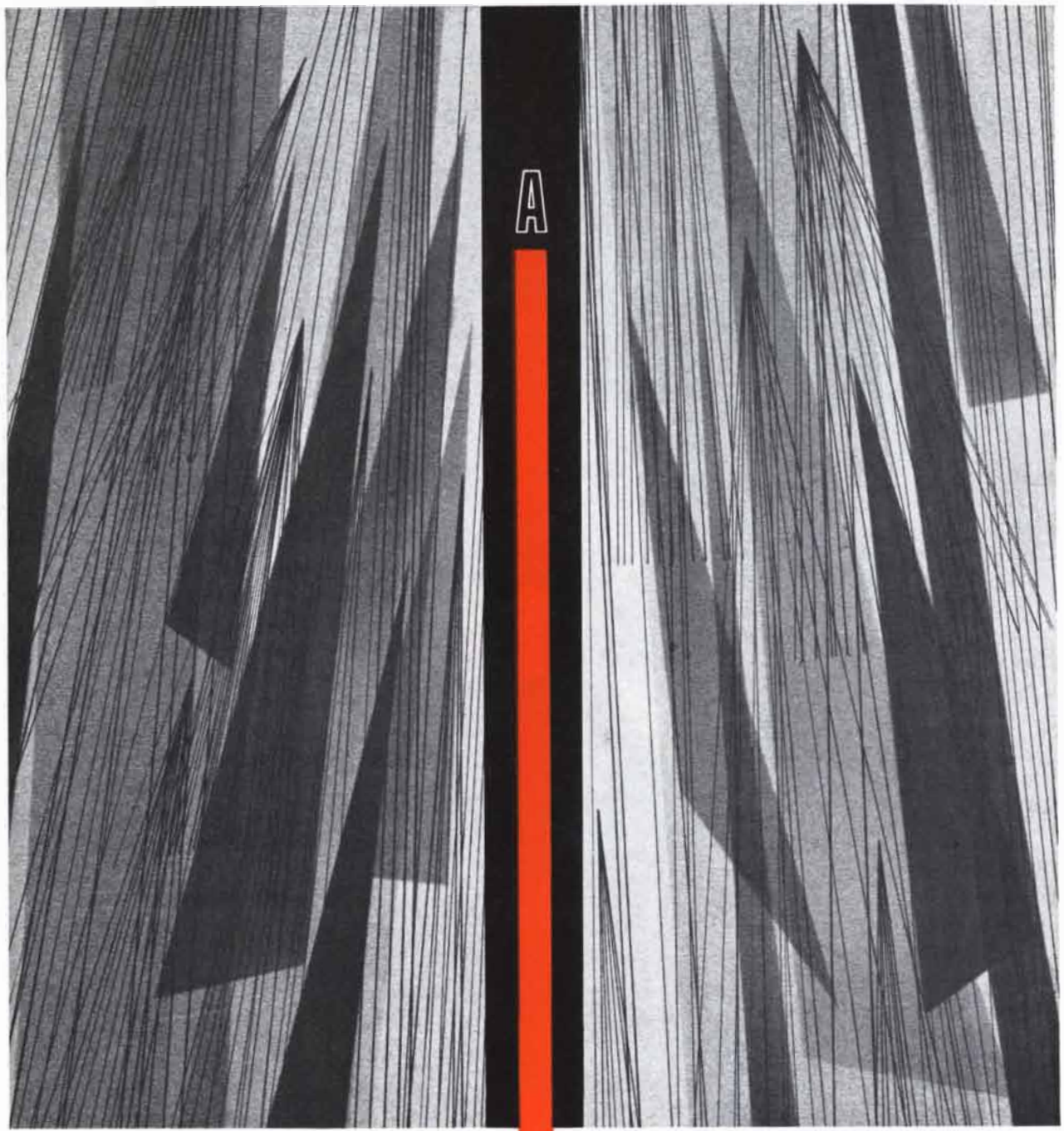
With respect to minimizing the effects of smoking, I had considered that the point had been fairly stated in the article on page 54: "Bronchitis-emphysema is considerably more common among city dwellers than country people. There is some indication, however, that the advantages of country living can be canceled by cigarette smoking, which is, in effect, a portable form of air pollution."

And on page 56: "But in the country, where cigarettes are a threat to barns, smoking is a less universal habit. To isolate the effect of urban air on smokers one should have the figures on groups of cigarette smokers who have moved en masse from city to country."

In short, I quite agree with them that smoking may prove to be a highly relevant factor, but the matter is a complicated one to analyze and at the time the article was prepared there was relatively little information on the subject.

WALSH MCDERMOTT, M.D.

Department of Public Health
and Preventive Medicine
Cornell University Medical College
New York, N.Y.



The challenge stirs the imagination and ingenuity of man perhaps more than any other in history. And in the drive to conquer the almost unthinkable infinitude of the heavens, Georgia Tech scientists joined the task early and have kept pace with space technology and developments. Notable achievements have been made in ceramics for rocket nose cones and work is being pressed forward in developing protective coatings for space ships re-entering earth's atmosphere with the speed of a shooting star. Heat-fighting nozzles are being created for uncooled solid propellant rockets. Another project may contribute to a nuclear propulsion system. Georgia Tech scientists have also tackled the job of finding a flexible ceramic for insulating the electrical systems in missiles and aircraft. Few earth materials have been exposed to the strange environment of space. Research at Georgia Tech will tell us which materials will stand the test before they are sent on a journey to the stars. We are proud of Georgia Tech's contributions. GASA will draw heavily on the school's resources in helping make America's space program a success. Your inquiry for information on this resource in research will be held in strict confidence.

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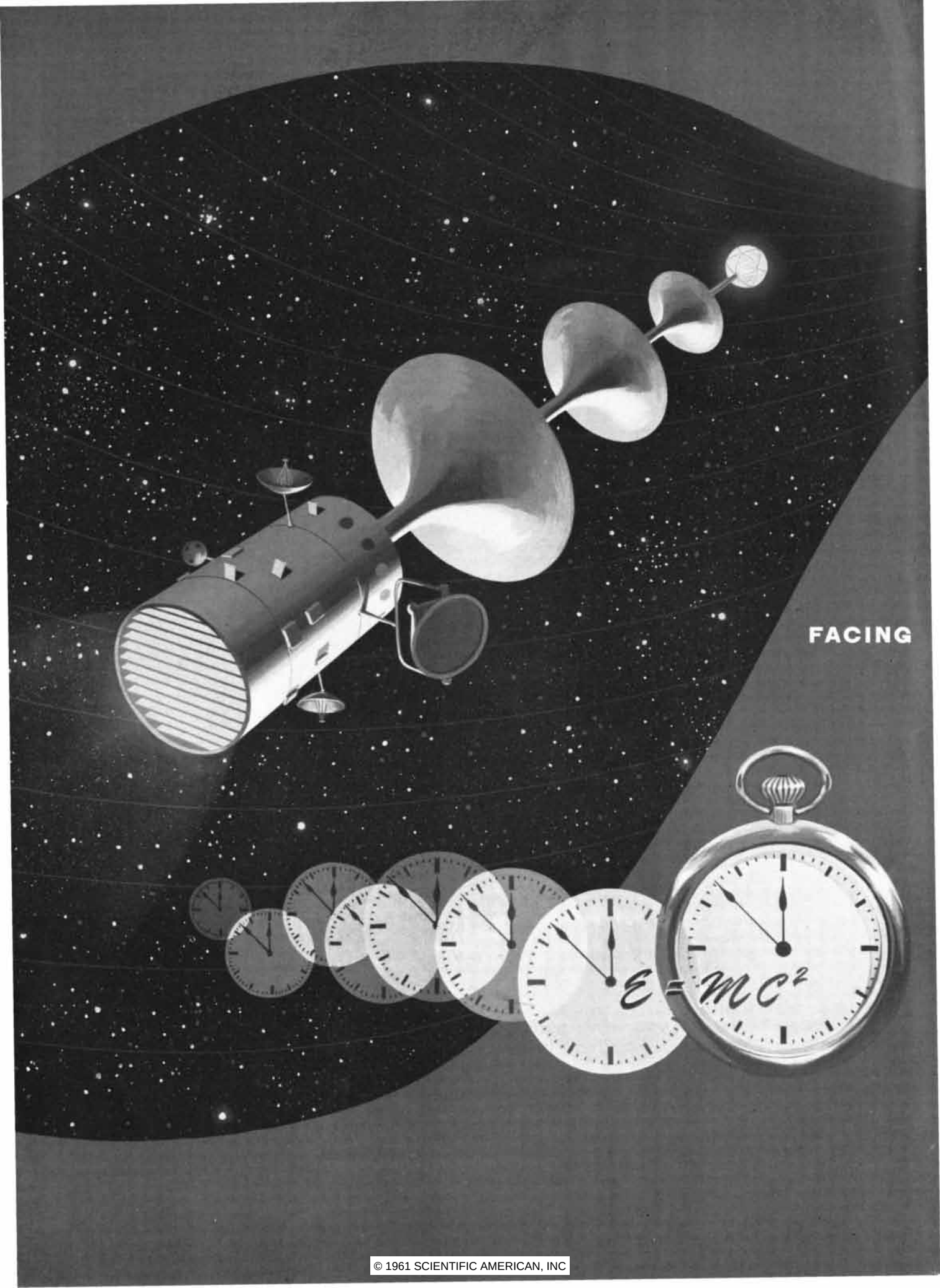

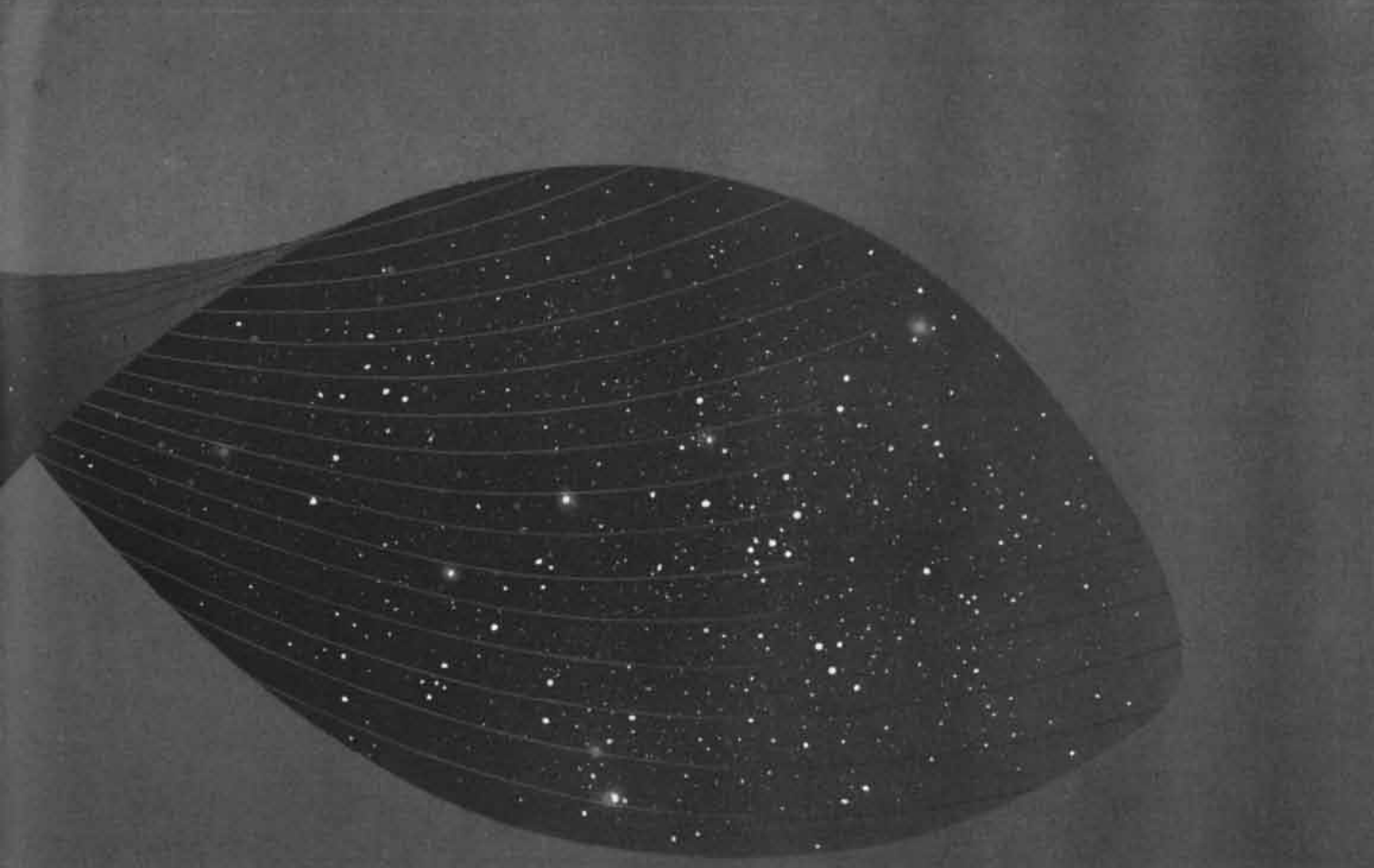

THE FOURTH DIMENSION IN PROPULSION DEVELOPMENT

Whether the universe has a "saddle shape," or any shape at all, is a matter of interesting conjecture. The matter of space travel, however, is the subject of intense experimentation. A nuclear/thermionic/ionic propulsion system, currently being studied at Lockheed Missiles & Space Company, might well become the power source for space vehicles.

Its design incorporates a nuclear reactor only one foot in diameter, generating heat at a temperature of 1850°K. This is transmitted to banks of thermionic generators, converting the heat directly into electrical energy for the ion beam motor which uses cesium vapor as a fuel. The entire system is designed without any moving parts, minimizing the possibility of failure.

Lockheed's investigation of propulsion covers a number of potential systems. They include: plasma, ionic, nuclear, unique concepts in chemical systems involving high-energy solid and liquid propellents, combined solid-liquid chemical systems. The fundamentals of magnetohydrodynamics, as they might eventually apply to propulsion systems, are also being examined. Just as thoroughly, Lockheed probes all missile and space disciplines in depth. The extensive facilities of the research and development laboratories—together with the opportunity of working with men who are acknowledged leaders in their fields—make association with Lockheed truly rewarding and satisfying.

Lockheed Missiles and Space Company in Sunnyvale and Palo Alto, on the beautiful San Francisco Peninsula, is an exciting and challenging place to work. For further information, write Research and Development Staff, Department M-24C, 599 North Mathilda Avenue, Sunnyvale, California. An Equal Opportunity Employer.

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A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

Systems Manager for the Navy POLARIS FBM and the Air Force AGENA Satellite in the DISCOVERER and MIDAS programs. Other current programs include SAINT, ADVENT and such NASA projects as OGO, OAO, ECHO, and NIMBUS.

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In the medium scale computer field, Recomp II is the only one with built-in floating point. In the small scale field, Recomp III offers the largest word size and largest memory. Recomp's accessory line and software advantages are the most up-to-date in the computer industry. And an extensive programming library is available without charge.

How do we know of Recomp's money-making ability? A feasibility study done by a prospective customer (now a satisfied user) showed that Recomp could save — or make — almost $70,000 more than its nearest competitor on a given project.

There are a number of small and medium scale computers on the market today. Only a few are really outstanding. Recomp is one of them.* For the full story, write:

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*No computer feasibility study is complete without Recomp.

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4260

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1912: "President Vail of the American Telephone and Telegraph Company has announced that a through telephone service between Los Angeles and New York will probably be established by the first of November. The cost of the line will be half a million dollars, and the tolls per conversation will run between $14 and $15."

"In the daily press two announcements have been made of projects that have for their purpose nothing more or less than the crossing of the ocean by means of aeroplanes. One of these plans comes from Harry N. Atwood, the other from James B. Martin. Both men, according to the newspapers, will depend upon hydroplanes."

"The Berliner patent, which was granted February 19, 1895, and which the courts have upheld as valid, covers what may be called the fourth decided step forward in the development of the modern talking machine, the invention being that of Mr. Emile Berliner. The first step was scientific rather than practically useful. Leon Scott in 1857 published his discovery that if sound waves be projected against a diaphragm having a hog's bristle glued thereto, and the end of the bristle be held against a moving paper covered with lampblack, so long as no sound is heard the bristle remains at rest and traces a straight line on the moving paper, but when a sound is heard, the diaphragm and bristle vibrate in unison, and the line traced is no longer straight but undulating. The second decided step was taken by Mr. Edison, who utilized Scott's discovery. Mr. Edison found that when a reproducer needle, fastened to the diaphragm, was made to track along in the undulating line made by the needle, it would reproduce the sound that produced the undulations. The third great step forward in the talking machine art is disclosed in the Bell and Tainter patent of May 4, 1886, wherein the record, instead of being indented, as by the Edison needle, was *cut* by the needle. It will be noticed that both in Edison and in Bell and Tainter the grooves are what are called 'hill and dale' record grooves. One disadvantage was that the reproducer, when it passed over a 'hill,' was liable to jump into the next groove. Mr. Berliner, in his fourth great step, kept the depth of his groove always the same and caused his recording stylus to cut sidewise."

"A note was published in SCIENTIFIC AMERICAN claiming that Columbia University, with a total enrollment of nearly 8,000, is the largest university in the world. This statement has been corrected by a Columbia man in *Science*. According to his figures the University of Paris heads the list with 17,000 students, after which follow Cairo with 10,000; Berlin, 9,600; Moscow, 9,000; and St. Petersburg, 9,000."

"Evidently the directors of the New Haven Railroad Company are satisfied with the electric operation of their trains between Stamford and New York, a stretch of 34 miles; for they have announced that the system is to be extended from Stamford to New Haven, a distance of 41 miles. It speaks well for the present installation that the new equipment will be practically identical with that on the existing electric road."

Scientific American.

JANUARY, 1862: "Oregon has no magnetic telegraph as yet, but it is arranged that before the middle of 1862 Portland shall be in communication with the wires of California, and through them with Chicago, New York and Boston. Sitka, in the Russian possessions, is only 900 miles from Portland; and when a line is completed between the two places, to connect with the Russian line, 3,500 miles long, soon to be undertaken between the Amoor River and Sitka, the circuit of the world will be complete."

"If we may judge from the tone of the Canadian press, the people of the British provinces are seized with a sort of war panic, and are actually engaged in organizing for a sanguinary conflict with the people of the United States. The supposition seems to prevail there that a war with us is inevitable, and that the brunt of it will naturally fall upon them. The same belligerent spirit seems also to have seized upon the people and press of Great Britain, and one is almost forced to the conclusion that the bold British

The Making of a Magnet. Bell scientists test new superconducting electromagnet, the small cylindrical object being removed from helium bath at minus 450 degrees F. An early experimental design produced a field strength over 65,000 gauss.

OUT OF SOLID STATE SCIENCE COMES A POWERFUL NEW MAGNET

Bell Telephone Laboratories' creation of a powerful superconducting electromagnet once again illustrates the role of materials research in the advancement of communications.

It has long been known that certain materials called superconductors have a zero electrical resistance at temperatures near absolute zero. A solenoid of superconductive wire carrying a large current should be capable of producing an extremely powerful magnetic field without the bulky power equipment that is needed for conventional electromagnets.

A formidable obstacle blocked the way, however. The strong magnetic field tended to destroy the wire's superconductivity.

Bell Laboratories scientists studying superconductors—as part of their endless search for new materials for communications—were led to the discovery of a number of alloys and compounds having exceptional superconductive properties. One of these materials, a compound of niobium and tin, was found to possess a startling ability to retain its superconductivity in intense magnetic fields of over 100,000 gauss. Bell scientists went on to show how the brittle, intractable material could be made into a wire and hence wound to make an extremely powerful electromagnet.

By finding a low-cost way to create enormously powerful magnetic fields, Bell scientists have brought closer new applications of magnetism in communications. Intense magnetic fields provide an invaluable tool in research, and offer an attractive means for containing hot plasma in thermonuclear experiments.

The new magnet is another example of how Bell Laboratories research not only works to improve Bell System communications but also benefits science on a broad front.

BELL TELEPHONE LABORATORIES

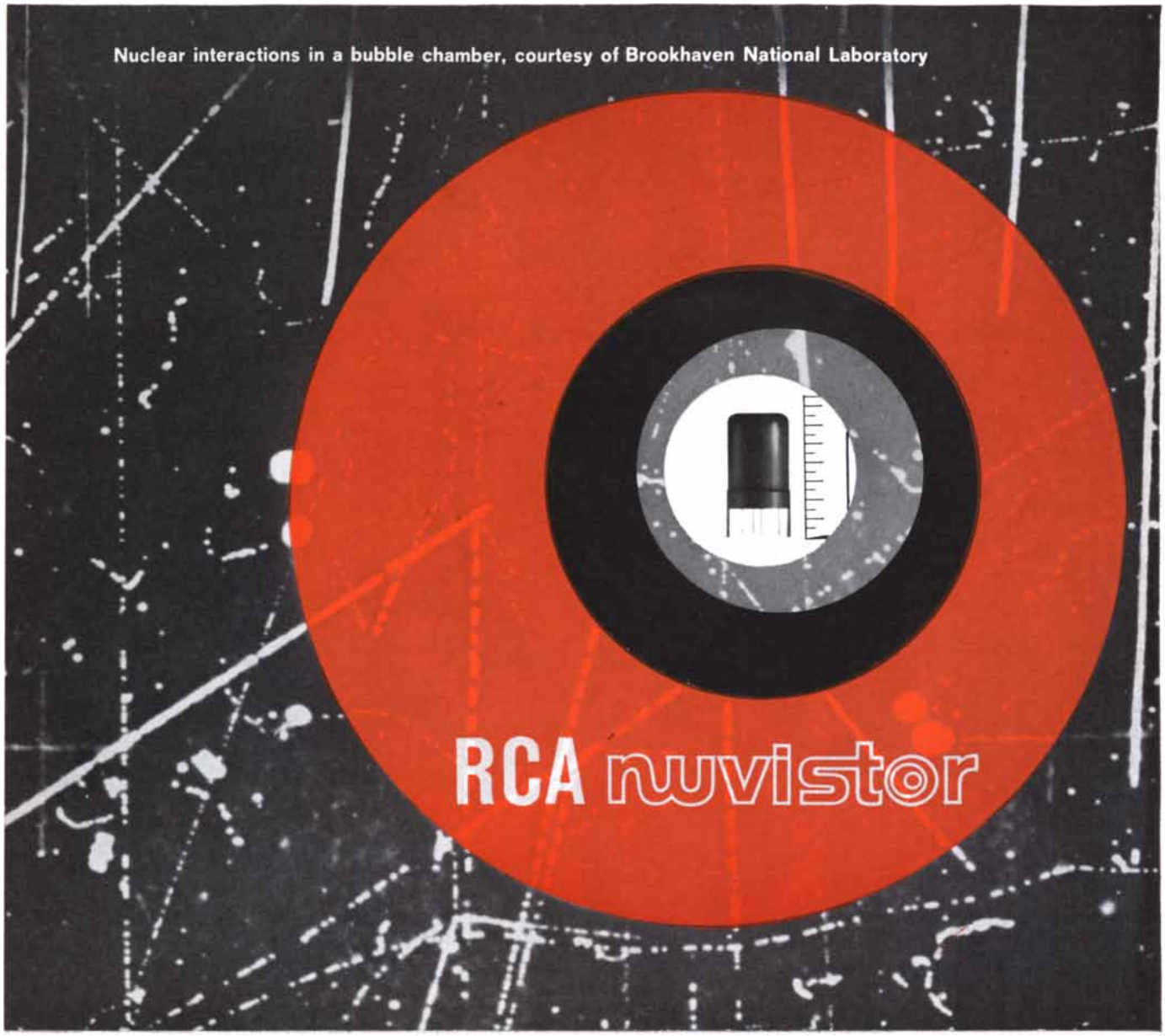
World center of communications research and development

lion is about ready to spring upon us with all his savage ferocity. The pretext or ground upon which this unwonted war flame has been fanned into life grows out of the seizure of Mason and Slidell on board an English vessel, the *Trent*. This can undoubtedly be made a cause of war; and if the British government is determined to push matters to that extreme, then there is no way of escape."

"His Royal Highness Prince Albert, the husband of Queen Victoria, died of gastric fever, after a short illness, in London at noon on the 14th of December, 1861. Albert Francis Charles Augustus Emmanuel, Duke of Saxe-Coburg-Gotha, was born at Rosenau, in the Duchy of Saxe-Coburg-Gotha, on the 26th of August, 1819. He was married to his first cousin, Victoria, the Queen of Great Britain and Ireland, on the 10th of February, 1840. He was an educated gentleman and took an extraordinary interest in agriculture and the mechanic arts. We have heard an American inventor describe the patience with which the Prince examined a complicated machine for sawing ship timber in forms, taking hold of the machine with his own hands and operating it in order to thoroughly master its details. His death will be mourned with sincere grief throughout the wide dominions of his consort."

"Professor Agassiz, in an article in the *Atlantic Monthly*, makes the following statement of the result of his life's study: —'It might seem invidious were I to show here how small is the sum total of the work accomplished even by the great exceptional men, whose names are known throughout the civilized world. But I may at least be permitted to speak of my own efforts. I have devoted my whole life to the study of nature, and yet a single sentence may express all that I have done. I have shown that there is a correspondence between the succession of fishes in geological times and the different stages of their growth in the egg—this is all.' "

"The survey of a parallel of north latitude running through Ireland, England, Belgium, Prussia and Russia is nearly completed, and the accurate length of a base line stretching from the west coast of Ireland to the Ural Mountains in Russia will shortly be ascertained. This will be the greatest feat in trigonometrical surveying ever accomplished. In order to triangulate the country along the parallel, platforms 70 feet high have been erected on the continent of Europe."



For use in electronic equipment that must perform dependably in strong nuclear radiation fields

Among conventional active electronic circuit components, the RCA nuvistor electron tube is in the class of components *least susceptible to catastrophic failure from nuclear radiation*. In addition nuvistors are commercially available and offer extremely small size, light weight, and exceptionally low power drain.

These facts are of utmost importance to you if you are designing communications or navigational equipment which must provide dependable performance in an environment of strong nuclear radiation. In such an environment, even momentary failure of equipment can disastrously curtail our vital communications or navigation operations.

Recent tests have shown that the RCA-7586 nuvistor triode and the RCA-7587 nuvistor tetrode have given dependable performance after being subjected to a nuclear radiation pulse of extremely high intensity as specified in the Neutron Radiation Damage Test, Military Standard MIL-STD-446A, November 25, 1960.

In these critical equipment design areas, one cannot afford to risk component failure. Specify RCA nuvistor for airborne communications, airborne controls, missile avionic systems, radar networks, telemetering equipment, and ground support equipment.

For additional information, see the RCA Field Representative at our office nearest you.

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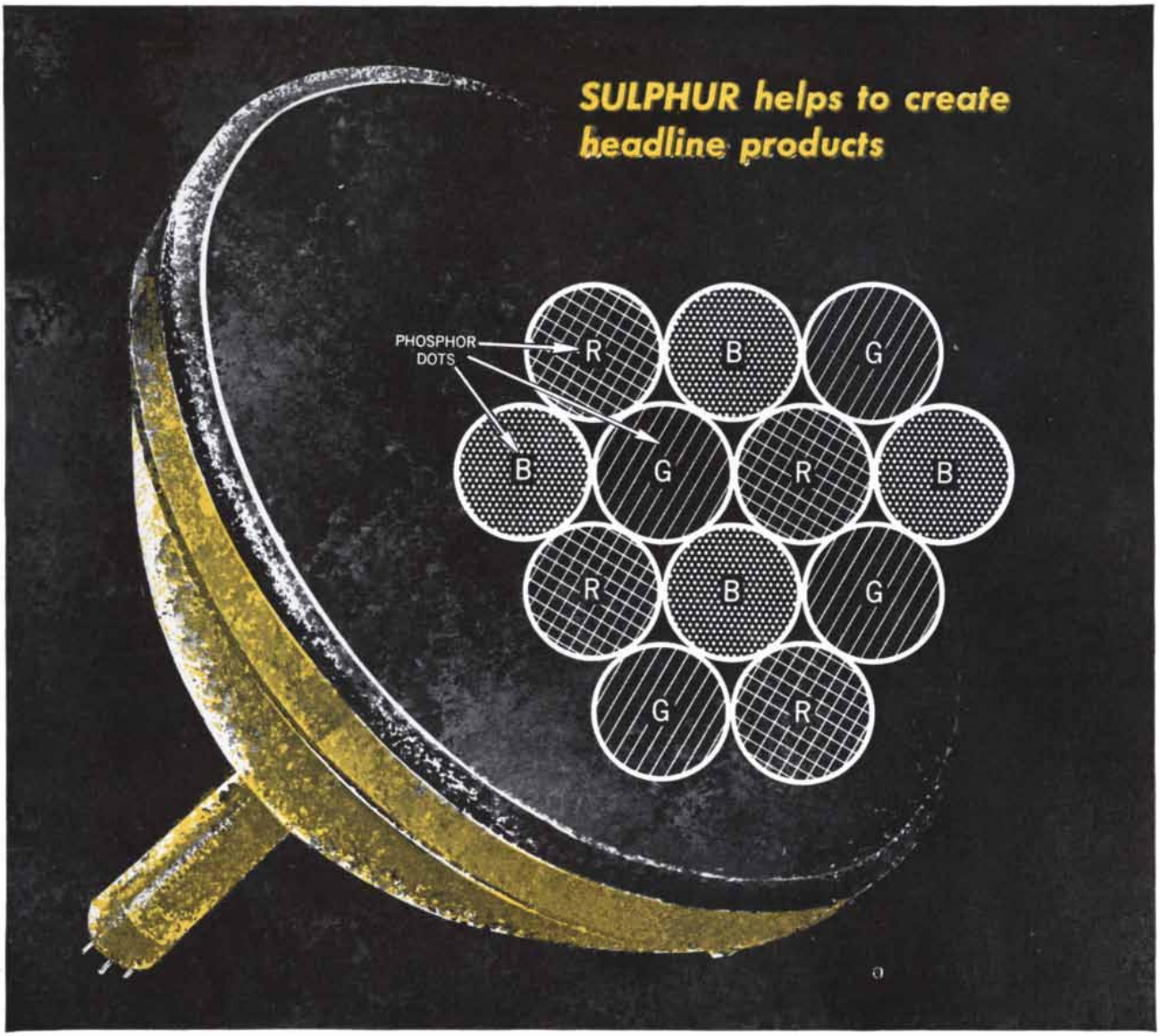

A Major Breakthrough in Color TV Tube Design

...with a key assist from special "sulphides"

Illustration above: Superimposed over the picture of the new RCA Color Picture Tube is a magnified schematic arrangement of the sulphide dots. Controlled mixing of the three primary colors, blue, green and red, creates the color effects seen by the eye.

Just what role do these sulphides play in this new RCA Color TV Tube which is so markedly superior to older tubes as to constitute a major breakthrough in tube design.

The viewing screen of the color tube consists of tiny dots of special sulphide 'phosphors,' arranged in a series of triangular groups, such as illustrated above. RCA Engineers discovered that use of sulphide phosphors resulted in the viewer seeing pictures of much greater brightness, more definitive sharpness and more natural colors.

True, no 'tonnage' of sulphur is involved in this achievement and never will be but it does serve to highlight again the important role that Sulphur and its derivatives play in the 'creation of headline products!' Many are in common use in all walks of life. Many more are bound to come from research based on this versatile natural substance.

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Hardware?

Maybe connectors were "hardware" twenty years ago.

That's when the P-38 was the hottest fighter plane we had. Pilots were proud when they could hit 300 MPH and go up to 50 or 60 thousand feet. With this kind of performance requirement, most connectors worked without a hitch. You just connected them and forgot about them, like nuts and bolts.

HOW TIMES HAVE CHANGED

Now we're up around Mach 5 and altitude has been pushed into outer space. Nose cones light up like giant soldering irons and components have to operate in a near vacuum.

Fortunately, Amphenol engineers saw that the old "hardware" concept was headed out the window. Programs coming up were going to need connectors that could put up with terrific environmental conditions of heat and altitude cycling. For example, at high temperatures most of the elastomers used as insert materials or connector seals either melt into a puddle, turn into a cinder, or set-up and lose compression.

What's more, connectors now have to keep on functioning *all* the time, with no allowance for failure. So—Amphenol designers went to work developing a connector to meet the new space-age standards.

DISSECTING MOLECULES

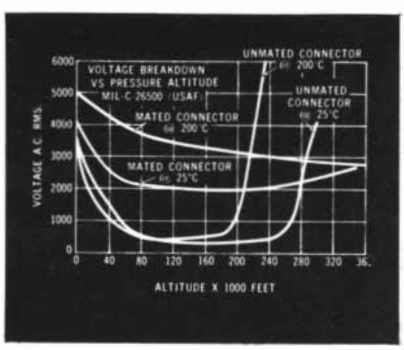
The Amphenol Materials Lab, with the help of a shiny new infra-red photospectrometer, began dissecting elastomer molecules. They were able to pinpoint the weak spots in molecular structure where breakdowns begin. Then they were able to plan and build new molecules, with built-in "armor" to protect against failure. Result: an exclusive silicone rubber compound that maintains its integrity and elasticity under severe temperature extremes and also withstands exposure to violent new propellants like hydrazine and nitrogen tetroxide.

At the same time, Amphenol design engineers were hard at work perfecting metal-to-metal shouldering of mating shells that allowed precision control over compression of the sealing ring. In addition, the metal-to-metal design damped vibrational stress nine times more effectively than resilient damping. Finally, they incorporated a semi-rigid anti-deflection disc to control insert expansion under thermal stress.

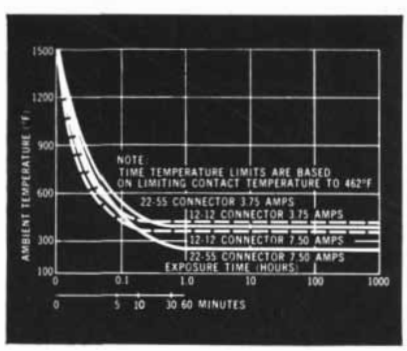
Having all the pieces, we put them together, called it the Amphenol 48 Series, and started testing. In the vacuum chamber, 48 Series connectors operate very nicely at a simulated altitude of 500,000 feet. They are quite comfortable in the hot box at 200°C ambient, *carrying full rated current.* They don't even mind going up to 600°C, if they don't have to stay too long. In short, Amphenol 48's can take almost anything you throw at them.

PROJECTS WANTED

Amphenol designers have established criteria for determining connector time-temperature-currentcapability. This information will be especially valuable to engineers presently engaged in "exotic" projects, perhaps the kind of project where previous connectors have failed to measure up to the new space-age standards. If this is the case, contact an Amphenol sales engineer. He's a "space-age hardware" expert. Or, write directly to Bob Dorrell, Vice President, Engineering, Amphenol Connector Division, 1830 South 54th Avenue, Chicago 50, Illinois.



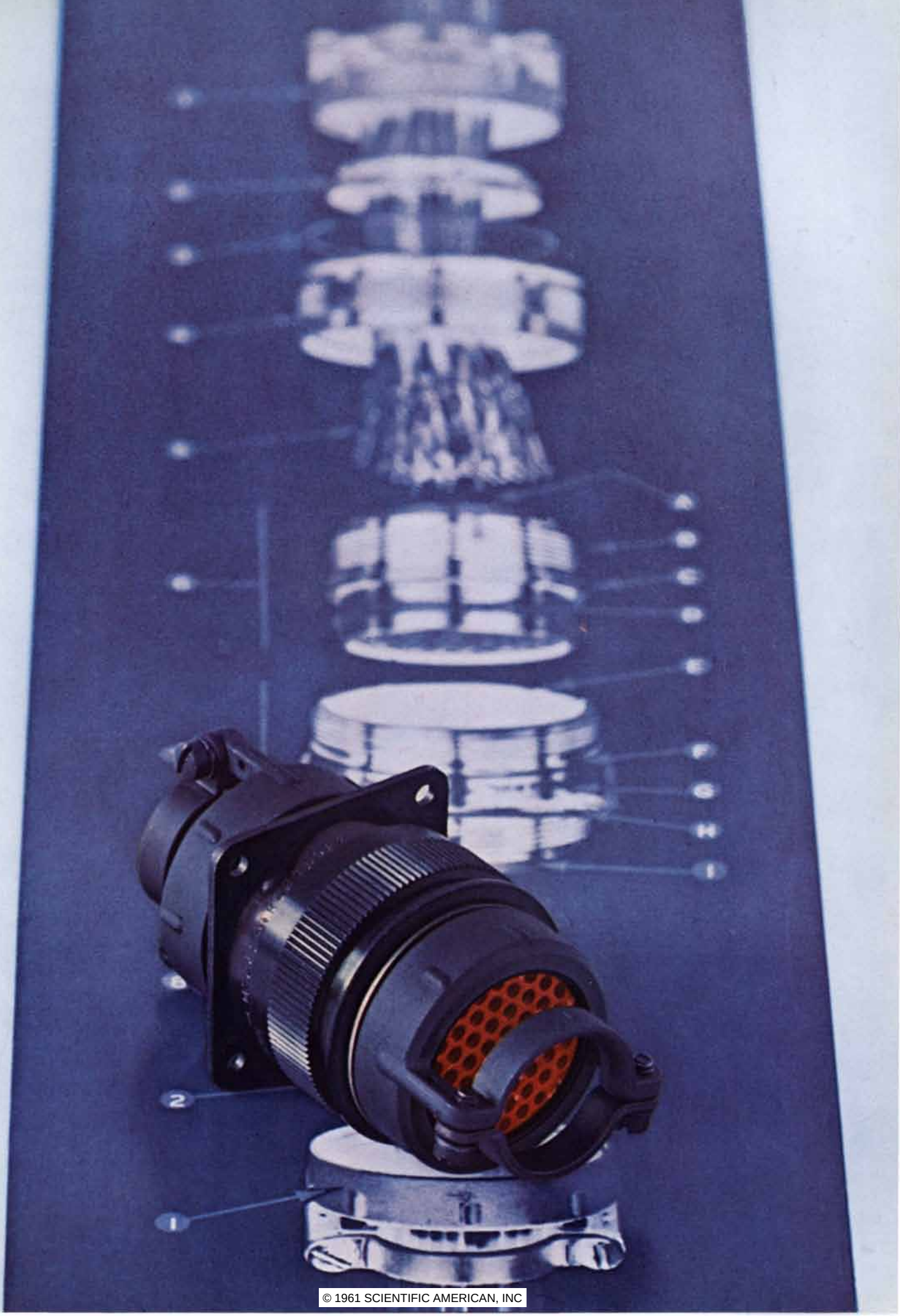
High altitude air has low dielectric strength. By maintaining an air-tight seal 48 Series Connectors enjoy extremely high voltage safety factors.



While Amphenol 48 Series Connectors are nominally rated at 200° C, they can also withstand considerably higher short-time temperature exposures.

Amphenol 48 Series Meets Mil C 26500 (USAF).

AMPHENOL **Connector Division** / Amphenol-Borg Electronics Corporation

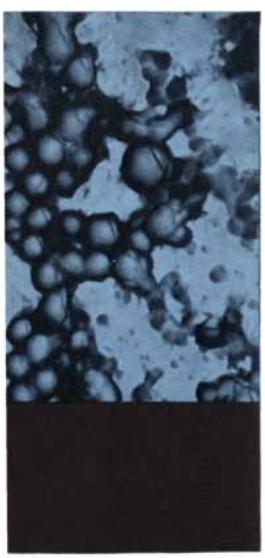


AND UNDERNEATH, PAINT MADE WITH WATER KEEPS HIS CAR FROM RUSTING

You're going to see fewer cars suffering from rust damage... even almost-unreachable crannies in unitized bodies are fully protected against weather and road chemicals by immersion-dipping in new water-base primers.

Formulated by Glidden especially for unitized construction, these special single-coat water-reducible coatings cover all nooks and crannies, eliminate "solvent wash-off," avoid unprimed pockets that can rust and weaken load-bearing panels.

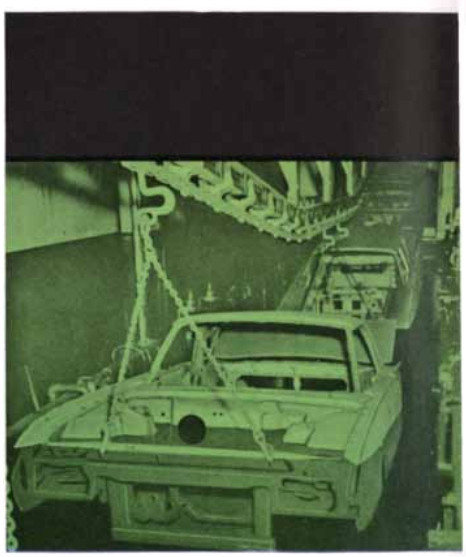
Glidden chemists took new-type water-reducible resins, combined them with pigments, dispersants and emulsifiers, added Glidden experience in finishing application methods... created a new, better, safer priming system for the automobile manufacturer... and helped him give car buyers more for their dollar.



1 Particle size of high solids latex resin emulsion in the Glidden water-reducible primer is kept below 0.3 micron. This assures maximum dispersion of weather-protective resins, producing low-viscosity primers suitable for dipping, flow-coating, and spraying.

2 To make sure that Glidden-developed water-reducible primers would withstand corrosive road chemicals, test panels were exposed for 500 hours to severe 5% solutions in the Glidden lab salt-spray cabinets.

3 To satisfy exacting coating standards, Glidden produces its own resins in latest-type universal reactors. Here, technician checks sample of resin for water-reducible primer... one of more than 100 tests made between initial production and final tank-wagon shipment.



4 Glidden field technicians assist the automobile finishing-line people in adjusting speed of dip-tank travel, and bake-oven temperature to produce ideal preprimer and primer coats.

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In Canada: The Glidden Company, Ltd., Toronto, Ontario

THE AUTHORS

HERBERT A. WILSON, JR. ("Sonic Boom") is manager of the Flight Reentry Programs Office at the Langley Research Center of the National Aeronautics and Space Administration. He acquired a B.S. degree in aeronautical engineering at the Georgia Institute of Technology in 1934 and until 1937 was at various times an insurance agent, a field engineer and an instructor in aeronautics. Wilson then joined the National Advisory Committee for Aeronautics (the predecessor to NASA) as an aeronautical research engineer and was assigned to the Full-Scale Wind Tunnel Section of the Langley Research Center. He became head of that section in 1943. In 1950 he was made head of the group responsible for designing, constructing and operating the Langley Unitary Plan Wind Tunnel, a laboratory for the development of aircraft, missiles and spacecraft having speeds from one and a half to five times that of sound. Wilson assumed his present post in May of last year.

W. C. H. PRENTICE ("Aftereffects in Perception") is Dean of Swarthmore College, where he has taught psychology since 1947. Prentice took a B.A. at Swarthmore in 1937, spent a year at the University of Oxford as a Rhodes Scholar and then studied at Harvard University, where he received his Ph.D. in 1942. During the next five years he taught briefly at Swarthmore and Johns Hopkins University, and from 1943 to 1945 he was a research psychologist for the National Defense Research Committee, first at Princeton University and later at the University of Wisconsin. Prentice was chairman of the department of psychology at Swarthmore from 1953 to 1956, in which year he was made Dean. He has been a contributing editor of the *American Journal of Psychology* since 1957.

V. L. TELEGDI ("Hypernuclei") is professor of physics at the Enrico Fermi Institute for Nuclear Studies at the University of Chicago. Born in Budapest in 1922, Telegdi studied chemical engineering in Brussels and at the University of Lausanne, receiving an M.S. in 1946. He then moved to Zurich to study physics at the Swiss Federal Institute of Technology, acquired a Ph.D. in 1950 and joined Fermi's group at Chicago the following year. Telegdi's work has included research on photonuclear reactions, nonconservation of parity in the decay of mu mesons and free neutrons, and the properties of mu mesons in general. In 1958 he developed a method for the precise measurement of the magnetic moment of the mu meson, and in 1959 he took a year's leave of absence to participate in the experimental work on mu mesons at the European Organization for Nuclear Research (CERN) in Geneva.

SEYMOUR BENZER ("The Fine Structure of the Gene") is professor of biophysics at Purdue University. After taking his B.A. at Brooklyn College in 1942, Benzer went to Purdue, where he acquired an M.S. the following year and a Ph.D. in physics in 1947. He then spent a year at the Oak Ridge National Laboratory, two years at the California Institute of Technology and a year at the Pasteur Institute in Paris before returning to Purdue in 1952.

WILLIAM C. DILGER ("The Behavior of Lovebirds") is assistant director of the Laboratory of Ornithology at Cornell University and head of the laboratory's research program. Dilger began his undergraduate studies at Cornell following the end of World War II, in which he had served as a combat and reconnaissance photographer with the Second Air Command Group in the Southeast Asia theater. He received his B.S. from Cornell in 1949, became curator of birds the same year and acquired his Ph.D. in 1955. Though trained primarily in evolutionary biology and vertebrate zoology, Dilger notes that he has "always been interested in living, whole animals." Dilger taught comparative anatomy and general zoology at St. Lawrence University for a year and then returned to Cornell in 1956.

NATHAN W. SHOCK ("The Physiology of Aging") is chief of the gerontology branch of the National Institutes of Health. Shock received B.S. and M.S. degrees from Purdue University in 1926 and 1927 respectively and a Ph.D. at the University of Chicago in 1930. He has been chief of the gerontology branch since 1941.

WILLIAM G. HAAG ("The Bering Strait Land Bridge") is chairman of the department of geography and anthropology at Louisiana State University. Haag acquired his B.S. and M.S. in geology at the University of Kentucky in 1932 and 1933 respectively. He spent the following year on an extensive survey

of the archaeological remains within the reservoir areas of the Tennessee Valley Authority. After a year of teaching geology at the University of Michigan, where he also studied under the vertebrate paleontologist E. C. Case, Haag went back to work for TVA. In 1937 he joined the faculty at Kentucky, where his principal job was to organize and co-ordinate archaeological excavations in various parts of the state. Haag returned to Michigan in 1941 to study vertebrate paleontology, zoology and anthropology. He completed one year there before he was drafted. He served three years with the Signal Corps and received his Ph.D. from Michigan in 1948. From 1949 to 1952 Haag taught and worked at the University of Mississippi. He joined the faculty of Louisiana State in 1952.

GAMES SLAYTER ("Two-Phase Materials") is a vice-president of the Owens-Corning Fiberglas Corporation. A prolific inventor in the field of glass-fiber technology, he is also known, less formally, as "the father of Fiberglas." His inventions are the subject of more than 135 patents covering various glass-fiber manufacturing processes, insulating materials, air filters, textile products, reinforced plastics and roofing materials. Slayter served as a lieutenant in the Army during World War I and received a B.S. in chemical and metallurgical engineering from Purdue University in 1921. From 1921 to 1928 Slayter was in business for himself, working to develop improved warm-air furnace systems. Among the results of his efforts were the first U.S. patent on glass foam and a method for "blowing" insulation into the wall spaces of constructed buildings. For the next three years he was a consulting engineer in the fields of heating, ventilation, sewage disposal, chemistry and metallurgy. In 1931 Slayter joined the Owens-Illinois Glass Company as head of research in the industrial materials research division. When Owens-Illinois merged with the Corning Glass Works in 1938 to form the Owens-Corning Fiberglas Corporation, Slayter became vice-president in charge of research.

MORRIS KLINE, who in this issue reviews the first six monographs of a series being published under the name of the New Mathematical Library, is professor of mathematics at New York University. Author of *Mathematics in Western Culture*, Kline has written several other pieces for SCIENTIFIC AMERICAN, including the articles "Projective Geometry" (January, 1955) and "The Straight Line" (March, 1956).

A-60 THE NEW NMR!
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The Varian A-60 Spectrometer is an analytical instrument that makes practical the widespread use of NMR (Nuclear Magnetic Resonance) in organic chemistry. The A-60 utilizes the magnetic moment of the spinning hydrogen nucleus to provide a rapid, non-destructive means for identifying compounds, functional groups, isotopic substitution sites, and components of mixtures. Studies of hydrogen bonding, chemical kinetics, tautomeric equilibria, and determinations of molecular structures and total hydrogen content all fall within the realm of the Varian A-60 Spectrometer.

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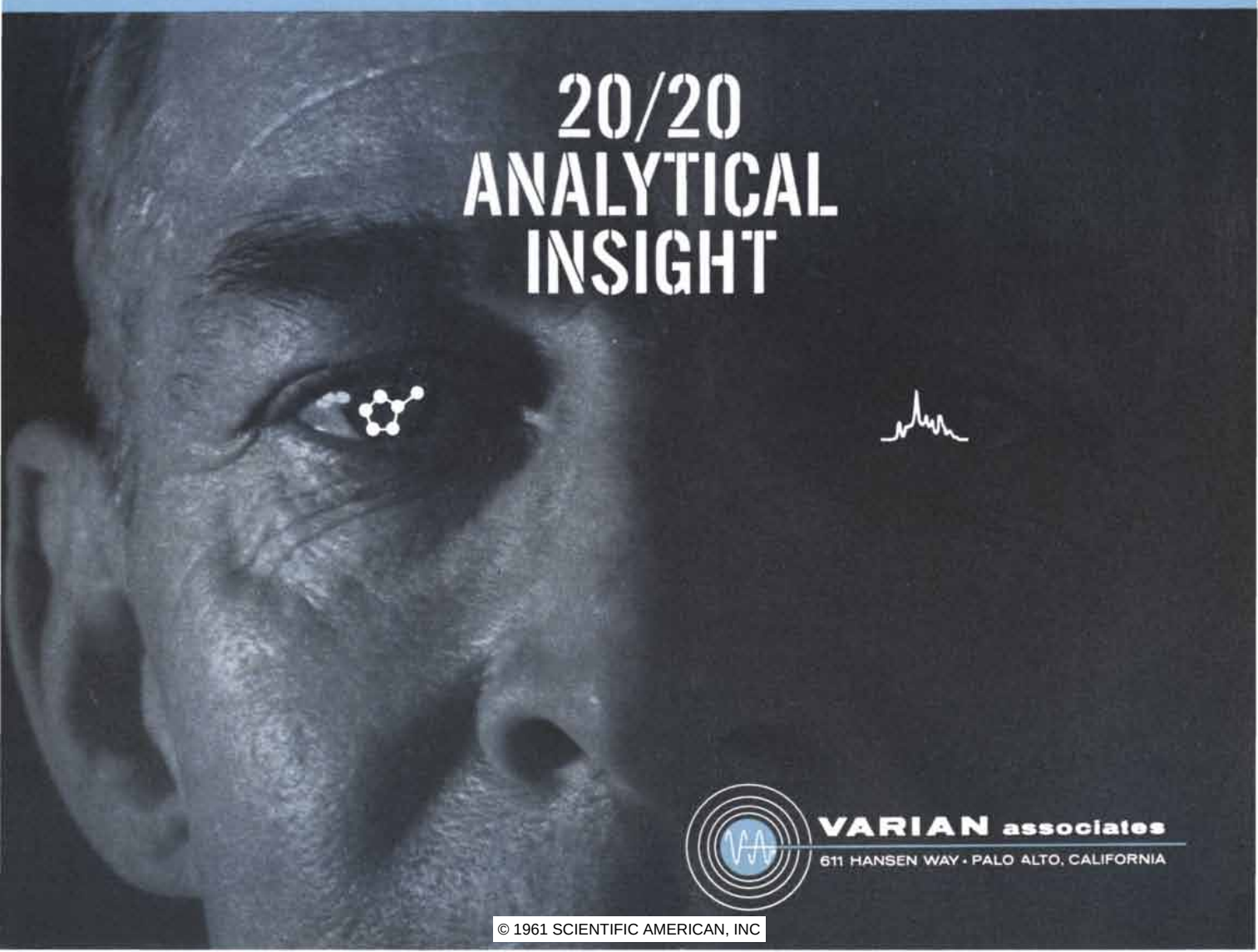
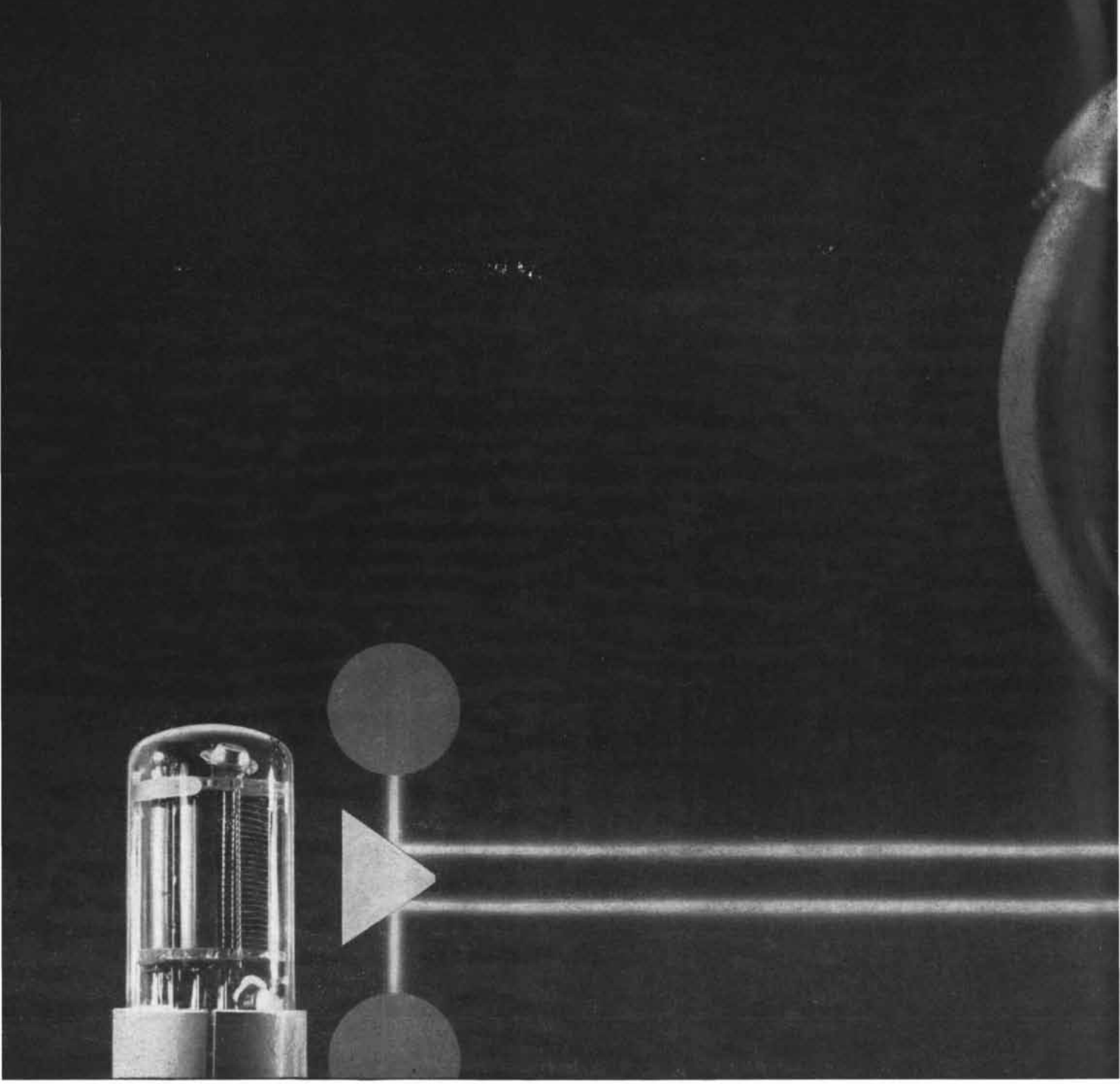
For a full description of the Varian A-60, an explanation of NMR principles, application data and case histories, write the INSTRUMENT DIVISION, DEPT. S.



VARIAN associates
611 HANSEN WAY · PALO ALTO, CALIFORNIA



BEAM SWINGS BRAIN BACK ON TRACK

Once the brain of a ballistic missile comes alive it must concentrate on a fine target point beyond the horizon. Even after the inertial guidance system has been oriented, tiny influences may cause it to deviate from its prescribed azimuth or compass heading before the missile is launched. A continuous correction is needed until the moment of flight.

A Perkin-Elmer alignment theodolite provides and maintains this precise accuracy. This highly developed electronic-optical system first establishes the correct azimuth heading, then automatically keeps the missile aligned with respect to known reference points. Constant monitoring is accomplished by a collimated beam of light which is projected from the theodolite to a mirror mounted on the missile's guidance platform, then reflected back to the theodolite. If the guidance platform is off course, the light beam will re-enter the theodolite "off center". This, in turn, will activate a photomultiplier tube in accordance with the amount

and direction of misalignment. The resulting error voltage is amplified and sent as a correction signal to a servo loop in the missile which resets the guidance platform to proper orientation within ±1.5 seconds of arc!

Perkin-Elmer has developed theodolite systems to set and monitor the inertial guidance systems of such missiles as Titan, Atlas, Mace, Thor and Pershing. In allied fields of navigation, P-E has developed alignment equipment for Polaris submarines and miniature optical pickoffs for super-gyros.

Theodolites are another example of Perkin-Elmer instruments for scientific measurement. P-E's experience with precise measurement techniques is applied in building other complex electronic-optical systems. These do vital jobs such as determining the structure of molecules, controlling chemical process streams, photographing heavenly bodies from the stratosphere.

Perkin-Elmer Corporation, Norwalk, Connecticut.

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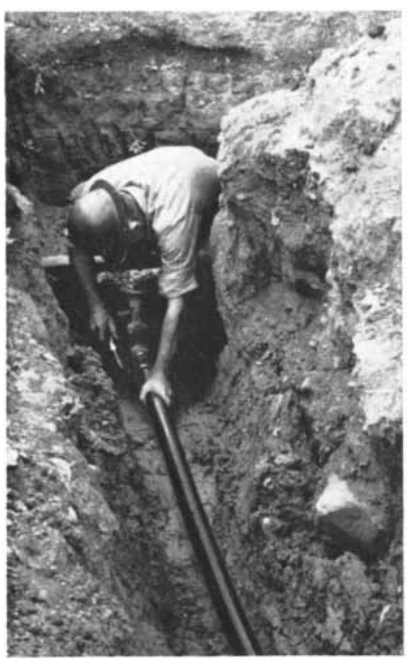
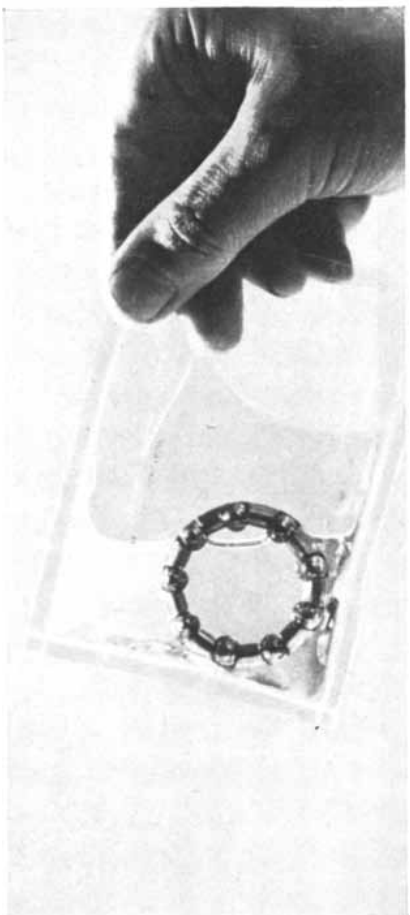
What's new in high polymers? What are the latest types? What methods are used to develop and modify these giant molecules so fascinating to contemporary chemists? Answers to such questions can be found in our new booklet, "High Polymers." In it you will read about polyethylene, for instance, an excellent example of polymer modification. First plastic to reach an output rate of a billion pounds a year, it is used in the familiar forms of packaging materials, squeeze bottles and unbreakable toys. Polymer research at Allied Chemical, by the way, has carried polyethylene far beyond these familiar uses. Our Plastics Division people have come up with an emulsifiable type to modify water-based products such as textile



finishes, floor polishes, and washable paints . . . as well as a superior high-density polyethylene pipe (shown here) engineered to last about fifty years. *Why not write today for your free copy of "High Polymers"?*



New moisture-barring film. ACLAR®, our General Chemical Division's new fluorohalocarbon film, is characterized by fantastically low moisture vapor transmission, transparency, impact strength. To get the moisture barrier benefits of ACLAR type 33 film, a saran film would have to be over 100 times as thick, a polyethylene film over 400 times as thick, and a polyester film over 700 times as thick. Indicated uses: packaging electronic and other delicate mechanical equipment components, drugs, and chemicals. Its application in *your* field of interest might be of value to *your* product, too. *Write for technical data.*

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For literature on any of the above-mentioned items, just write, on your company letterhead, to Allied Chemical Corp., Dept. 12-S, 61 Broadway, N. Y. 6, N. Y., or phone HAnover 2-7300.

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Basic to America's Progress

No. 1 in a series of science-fiction originals created expressly for Hoffman Electronics Corporation.

ITSELF!

By A. E. VAN VOGT

Itself, king of the Phillipine Deep—that awesome canyon where the sea goes down six miles—woke from his recharge period, and looked around suspiciously.

His Alter Ego said, "Well, how is it with Itself today?"

The Alter Ego was a booster, a goader, a stimulant to action, and, in his limited way, a companion.

Itself did not answer. During the sleep period, he had drifted over a ravine, the walls of which dropped steeply another thousand feet. Suspiciously, Itself glared along the canyon rim.

...Not a visual observation. No light ever penetrated from above into the eternal night here at the deepest bottom of the ocean. Itself perceived the black world, which surrounded him, with high frequency sounds which he broadcast continuously in all directions. Like a bat in a pitch dark cave, he analyzed the structure of the things in his watery universe by interpreting the returning echoes. And the accompanying emotion of suspicion was a device which impelled Itself to record changing pressures, tem-

peratures and current flows. Unknown to him, what he observed became part of the immense total of data by which computers far away estimated the inter-relationship of ocean and atmosphere, and thus predicted water and air conditions everywhere with uncanny exactness.

His was almost perfect perception. Clearly and unmistakably Itself made out the intruder in the far distance of that twisting ravine. A ship! Anchored to rock at the very edge of the canyon.

The Alter Ego goaded, "You're not going to let somebody invade your territory, are you?"

Instantly, Itself was furious. He activated the jet mechanism in the underslung belly of his almost solid metal body. In a flash, a nuclear reactor heated the plates of the expansion chamber. The sea water which flowed through the chamber burst into hissing clouds of steam, and he jetted forward like a missile.

Arrived at the ship, Itself attacked the nearest of four anchor lines with the nuclear-powered heat beam in his head. When he had severed it, he turned to the second cable, and burned through it. Then he headed for the third cable.

But the startled beings aboard the alien ship had spotted the twenty-foot monster in the black waters below.

"Analyze its echo pattern!" came the command. That was done, with total skill.

"Feed the pattern back through the infinite altering system till the recorders register a response."

The significant response was: Itself forgot what he was doing. He was drifting blankly away, when his Alter Ego goaded, "Wake up! You're not going to let them get away with that, are you?"

The defeat had galvanized Itself to a more intense level of rage. He became multiples more sensitive. Now, he simply tuned out the alien echo copies.

The new greater anger triggered a second weapon.

Itself's echo system of perception, normally monitored to be safe for all living things in the sea...suddenly strengthened. It became a supersonic beam. Purposefully, Itself started towards the ship.

Watching his approach, the enemy decided to take no chances. "Pull the remaining anchors in!"

Itself headed straight for the nearest part of the vessel. Instantly, those ultrasonic waves started a rhythmic vibration in the hard wall, weakening it.

The metal groaned under a weight of water that at these depths was thousands of tons a square inch. The outer wall buckled with a metallic screaming.

The inner wall trembled, but held.

At that point, the appalled defenders got a counter-vibration started, nullified the rhythm of Itself's projections, and were safe.

But it was a sorely wounded ship that now drifted helplessly in a slow current. The aliens had so far used no energy that might be detected from the surface. But they had come to earth to establish a base for invasion. Their instructions were to accumulate enough data about underwater currents, to enable them to leave the Deep, and eventually to be able to drift near land, launch atom bombs, and drift away again. For this purpose they were mightily armed, and they refused to die in these black waters without a fight.

"What can we do with that demon?"

"Blast it!" someone urged.

"That's dangerous!" the commander hesitated.

"We can't be in greater danger than we already are."

"True," said the captain, "but frankly I don't know why he's armed at all, and I can't believe he has anything more." His command when it came held a restriction: "Set up a response system. If he does attack with anything new, it will automatically fire back. We'll take that much of a chance."

The second setback had driven Itself completely berserk. He aimed his nuclear pellet gun, and fired twice. The next split second a blast from the invader pierced his brain.

The Alter Ego yelled, "You're not going to let them get away with that, are you?"

But the king of the Phillipine Deep was dead, and could not be goaded.

In due course there came a report to weather headquarters:

"Computer Center shows no recent data from Itself. It therefore seems as if another of the war-time antisubmarine water-weather robots has worn out. You may recall that these electronic monsters were programmed to suspicion, anger, and the idea that they owned part of the ocean. After the war we could never get these creatures to surface; they were too suspicious of us."

The ocean of water, like the ocean of air far above, flowed and rolled and moved, a ceaseless, dynamic, driving motion, many, many times more powerful, however, than any comparable air current. Yet, in essence, the quadrillions of water movements solely and only balanced each other out.

Through the Phillipine Deep there began presently to flow an enormous balancing river. It carried the invader vessel in a long, slanting, upward direction. But it was many weeks before the drifting ship actually broke surface, and another day or so before it was seen.

A naval patrol boarded it, found aliens dead more than a month from concussion, and—after examining the damage—correctly analyzed what had happened. And so—

A new king "woke" to the first "day" of his reign, and heard *his* Alter Ego say, "Well, Itself, what's the program?"

Itself glared with a royal suspicion.

Would you like your own pocket model of "Itself"? See column at right.

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Sonic Boom

The loud noises caused at the ground by an airplane flying faster than the speed of sound will have to be brought under control before supersonic transports can come into service

by Herbert A. Wilson, Jr.

The target date for the first flight of a U.S. supersonic transport plane is 1967. Only two and a half years after the introduction of their first commercial jet transports, U.S. aircraft companies are actively investigating the development of airliners that will carry several hundred passengers at two or three times the speed of sound—from New York to Paris in about two and a half hours. Last year Congress appropriated $11 million for the Federal Aviation Agency to begin the development of a prototype supersonic transport, with technical support from the National Aeronautics and Space Administration.

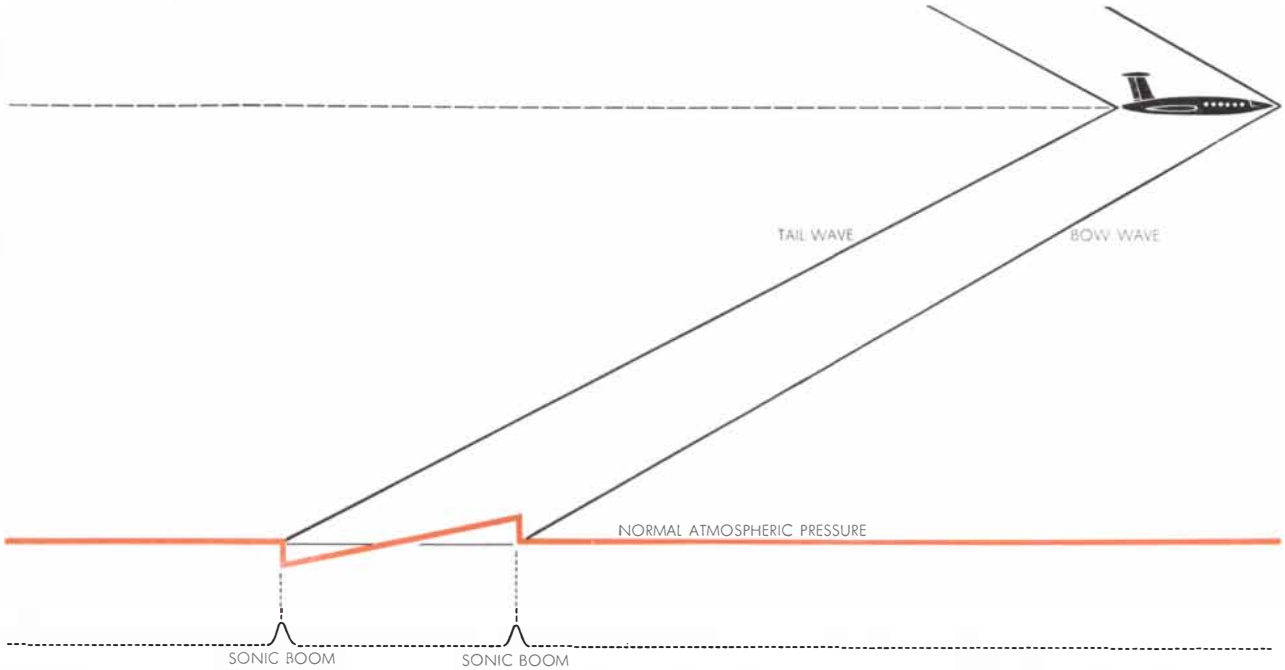
Among the large questions of design, construction and operation that remain to be solved before airliners travel faster than sound, one of the most difficult is the problem of sonic boom: the explosive sounds generated when an object moves through the air at supersonic speed. These booms are heard on the ground beneath the flight path of a supersonic airplane; they are loud and annoying when the airplane is below about 40,000 feet. The pressure wave that makes the boom can also break windows and, if the airplane is much below 25,000 feet, perhaps damage the structure of buildings. Sonic booms have caused alarm and damage when they have been produced in isolated cases by supersonic military jets flying over thinly populated areas; to allow a new fleet of booming supersonic transports to pass over cities at low altitudes during operations near metropolitan airports is clearly impossible. The airlines, which have already heard bitter complaints about the roar and whine of subsonic jets, are no more likely than the Government to be attracted to transports producing sonic booms.

Can the booms be eliminated? The answer is a categorical negative; they are an inherent part of supersonic flight. Can the booms be reduced to a tolerable level? Although the answer is not yet certain, they probably can be, by proper design of aircraft and careful planning of flight paths. To this end Government and private research is now under way to improve understanding of how booms vary with aircraft shape, size and maneuvers and with atmospheric conditions.

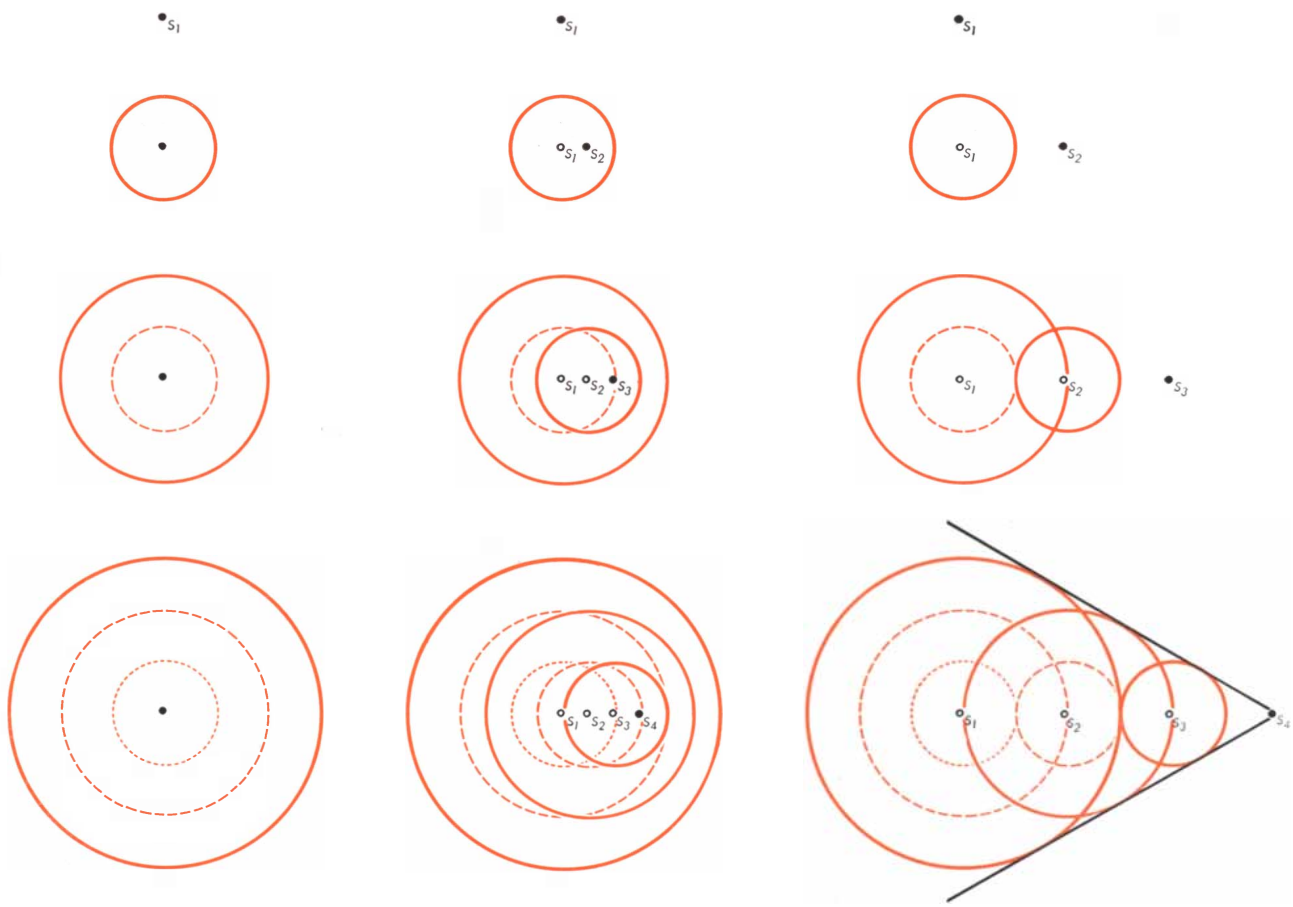
A sound is a pressure disturbance; a sonic boom, like other explosive sounds, is the result of an abrupt change in pressure. An airplane in subsonic flight produces weak changes in pressure. Because these disturbances travel at the speed of sound, they move faster than the airplane and stay in front of it. In other words, the airplane sends a message ahead warning the air to get out of the way. The air does just that, parting in smooth, curving streamlines to pass around the airplane's surfaces. But a supersonic jet gets ahead of its own pressure disturbances. The air has no advance notice that the jet is coming; it must therefore get out of the way abruptly. A wave of suddenly compressed air—a shock wave—builds up and is thrown off to the sides like the wave that spreads from the bow of a speedboat. The streamlines develop sharp angles where they cross the shock wave.

To understand the anatomy of the shock wave, consider the behavior of any moving source of sound, or pressure disturbance [*see bottom illustration on opposite page*]. If the source is stationary, the sound waves move out from it in a series of concentric spheres of pressure disturbance that can be visualized in two dimensions as a series of concentric circles, like the ripples created by a stone dropped into a pond. If the source moves at less than the speed of sound, the same spherical wave pattern is propagated. But since the sound is now being emitted from a series of points along a path, the successive spheres are crowded in the direction of travel. Still, the source remains within the spheres of disturbance. But if the source moves faster than the speed of sound, the source gets ahead of the spheres propagated previously. The spheres emitted at successive points become tangent to lines sloping backward from the moving source. These lines define a cone, the surface of which is the shock wave.

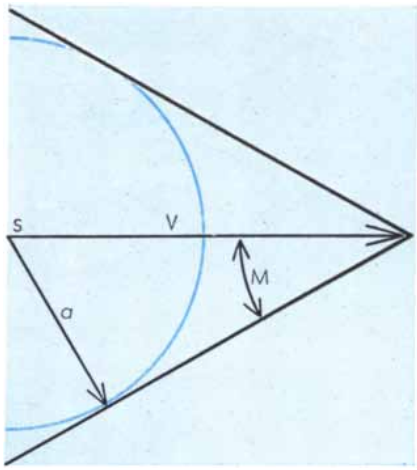
The geometry of the shock wave depends on the relationship between two velocities, as shown in the top illustration on page 38. In a given time the source moves distance V while the disturbance it created at point s moves distance a. So V is the speed of the aircraft and a the local speed of sound. The speed of sound varies with temperature



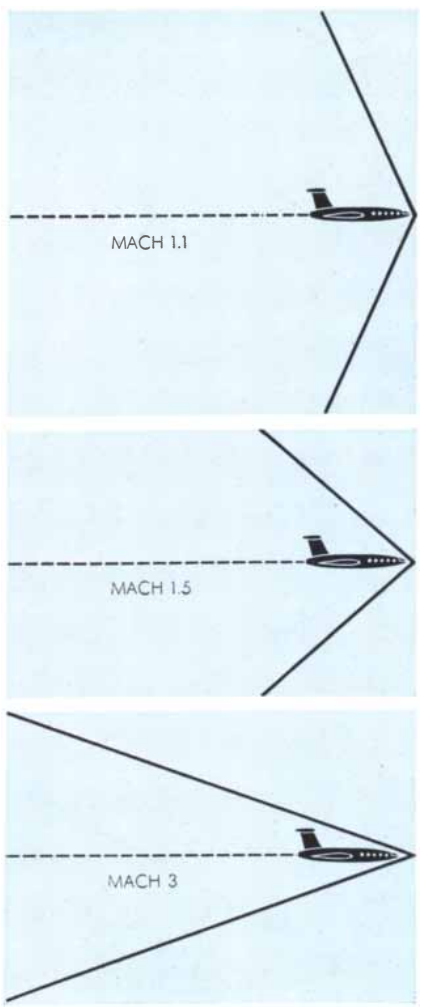
SHOCK WAVES created by the passage through the air of a supersonic airplane coalesce into two large cone-shaped shock fronts, shown here in cross section, that are carried along with the airplane. Each front is a region of compressed air that creates a distinct "pressure jump" at the ground. The changes in atmospheric pressure are heard by an observer as two sonic booms in succession.



SONIC BOOM arises because a supersonic airplane moves faster than the pressure disturbances, or sound waves, it propagates. A stationary source (*left*) emits spherical sound waves that move outward like concentric ripples. If the source moves at less than the speed of sound (*middle*), waves emitted at successive positions are crowded in the direction of movement; they overtake the moving source and "warn" the air of its approach. But disturbances from the earlier emissions of a supersonic source (*right*) cannot overtake the source, which arrives without warning and creates a shock wave. The spheres become tangent to the sides of the shock-wave cone.



SHAPE OF CONE is controlled by the speed of the airplane. The airplane travels distance V while the sound wave emitted at s travels distance a; V is the airplane speed and a the local speed of sound. V/a is the Mach number. The angle whose sine is a/V is known as the Mach angle (M). Because in this case V is 2 and a is 1, the Mach number is 2 and the Mach angle is 30 degrees.



MACH ANGLE varies with Mach number as shown here, and with it the inclination of the shock front with respect to the ground.

and therefore with altitude, from 760 miles per hour at the ground to 660 m.p.h. near 36,000 feet, after which it remains constant to a much higher altitude. V divided by a yields the Mach number, the ratio of the speed of an airplane to the local speed of sound. Because of the variation in the speed of sound with altitude, it is Mach number rather than absolute speed that is important in sonic boom and in supersonic flight in general. The Mach number determines the shape of the shock-wave cone: a/V is the sine of the "Mach angle" at the vertex of the cone. The higher the Mach number, the smaller the vertex and the narrower the cone.

When an airplane moves faster than sound, shock waves are produced by its nose, wings, cockpit canopy, engine air inlets and tail surfaces. Accordingly a number of distinct shock cones are created; within a few hundred feet of the airplane a succession of explosive noises is heard. With distance, however, the shock waves tend to coalesce into two large shock fronts, a bow wave and a tail wave. These extend for several miles and move along with the airplane. Each cone is a region of "pressure jump" and wherever a cone intersects the ground a boom is heard [*see top illustration on preceding page*]. If the airplane is in straight and level flight, the intersection of the cone with the ground delineates a hyperbola. Booms are heard simultaneously at all points along the hyperbola, and no sound is heard outside the path drawn by the hyperbola as it travels over the ground [*see top illustration on opposite page*].

Although workers in aerodynamics and ballistics were acquainted with shock-wave theory before the era of supersonic flight, booms were not actually heard until after World War II. The first booms were produced in level flight by the X-1 rocket research airplane in 1947. Soon afterward booms were noted when advanced fighters were dived to supersonic speed. At first the booms were considered a novelty and their destructive effects were not anticipated. During the 1952 and 1953 air shows at Farnborough in England pilots entertained spectators by diving at the airfield to produce booms. In the U.S. in 1953 a pilot practicing for a demonstration at a Western air base dived his jet to supersonic speed and pulled out at 8,000 feet—a safe altitude for even a fast subsonic fighter. The boom that resulted shattered windows in virtually every building on the base and damaged doorframes and floors.

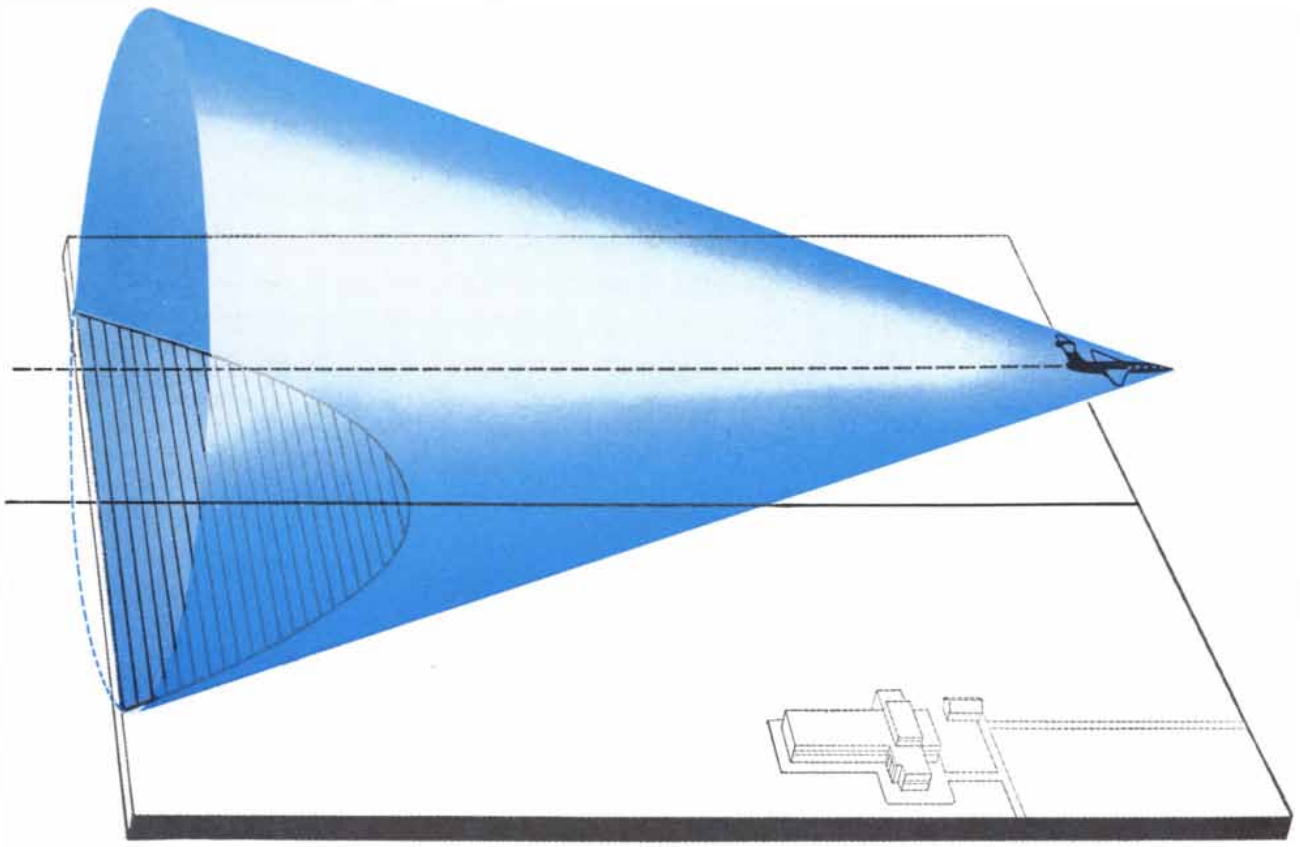
The novelty soon wore off. As the number and speed of supersonic aircraft increased, so did the frequency and intensity of the booms. The sound became familiar to people living near jet-fighter bases. Mysterious "explosions" and "earthquakes" were reported in the press and traced to supersonic flights. Finally supersonic operations near the ground over populated areas had to be abandoned in the face of the adverse public reaction, and the aeronautical community settled down to learn about sonic boom and how to control it. Extensive flight tests were undertaken to establish the effects on the ground of various boom intensities and to find out what factors affect boom intensity, and how.

It is generally accepted that booms producing pressure jumps at the ground of less than .3 pound per square foot are hardly noticed at all; between .3 pound and one pound the boom is not objectionable. But a pressure jump of more than one pound per square foot produces a noise like a cannon shot or a nearby thunderclap and causes some damage to windows—effects that would clearly not be acceptable for airplanes flying with airline frequency.

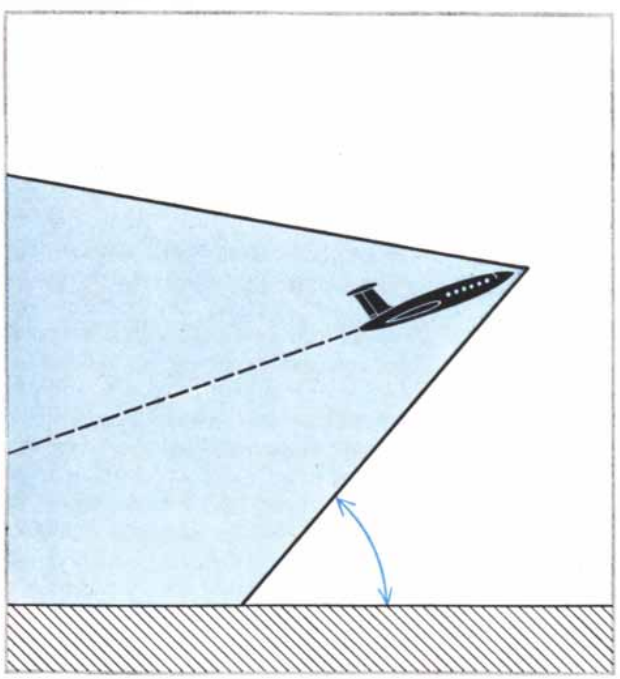
The most obvious factor affecting boom intensity is the speed of the airplane. When this exceeds the speed of sound (Mach 1) by even the smallest amount, a boom occurs. As the airplane speed increases beyond Mach 1, boom intensity builds up rapidly at first and then more gradually: the pressure jump in pounds per square foot is proportional to the 1/8 power of the square of the speed minus 1, or $(M^2 - 1)^{1/8}$. This relationship indicates that the booms produced by a supersonic transport at a speed of Mach 3, or about 2,000 miles per hour, should not be much more intense than those from present-day fighters flying at about Mach 1.3.

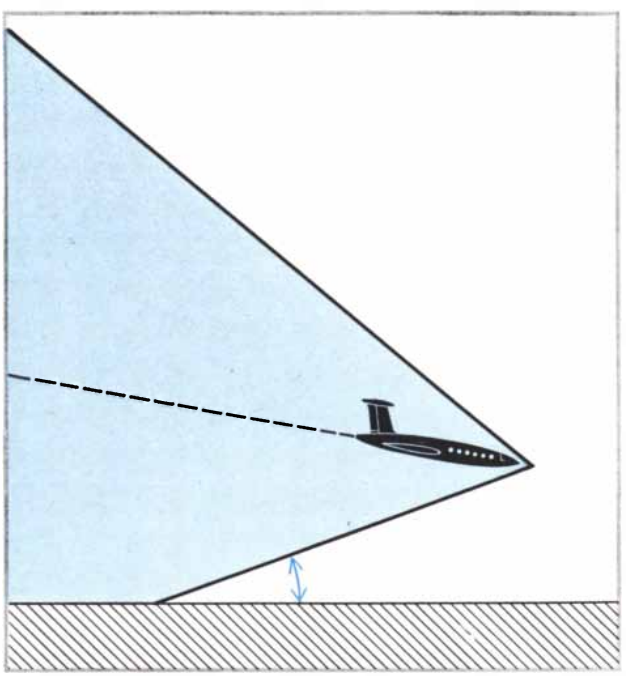
In addition to affecting the intensity of the boom, the speed of the aircraft also affects the inclination of the shock front, because of the relationship between Mach number and Mach angle. The inclination of the front, in turn, affects the time at which a boom generated at a given instant in the air is heard on the ground. The boom an observer hears may have been produced when the airplane was as much as 25 miles away and is not heard until after the airplane has passed overhead. The boom comes from where the airplane used to be, not where it is. This could be important in planning the operations of transports leaving or approaching populated areas.

The magnitude of a boom at the ground is significantly affected by the

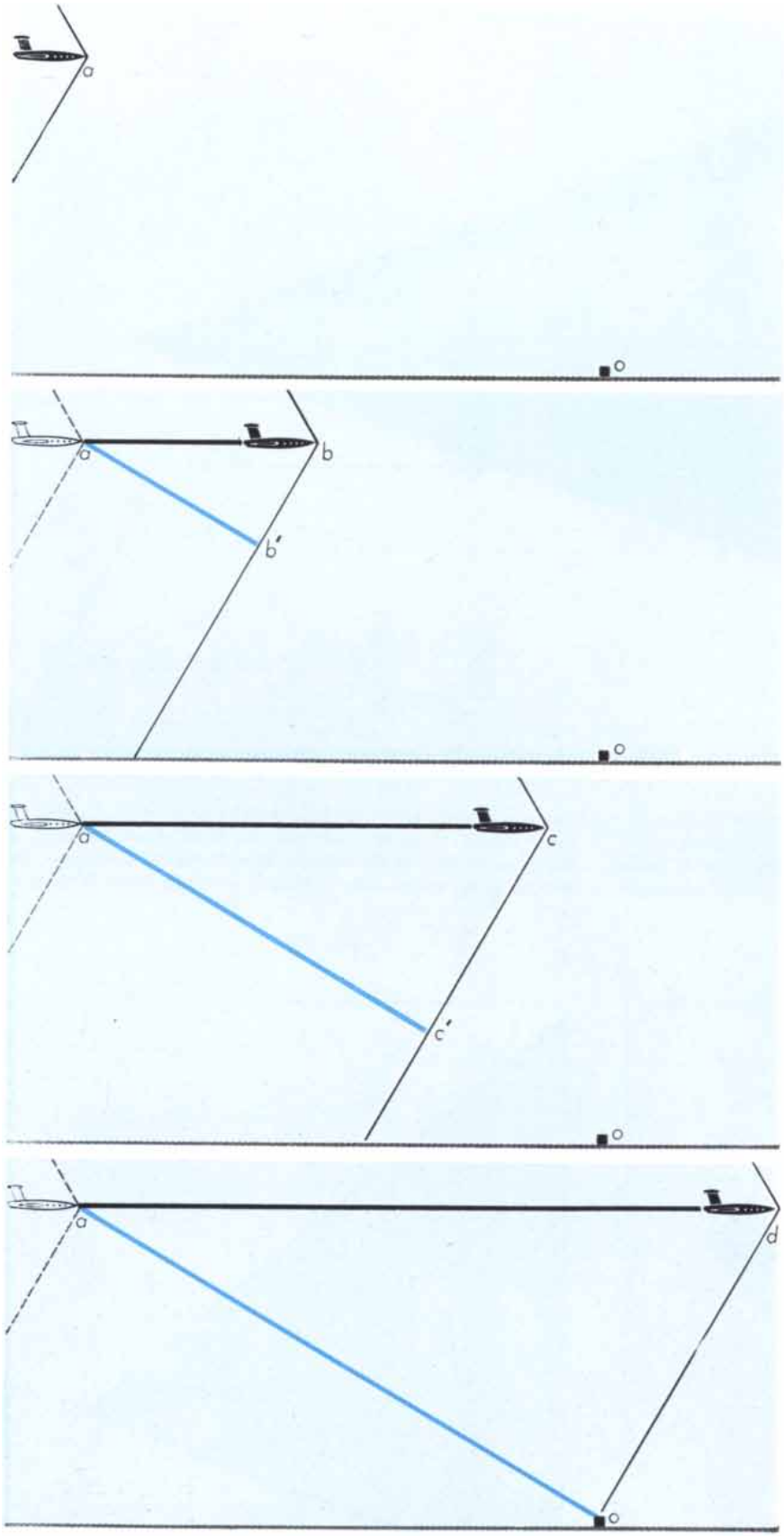


SUPERSONIC AIRPLANE carries along with it two shock cones, one of which is visualized here in color. The intersection of the cone with the ground delineates a hyperbola. The boom is heard simultaneously at all points along the hyperbola and is eventually heard everywhere within the hyperbola's path over the ground; no sound is audible outside it. In the case of an airplane moving at Mach 2 at 20,000 feet, the distance along the shock front from the airplane to the vertex of the hyperbola would be about 40,000 feet.





ANGLE OF FLIGHT, like the Mach number, affects the inclination of the cone with respect to the ground. At a given Mach number the shock front from a climbing airplane (*left*) makes a larger angle with the ground than the front from a diving airplane (*right*).



THEORETICAL PATH OF BOOM from airplane to observer is shown by the colored line. The boom produced at *a* travels at about the speed of sound toward the observer at point *o*. In so doing it moves down the diagonal shock front: as the airplane reaches point *b* and then point *c*, the boom has moved to *b′* and then to *c′*. By the time the observer hears the boom, the airplane has flown on to point *d*, which may be several miles beyond *o*.

distance to the flight path of the airplane: the intensity of the pressure jump varies inversely with the 3/4 power of the distance. A supersonic transport will cruise most efficiently at an altitude of about 70,000 feet (more than 13 miles); even directly below a plane flying at this altitude the pressure jump should be in the tolerable range. As the observer moves laterally away from the ground path of the airplane, the boom intensity diminishes further [*see illustrations on page 43*].

A supersonic transport will, of course, not always be in straight and level flight. As an airplane maneuvers, its cone of shock waves is distorted and there is a consequent change in the pattern of shock waves at the ground. If the airplane climbs or dives at a constant angle and Mach number, the shock cone rotates about the inclined flight path [*see illustration at bottom of preceding page*]. When an airplane climbs, the shock front reaching the ground is more nearly perpendicular to the ground. In a dive the reverse is true: the shock front is more nearly parallel to the ground.

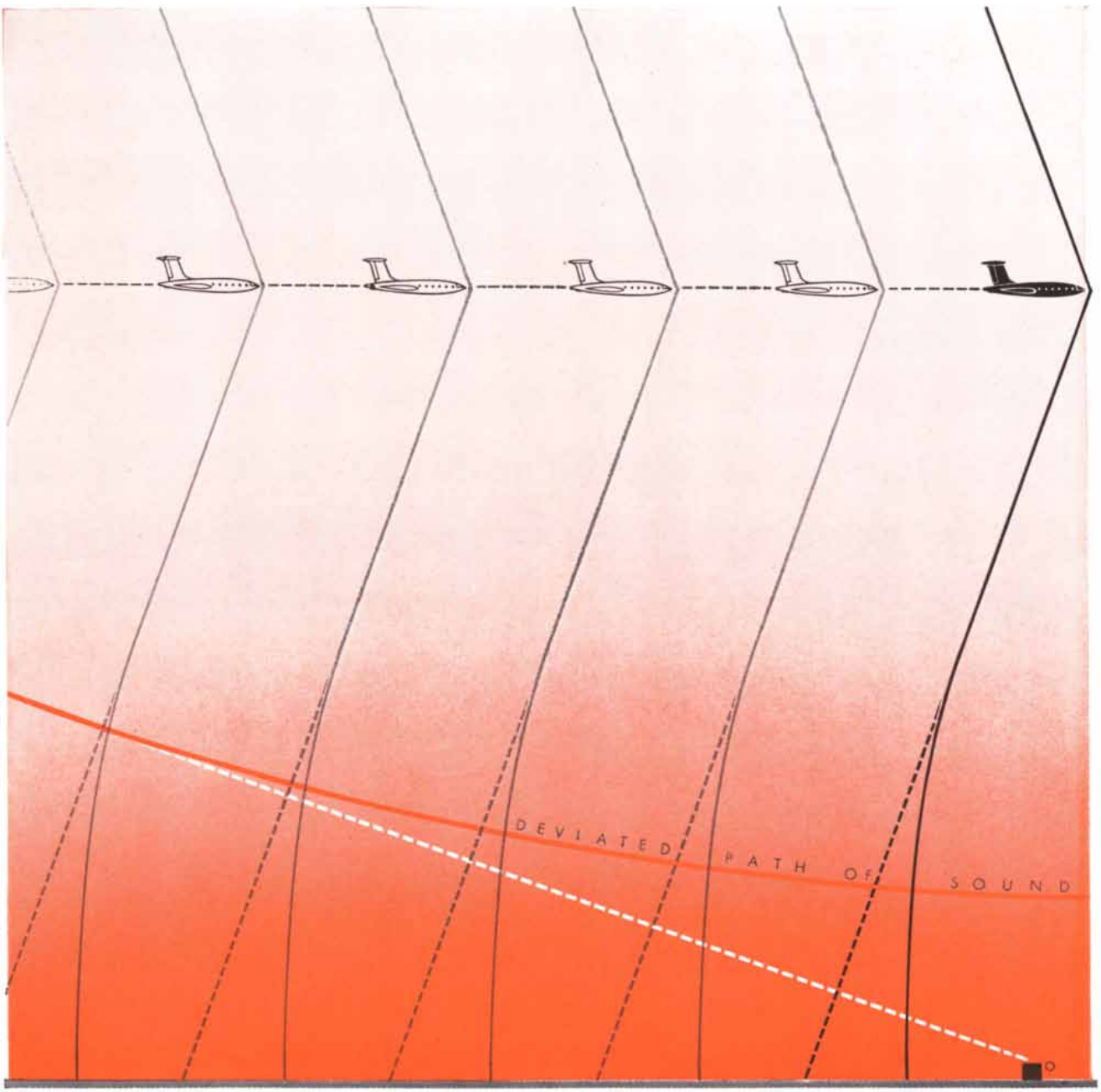
When a jet makes a turn of small radius, a special "focusing" effect on the shock waves causes a reinforced double boom over a curved path on the ground. Where military jets are concerned, this effect is important. Supersonic airliners are of course unlikely to make such maneuvers, if only because they are quite uncomfortable for the passenger.

Since the boom-producing sound waves are created because the air in front of the airplane cannot get out of the way, it follows that the less the air has to move, the less intense is the pressure jump. Consequently the size and shape of the airplane have important effects on the intensity of the shock. Fortunately the factors that generate large pressure jumps are the same ones that cause drag; they are avoided by designers of any high-speed aircraft. The slender, pointed nose, the high ratio of length to diameter, the thin, sharp-edged wings and tail surfaces that will help to keep boom levels low will not add any new constraints on aircraft shape to those imposed by considerations of aerodynamic efficiency.

The size and weight of the supersonic transport, however, may be significant new elements in the situation. The length of the plane should have a large effect on boom intensity, because the pressure jump is theoretically proportional to the 3/4 power of the length. Theory suggests that the lift of the airplane, which increases with weight, may also be im-

portant. To date this variation with size has been investigated experimentally only over a small range—between the smallest supersonic fighters and the one supersonic U.S. bomber now flying, the B-58—and the theory does not seem to be borne out. The B-58 has generated booms only slightly more intense than those from a fighter three-fifths as long and weighing one-fourth as much. Whether or not this unexpectedly small effect of size will persist in a supersonic transport much longer than the B-58 and two or three times as heavy is still a matter for speculation.

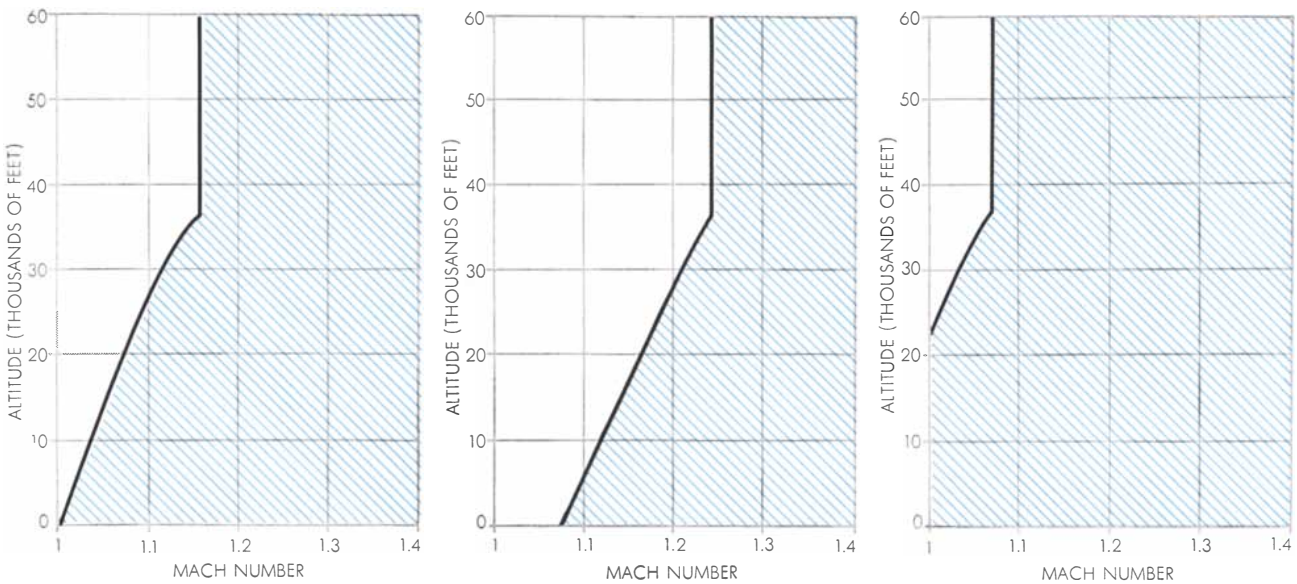
Airplane speed, distance from the ground, flight path and shape are all factors that can be controlled by designers and operators and that can to some extent be modified if necessary. The atmosphere, on the other hand, is not subject to control, and it has important effects on the boom that actually reaches the ground. The most important atmospheric effect, which tends to mitigate the problem of sonic boom, arises from the fact that the speed of sound increases with temperature and therefore decreases with altitude. The result is that the advancing shock front is not straight, as the preceding discussion has assumed. As the front enters increasingly warm air it is refracted, just as light is refracted on passing from one medium into another in which its speed is greater. The shock front behaves much like a



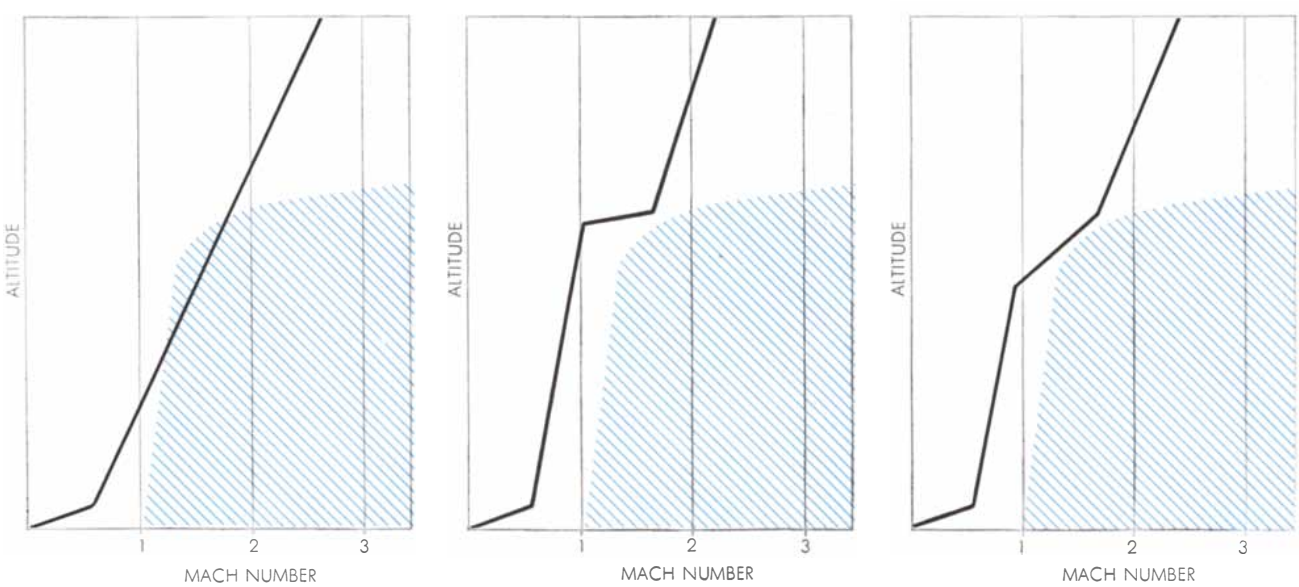
ACTUAL PATH OF BOOM is modified by air temperature, which decreases with altitude to the troposphere. Because the speed of sound is greater in the warmer lower air than it is at flight altitude, the shock front of sound waves is refracted toward the vertical (*curved gray and black lines*). The "ray" of pressure-jump from the airplane toward the observer *o* (*broken white line*) remains perpendicular to the front and is therefore deflected (*solid colored line*) away from the ground. At Mach numbers just above 1 this mechanism can cause the boom rays to miss the ground completely. The speed at which this occurs is the cutoff Mach number.

rank of soldiers advancing obliquely from a muddy field onto an increasingly dry surface. The rank tends to wheel as some of the soldiers reach the "faster" surface. In the same way the shock front is skewed toward the vertical as it approaches the ground [*see illustration on preceding page*]. As it does so, the "rays" of sound from the source are deflected so as to remain perpendicular to the front, and curve upward. If they curve enough—that is, if the front is perpendicular to the ground and the rays are parallel—they never reach the ground. The importance of the Mach angle and of the angle of climb or dive in this situation is clear. Wind direction and wind gradient are also factors. A tail wind that is greater at the altitude of the aircraft than at the ground will tend to speed up the higher segments of the shock front and in so doing tend to keep it oblique. A head-wind gradient, on the other hand, makes the shock front more vertical, working in the same ameliorating direction as the temperature effect.

Whenever, as a result of airplane speed, flight path, temperature or wind gradient, the shock front is rotated until it is perpendicular to the ground, a limiting condition is reached and the boom is not heard. The speed at which this occurs is called the cutoff Mach number, and it can be calculated for the assumed standard temperature variation and for various flight angles or wind gradients [*see upper illustration on this page*]. The cutoff mechanism means that even when an airplane generates



CUTOFF MACH NUMBER, below which the temperature gradient will cause boom rays to miss the ground, varies with altitude and wind conditions. These graphs give the cutoff number at various altitudes in the absence of a wind gradient (*left*), with a head wind 50 knots greater at flight altitude than at the ground (*center*) and with a 50-knot tail-wind gradient (*right*). The hatched area to the right of each curve indicates the Mach numbers above cutoff, or those speeds at which sonic booms would be audible on the ground.



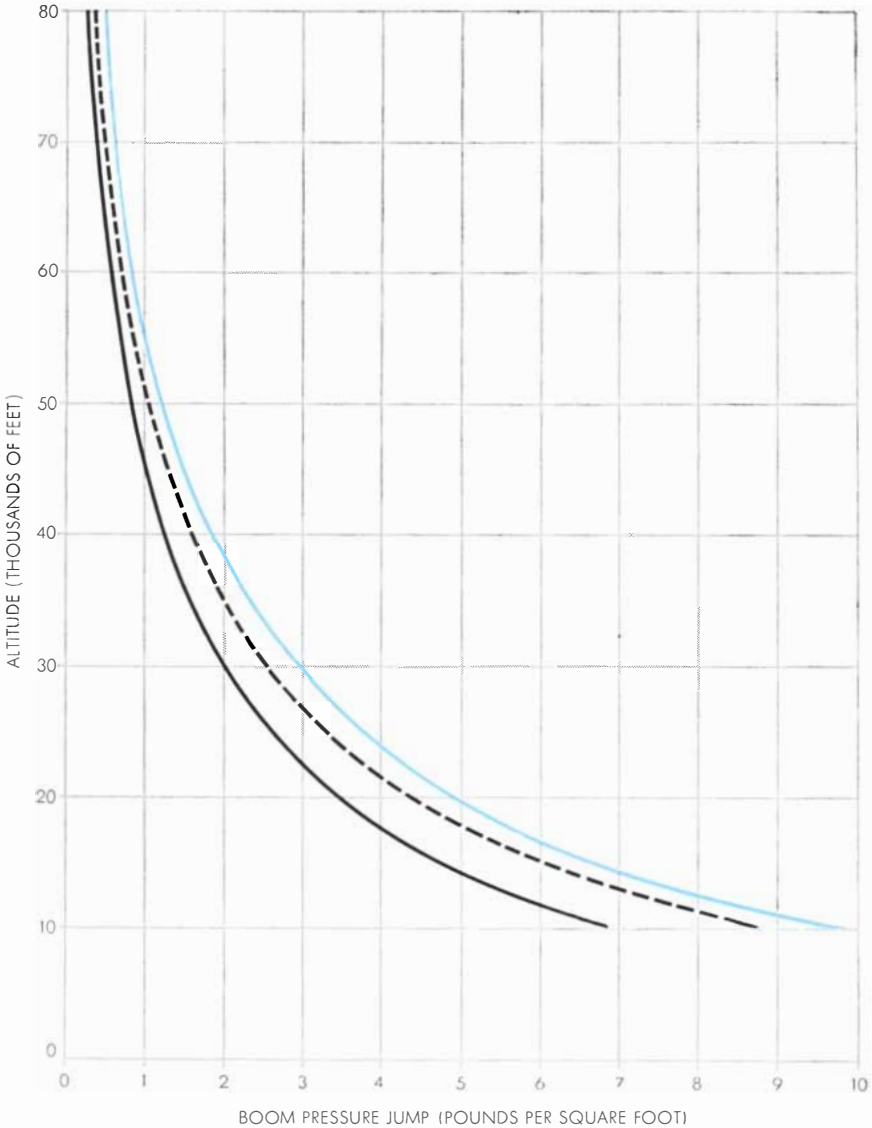
CRITICAL PHASE of a supersonic transport's flight plan will be the initial climb-out to cruising altitude. Early acceleration to supersonic speed, at about 25,000 feet, would be most efficient (*left*) but would cut into the zone of speed and altitude (*hatched area*), producing objectionable booms. A plan that would avoid this zone by delaying acceleration to perhaps 45,000 feet (*center*) requires extra engine performance. A compromise plan (*right*) would take advantage of the increase in cutoff during a climb.

booms that are capable of reaching the ground, they do not always do so. The flight plan of a supersonic transport can be modified to take advantage of this.

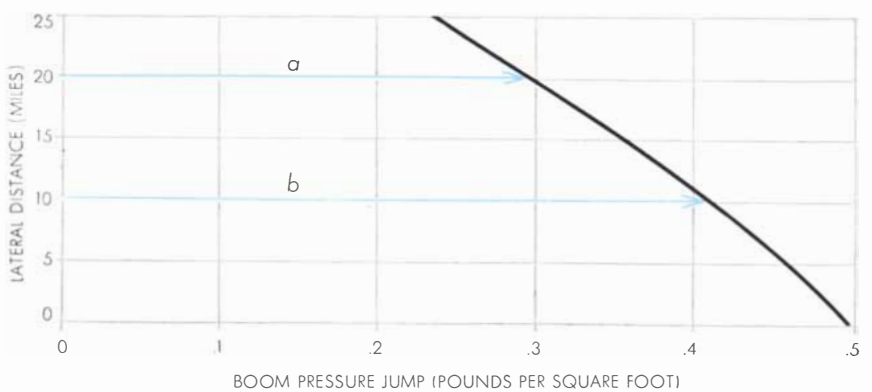
A supersonic transport would ideally take off, climb to a convenient altitude at subsonic speed, accelerate to supersonic speed, continue its climb and level out to cruise at a speed between Mach 2 and Mach 3 at an altitude of some 70,000 feet. At its destination the transport would start a letdown glide, cutting back to subsonic speed at an altitude substantially greater than that at which it had accelerated to supersonic speed during climb-out. Neither the high-altitude cruise portion of the flight nor the landing at subsonic speed should produce intolerable booms. The critical phase, therefore, is the first acceleration to supersonic speed.

Efficiency alone would dictate acceleration to supersonic speed at about 25,000 feet; such a climb-out plan would cut through the zone of speed and altitude that makes for damaging booms [*see illustration at left at bottom of opposite page*] and would clearly not be acceptable. How high will the transport have to climb before going supersonic? Aeronautical engineers still do not agree, but it will be about 40,000 feet or even higher. A flight plan involving such a long climb at subsonic speed would require extra power-plant performance capability or even changes in the transport's configuration [*see center illustration at bottom of opposite page*]. An alternative, not quite so demanding, would make use of the increase in cut-off Mach number during a climb [*see illustration at right at bottom of opposite page*]. To pick the right path either the pilot or airport personnel will need to know enough about atmospheric conditions at take-off time to predict the cut-off number at various altitudes.

A breakthrough that will eliminate sonic boom as a problem seems most unlikely. When the supersonic transport comes, it will boom. But it may be feasible to keep those booms from reaching the ground at an objectionable intensity. This will require careful design of the airliner, with special consideration given to configuration and structure and possibly an extra margin of engine performance. And it will surely require carefully laid out and strictly maintained flight plans in which sonic boom will become an integral factor along with weather, visibility and traffic in the increasingly crowded air.



ALTITUDE of the airplane has a large effect on the intensity of the boom reaching the ground. These curves, calculated for a 200-foot-long transport flying at Mach 1.2 (*solid black curve*), 2 (*broken black*) and 3 (*color*), show the booms are tolerable at cruising altitude.



LATERAL DISTANCE of the observer from the airplane's flight path also decreases boom intensity. This curve is for a small jet fighter doing Mach 2 at 60,000 feet. The pressure jump is smaller at a point 20 miles away from the flight path (*a*) than half as far away (*b*).

Aftereffects in Perception

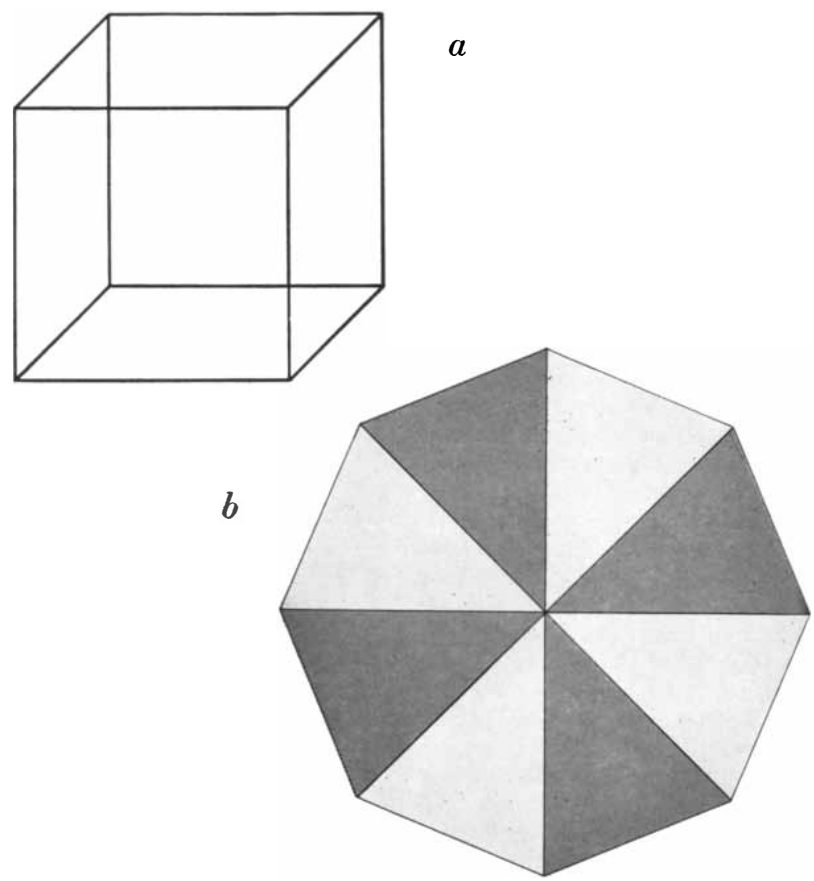
Certain optical illusions involve the reversal of a geometrical figure on prolonged viewing. These aftereffects and similar ones appear to be due to a special electrical phenomenon in the brain

by W. C. H. Prentice

Human experience and human behavior are accessible to observation by everyone. The psychologist tries to bring them under systematic study. What he perceives, however, anyone can perceive; for his task he requires no microscope or electronic gear. A genuine discovery in this field—a wholly new item of experience or a fact about behavior previously unknown—is accordingly rare. Once in a while, nonetheless, such a discovery is made. Within the past few years some simple observations have uncovered new and disturbing facts about human sensory experience, particularly visual experience. Comprehension of these facts is bringing about a radical revision in the prevailing concept of the nature of that experience.

The work that led to this development began with experiments involving familiar optical illusions. One is the illusion associated with the schematic diagram of a cube, in which the lines are drawn to represent the edges of the six faces of the cube [*see "a" in illustration at right*]. If one looks at such a diagram for any length of time, the cube will periodically shift its apparent orientation in space. At first the lower face may seem to be projecting toward the observer. Then the upper face will. This shifting continues for as long as one looks at the figure. Another such illusion is presented by an octagon in which equal sections are alternately dark and light [*see "b" in illustration at right*]. This figure also changes its organization with prolonged viewing. If it appears at first to show a dark cross on a light ground, it will in time shift and appear to show a light cross on a dark ground. These reversals are in large part involuntary. The observer cannot maintain the cube or the octagon in either of their configurations indefinitely. Sooner or later the figures will reverse.

The peculiar behavior of these figures is now known to be an instance of the general class of "figural aftereffects." As the reversibility of the figures suggests, something connected with the initial way of seeing the figure becomes fatigued or satiated, permitting the competing configuration to take over for a while until it too weakens and gives way to the configuration originally perceived. These reactions, which were first demonstrated by the classical methods of psychology, have been correlated with electrochemical changes in the brain, the study of which does involve delicate instruments. The instruments show that a sensory stimulus produces a current flow through the area of the cerebral cortex to which the stimulus is relayed and that the current, by satiating and fa-



PERCEPTUAL ANOMALIES associated with figural aftereffects are shown here. The cube (*a*) and the cross (*b*) periodically reverse with prolonged viewing. Reversibility is a special case of a general perceptual process, related to the self-limiting direct-current flow in the brain caused by sensory stimulation and to its effects on the future reactivity of brain tissue.

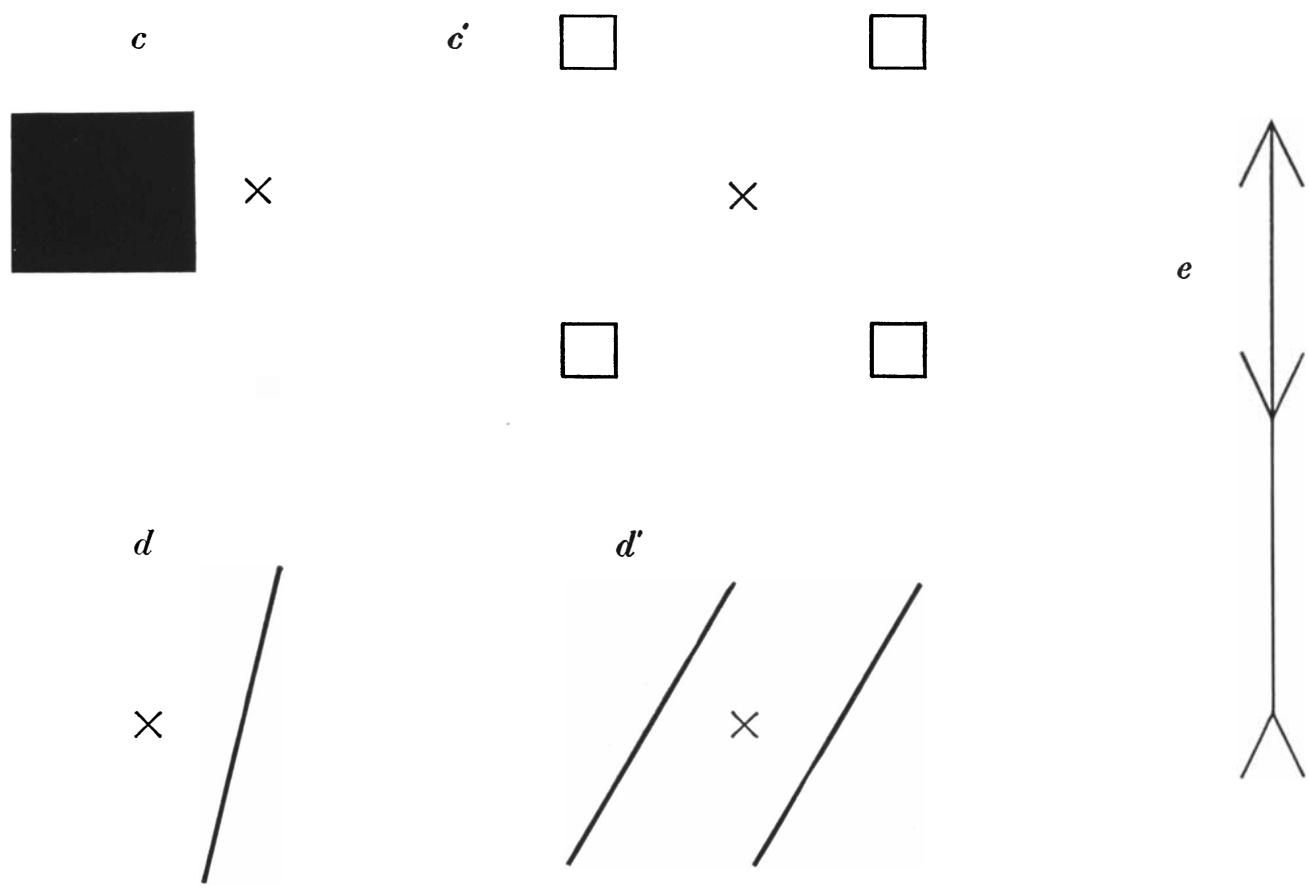
tiguing the current-carrying capacity of that area, obstructs its own passage and so diminishes and fades out.

It follows that what a person experiences at a given moment must be in important ways a function of what he has experienced in the recent past. Perception cannot be regarded as a one-way operation, to be understood entirely in terms of the effect of a stimulus on the perceptual system. The operation is a reciprocal one: changes in the perceptual system attending its response to a stimulus play a part in determining the way a subsequent stimulus is perceived.

The investigator who first recognized the real significance of the reversible figure is Wolfgang Köhler, the founder of the Gestalt school of psychology and professor of psychology at Swarthmore College since he emigrated from Germany in the 1930's. Köhler was interested in the fundamental question of how visual patterns become organized into the objects people see and was using reversible figures as his experimental tool. In the 1940's his work received important impetus from the quite independent researches of James J. Gibson, then at Smith College and now at Cornell University. Gibson was interested in the role of learning in human vision. Various people had wondered how a person would respond if he were forced to live in a visual world markedly different from the normal one. Would he learn to see things as they are even though his visual image of them was distorted? To answer this question Gibson devised an ingenious experiment. He equipped a group of subjects with spectacles that made all vertical straight lines appear curved and asked them to report on their experiences. Every one of them reacted in the same way. At first, they told him, the distortion held. Then, after some minutes, the distorting effect was noticeably diminished and the world looked increasingly normal. This normalization of the perceived world fitted the learning hypothesis nicely.

But the experiment produced another finding. For a short time after the subjects took off the distorting glasses, all straight lines appeared to them to be curved—in the direction opposite to that in which the glasses had curved them. Gibson later discovered that an analogous aftereffect could be produced without the help of distorting spectacles. If a subject looked fixedly at a slightly curved line long enough, the line would eventually seem straight to him. Immediately thereafter the same subject would see a straight line as being curved in the opposite direction. In precisely the same way a straight but slightly tilted line would straighten up under inspection, and subsequently an untilted line would appear to be leaning in the opposite direction.

When these findings came to Köhler's attention, he was immediately struck by their similarity—in certain respects—to the perceptual phenomena associated with the reversible figures. That Gibson's subjects had been able to correct the distortion introduced by their spectacles, and that they had straightened out curved or tilted lines by fixing their gaze on them, could be attributed to the operation of the learning process Gibson had set out to study. But the curious aftereffects of these experiments—the curving and tilting of straight lines—could not be explained as "normalization." To Köhler the aftereffects and



Drawings *c*, *c'*, *d* and *d'* demonstrate these effects. Prolonged viewing of cross in *c* causes apparent vertical displacement of left-hand squares when gaze is shifted to cross in *c'*. Similarly, prolonged inspection of cross in *d* causes an apparent displacement of right-hand line in *d'* when gaze is shifted to cross between parallel lines. Drawing *e* is the Müller-Lyer illusion, in which the upper half of the line appears shorter than the lower. Brief inspections of this figure, repeated over a period of days, can reverse the original illusion.

the shifts in appearance of reversible figures seemed inseparable: the same mechanism must be responsible for both phenomena, and the behavior of the reversible figures must be merely a special case of a principle at work in every visual experience.

Köhler had already postulated that the reversibility of these figures could be due to some self-limiting process in the nervous system. Gibson's results now suggested that every visual experience might have such a self-limiting process underlying it. If this was the case, then prolonged inspection of almost any simple figure should so affect the visual system of the subject that other figures viewed later on in the same part of the visual field would be modified or distorted. With the collaboration of Hans Wallach, also at Swarthmore, Köhler proceeded to design a series of experiments to test his hypothesis.

One of the earliest and simplest of their experimental devices is shown at *c* in the illustration on the preceding two pages. Subjects looked at the cross next to the large black rectangle for a minute or so. Then they shifted their gaze to a cross at the mid-point of the imaginary diagonals connecting four small squares.

The reader is invited to try this experiment and see if the symmetrical pattern of the second figure is influenced in any way by the visual stimulation produced by inspection of the first. The majority of subjects report that the two small squares to the left of the cross—those on the side that has previously been stimulated by the large rectangle—now seem farther apart than those to its right. Sometimes these squares also look smaller, fainter, farther away or all three. But the spatial separation that now makes the square of squares look unsymmetrical is the most striking effect.

Gibson's finding that lines could appear to be displaced from the position in which they actually lay provided the basis for the next Köhler-Wallach experiment [*see "d" in illustration on preceding two pages*]. Subjects were asked to look for a few moments at the cross to the left of the slightly tilted line. Then they shifted their gaze to the cross enclosed by the pair of parallel lines, tilted at a slightly different angle from the first. Although these two lines are parallel, the aftereffect produced by the first line made them appear convergent. Lines of any shape will, in fact, tend to repel other lines or parts of lines later presented in the same part of the visual field.

As Köhler and David A. Emery showed in other experiments, the figural aftereffect is by no means limited to the two dimensions of a plane. It shows up in depth as well. If one looks steadily at some point on a curved surface and then looks at a comparable point on a flat surface immediately behind it, the flat surface will appear to be curved in the opposite direction [*see illustration below*].

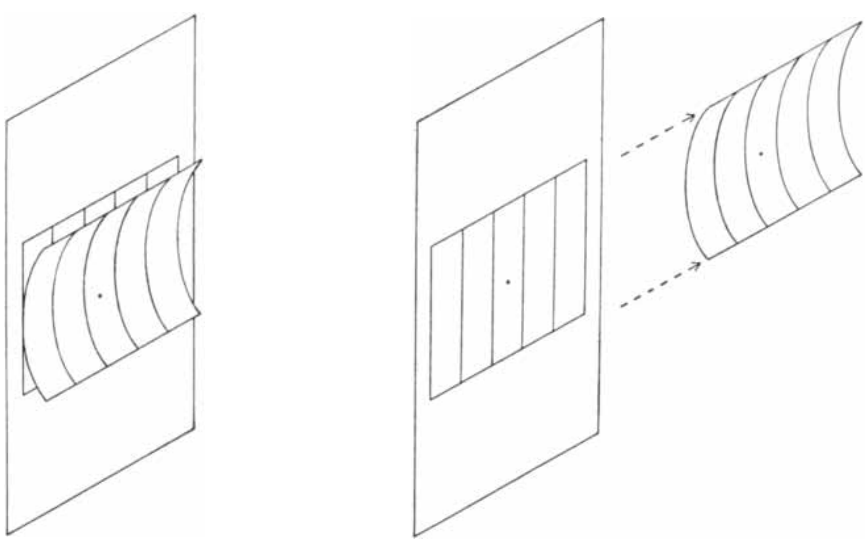
With Köhler's self-limiting neural process confirmed as a general element in visual perception, the time had come to seek physiological evidence for it. The neurological model that Köhler now proposed to explain the figural aftereffect has created great interest and controversy and has stimulated fruitful work by several investigators. Previously investigators of the physiology of the nervous system had focused their attention on the electrochemical changes that occur within a single nerve cell when it is stimulated, and with the activity that transmits nerve impulses from one cell to another. Köhler's proposal was a radical departure because it suggested the importance of physical phenomena other than those that follow anatomical pathways.

Specifically Köhler proposed that when the impulses set up by a sensory stimulus reach the nerve cells in the appropriate centers of the cerebral cortex, the activity of the cells must generate direct currents through and around the tissue. This current must in turn rapidly induce a state of polarization at cell interfaces that increases the resistance of the tissue to the flow of the current. As a result the conductivity and polarizability of the tissue is changed, and new impulses from later stimulation behave differently.

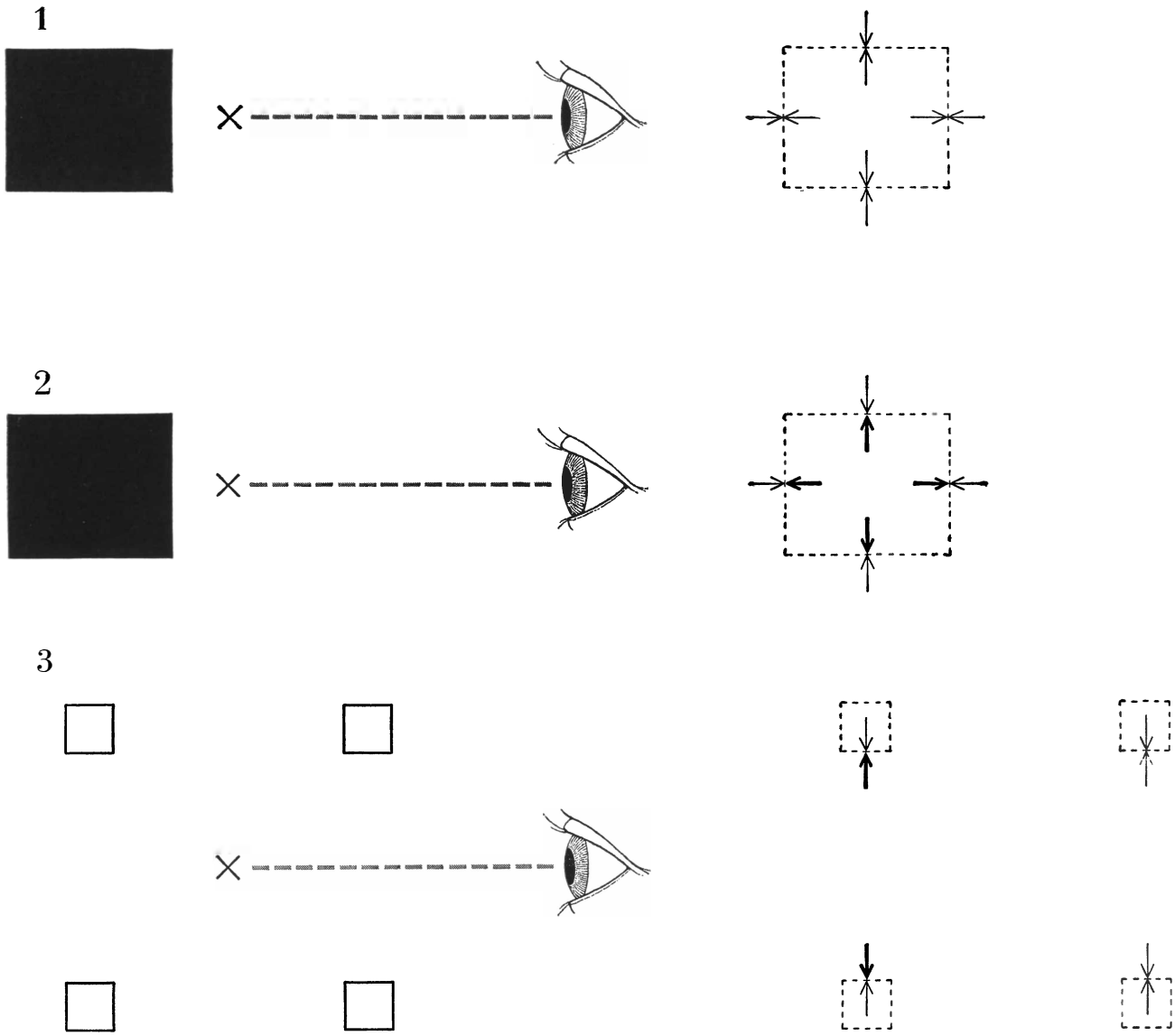
In visual perception such currents would be set up especially by the electrical imbalance resulting from the contrasting pattern of stimulation produced by a simple figure. The density of current would be greater in that section of the cerebral cortex associated with the retinal image of the figure's edge or contour. As resistance builds up, the flow of this current would be displaced to sections of the visual cortex in which the tissues offer less resistance—sections that correspond to the periphery rather than to the interior of the object. If the image of a new object now falls on the same place on the retina, the corresponding section of the visual cortex, having been already satiated, will no longer be able to react as it did initially. The object under inspection will accordingly appear distorted or displaced from its former location [*see illustration on opposite page*].

Only one aspect of Köhler's hypothesis proved easy to test. It was simple to demonstrate that the brain, rather than the retina, is responsible for the development of figural aftereffects. The reader can prove this to his own satisfaction by covering one eye when fixating the "inspection" figures that illustrate this article and covering the other when examining the "test" figures. The aftereffect will still be present.

Demonstration of the direct-current flow Köhler had postulated was far more difficult to achieve. It had long been known, of course, that electrical impulses do spread throughout the brain. They can be readily detected with electrodes



THREE-DIMENSIONAL AFTEREFFECT can be demonstrated by gazing at a point on a curved card in front of a straight one and then at a corresponding point on the straight card when curved one is removed. Straight card will now appear to curve in opposite direction.



SATIATION PRODUCING FIGURAL AFTEREFFECTS is diagramed. When brain is first stimulated by inspection of rectangle in *1*, current flow concentrates in area corresponding to interior of figure (*broken rectangle*). With prolonged viewing of rectangle (*2*), current flow is displaced outward. When same portion of brain is affected immediately thereafter by new stimuli (*left-hand squares in 3*), altered polarizability of tissue makes it react differently to them than to right-hand squares (*see broken squares at far right*).

outside the skull, as in electroencephalography. But nerve physiologists had concentrated on pulsating, or wave, effects and rarely, if ever, considered direct currents in the brain as objects of interest. In fact, even after Köhler had shown the relevance of these currents to his psychological findings, psychologists and physiologists continued to try to explain the figural aftereffect without recourse to the spread of direct currents. They proposed instead complex models of a brain built with essentially insulated pathways. The implicit premise of these models is, of course, the idea that volume currents or potential changes such as those revealed by the electroencephalogram do not themselves influence behavior or perception but merely reflect the basic activities of the individual cells and groups of cells involved in particular psychological functions.

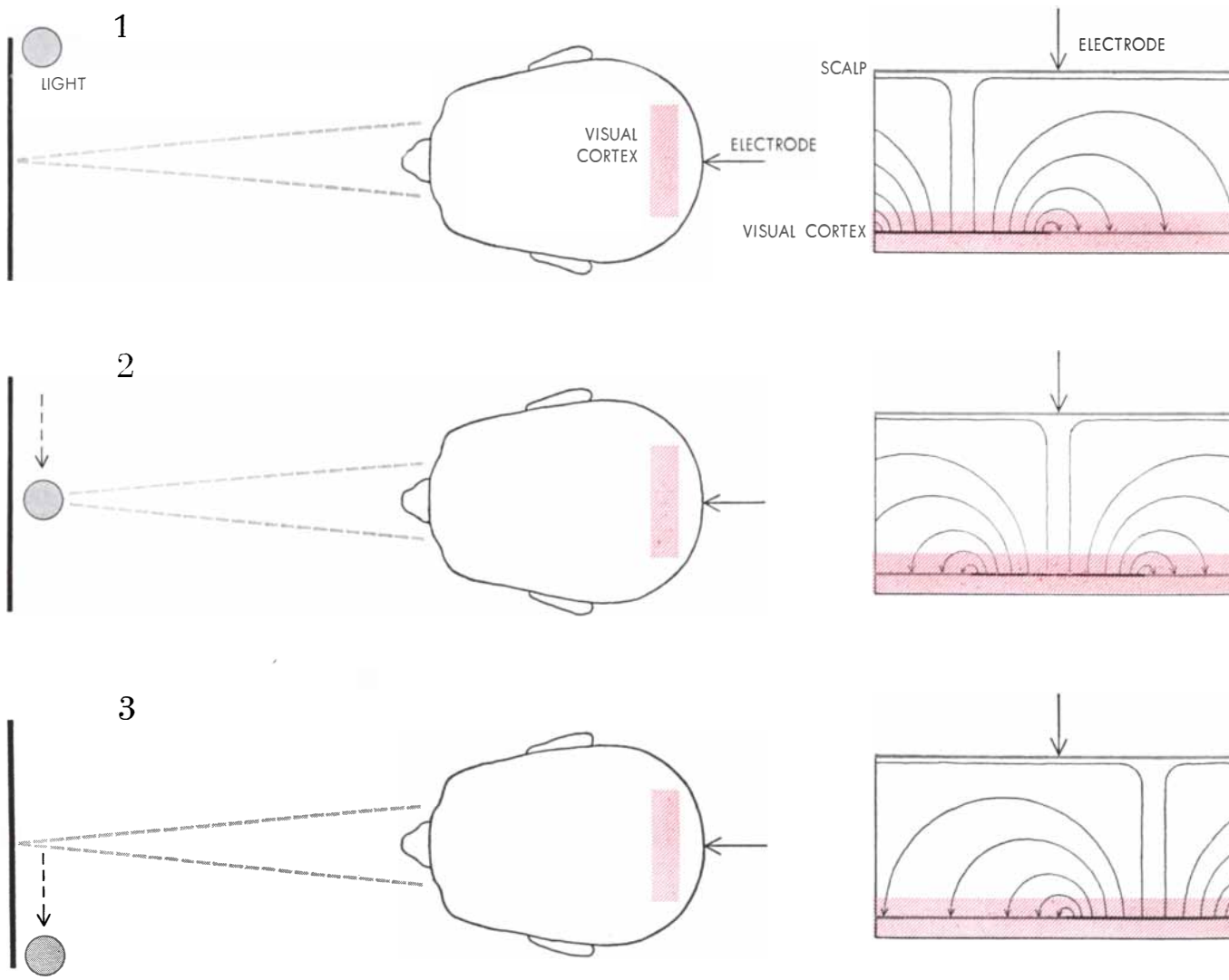
From 1946 to 1952 Köhler and his associates Richard Held, Donald Neil O'Connell and Jonathan Wegener searched for the proper combination of electrodes, amplifiers and recording equipment and finally were able to test the hypothesis on human subjects. A stationary visual stimulus produces such rapid satiation—such rapid diminution of the current in the cortical tissue—that it is virtually impossible to detect the effect. But the current generated by a moving stimulus can be demonstrated. The subject, sitting in a darkened room, fixates a point directly ahead of him as a bright light is moved across his visual field. One electrode is attached to the skull over the area of the visual cortex corresponding to the point on the retina that is stimulated when the light is directly ahead of the eye; the second electrode is grounded. Now, as the light moves across the field of vision, a wave of potential change can be seen to precede it [*see illustration on next two pages*]. If the moving stimulus is stopped, the potential difference between the electrodes drops to zero within a fraction of a second—dramatic evidence of the speed with which these currents obstruct their own passage and the speed with which satiation is set up.

Later studies have explored similar

effects in cats and monkeys. Hearing as well as vision has been investigated. Records from the exposed brains of animals have been made and compared with those obtained when the electrode is attached to the skull. In spite of variations in species, the sense involved and the placement of electrodes, the agreement among results is spectacular. There can no longer be any doubt about the basic facts. Direct currents do flow through cortical tissue in response to stimulation, and these currents do build up resistance to their own passage by changing the electrical properties of the cortical tissue. Looking back over the course of these investigations, one is impressed by the fact that Köhler deduced most of these findings at the outset, from his observation of the visual effects of simple reversible figures.

How long do figural aftereffects last? Are they fleeting phenomena or do they persist long enough to disturb visual function? In one experiment Köhler and Julia Fischback demonstrated an effect that could be detected for months after the end of the stimulation that produced the satiation. This work concerned the familiar Müller-Lyer illusion [*see "e" in illustration on pages 44 and 45*]. Psychologists had maintained they could teach their subjects to rectify the illusion by repeated examination. Köhler believed that they might really have been dealing with the satiation effects of repeated viewing rather than with a learning process. That he was correct is shown first by the fact that too much staring at the pattern actually works against a correction of the illusion. Apparently the spread of satiation under those circumstances is so general that the appearance of the figure is not affected in a predictable direction. But if the pattern is fixated for a minute or so and the periods of fixation are spread over a period of days, the satiation localized in the area of the arrowheads seems to be strengthened until it becomes quasi-permanent. Indeed, the illusion can be overcome to such an extent that it is reversed, a fact that demonstrates rather conclusively that something more is involved than the subject's having learned to allow for error in some rational way.

It is interesting to speculate on the general implications of these findings. Do the things people look at daily so distort their visual systems that they no longer see the world as it really is? The experimental evidence seems to indicate that permanent effects do exist and that

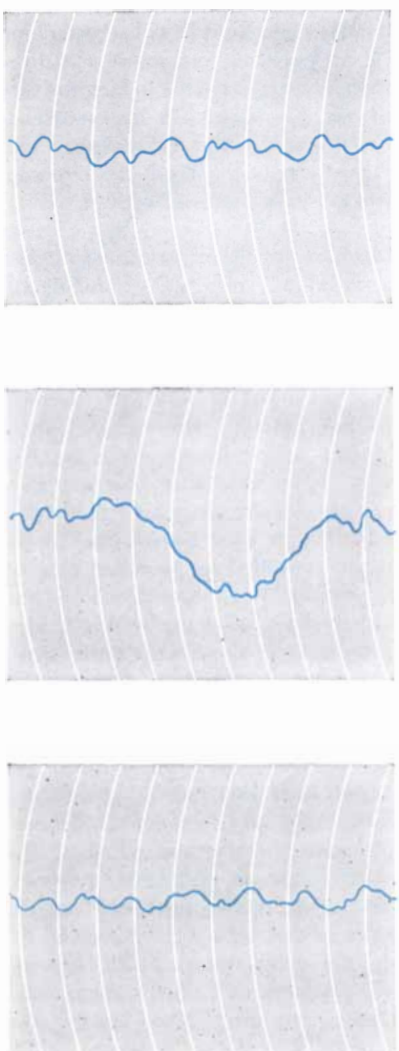


DIRECT-CURRENT FLOW IN BRAIN was demonstrated by Wolfgang Köhler and associates in experiment diagramed here. Subject sits in dark room, fixating point directly ahead of his eye. Electrodes on scalp pick up potential difference between two areas of cortex as periphery of retina is stimulated (*1*). Currents are shown as curved lines in the rectangle. The part of the cortex stimulated by the light is indicated by the dark portion of line from which currents fan. Trace from recording equipment is shown at right. When light is directly ahead of eye (*2*), stimulating portion of brain directly under electrode, currents fanning from it

the world one sees at any one time must be determined by what one has seen in the past. Probably a great deal of what is considered "learning to see" is a matter of establishing steady levels of satiation so that each new contour presented to the eye does not upset the operation of the visual system. Since the eyes move rapidly and often over a great variety of lines and colors, it is probable that there is little tendency for satiation to build up in one portion of the visual cortex rather than in others. The result of such homogeneity is a relatively stable visual system.

Since the great majority of the world's objects lie below the level of straightforward gaze, there may well be—and according to Köhler there is—a difference in the states of permanent satiation associated with the upper and lower halves of the visual field. No adequate quantitative studies of this problem have been made. It is known, however, that the same object may appear to have one size when its image falls on the upper periphery of the retina and another when the image falls on its center.

The work on figural aftereffects would also suggest that the visual world of a newborn child or of an adult who has just had congenital cataracts removed should be different from the visual world in which older children and normal adults live. Experiments with animals whose eyes have been covered with translucent plastic during infancy show that when the caps are removed, these animals do not make visual discriminations normally. In time, however, the handicap partially disappears—possibly because a relatively steady distribution of satiation effects has been achieved.



cause downward deflection on trace, corresponding to an increase in voltage. As light passes eye (*3*), steady current level is restored. Drawings of traces are taken directly from records obtained by experimenters.

Phenomena closely resembling figural aftereffects have been found in the other senses. Köhler and Dorothy Dinnerstein have reported that subjects who run their hands back and forth along the edges of two strips of wood of unequal width for 30 seconds show a marked tendency to overestimate the width of a third strip substituted for the narrower of the first two strips. This is clearly related to the tendency, reported by all subjects, to feel gradually that the two strips initially inspected are the same width. It is also related to an early finding of Gibson's that stroking a curved edge with one's finger leads first to a seeming decrease in the curvature and later to a tendency for a straight edge to seem curved in the opposite direction. Sounds can be similarly displaced. If one listens to a tone for a few minutes and then hears another, slightly different, it may sound further away in pitch from the original than it actually is.

Not all the problems connected with figural aftereffects have been solved. There is, for example, the distance paradox. One would assume that the displacement of an object due to the figural aftereffect should be maximal at those of its contours that lie in the same part of the visual field as the contours of a figure inspected immediately beforehand. It turns out, however, that this is not the case. The maximum displacement occurs when the contours of the second object lie in a slightly different part of the field, and the amount of displacement falls off as distance from that point increases or decreases. There is another puzzle in the relationship of the figural aftereffect to the size of an object: Although the size of the retinal image of an object does not determine the perceived size of the object (a man who stands at a distance of 10 feet does not look twice as big as a man standing at a distance of 20 feet), the size of the retinal image does determine the aftereffect.

It should also be mentioned that Gibson's original work still leaves a number of outstanding questions to be answered by the Köhler hypothesis. When Gibson's subjects wore the distorting spectacles, they did not fixate particular objects but let their gaze wander freely over the landscape. It is not easy to reconcile this aspect of Gibson's experiments with the work of Köhler and his associates. Indeed, the entire question of normalization needs more study. It is difficult to believe that this "learning" process is basically different from the process that underlies the figural aftereffect. The "correction" of the Müller-Lyer illusion suggests one way the two processes can be shown to converge.

The remarkable work of the Austrian psychologist Ivo Kohler must also someday be brought together with the work on figural aftereffects. Kohler's subjects wore spectacles with the left half of each lens red and the right half green. Eventually they learned to see the world in its normal colors. But when they took the glasses off, they found that a look to the left gave a green aftereffect and a look to the right gave a red one!

Someday, no doubt, it will be possible to subsume all these findings, for all the senses, under one general theory and so broaden our understanding of the whole process of perception. Meanwhile at least one practical suggestion seems in order. Obviously it is unwise to stare at fixed contours too long lest subsequent vision be distorted. This poses a pretty problem for the billiard player, to take a trivial example. In the very act of fixating the ball in order to determine the best angle from which to approach it, he may so satiate his visual system that he cannot judge angles or distance accurately enough to make the shot. Of more general importance is the question of such possible effects of visual satiation as those on people driving cars along the straight, monotonous stretches of our superhighways. No studies have as yet been made, but it may be that the continuous stimulation of a driver's eye by the unending straight line of the side of the highway affects his ability to judge distances on that side. The danger of accident could thereby be seriously increased.

HYPERNUCLEI

When the fundamental particle called the lambda hyperon sticks to a nucleus, a short-lived artificial nucleus results. The behavior of these hypernuclei sheds light on the forces between particles

by V. L. Telegdi

Analogy is perhaps the physicist's most powerful conceptual tool for understanding new phenomena or opening new areas of investigation. Early in this century, for example, Ernest Rutherford and Niels Bohr conceived the atom as a miniature solar system in which electrons circle the nucleus as planets circle the sun. The concept of the electron moving in orbit around the proton (to form the hydrogen atom) led to the prediction that an electron might also move in orbit around its antiparticle the positron, or positive electron. The short-lived electron-positron atom, called positronium, was later discovered. By analogy one can also predict that the antiproton (the negative antiparticle of the proton) should be able to enter into an antiproton-proton atom, similar to positronium and still to be discovered and named.

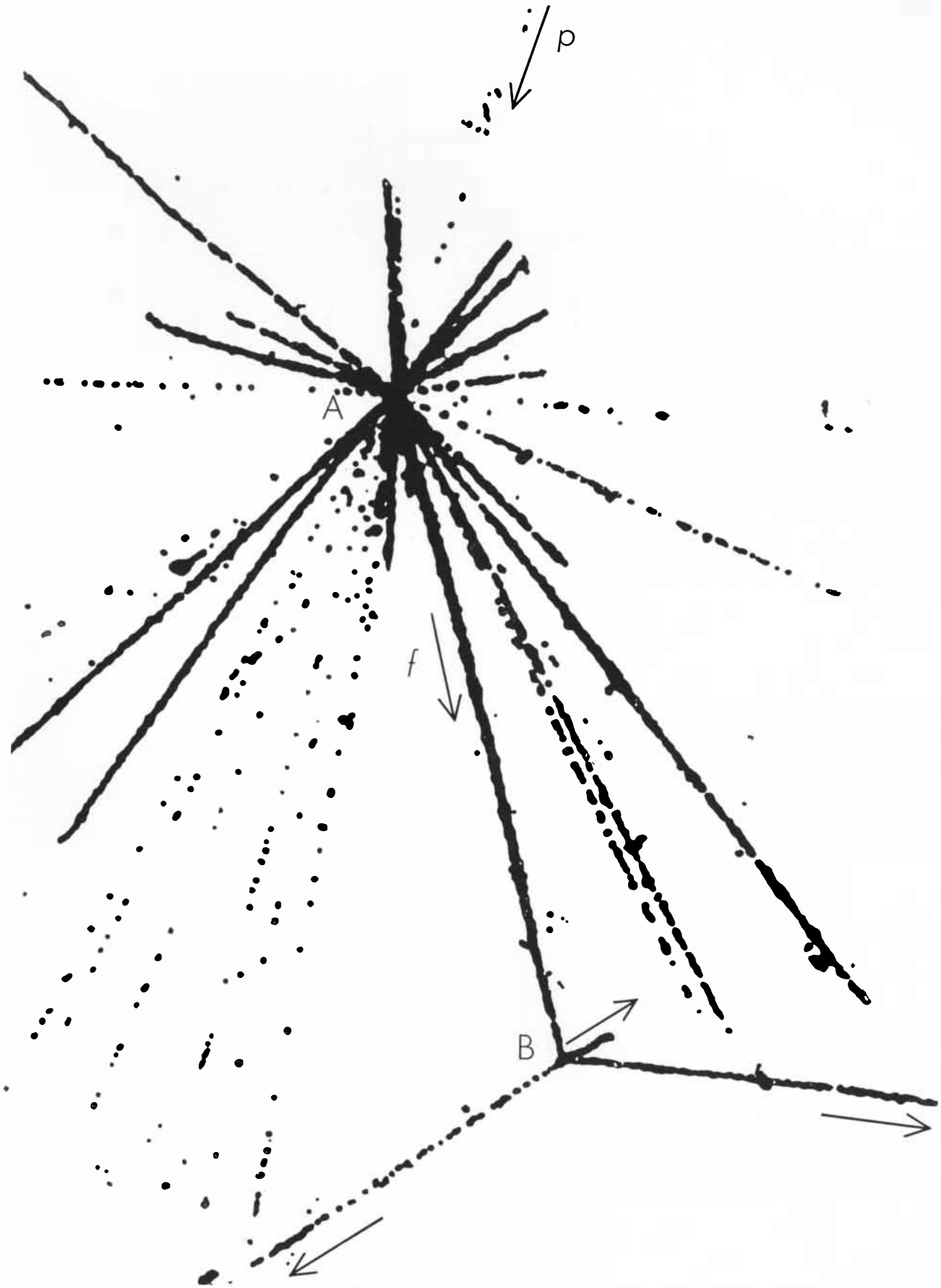
Unfortunately nuclear physics has not profited as much from analogy as has atomic physics. The reason seems to be that the nucleus is the domain of new and unfamiliar forces, for which men have not yet developed an intuitive feeling. In contrast, the structure of atoms is governed mainly by electrical forces, which have been familiar to some degree since the days of the ancient Greeks. In the atom any negative particle can usurp the role usually played by the electron, and any positive particle can substitute for the ordinary positively charged nucleus.

Within the nucleus things are far less clear. But it is not too difficult to set down the conditions that must be fulfilled to build observable structures analogous to atomic nuclei. What one needs, of course, are particles that behave something like protons and neutrons, the common nuclear building blocks. For convenience, protons and neutrons are often referred to jointly as nucleons. If a particle is to serve as a pseudo-nucleon, it must have a significant lifetime, as measured on a nuclear time scale, and it must exhibit the intense short-range attractive force characteristic of nucleons.

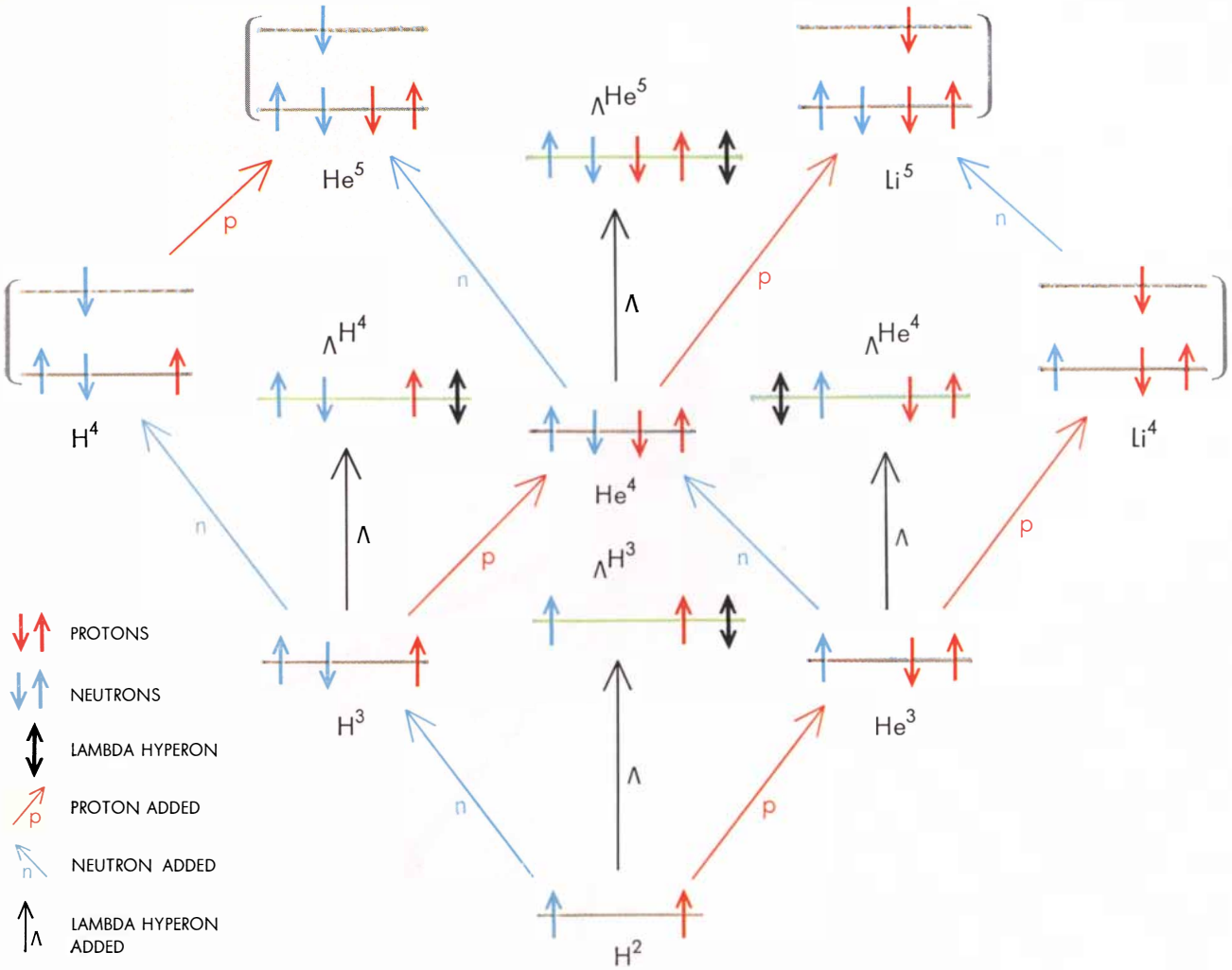
In the past decade physicists have discovered a whole series of unstable elementary particles heavier than the nucleons—the hyperons. The question naturally arises: Can any of the hyperons be used as building blocks to form hypernuclei? By hypernuclei is meant structures analogous to ordinary nuclei in which hyperons replace, partly or totally, ordinary nucleons. As the table on page 56 shows, each hyperon decays spontaneously into the next lighter hyperon or into a nucleon after a mean life of about 10^{-10} (one ten-billionth) second. This might seem too brief a time for hyperons to play the role of nucleons, but of course time scales are relative. A really short period of time is that required for light to travel the diameter of an atomic nucleus: 10^{-23} second. Since light can travel 10^{13} nuclear diameters in 10^{-10} second, the mean lifetime of a hyperon can be regarded as impressively long. In short, hyperons live long enough to qualify as "elementary" particles, but they are unusual enough to be included in the class of elementary particles known as "strange" particles.

Not all hyperons are sufficiently stable in the presence of nucleons to be useful for building hypernuclei. As the table on page 56 shows, most of them would enter into fast reactions with nucleons and rapidly melt away if they were brought in contact with ordinary nuclear matter. Only the lambda hyperon appears to be stable in the presence of both neutrons and protons. Therefore the lambda particle, which has no electric charge and hence can be considered a sort of fat neutron, is the most promising potential ingredient for synthesizing hypernuclei. In the absence of an adequate theory for predicting whether or not the lambda particle will actually bind itself to nucleons, one must settle the question observationally. In fact, the very purpose of a search for hypernuclei is to enable physicists to measure, and eventually to understand, the hyperon-nucleon forces that may exist.

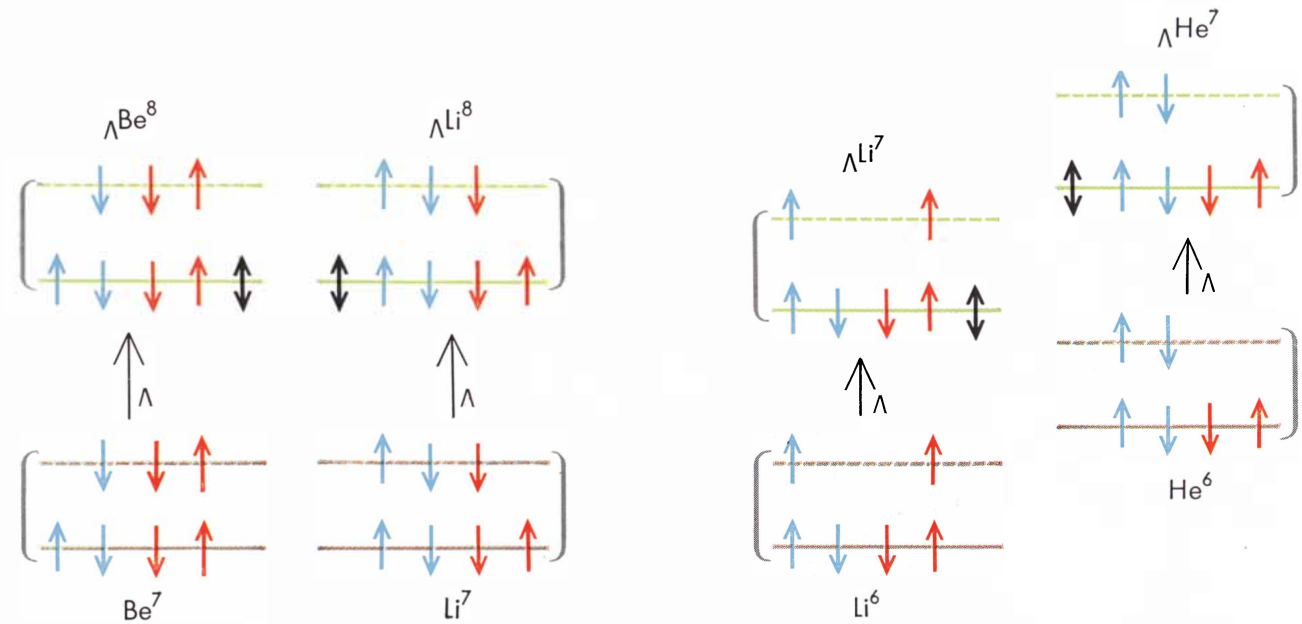
The first hypernucleus turned up in a solid block of photographic emulsion that had been exposed to primary cosmic rays in a high-altitude balloon flight. The interpretation of the unusual event was made in 1952 by two Polish physicists, Marian Danysz and Jerzy Pniewski, who evidently made the discovery quite by chance and not as a result of a deliberate search for hypernuclei. When they traced one of the energetic cosmic rays that had entered the emulsion, they found that it had collided with a heavy nucleus embedded in the emulsion, a nucleus of either silver or bromine, which then disintegrated to produce a many-pronged "star." As shown in the illustration on the opposite page, a particularly thick track (*f*) emerges from the star at about "five o'clock" and gradually tapers until it connects with a three-pronged star. The event thus consists basically of two connected stars, representing two nuclear disintegrations. The problem was to explain the second star. Thick, tapered tracks produced by a single violent disintegration are often seen leaving the star; they are created by heavy, multicharged fragments such as lithium or beryllium nuclei thrown out by the exploding nucleus. Their initial thickness is due to the great ionizing power of such fragments, and their taper results as the



PRODUCTION OF A HYPERNUCLEUS was first recorded in 1952 in this nuclear-emulsion photomicrograph made by Marian Danysz and Jerzy Pniewski of the University of Warsaw. A cosmic ray particle (*p*) causes the disintegration of an atomic nucleus (either silver or bromine) at *A*. The heavy fragment (*f*) emitted in this disintegration is a hypernucleus (probably boron); it comes to rest and then explodes at *B*, yielding three charged particles and a number of neutrons. The neutrons, because they have no charge, leave no tracks.



NUCLEI AND LAMBDA HYPERNUCLEI of hydrogen (*H*), helium (*He*) and lithium (*Li*) are identified by mass number (*superscripts*). Horizontal lines are energy levels; the arrows show spin orientation. Lambda's double-headed arrow indicates that either spin orientation is allowed. "Mirror image" nuclei (e.g., H^4 and Li^4) and hypernuclei (e.g., ${}_\Lambda H^4$ and ${}_\Lambda He^4$) have identical binding energies.



ISOBARIC PAIRS of nuclei (i.e., those having same number of nucleons but different number of protons) and hypernuclei are compared. Beryllium (*Be*) and lithium nuclei of mass 7 and hypernuclei of mass 8 (*left*) are "mirror image" pairs and thus have same binding energies and stability. Pairs at right are not mirror images: Li^6 and ${}_\Lambda Li^7$ have higher binding energies than He^6 and ${}_\Lambda He^7$.

fragments slow down in the emulsion and gradually pick up electrons, thereby losing charge.

Danysz and Pniewski concluded that the second star was produced by the disintegration of an unusual nuclear fragment that had carried more energy away from the first star than ordinary nuclear matter could carry. Their measurements of the tracks issuing from the second star indicated that at least 95 Mev (million electron volts) were released in the second disintegration; additional energy could have been carried off by neutral particles, which leave no tracks. If the fragment had been a boron nucleus, as was suggested by its apparent mass and charge, it could normally carry an excitation energy not much greater than about 8 Mev, the binding energy of any one of its constituent nucleons. Moreover, the fragment carried the 95 Mev (or more) for a period of about 10^{-12} second, as indicated by the length of the track connecting the two stars. Ordinary nuclear matter cannot bear excess excitation for such a "long" period. Danysz and Pniewski argued that the excitation must have been carried in the form of an unstable particle bound to an ordinary fragment and proposed that this particle was the lambda hyperon.

Even so, it appeared that the lambda particle might not have decayed in its normal fashion into a nucleon and a pi meson: that decay yields only 37.6 Mev. Under certain circumstances a lambda particle might conceivably interact slowly with a nucleon and yield two nucleons along with 177 Mev, representing the entire difference in mass between a lambda particle and a nucleon. Danysz and Pniewski suggested that some such reaction was needed to account for the large energy release in the event they had studied.

Other physicists soon found more examples of the occurrence of lambda hypernuclei. In some of the events the tracks produced by the disintegration of the hyperfragment include that of a negative pi meson, or negative pion, which would be expected if the lambda particle decayed normally into a proton and a pion. These were called "mesic decay" events; the bound lambda particle decays much as though it were free. Since the slowing-down time of hyperfragments in an emulsion can be as long as 10^{-10} second, one can find examples of lambda hypernuclei decaying after the fragment has come to rest as well as in flight [*see illustration on next page*].

The discovery of hyperfragments led to a rapid development of a new field: hypernuclear physics. Nuclear emulsions —to a large extent replaced by bubble chambers in other areas of high-energy research—have to date remained the prime tool of investigation. Initially, isolated hypernuclear events, obtained as by-products of various emulsion experiments, were reported from all over the world. A first survey of these, prepared at the University of Milan in 1954, listed a total of eight mesic decay events, representing three different hypernuclear species. By 1957 a new world survey, prepared at the University of Chicago by Riccardo Levi-Setti, William E. Slater and the author, covered 120 mesic decays, of which 61 were uniquely identified events, representing eight well-established kinds of hypernucleus. By that time high-energy beams from accelerators had become available for emulsion experiments. A series of emulsion blocks exposed to the 4.5-Bev (billion-electron-volt) negative-pion beam of the University of California Bevatron provided our group in Chicago with 43 hyperfragments disintegrating by mesic decays and about 200 "nonmesic" events.

A pion beam is reasonably effective at producing hypernuclei, but a beam of negative K mesons is better still. The reason is that the K meson, like the lambda hyperon, belongs to the class of strange particles, according to the classification scheme worked out independently by K. Nishijima of Japan and Murray Gell-Mann of the California Institute of Technology [see "Elementary Particles," by Murray Gell-Mann and E. P. Rosenbaum; SCIENTIFIC AMERICAN, July, 1957]. Implicit in this scheme is the rule "Want a strange particle, use a strange particle." Thanks to the efforts of the Bevatron workers, a beam consisting mostly of negative K mesons was made available to physicists all over the world in 1957. In that year a single block of emulsion exposed to the negative-K beam provided our group in Chicago, working in collaboration with a group at Northwestern University, with about 400 mesic hyperfragments. Today the chief limitation to the study of hypernuclei is the length of time it takes to measure and analyze such events.

The existence of lambda hypernuclei proves that there exists a net attractive force between lambda hyperons and nucleons. The first quantitative question of interest is: How strong is this force? The question is answered by measuring the energy that binds a lambda particle to a particular complex of nucleons. This complex, consisting of the lambda particle and a particular number of protons and neutrons, is called a hypernuclear species, or hypernuclide. The standard way to designate ordinary nuclides is to write down the name of the element followed by a number showing the total number of nucleons it contains. This can be abbreviated by using the chemical symbol for the element and indicating the number of nucleons by a superscript. Thus a normal helium nucleus containing two protons and two neutrons is written "helium 4," or "He^4." To describe the same nucleus to which a lambda hyperon is attached one writes "hyperhelium 5," or "$_{\Lambda}He^5$." The lambda particle is counted as an additional nuclear particle.

To determine the binding energy for a lambda particle one must make a careful accounting of the total kinetic energy released by the particular hypernucleus whose disintegration has been recorded. Suppose, for example, one observes the decay at rest of hyperhelium 4 and finds that the decay products are helium 3 (a nucleus consisting of two protons and one neutron), a proton and a negative pion. The total kinetic energy released in the disintegration is calculated by measuring the three tracks produced by the decay products.

If the lambda were bound to the helium-3 core with exactly zero energy, the kinetic energy observed in the decay products should equal 37.6 Mev, the energy released by the decay of a free lambda. If, however, the lambda is positively bound to the helium core, a certain amount of the decay energy will be absorbed in breaking the bond and less will be observed in the kinetic energy of the decay products. To make an accurate calculation of the kinetic energy released it is important, of course, that all decay products be visible. This is usually the case only in mesic decays. In the violent nonmesic decays (such as the one first studied by Danysz and Pniewski) the decay products usually include several neutrons, which leave no tracks to be measured.

The illustration on page 55, based on about 200 mesic hyperfragments, shows the energies by which the lambda hyperon is bound in the 13 different hypernuclides so far specifically identified. The indicated uncertainties are purely experimental and do not include systematic errors, such as the uncertainty in the mass of the lambda particle (equal to about .2 Mev). Although 200 events may seem rather few, they have told physicists more about the binding energies of hypernuclei than was known about the binding energies of ordinary nuclei 25 years ago.

Our knowledge of hypernuclei in-

cludes the following salient facts. The simplest possible lambda hypernucleus, consisting of a proton and a lambda (hyperhydrogen 2), has not been observed, suggesting that the lambda-nucleon forces are insufficient to produce a bound state for this elementary system. The binding energy increases in general with the number of nucleons in the core up to the heaviest hypernuclide yet observed, hypercarbon 13, but the increase is not strictly proportional to the number of core nucleons. Several isobaric pairs of hypernuclides (meaning nuclides with the same total number of nucleons but different numbers of protons), such as hyperhydrogen 4 and hyperhelium 4, and hyperlithium 8 and hyperberyllium 8, have essentially the same binding energy; but another isobaric pair, hyperlithium 7 and hyperhelium 7, shows a great difference in binding energy. Finally, there are striking differences between the stability of certain hypernuclei and ordinary nuclei containing the same number of particles. For example, ordinary hydrogen 3 is strongly bound, whereas hyperhydrogen 3 is just barely bound. On the other hand, hyperhydrogen 4, hyperhelium 5 and hyperhelium 7 are strongly bound (and stable in the sense that they exist until the lambda particle itself disappears), whereas the ordinary analogues of these three nuclei are exceedingly unstable.

These various observations are found to be consistent with our present knowledge of ordinary nuclear forces:

1. The nuclear force is the same between any two nucleons, whether neutrons or protons, in a given configuration. This is called charge independence.

2. The nuclear force between two nucleons depends on the mutual orientation of their spins; that is, on whether the spin axes of the nucleons are pointed in the same direction (parallel) or in opposite directions (antiparallel). This is called spin dependence.

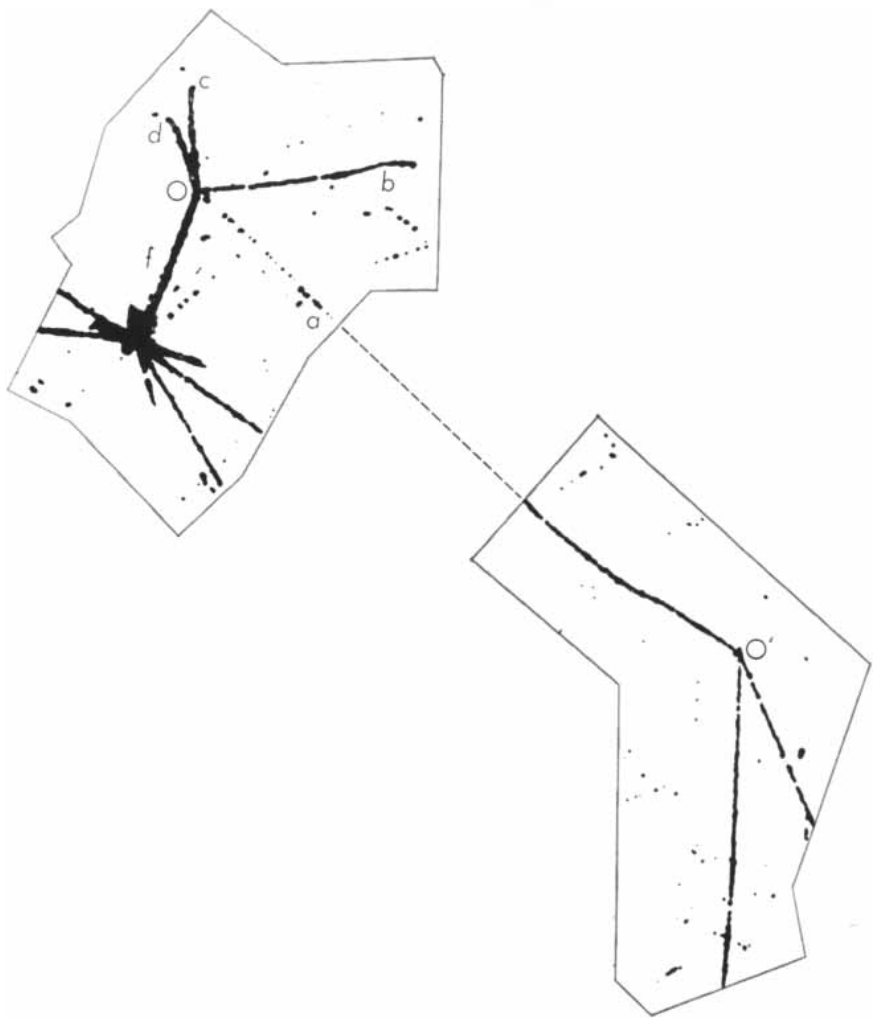
3. Neutrons and protons obey the exclusion principle, which requires that two identical particles in the same state of motion in a nucleus have opposite spins. This means that no more than two neutrons and two protons may "sit" on the same energy level.

For hypernuclear forces one expects a situation that is partly similar and partly different:

1. Lambda-hypernuclear forces should be charge-independent, meaning that the energy binding a lambda particle to a neutron should be the same as that binding a lambda particle to a proton in any given configuration. Charge independence is surmised because it seems to be a characteristic of the strong interactions of hyperons as well as of ordinary nucleons.

2. There is, however, no way to predict whether or not lambda-nucleon forces are spin-dependent. This can only be decided by observation.

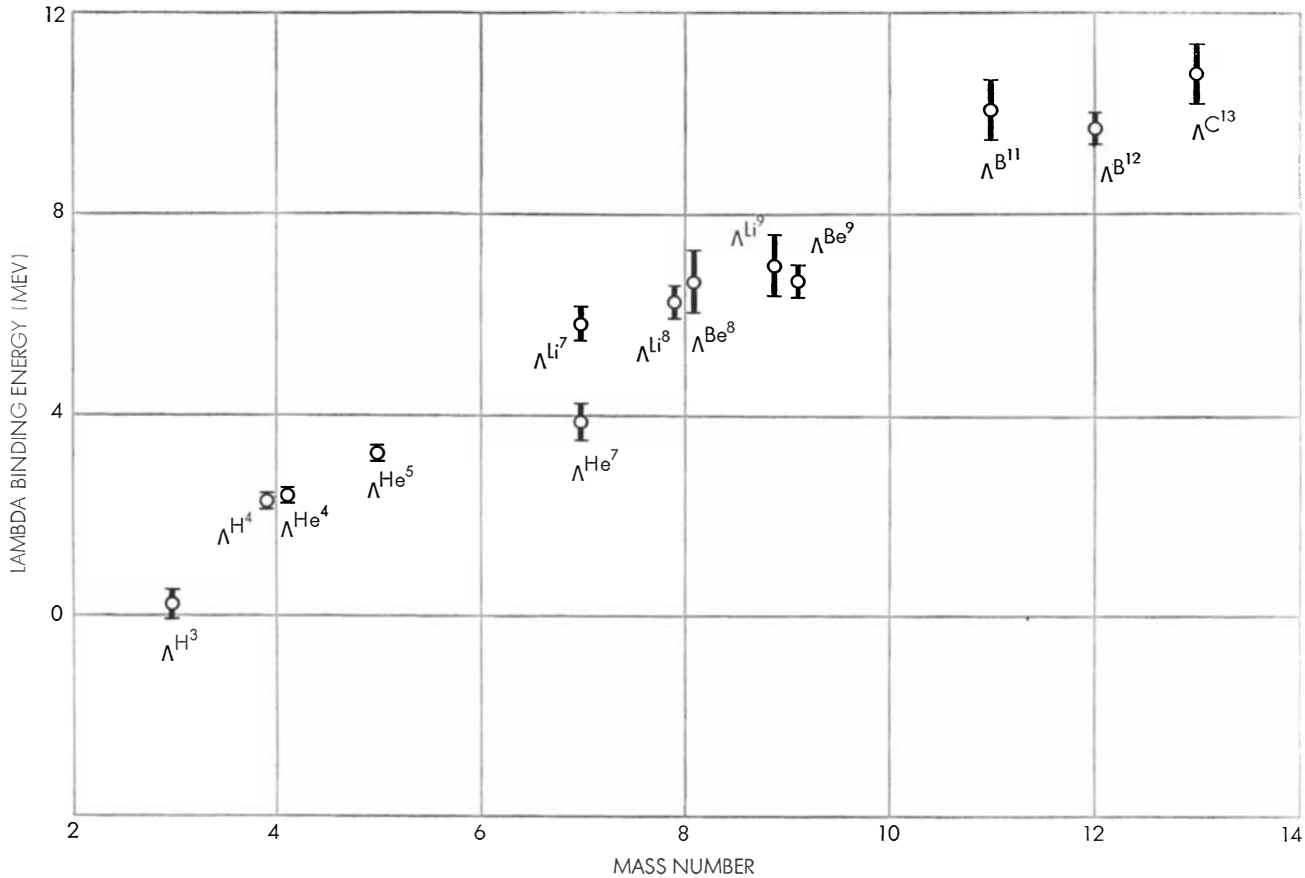
3. Since the exclusion principle applies only to identical particles, at least one lambda particle can be added to an energy state already containing a full quota of two protons and two neutrons.



HYPERBERYLLIUM (*f*), resulting from the nuclear disintegration caused by a high-energy negative pi meson, decays mesonically "in flight" at *O*. The negative pi meson emitted (*a*) stops at *O'* and is captured by a nucleus, which it then disintegrates. Heavier particles ("*b*," "*c*" *and* "*d*") are emitted in a "forward" direction. The nuclear emulsion photomicrograph shown here in two sections was made by William E. Slater of the University of Chicago. The broken line is path taken by negative pi meson through emulsion.

The top illustration on page 52 should help to make clear how these various principles apply to nuclear and hypernuclear systems containing from two to five nuclear particles. In this illustration protons are represented in red, neutrons in blue and lambda particles in black. A single-headed short arrow represents a nucleon and specifies whether its spin direction is up or down; a short arrow with a double head (because the spin direction is not predictable) stands for a lambda particle.

We first consider an ascending sequence of ordinary nuclei. The simplest stable two-particle system is hydrogen 2, consisting of a neutron and a proton with parallel spins. (The preference for this orientation is an experimental fact; the force between two nucleons with antiparallel spins is just not strong enough to produce binding.) By adding a neutron to hydrogen 2 we get hydrogen 3; by adding a proton to hydrogen 2 we obtain helium 3. In either case the third nucleon must have its spin oriented opposite to those already present in hydrogen 2, thereby fulfilling the exclusion principle. We know from experiments



BINDING ENERGIES of the lambda hyperon in the known hypernuclei are based on data obtained from a total of about 200 events. Vertical bars represent experimental uncertainties. The binding energies of the hyperon in the isobaric pair $_{\Lambda}He^{7}$ and $_{\Lambda}Li^{7}$ show a considerable difference, in contrast to the isobaric pairs at mass numbers 8 and 9 *(see bottom illustration on page 52)***.**

that both hydrogen 3 and helium 3 are stable systems with essentially equal binding energies. This energy equality is a direct consequence of the law of charge independence. As applied to the illustrations on page 52, this law says that wherever two isobaric nuclei are represented by the same configuration of arrows, regardless of color, they must have the same energy. Whether unbound or stable, isobars have exactly the same energy. Adding a third neutron to hydrogen 3 yields hydrogen 4; adding a third proton to helium 3 yields lithium 4. Both of these nuclei are unbound, that is, unstable. The explanation is found in the exclusion principle. The neutron that one tries to attach to hydrogen 3 cannot be accommodated in the same state as the nucleons present, because that state already contains two neutrons; the same thing happens when one tries to attach a proton to helium 3. Thus the extra nucleon must go into an as yet unoccupied state of higher kinetic energy, indicated by a broken line. Because this energy is greater than the attractive force between the extra nucleon and the three nucleons in the lowest state, the extra nucleon is not bound. On the other hand, hydrogen 3 can accommodate another proton and helium 3 another neutron in the same energy state occupied by the nucleons already present. In either case the resulting nucleus is helium 4, which is bound with particular strength because of its high symmetry. Helium 5 and lithium 5, obtained by adding a nucleon to helium 4, are again unstable as a consequence of the exclusion principle.

Let us now consider some of the hypernuclei in the same illustration. Adding a lambda particle to hydrogen 2 yields hyperhydrogen 3. We do not know how the lambda-particle spin will prefer to orient itself with respect to those of the two core nucleons already present. Nor do we know which orientation will produce the stronger binding. Hence the use of the double-headed arrow for lambda particles. In experiments hyperhydrogen 3 turns out to be bound. But one cannot conclude by analogy with hydrogen 3 and helium 3 that hyperhelium 3 should also be bound. The core of hyperhelium 3, helium 2, is quite different from hydrogen 2; in fact, it is not stable. All we can say is that hyperhelium 3 has not yet been observed. In contrast, hyperhydrogen 4 and hyperhelium 4, represented by identical diagrams if color is ignored, should both either be unstable or have identical binding energies. It happens that both are stable because the core nuclei themselves are stable and the lambda particle is permitted to occupy a seat in the lowest state. Experiment confirms the close identity of their binding energies. The lambda-particle binding energy in hyperhydrogen 4 is 2.20 ± .14 Mev; in hyperhelium 4 it is 2.36 ± .12 Mev. Finally, the uppermost hypernucleus in the illustration, hyperhelium 5—unlike ordinary helium 5—can accommodate all five particles in its lowest state. Because the core, helium 4, is already stable, hyperhelium 5 should be stable also, and is.

Nuclear diagrams of the sort we have been discussing, which transform into each other when blue arrows are replaced by red arrows and vice versa, represent what are known as mirror nuclei. In fact, in the top illustration on page 52 they occupy positions that are mirror images of each other with respect to the center line of the illustration. Systems lying along the center line are called self-mirrored, and their stability

allows no conclusions, on the basis of charge independence, as to the stability of other systems with an equal number of nuclear particles. Mirror nuclei plus a lambda particle become mirror hypernuclei; self-mirrored nuclei plus a lambda become self-mirrored hypernuclei.

Turning now to hypernuclides with more than five particles, let us consider hyperlithium 8 and hyperberyllium 8, which are represented at the left in the bottom illustration on page 52. Their core nuclei, respectively lithium 7 and beryllium 7, are a mirror pair. Therefore we expect to find that lambda particles are bound to the two cores with the same energy, an expectation that is closely confirmed by observation.

When we compare hyperhelium 7 with hyperlithium 7, we find that the binding energies for the lambda particle are significantly different in the two systems. The reason is that their cores, helium 6 and lithium 6, are not mirror images of each other, as shown at the right in the bottom illustration on page 52. The exclusion principle requires that the two neutrons (blue arrows) in the second level of helium 6 be antiparallel, while in lithium 6 at the same level the neutron and proton (blue and red arrows) may assume the energetically most favorable mutual orientation, which is parallel. Furthermore, lithium 6 is more strongly bound than helium 6. The lambda particle added to either helium 6 or lithium 6 is free to go into the lowest level with whatever spin orientation is most favorable. Thus the energies with which the lambda particle is bound to helium 6 and lithium 6 give a direct measure of the spin-dependence of the lambda-nucleon force. Further analysis indicates that the lambda-nucleon force is stronger for antiparallel orientation of the two spins involved, whereas the neutron-proton force is stronger when the spins lie parallel. Most of the above arguments concerning the nature of lambda and nucleon forces are those of the Australian physicist Richard H. Dalitz, who is now at the University of Chicago.

So far all hypernuclei observed contain only one lambda particle. We can dream, however, of building hypernuclei that contain more than one. The negative xi particle, which is almost 20 per cent heavier than the lambda particle, can react with a proton to produce two lambda particles. Since the reaction creates two lambda particles at the same spot, there is a chance that they might both attach themselves to an ordinary nucleus. Such a double hypernucleus would be very valuable, because it could supply information about the lambda-lambda force.

There is also a chance that we may get some strange particle other than a lambda particle to form a hypernucleus. Although other strange particles tend to react instantly with neutrons and protons, there may be certain exceptions to this behavior. For example, a negative sigma particle could conceivably bind itself to one or two neutrons if the sigma-nucleon forces happen to be appropriate.

In the long run investigations of hypernuclei will undoubtedly improve our understanding of ordinary nuclear forces. At some future time we may retrace the road of analogy that has led us from ordinary nuclei to hypernuclei and find the view surprising.

p PROTON
n NEUTRON
π PI MESON
γ GAMMA RAY

NAME	SYMBOL	MASS (MEV)	MEAN LIFE (SECONDS)	MODE OF DECAY	FAST REACTIONS WITH NUCLEONS
XI ZERO	Ξ^0	~1,320	$\sim 10^{-10}$	$\Xi^0 \longrightarrow \Lambda + \pi^0$	$\Xi^0 + n \longrightarrow \Lambda + \Lambda$
XI MINUS	Ξ^-	1,318	$\sim 10^{-10}$	$\Xi^- \longrightarrow \Lambda + \pi^-$	$\Xi^- + p \longrightarrow \Lambda + \Lambda$
SIGMA PLUS	Σ^+	1,189	$.8 \times 10^{-10}$	$\Sigma^+ \longrightarrow p + \pi^0$ OR $n + \pi^+$	$\Sigma^+ + n \longrightarrow \Lambda + p$
SIGMA ZERO	Σ^0	1,192	$\sim 10^{-19}$	$\Sigma^0 \longrightarrow \Lambda + \gamma$	$\Sigma^0 + p \longrightarrow \Lambda + p$ $\Sigma^0 + n \longrightarrow \Lambda + n$
SIGMA MINUS	Σ^-	1,196	1.6×10^{-10}	$\Sigma^- \longrightarrow n + \pi^-$	$\Sigma^- + p \longrightarrow \Lambda + n$
LAMBDA	Λ	1,115	2.8×10^{-10}	$\Lambda \longrightarrow p + \pi^-$ OR $n + \pi^0$	NONE

HYPERONS are listed here with their symbols and data. Other symbols are keyed to legend at top left. The lambda hyperon does not react rapidly with nucleons and is thus the only one that can form hypernuclei. On the mass scale used here, the proton and neutron have masses of 938.2 Mev and 939.5 Mev respectively; the charged pi mesons and neutral pi meson, 139.6 Mev and 135 Mev.

Kodak reports on:

what to do till the flying-spot scanner comes... light-sensitive liquids for less-than-juicy volume... why there are several spectrochemical emulsions

Disc electrophoresis

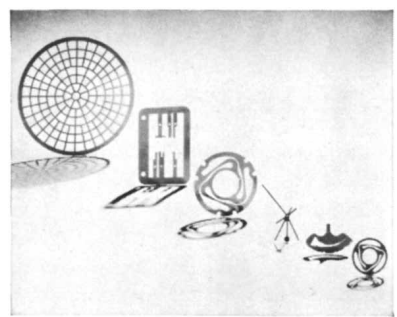
Each of the dark discs in this little tube of gel represents a different protein in a *3-microliter* sample of normal human serum. The separation was effected in 30 minutes. The pattern tells a detailed story to the practiced eye. The equipment can be jerry-built in the laboratory for a materials outlay of about $12.* The chemicals we recommend are *N,N-Methylenebisacrylamide* (Eastman 8383, meticulously recrystallized, gratefully praised for the purpose by those who know), *Acrylamide* (Eastman 5521), *2-Amino-2-(hydroxymethyl)-1,3-propanediol* (Eastman 4833), and *N,N,-N′,N′-Tetramethylethylenediamine* (Eastman 8178). To reduce dependence on perceptual machinery in the skull of the operator, a program is under development wherein protein concentrations represented by the discs are to be determined by a TV-like flying-spot scanner and the signals fed to a digital computer programmed to identify patterns at the rate of 10^4 per week.

Peripheral as may be our connection with the new disc electrophoresis, we can do our part by drum-beating in print for people to learn how Drs. B. J. Davis and Leonard Ornstein of The Mount Sinai Hospital Cell Research Laboratory in New York City have extended electrophoresis in the directions of 1) more simplified equipment that gets you into the technique easily; 2) more sophisticated equipment that speeds and refines results once you have found the technique indispensable; 3) a clear (albeit concentrated and mathematical) exposition of the physical chemistry at work.

We propose a little experiment in casting bread upon the waters. We shall count how many will accept an offer hereby made by Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), to send a free preprint of a paper by Dr. Ornstein on the theory and a fully illustrated set of directions by Dr. Davis on how to proceed. Then we shall wait and count how many orders come in for the above-named Eastman Organic Chemicals. The results of this experiment you will never know.

*Or it can be purchased in a variety of models from CANALCO, 4935 Cordell Avenue, Bethesda 14, Md.

Never say "die"?



These metal parts are not stampings, nor were they cut out by knife, scissors, or milling machine. They are too fussy and tricky for the latter implements and were needed in too much of a hurry and in insufficient numbers to justify the fabrication of dies.

Note for historians: "Insufficient numbers" sticks like a bone in the throats of businessmen who made their mark in the days not so long ago when the only kind of production that really mattered was mass production. Mass production has certainly not diminished. On the contrary, it has become more efficient and automatic. This frees a growing fraction of the population to upgrade itself. Heavily educated people would rather turn out ideas than piecework. The air grows thick with ideas, each outmoding its predecessor. Ideation itself becomes a major industry that finds money easier and easier to come by. However, since advanced ideation may be done for its own sweet sake and soon outmoded, the kind of production that results, though vast in consequence, rarely attains a juicy physical volume.

They are products of photo-etching, which is catching on. Some organizations are doing photo-etching (or photo-milling) for themselves, and we now know of at least four companies that do it for hire. The method uses either *Kodak Photo Resist* or *Kodak Metal-Etch Resist*, depending on the metal to be worked. Both are light-sensitive liquids. The object is drawn to enlarged scale and photographed. The metal is coated with *KPR* or *KMER* and exposed to light through the negative. Where the negative protects from the light, the resist will subsequently flush away; where light-struck, it becomes resistant to an etchant. Etchants leave no burrs. The thinner the metal the closer an etchant can work within tolerance. Designers can keep changing their minds, fancy-free, with less peril to their budgets, if any.

Eastman Kodak Company, Graphic Reproduction Division, Rochester 4, N. Y., can provide all sorts of information about photo-etching. We even hold seminars on the subject.

The grateful but cautious spectrographer

A small pamphlet has been issued under the title "Spectrum Analysis with Kodak Materials." The words it contains may prove less useful than its graphs and numbers, though the words devoted to a warning against taking the graphs and numbers too seriously must be taken seriously. That's life.

Life lived with the photographic emulsion as a measuring instrument for radiation intensity must be filled with gratitude for its simplicity, versatility, and economy and filled with caution against glib assumptions. Those who live that life have learned that:

1) *Kodak Spectroscopic Plates and Film, Type 103-0* work fast, capture quick-vanishing spectra.

2) *Kodak Spectrum Analysis No. 1 Plates and Film* are contrasty and good for trace-element lines against heavy background, for semi-quantitative comparison, and for all-out-quantitative jobs.

3) For faint trace-element lines or for cutting corners on the number of wavelengths for which sensitometric calibration is done, one resorts to *Kodak Spectrum Analysis No. 2 Plates and Film.*

If you still want the pamphlet, write Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. It is best to write or phone anyway for information about dealers, sizes, etc.

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

Kodak
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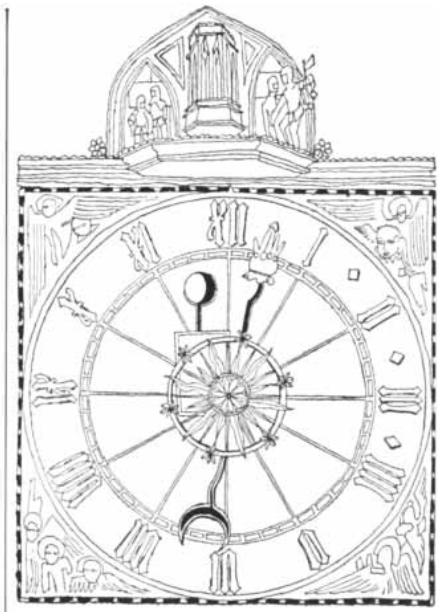


SCIENCE AND

Quarantining the Atom

As the nuclear powers resumed their deadlock at the Geneva test-ban conference, most of the nations of the world were maneuvering to keep themselves clear of the atomic incubus. Acting through the United Nations, these countries passed a quick succession of anti-atom resolutions.

First, the General Assembly voted 71 to 20 to request all powers to stop nuclear testing immediately and permanently. Voting against the measure were the nuclear powers—the U.S., Great Britain, France and the U.S.S.R.—who also declared that they would not be bound by the resolution. They were joined in the balloting by seven other Western and nine communist countries.

Next the General Assembly declared the use of nuclear weapons in war "a direct violation of the United Nations Charter." This statement was passed 55 to 20, with 26 nations abstaining and two absent. It was supported by the U.S.S.R. and opposed by the U.S., whose representative said "the Soviet Union has not the slightest intention of heeding it, despite the enthusiastic vote in its favor." At the same time the Assembly voted 55 to 0, with 44 abstaining, including the U.S., "to consider and respect the continent of Africa as a denuclearized zone," calling on member states to refrain from nuclear tests in Africa and from storing or transporting atomic weapons there.

Finally, the Political Committee of the General Assembly passed two resolutions aimed at preventing the spread of nuclear weapons. One, sponsored by Sweden, provided that no state not already in possession of nuclear weapons should acquire them, manufacture them or permit other countries to store them in its territory. The vote was 57 in favor, 12 (including the U.S.) against and 32 abstentions. The second resolution, offered by Ireland, acknowledged "the necessity of an international agreement, subject to inspection and control, whereby the powers producing nuclear weapons would refrain from relinquishing control of such weapons to any nation not possessing them and whereby powers not possessing such weapons would refrain from manufacturing them." It called for "all states, and particularly on the states at present possessing nuclear weapons, to use their best endeavors to secure the conclusion of an international agreement." Speaking on behalf of the resolution, the Irish representative told the committee "we remain firmly convinced that if nonnuclear states become one by one the possessors of nuclear weapons, war is inevitable."

Meantime at Geneva the test-ban talks got under way after time out for the Soviet test series, when the U.S.S.R. accepted a formal proposal to resume from the U.S. and Britain. Simultaneously with the proposal the Western powers declared that they would in no circumstances consent to a halt in testing, temporary or permanent, except under an agreement subject to international control and inspection. In return the U.S.S.R. proposed a new agreement in which the nuclear powers would "solemnly pledge themselves not to hold tests of any types . . . in the atmosphere, in outer space and under water." This pledge would be policed by individual states, using their own detection systems. At the same time the parties would "assume the obligation" not to test underground pending agreement on a control system. At the next meeting of the conference the negotiations appeared to be stalled as before, and the chief Western delegates announced that they were leaving Geneva temporarily. The talks were scheduled to continue, however.

Chemically Sterilized Insects

Experiments under way at a number of U.S. Department of Agriculture research stations promise a powerful new

weapon for controlling insect pests. Investigators have found more than 60 chemical compounds, out of 2,000 screened so far, that induce at least partial sexual sterility in insects; half a dozen have been found to cause complete, irreversible sterility. Agricultural experts foresee the use of such chemosterilants, either alone or in combination with conventional insecticides, as a means of rapidly reducing or eliminating altogether many insect pests that have hitherto escaped control.

The idea of combating insects by preventing them from reproducing originated nearly 25 years ago with E. F. Knipling, now head of entomological research for the Department of Agriculture, who devised an ingenious X-ray-sterilization scheme for eradicating the screw-worm fly in the southeastern U.S. [see "The Eradication of the Screw-Worm Fly," by E. F. Knipling; SCIENTIFIC AMERICAN, October, 1960]. In Knipling's scheme screw-worm flies were reared and X-rayed at a rate of 50 million a week. When the sterile flies were released, they mated with normal flies and drastically reduced the number of fertile matings. Fertile egg masses, and then the screw-worm fly itself, soon became impossible to find.

The X-ray technique is relatively expensive and cannot be applied to insects with a wide geographic distribution. Knipling and his colleagues accordingly turned to chemical sterilizing agents. The most promising are derivatives of ethylenimine, a compound that has been studied as an anticancer agent. One ethylenimine derivative has proved effective against houseflies in small-scale field trials and against mosquitoes and stable flies in laboratory trials.

The ethylenimine derivatives are toxic to warm-blooded animals and cannot be sprayed broadcast. They could, however, be combined with attractants such as the gypsy moth and other insects employ to attract mates. Attractant-chemosterilant combinations could be designed to pick out a single species of pest and leave other insects undisturbed. In addition, nontoxic chemosterilants may be found. In combination with insecticides these would furnish a double-barreled method of coping with the problem of insecticide resistance. The insecticide would reduce the insect population, and

the chemosterilant would destroy the reproductive ability of the survivors and prevent them from passing on the capacity to resist the insecticide.

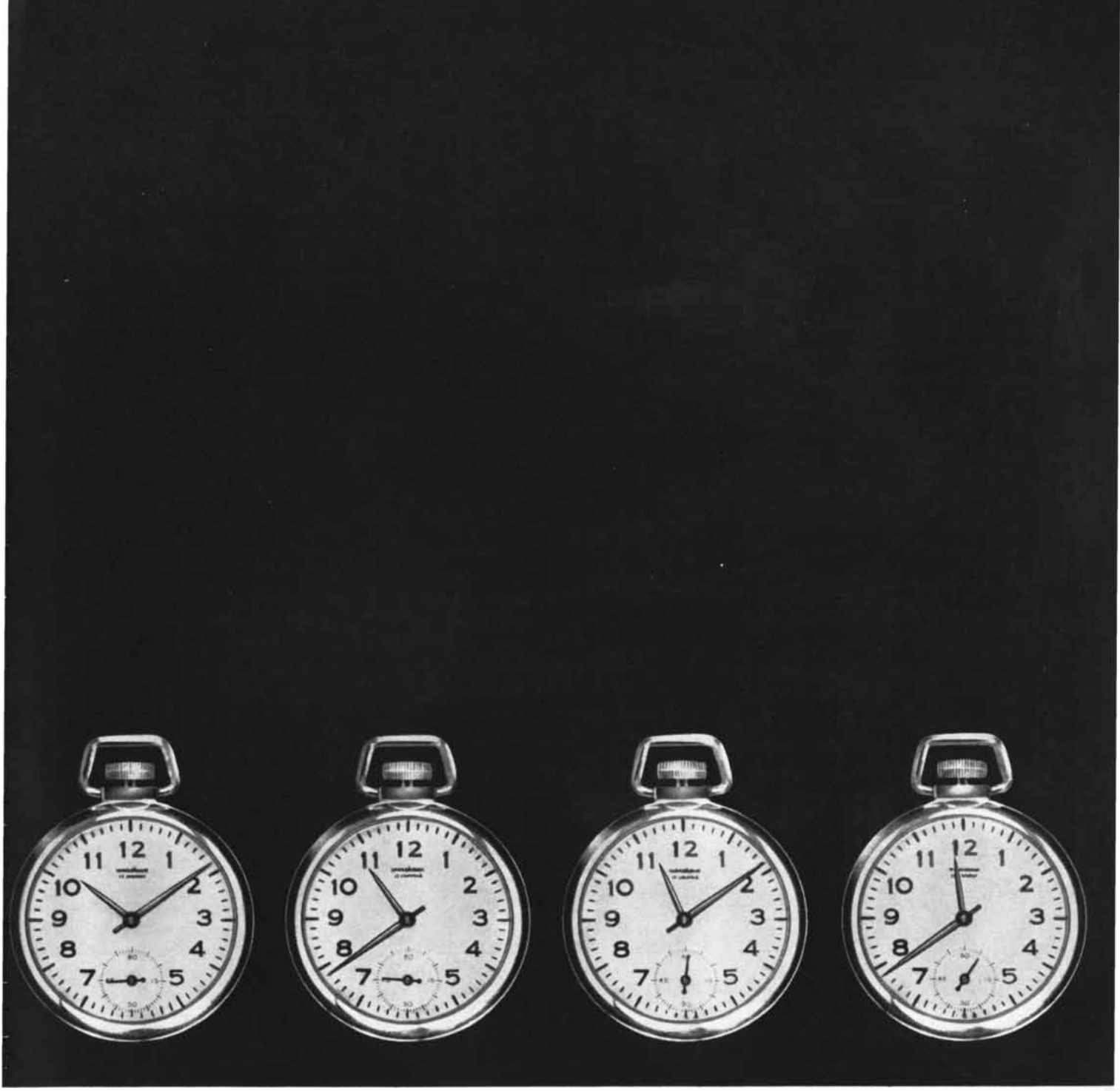
Safer Air

Under instructions from the President, the Federal Aviation Agency has taken action to carry out a new scheme for controlling traffic along the nation's airways. The heart of the plan, which was drawn up by an air-safety "task force" appointed last spring, is a pair of new cockpit devices, one for large planes and one for small. The two devices would overcome one of the principal deficiencies of the present air-traffic control system by providing ground controllers with continuous information on each plane's altitude; the information would appear as a number that would move along with the plane's blip on the traffic controller's radarscope. In perhaps as few as two years all planes flying in terminal areas or at altitudes above 3,000 feet would be required to carry one of the altitude-reporting devices.

The task force, which was headed by Richard R. Hough, vice-president of the Ohio Bell Telephone Company, was set up to see what could be done to speed improvements in air-traffic control following the collision between two airliners over New York City in December, 1960. The group's attention was soon focused on the fact that ground controllers now have no way to check a plane's altitude except by asking the pilot verbally; airway radars do not measure altitude. Lack of altitude information was a factor in the New York disaster.

The FAA has been working on an altitude-reporting radar. The Hough group found, however, that the project would take too long to complete and that the new radar would be less accurate than a cockpit device and would require large towers that would create a new airport hazard. The possibility of utilizing the SAGE air-defense network was also examined; most SAGE equipment was found unsuited to air-traffic control.

The task force called for further development of a device already carried by many airline planes—the automatic radio transmitter called "beacon." Beacon responds to radar pulses by sending back an augmented radar signal, as well as information on the plane's identity. The beacon transmitter would be modified to report in addition the reading of the plane's altimeter. A special form of beacon, without the automatic identification feature, would be devised for light



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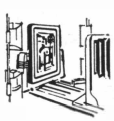

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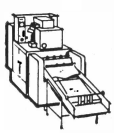

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planes. The FAA reported that development contracts for both types of equipment have already been let and that prototypes should be available for testing within a year.

Light Overtones

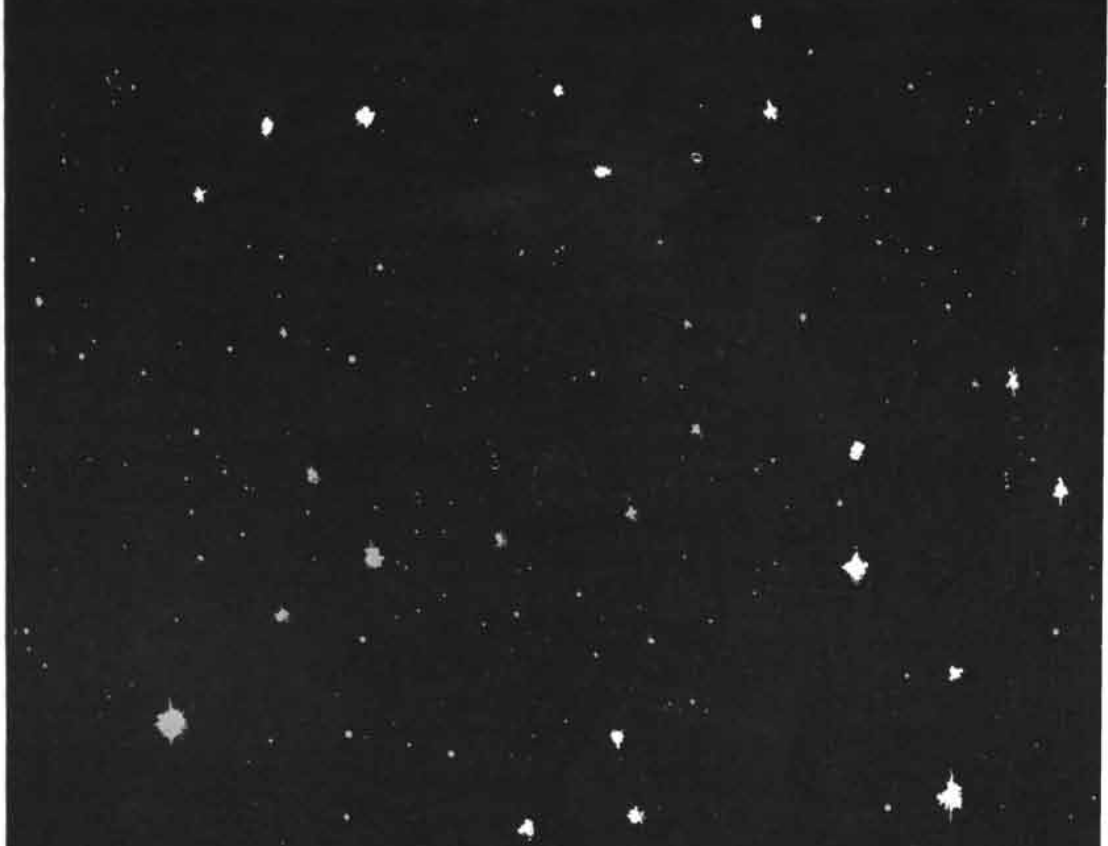
The invention of the optical maser has made it possible to treat light waves like radio waves; in other words, it extends the art of electronics to the visual portion of the electromagnetic spectrum [see "Optical Masers," by Arthur L. Schawlow; SCIENTIFIC AMERICAN, June, 1961]. One of the first successful experiments in optical electronics has recently been reported from the University of Michigan. Physicists Peter A. Franken, Alan E. Hill, C. Wilbur Peters and Gabriel Weinreich have produced and detected the second harmonic of a light wave.

In ordinary electronic devices the production of harmonics, or overtones, is almost unavoidable. Unless a circuit element, such as an amplifier, is absolutely "linear" (that is, unless its output is exactly proportional to its input), the output will always contain harmonics of the input wave. The only way to avoid harmonics is to limit the input energy to a narrow range of frequencies, over which the operation of the device is virtually linear.

Optical circuit elements—for example, transparent quartz or glass—are linear over a much wider range of energies. In fact, until now it has been impossible to concentrate enough energy to drive them into the nonlinear range. With the optical maser this can be done. The beam from a commercially available ruby maser can be focused so sharply as to produce in a small volume of quartz an electric field of some 100,000 volts per centimeter, at the accurately defined wavelength of 6,943 angstrom units, in the red region of the spectrum. Franken and his co-workers exposed a quartz crystal to the intense illumination and analyzed the emitted light with a spectroscope. They found a faint, though sharp, blue line close to 3,472 angstrom units—half the wavelength of the fundamental wave. This is the wavelength of the second harmonic, or "first overtone."

Subsequently the Michigan group carried their optical electronics a step further and were able to "heterodyne" two light waves. In other words, they mixed together light waves of two different frequencies in a nonlinear element and obtained a "beat note" equal to the sum of the two input frequencies. In this experi-

WHAT'S UP... AND WHERE ?



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ment they operated a pair of ruby optical masers at different temperatures, which provided beams of two different wavelengths, or frequencies, to feed into the quartz crystal. In the output of the crystal they now found three distinct lines: two representing the first harmonic of each of the inputs, and the third a wave at a frequency equal to the sum of the two input frequencies.

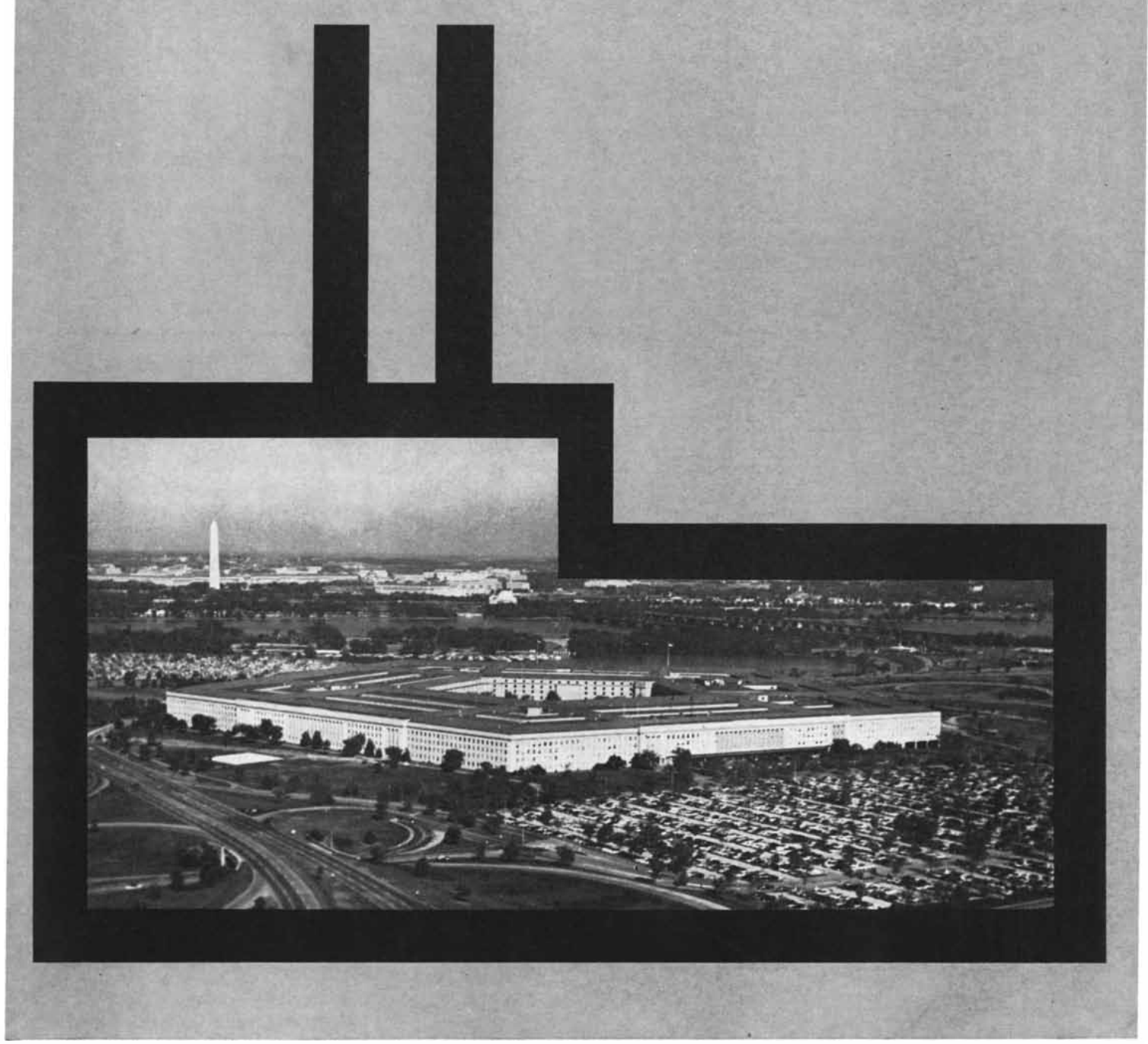
The harmonics and beat note were extremely faint compared with the fundamental frequency—far too weak to exploit in any practical way. The experiments may, however, be the forerunner of an optical electronic technology. Franken is now looking for more highly nonlinear optical elements, which might produce useful amounts of power as harmonic generators or heterodyne circuits.

Primordial Crust?

A new method of seismic shooting—the technique of mapping strata in the earth's crust by means of echoes from explosions—has provided a strong clue to the nature of the mysterious "second layer" in the ocean floor. The layer, which lies between the sediments at the bottom of the sea and the "basement" rocks of the earth's crust and which has been thought to consist of hardened sediments, now appears to be composed of igneous rocks. These rocks may well represent the original solid surface of the earth.

The finding was made by Maurice Ewing, director of Columbia University's Lamont Geological Observatory, and his brother John, also on the Lamont staff, and was reported by Maurice in the course of an address as the American Geographical Society's Cullum medalist. Last year John Ewing worked out a method, based on a novel automatic explosion-echo recording instrument, of charting layers below the deep ocean floor in unprecedented detail. The method was used on board the *Vema*, the Lamont research vessel, to obtain sub-bottom charts along 30,000 miles of track in the Atlantic, Antarctic and Pacific oceans.

When the records were examined, they revealed everywhere a layer of relatively hard rock above the basement rocks—the second layer, previously known chiefly in shallow seas and only occasionally detected in the deep ocean. Surprisingly, the second layer was not smooth, as it should have been if it had been formed from sediment, but was quite rough; this suggests that the layer is composed of igneous rock, that is,



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rock that has solidified out of the molten state. Moreover, no signs of disturbance were found in overlying sediments. The layer could not have been intruded after the sediments began to collect, Ewing noted; it must have been there before the sediments began to collect.

The Comet Earth

Astronomers have begun to suspect that the earth is embedded in a gigantic comet-shaped cloud of hydrogen gas and dust. According to calculations published in *The Astrophysical Journal* by John C. Brandt of the University of California, the head of the "geocomet" is about 800,000 miles across and probably contains 10 free hydrogen atoms per cubic centimeter; the tail, with an average concentration 100 times lower, is about four million miles long.

The main reason for thinking that such a cloud exists is the discovery of Lyman-alpha radiation—an emission of un-ionized hydrogen atoms in the ultraviolet region of the spectrum—high in the night sky. The radiation was detected only when rockets could ascend to altitudes of 30 miles or more; it cannot be seen below that level because of atmospheric absorption. Lyman-alpha radiation in the sky is believed to come from scattering of ultraviolet solar radiation by free un-ionized hydrogen atoms. At first astronomers supposed that the scattering material was the hydrogen in interplanetary space, but recent data indicate that there is not enough of it to produce the observed brightness. Then I. S. Shklovsky, a Soviet astrophysicist, suggested an earth-borne hydrogen cloud.

Calculating the necessary dimensions of this cloud, Brandt notes that the night scattering cannot come from hydrogen atoms less than five to 10 earth radii from the earth; they are within the earth's shadow. His figures indicate that the main body of the scattering cloud must go out to about 100 earth radii. Such an enormous, attenuated body of gas would be bound to acquire a comet-like tail in the antisolar direction (that is, pointing away from the sun and at right angles to the earth's orbit) because of solar radiation pressure and the solar wind (particles streaming from the sun).

The idea of scattering of sunlight on the side of the earth opposite the sun suggested that the same process might account for another puzzling phenomenon that had been known for many years. This is the Gegenschein, a diffuse, moderately bright area that can sometimes be seen on very dark nights, to the south in the Northern Hemisphere and

Research and Engineering at Sun Oil Company

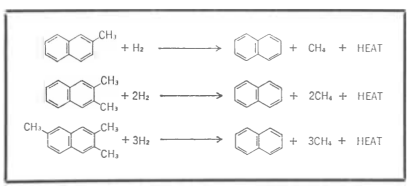
Process Simulation Using Analog Computers

Process simulation, one of the most exciting new developments in engineering, provides a faster, more economical way to secure the fundamental engineering information required for the design of new chemical processes.

Formerly, this information was obtained through a long and costly series of calculations and pilot plant runs. Now, with process simulation, basic data from a few carefully planned test runs are converted into a mathematical description of the process with the help of an analog computer. Then the computer becomes in effect the pilot plant.

This technique provides the bulk of the data required. In addition, the range of investigation can be extended to cover situations that would be unwieldy or impossible to produce in pilot runs.

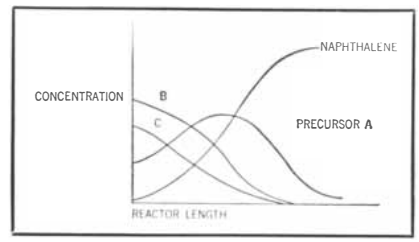
Here's a typical example: To properly design a new commercial petronaphthalene plant, it was vital to accurately predict the performance of the hydrogenolysis reactor. In this reactor, naphthalene precursors (essentially mono-, di- and tri-methylnaphthalene) are demethylated to produce the desired product, as shown below:



In this investigation, necessary basic data were obtained from a short pilot plant experimental program on a complex feed mixture. From these data, the kinetic and thermodynamic functions required to describe the reaction were determined. These were then applied in an analog model, which described the system under a wide range of operating conditions.

Plant yields were optimized and safe operating levels were set for this new naphthalene plant at Sun's Toledo Refinery by process simulation using an analog computer.

The results of this process simulation investigation indicated the practicability of the proposed commercial plant, see illustration. This graph shows the decrease in concentration of each of the three naphthalene precursors—and the increase in concentration of product naphthalene—as reactor time increases.



Solving Surface Ignition Problems By Modifying Engine Deposit Characteristics

Surface ignition in high-compression automotive engines—with its uncontrolled flame front, exceedingly fast pressure rise and disturbing audible rumble—is one of the most troublesome problems plaguing automotive designers today.

The problem, which becomes increasingly critical as horsepower and compression ratios rise, is caused by combustion chamber deposits that act as hot spots to cause uncontrolled, out-of-phase, pre-ignition of fuels.

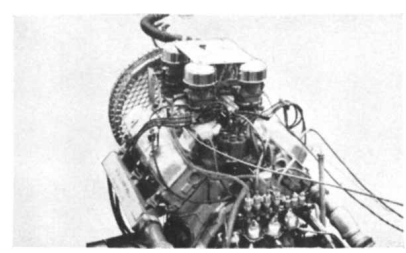
Proper fuel design—could remove one of the major limitations preventing the use of higher compression ratios.

Here, an engineering-scientific team, composed of automotive and chemical engineers and physical and organic chemists, is studying how fuel additives can modify combustion chamber deposits to eliminate the causes of surface ignition.

These studies involve both laboratory analyses of engine deposits and combustion tests of various fuel-additive mixtures. Laboratory work reveals the physical, electrical, chemical and thermal properties of combustion chamber deposits and indicates the types of additives that offer the greatest promise.

Combustion tests, conducted in specially designed experimental engines, reveal the ability of various additives to control the heat dissipation properties, the surface characteristics and the pre-ignition tendencies of engine deposits.

This continuing research effort, involving thousands of hours of laboratory and engine tests, enables Sun to develop new fuels that will make possible the high performance engines of the future.



Multi-carburetor, high-compression-ratio experimental engines evaluate four separate test fuels simultaneously. Use of these experimental engines shortens testing time, provides identical conditions for the evaluation of the four fuels being tested and insures that test results are valid for these fuels in contemporary engines.

Engineering Division

The Engineering Division of Sun Oil Company's Research and Engineering Department is responsible for the design and installation of all major projects involving refinery and petrochemical processes. It also provides assistance and service to other divisions within R and E and to other departments of the Company.

The activities of the Engineering Division are divided into several functional groups:

Process Engineering initiates the engineering development of a new project. The process engineer establishes the general design basis, sets the optimum process conditions, and specifies detailed design requirements. Another responsibility of this group is to provide engineering guidance to the Research and Development Division in order to "shorten the time between test tube and customer."

Project Engineering executes plans and specifications and supervises the contracting, procurement, expediting and administration of the project to its conclusion.

Design and Drafting is responsible for the detailed drafting normally associated with plant design. The range of design activity includes piping, vessels, buildings, electrical systems, instrumentation, model building—design from the bottom to the top of a new facility.

Metallurgical Engineering recommends materials of construction, analyzes metals performance, and consults in the fields of corrosion and welding.

Engineering Economics conducts cost studies for management justification of appropriations. As a group, it provides preliminary engineering and revised cost estimates on projects. It also controls and analyzes cost of construction, and schedules and plans manpower and materials budgets.

Specialist Consultants provide advisory service throughout the Company. They work on underground storage, in the electrical and architectural fields and in pollution abatement.

Through Sun's company wide liberal educational assistance policy the engineer is encouraged to continue his education at nearby technical institutions. This is supplemented by visiting lecturers, and intensive short courses in mathematics and engineering given by local schools at the location of employment.

In the work of the Division every effort is made to apply the most modern technological practices to problem solving.

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PROMOTING PROGRESS THROUGH RESEARCH

to the north in the Southern Hemisphere. Recent spectrographic studies indicate, however, that the Gegenschein lacks some spectral lines it ought to have if it is a result of hydrogen scattering. This visible light, Brandt believes, is probably scattered by dust particles. Therefore the geocomet seems to contain dust as well as hydrogen.

Artificial Heart Valve

Three groups of surgeons have attained one of the most elusive goals in heart surgery—the development of an effective man-made replacement for the aortic valve. This valve stands at the main exit from the heart and is often impaired by disease. At a meeting of the American Heart Association in Florida, Charles A. Hufnagel and Peter W. Conrad of Georgetown University Hospital said they had put an artificial aortic valve into 40 patients, with 32 long-term survivors; a University of Virginia team headed by William H. Muller, Jr., reported successful replacement in 18 of 27 patients, and Dwight C. McGoon and his associates at the Mayo Clinic reported success with nine of 15 patients.

The aortic valve is one of four valves that guide the flow of blood through the four chambers of the heart. Surgeons are able to carry out a wide variety of repairs on three of the valves, particularly since the advent of open-heart surgery. The aortic valve, however, has been singularly difficult to deal with because of its location between the left ventricle and the aorta, where the blood rushes from the heart with maximum force and turbulence to begin its journey around the body. When the aortic valve is damaged (usually as a result of rheumatic fever or bacterial infections of the heart), the impairment is usually much greater and the patient much sicker than when other valves are involved.

Many artificial valves have been investigated during the past decade as possible substitutes for aortic valves damaged beyond repair. The three groups of surgeons have now evolved essentially the same device—a duplicate in tough, flexible plastic of the three leaflets or flaps of tissue of the natural aortic valve. The synthetic leaflets are separate; one, two or three can be fitted in the patient as needed to assure a free flow of blood forward and prevent leakage back into the heart. The cases mentioned all involved complete replacement of the aortic valve; successful replacement of one or two leaflets has been carried out in an equally large number of patients.

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The Fine Structure of the Gene

The question "What is a gene?" has bothered geneticists for fifty years. Recent work with a small bacterial virus has shown how to split the gene and make detailed maps of its internal structure

by Seymour Benzer

Much of the work of science takes the form of map making. As the tools of exploration become sharper, they reveal finer and finer details of the region under observation. In last month's issue of *Scientific American* John C. Kendrew of the University of Cambridge described the mapping of the molecule of the protein myoglobin, revealing a fantastically detailed architecture. A living organism manufactures thousands of different proteins, each to precise specifications. The "blueprints" for all this detail are stored in coded form within the genes. In this article we shall see how it is possible to map the internal structure of a single gene, with the revelation of detail comparable to that in a protein.

It has been known since about 1913 that the individual active units of heredity—the genes—are strung together in one-dimensional array along the chromosomes, the threadlike bodies in the nucleus of the cell. By crossing such organisms as the fruit fly *Drosophila*, geneticists were able to draw maps showing the linear order of various genes that had been marked by the occurrence of mutations in the organism. Most geneticists regarded the gene as a more or less indivisible unit. There seemed to be no way to attack the questions "Exactly what is a gene? Does it have an internal structure?"

In recent years it has become apparent that the information-containing part of the chromosomal chain is in most cases a giant molecule of deoxyribonucleic acid, or DNA. (In some viruses the hereditary material is ribonucleic acid, or RNA.) Indeed, the threadlike molecule of DNA can be seen in the electron microscope [*see bottom illustration on opposite page*]. For obtaining information about the fine structure of DNA, however, modern methods of genetic analysis are a more powerful tool than even the electron microscope.

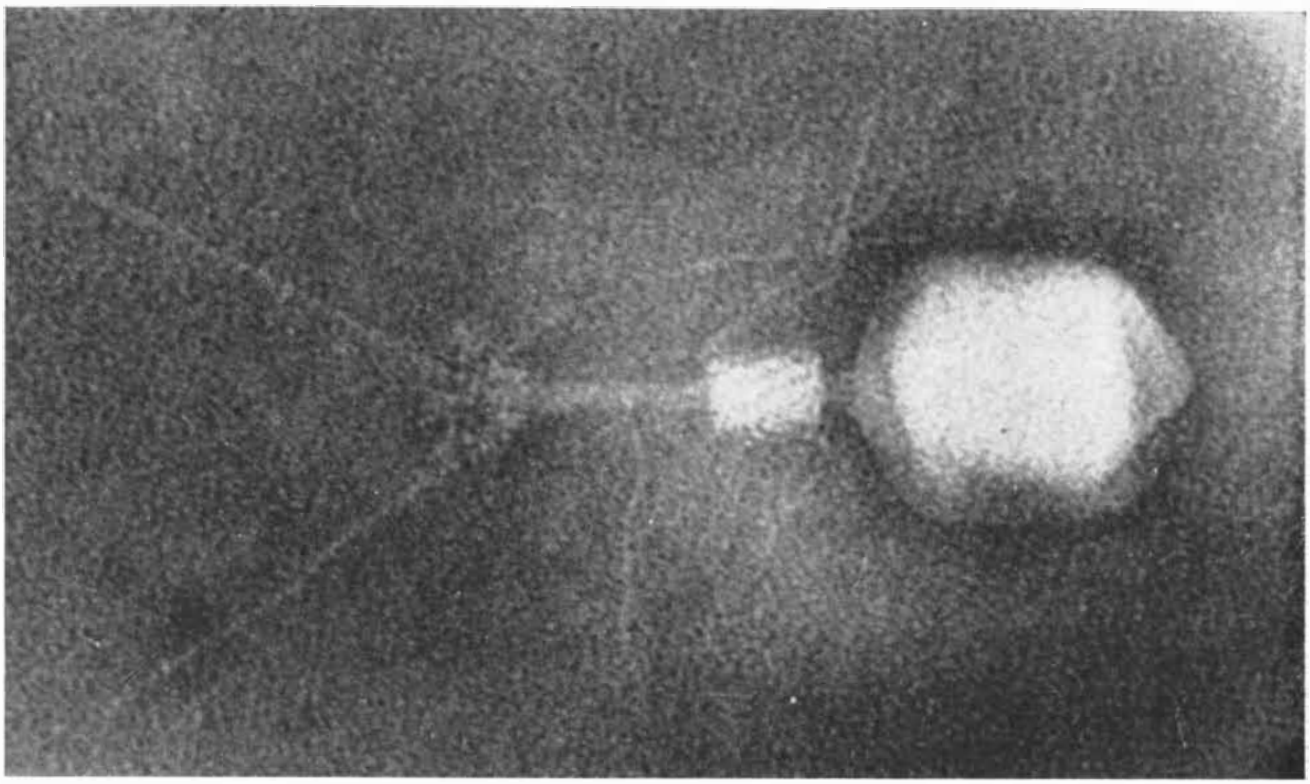
It is important to understand why this fine structure is not revealed by conventional genetic mapping, as is done with fruit flies. Genetic mapping is possible because the chromosomes sometimes undergo a recombination of parts called crossing over. By this process, for example, two mutations that are on different chromosomes in a parent will sometimes emerge on the same chromosome in the progeny. In other cases the progeny will inherit a "standard" chromosome lacking the mutations seen in the parent. It is as if two chromosomes lying side by side could break apart at any point and recombine to form two new chromosomes, each made up of parts derived from the original two. As a matter of chance two points far apart will recombine frequently; two points close together will recombine rarely. By carrying out many crosses in a large population of fruit flies one can measure the frequency—meaning the ease—with which different genes will recombine, and from this one can draw a map showing the parts in correct linear sequence. This technique has been used to map the chromosomes of many organisms. Why not, then, use the technique to map mutations inside the gene? The answer is that points within the same gene are so close together that the chance of detecting recombination between them would be exceedingly small.

In the study of genetics, however, everything hinges on the choice of a suitable organism. When one works with fruit flies, one deals with at most a few thousand individuals, and each generation takes roughly 20 days. If one works with a microorganism, such as a bacterium or, better still, a bacterial virus (bacteriophage), one can deal with billions of individuals, and a generation takes only minutes. One can therefore perform in a test tube in 20 minutes an experiment yielding a quantity of genetic data that would require, if humans were used, the entire population of the earth. Moreover, with microorganisms special tricks enable one to select just those individuals of interest from a population of a billion. By exploiting these advantages it becomes possible not only to split the gene but also to map it in the utmost detail, down to the molecular limits of its structure.

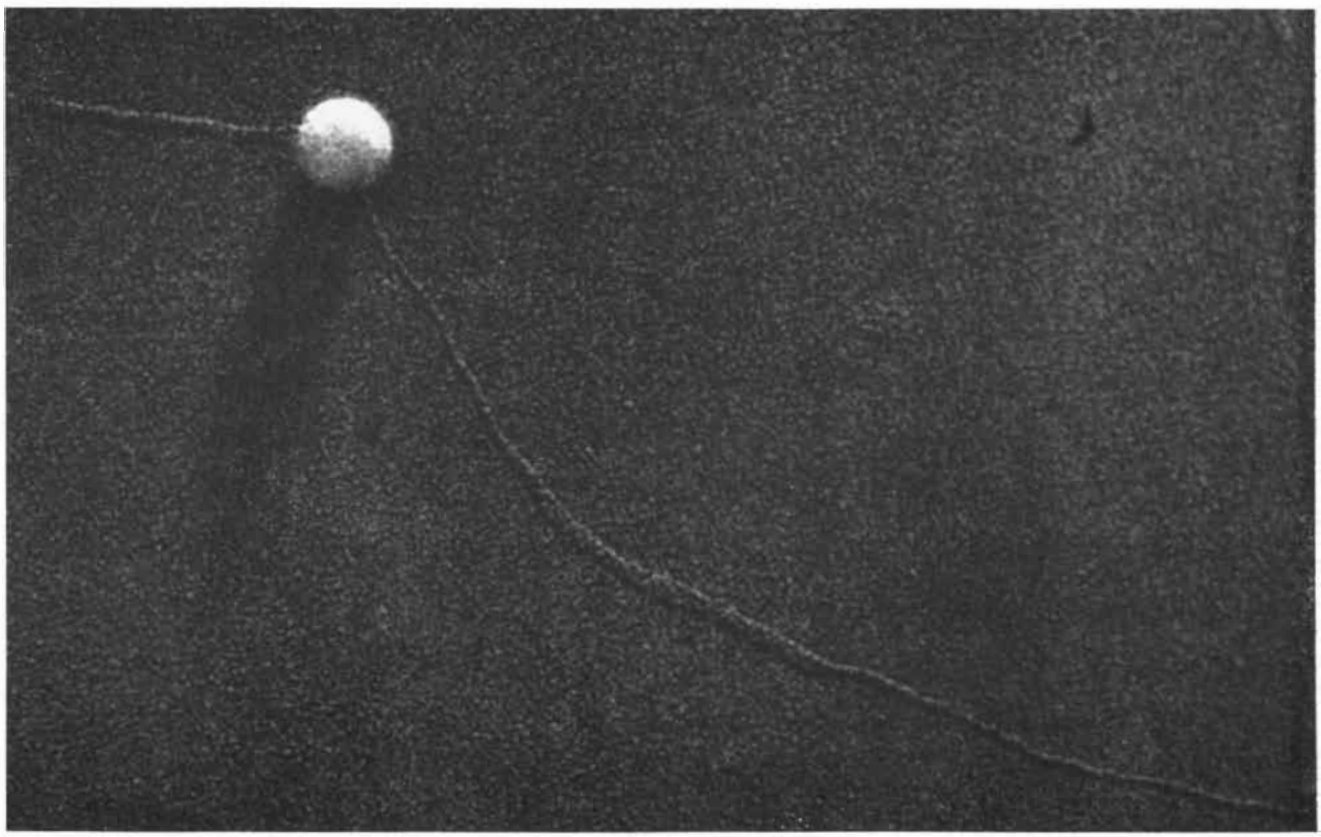
Replication of a Virus

An extremely useful organism for this fine-structure mapping is the T4 bacteriophage, which infects the colon bacillus. T4 is one of a family of viruses that has been most fruitfully exploited by an entire school of molecular biologists founded by Max Delbrück of the California Institute of Technology. The T4 virus and its relatives each consist of a head, which looks hexagonal in electron micrographs, and a complex tail by which the virus attaches itself to the bacillus wall [*see top illustration on opposite page*]. Crammed within the head of the virus is a single long-chain molecule of DNA having a weight about 100 million times that of the hydrogen atom. After a T4 virus has attached itself to a bacillus, the DNA molecule enters the cell and dictates a reorganization of the cell machinery to manufacture 100 or so copies of the complete virus. Each copy consists of the DNA and at least six distinct protein components. To make these components the invading DNA specifies the formation of a series of special enzymes, which themselves are proteins. The entire process is controlled by the battery of genes that constitutes the DNA molecule.

According to the model for DNA de-



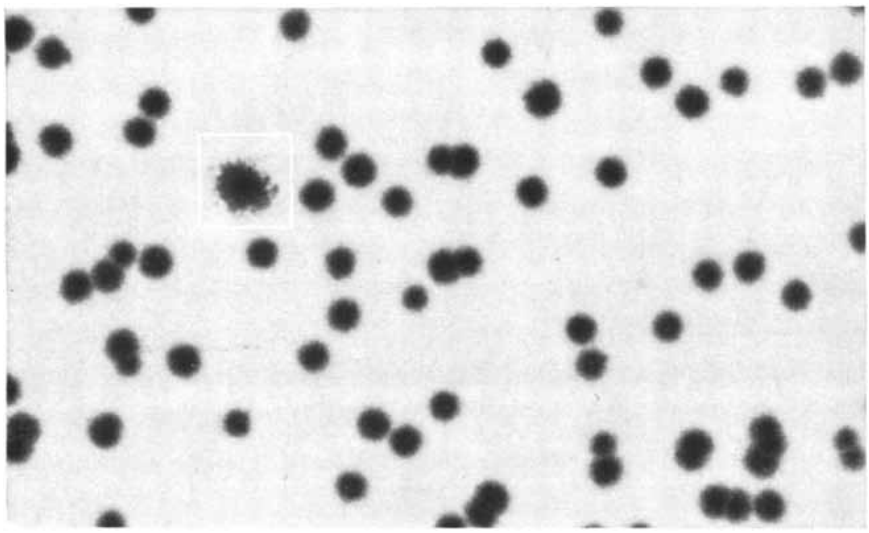
T2 BACTERIOPHAGE, magnified 500,000 diameters, is a virus that contains in its head complete instructions for it own replication. To replicate, however, it must find a cell of the colon bacillus into which it can inject a giant molecule of deoxyribonucleic acid (DNA). This molecule, comprising the genes of the phage, subverts the machinery of the cell to make about 100 copies of the complete phage. The mutations that occasionally arise in the DNA molecule during replication enable the geneticist to map the detailed structure of individual genes. The electron micrograph was made by S. Brenner and R. W. Horne at the University of Cambridge.



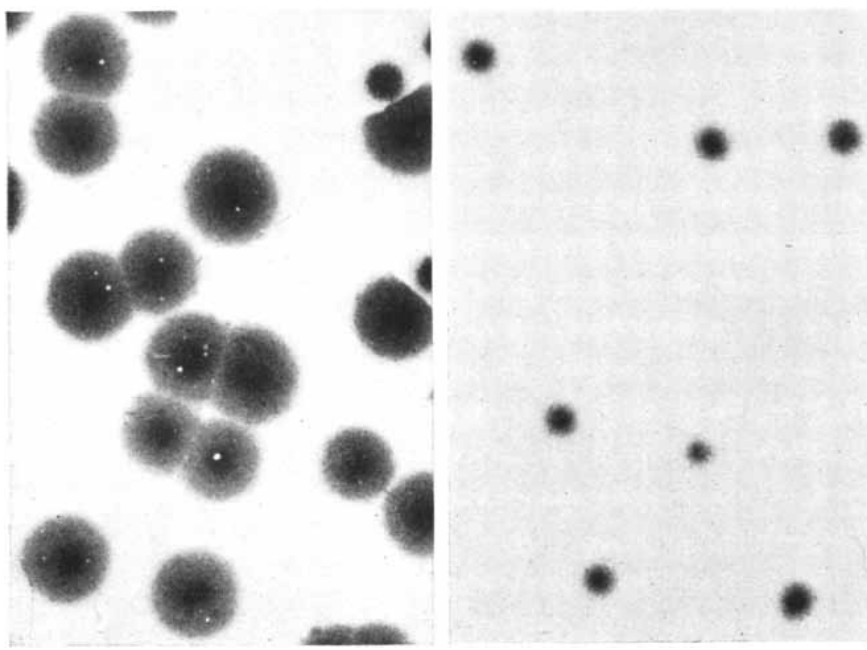
MOLECULE OF DNA is the fundamental carrier of genetic information. This electron micrograph shows a short section of DNA from calf thymus; its length is roughly that of the *r*II region in the DNA of T4 phage studied by the author. The DNA molecule in the phage would be about 30 feet long at this magnification of 150,000 diameters. The white sphere, a polystyrene "measuring stick," is 880 angstrom units in diameter. The electron micrograph was made by Cecil E. Hall of the Massachusetts Institute of Technology.

vised by James D. Watson and F. H. C. Crick, the DNA molecule resembles a ladder that has been twisted into a helix. The sides of the ladder are formed by alternating units of deoxyribose sugar groups and phosphate groups. The rungs, which join two sugar units, are composed of pairs of nitrogenous bases: either adenine paired with thymine or guanine paired with cytosine. The particular sequence of bases provides the genetic code of the DNA in a given organism. The DNA in the T4 virus contains some 200,000 base pairs, which, in amount of information, corresponds to much more than that contained in this article. Each base pair can be regarded as a letter in a word. One word (of the DNA code) may specify which of 20-odd amino acids is to be linked into a polypeptide chain. An entire paragraph might be needed to specify the sequence of amino acids for a polypeptide chain that has functional activity. Several polypeptide units may be needed to form a complex protein.

One can imagine that "typographical" errors may occur when DNA molecules are being replicated. Letters, words or sentences may be transposed, deleted or even inverted. When this occurs in a daily newspaper, the result is often humorous. In the DNA of living organisms typographical errors are never funny and are often fatal. We shall see how these errors, or mutations, can be used to analyze a small portion of the genetic information carried by the T4 bacteriophage.



SPONTANEOUS MUTATIONAL EVENT is disclosed by the one mottled plaque (*square*) among dozens of normal plaques produced when standard T4 phage is "plated" on a layer of colon bacilli of strain B. Each plaque contains some 10 million progeny descended from a single phage particle. The plaque itself represents a region in which cells have been destroyed. Mutants found in abnormal plaques provide the raw material for genetic mapping.



DUPLICATE REPLATINGS of mixed phage population obtained from a mottled plaque, like that shown at top of page, give contrasting results, depending on the host. Replated on colon bacilli of strain B (*left*), *r*II mutants produce large plaques. If the same mixed population is plated on strain K (*right*), only standard type of phage produce plaques.

Genetic Mapping with Phage

Before examining the interior of a gene let us see how genetic experiments are performed with bacteriophage. One starts with a single phage particle. This provides an important advantage over higher organisms, where two different individuals are required and the male and female may differ in any number of respects besides their sex. Another simplification is that phage is haploid, meaning that it contains only a single copy of its hereditary information, so that none of its genes are hidden by dominance effects. When a population is grown from a single phage particle, using a culture of sensitive bacteria as fodder, almost all the descendants are identical, but an occasional mutant form arises through some error in copying the genetic information. It is precisely these errors in reproduction that provide the key to the genetic analysis of the structure [*see upper illustration on pages 74 and 75*].

Suppose that two recognizably different kinds of mutant have been picked up; the next step is to grow a large population of each. This can be done in two test tubes in a couple of hours. It is now easy to perform a recombination experiment. A liquid sample of each phage population is added to a culture of bacterial cells in a test tube. It is arranged that the phage particles outnumber the bacterial cells at least three to one, so that each cell stands a good chance of being infected by both mutant forms of phage DNA. Within 20 minutes about 100 new phage particles are formed within each cell and are released when the cell bursts. Most of the progeny will resemble one or the other parent. In a few of them, however, the genetic information from the two parents may have been recombined to form a DNA molecule that is not an exact copy of the molecule possessed by either parent but a combination of the two. This new recombinant phage particle can carry

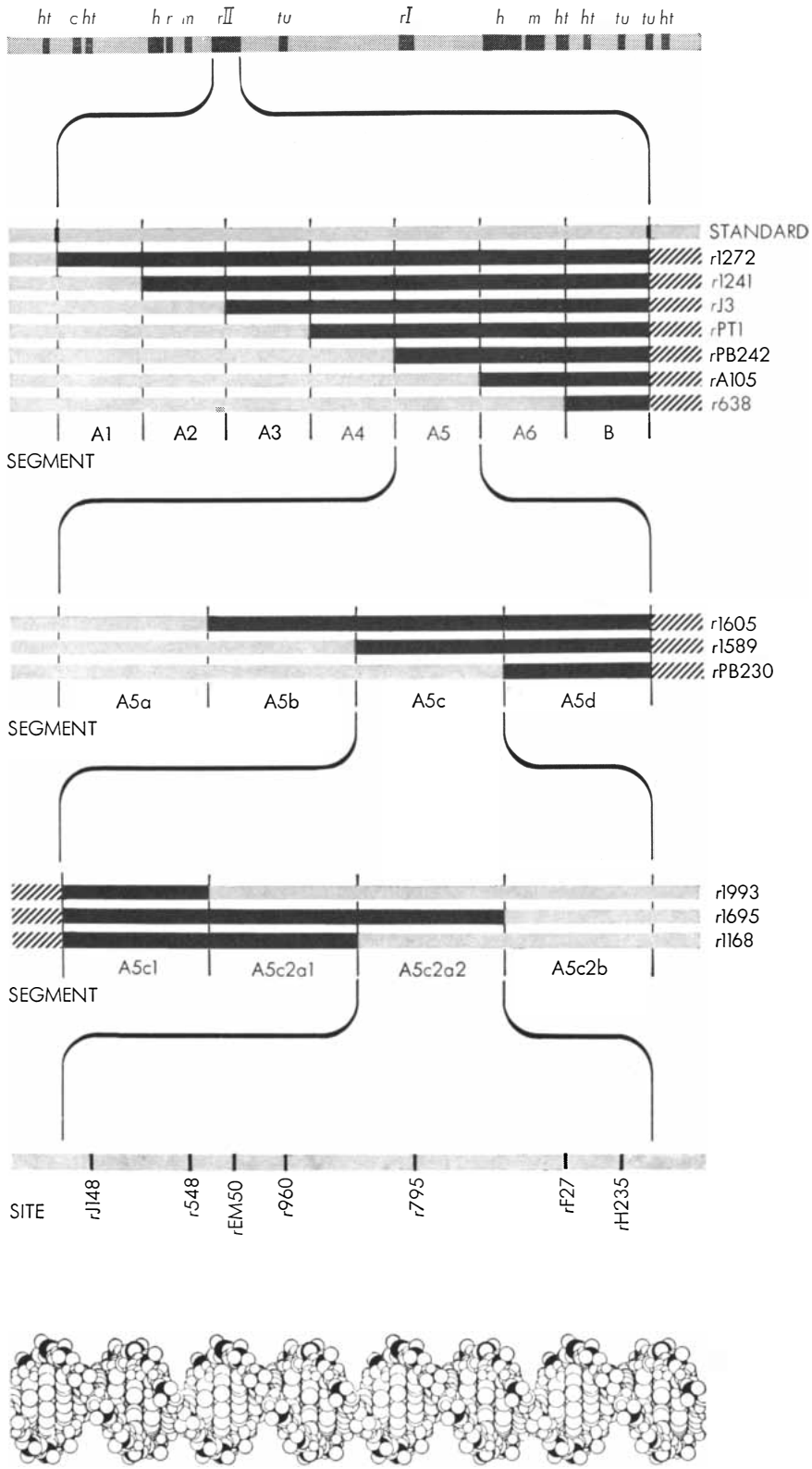
both mutations or neither of them [*see lower illustration on next two pages*].

When this experiment is done with various kinds of mutant, some of the mutant genes tend to recombine almost independently, whereas others tend to be tightly linked to each other. From such experiments Alfred D. Hershey and Raquel Rotman, working at Washington University in St. Louis, were able to construct a genetic map for phage showing an ordered relationship among the various kinds of mutation, as had been done earlier with the fruit fly *Drosophila* and other higher organisms. It thus appears that the phage has a kind of chromosome —a string of genes that controls its hereditary characteristics.

One would like to do more, however, than just "drosophilize" phage. One would like to study the internal structure of a single gene in the phage chromosome. This too can be done by recombination experiments, but instead of choosing mutants of different kinds one chooses mutants that look alike (that is, have modifications of what is apparently the same characteristic), so that they are likely to contain errors in one or another part of the same gene.

Again the problem is to find an experimental method. When looking for mutations in fruit flies, say a white eye or a bent wing, one has to examine visually every fruit fly produced in the experiment. When working with phage, which reproduce by the billions and are invisible except by electron microscopy, the trick is to find a macroscopic method for identifying just those individuals in which recombination has occurred.

Fortunately in the T4 phage there is a class of mutants called *r*II mutants that can be identified rather easily by the appearance of the plaques they form on a given bacterial culture. A plaque is a clear region produced on the surface of a culture in a glass dish where phage particles have multiplied and destroyed the bacterial cells. This makes it possible to count individual phage particles without ever seeing them. Moreover, the shape and size of the plaques are hereditary characteristics of the phage that can be easily scored. A plaque produced in several hours will contain about 10 million phage particles representing the progeny of a single particle. T4 phage of the standard type can produce plaques on either of two bacterial host strains, B or K. The standard form of T4 occasionally gives rise to *r*II mutants that are easily noticed because they produce a distinctive plaque on B cultures. The key to the whole mapping technique is that



MAPPING TECHNIQUE localizes the position of a given mutation in progressively smaller segments of the DNA molecule contained in the T4 phage. The *r*II region represents to start with only a few per cent of the entire molecule. The mapping is done by crossing an unknown mutant with reference mutants having deletions (*dark gray tone*) of known extent in the *r*II region (*see illustration of method on page 76*). The order and spacing of the seven mutational sites in the bottom row are still tentative. Each site probably represents the smallest mutable unit in the DNA molecule, a single base pair. The molecular segment (*extreme bottom*), estimated to be roughly in proper scale, contains a total of about 40 base pairs.

these mutants do not produce plaques on K cultures.

Nevertheless, an *r*II mutant can grow normally on bacterial strain K if the cell is simultaneously infected with a particle of standard type. Evidently the standard DNA molecule can perform some function required in K that the mutants cannot. This functional structure has been traced to a small portion of the DNA molecule, which in genetic maps of the T4 phage is designated the *r*II region.

To map this region one isolates a number of independently arising *r*II mutants (by removing them from mutant plaques visible on B) and crosses them against one another. To perform a cross, the two mutants are added to a liquid culture of B cells, thereby providing an opportunity for the progeny to recombine portions of genetic information from either parent. If the two mutant versions are due to typographical errors in different parts of the DNA molecule, some individuals of standard type may be regenerated. The standards will produce plaques on the K culture, whereas the mutants cannot. In this way one can easily detect a single recombinant among a billion progeny. As a consequence one can "resolve" two *r*II mutations that are extremely close together. This resolving power is enough to distinguish two mutations that are only one base pair apart in the DNA molecular chain.

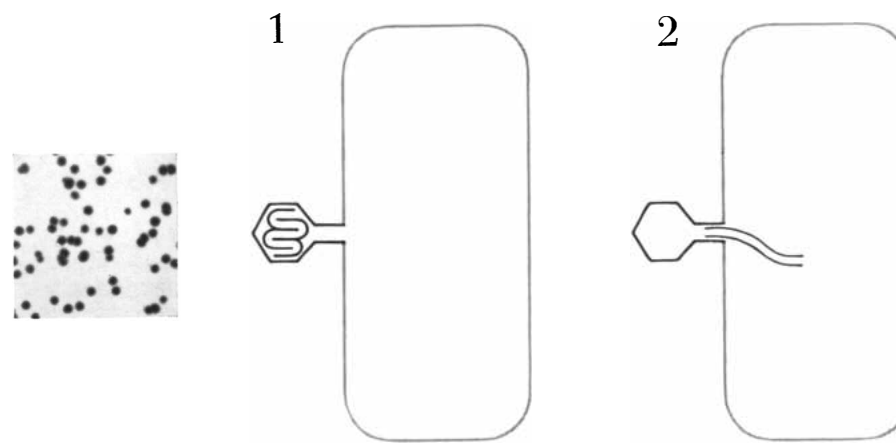
What actually happens in the recombination of phage DNA is still a matter of conjecture. Two defective DNA molecules may actually break apart and rejoin to form one nondefective molecule, which is then replicated. Some recent evidence strongly favors this hypothesis. Another possibility is that in the course of replication a new DNA molecule arises from a process that happens to copy only the good portions of the two mutant molecules. The second process is called copy choice. An analogy for the two different processes can be found in the methods available for making a good tape recording of a musical performance from two tapes having defects in different places. One method is to cut the defects out of the two tapes and splice the good sections together. The second method (copy choice) is to play the two tapes and record the good sections on a third tape.

Mapping the *r*II Mutants

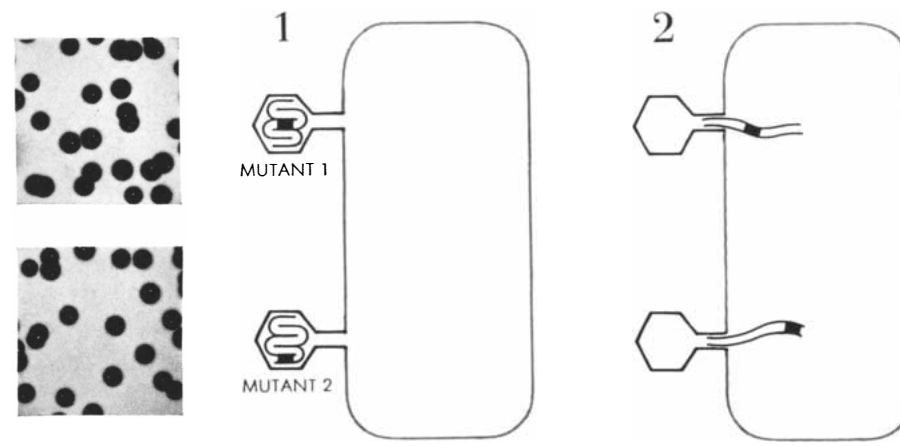
A further analogy with tape recording will help to explain how it has been established that the *r*II region is a simple linear structure. Given three tapes, each with a blemish or deletion in a different place, labeled *A*, *B* and *C*, one can imagine the deletions so located that deletion *B* overlaps deletion *A* and deletion *C*, but that *A* and *C* do not overlap each other. In such a case a good performance can be re-created only by recombining *A* and *C*. In mutant forms of phage DNA containing comparable deletions the existence of overlapping can be established by recombination experiments of just the same sort.

To obtain such deletions in phage one looks for mutants that show no tendency to revert to the standard type when they reproduce. The class of nonreverting mutants automatically includes those in which large alterations or deletions have occurred. (By contrast, *r*II mutants that revert spontaneously behave as if their alterations were localized at single points). The result of an exhaustive study covering hundreds of nonreverting *r*II mutants shows that all can be represented as containing deletions of one size or another in a single linear structure. If the structure were more complex, containing, for example, loops or branches, some mutations would have been expected to overlap in such a way as to make it impossible to represent them in a linear map. Although greater complexity cannot be absolutely excluded, all observations to date are satisfied by the postulate of simple linearity.

Now let us consider the *r*II mutants that do, on occasion, revert spontaneously when they reproduce. Conceivably they arise when the DNA molecule of the phage undergoes an alteration of a single base pair. Such "point" mutants are those that must be mapped if one is to probe the fine details of genetic structure. However, to test thousands of point mutants against one another for recombination in all possible pairs would



REPLICATION AND MUTATION occur when a phage particle infects a bacillus cell. The experiment begins by isolating a few standard particles from a normal plaque (*photograph at far left*) and growing billions of progeny in a broth culture of strain B colon bacilli. A sample of the broth is then spread on a Petri dish containing the same strain, on which the



PROCESS OF RECOMBINATION permits parts of the DNA of two different phage mutants to be reassembled in a new DNA molecule that may contain both mutations or neither of them. Mutants obtained from two different cultures (*photographs at far left*) are introduced into a broth of strain B colon bacilli. Crossing occurs (*1*) when DNA from each mutant type

require millions of crosses. Mapping of point mutations by such a procedure would be totally impracticable.

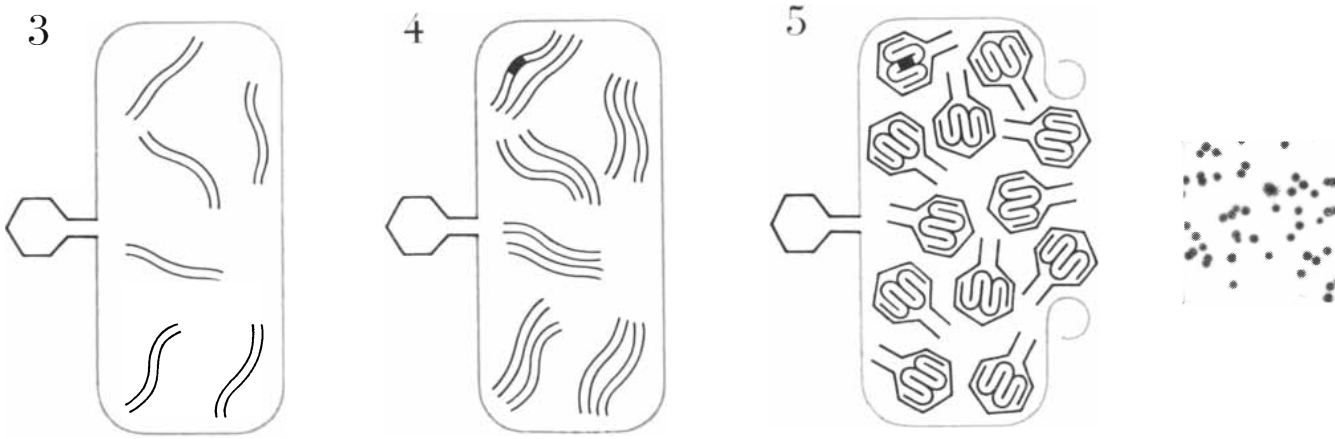
The way out of this difficulty is to make use of mutants of the nonreverting type, whose deletions divide up the *r*II region into segments. Each point mutant is tested against these reference deletions. The recombination test gives a negative result if the deletion overlaps the point mutation and a positive result (over and above the "noise" level due to spontaneous reversion of the point mutant) if it does not overlap. In this way a mutation is quickly located within a particular segment of the map. The point mutation is then tested against a second group of reference mutants that divide this segment into smaller segments, and so on [*see illustration on pages 78 and 79*]. A point mutation can be assigned by this method to any of 80-odd ordered segments.

The final step in mapping is to test against one another only the group of mutants having mutations within each segment. Those that show recombination are concluded to be at different sites, and each site is then named after the mutant indicating it. (The mutants themselves have been assigned numbers according to their origin and order of discovery.) Finally, the order of the sites within a segment can be established by making quantitative measurements of recombination frequencies with respect to one another and neighbors outside the segment.

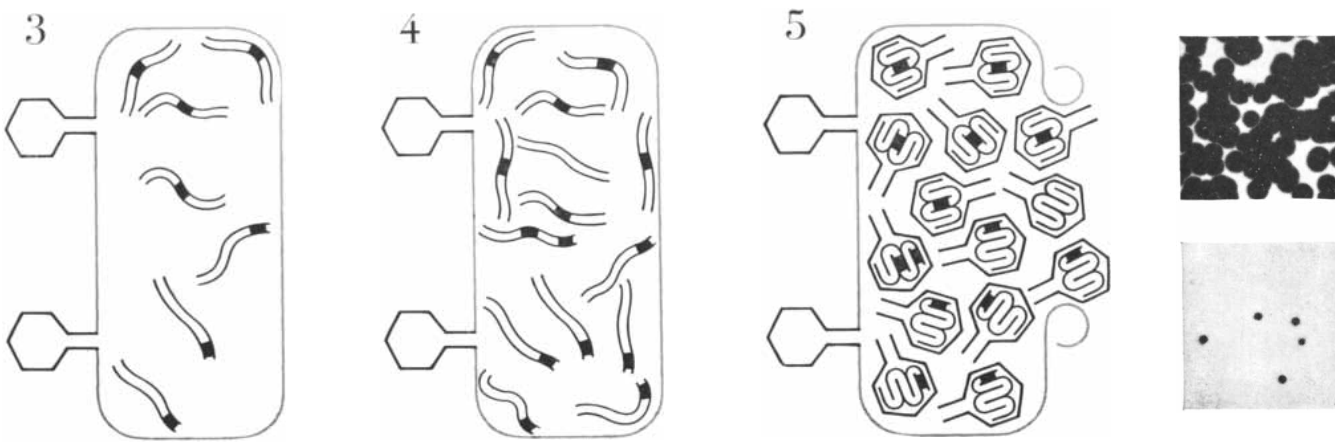
The Functional Unit

Thus we have found that the hereditary structure needed by the phage to multiply in colon bacilli of strain K consists of many parts distinguishable by mutation and recombination. Is this region to be thought of as one gene (because it controls one characteristic) or as hundreds of genes? Although mutation at any one of the sites leads to the same observed physiological defect, it does not necessarily follow that the entire structure is a single functional unit. For instance, growth in strain K could require a series of biochemical reactions, each controlled by a different portion of the region, and the absence of any one of the steps would suffice to block the final result. It is therefore of interest to see whether or not the *r*II region can be subdivided into parts that function independently.

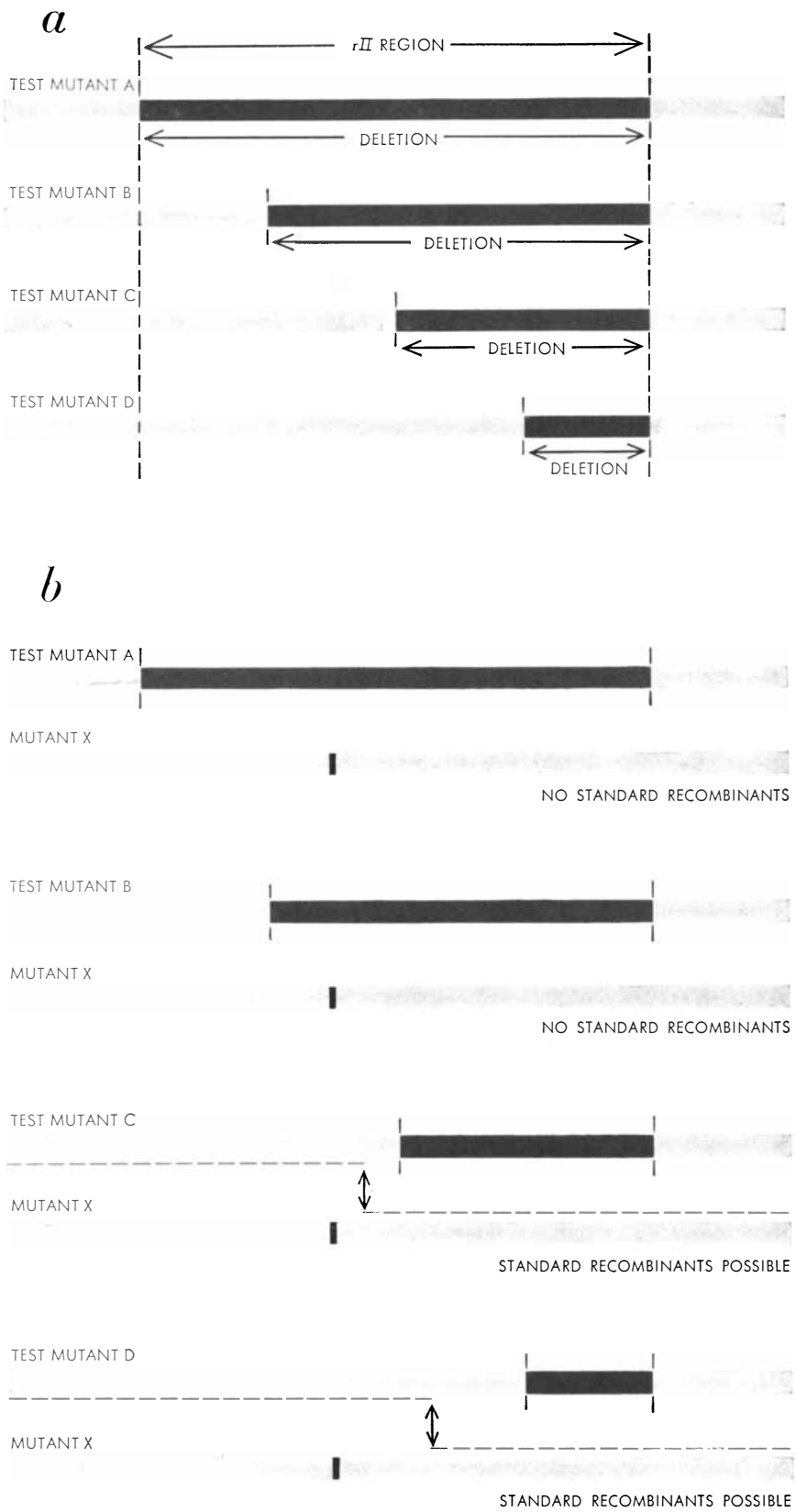
This can be done by an experiment known as the *cis-trans* comparison. It will be recalled that the needed function can be supplied to a mutant by simultaneous infection of the cell with standard phage; the standard type supplies an intact copy of the genetic structure, so that



mutants and standard phage produce different plaque types. The diagrams show a bacillus infected by a single standard phage. The DNA molecule from the phage enters the cell (*2*) and is replicated (*3 and 4*). Among scores of perfect replicas, one may contain a mutation (*dark patch*). Encased in protein jackets, the phage particles finally burst out of the cell (*5*). When a mutant arises during development of a plaque, the mixture of its mutant progeny and standard types makes plaque look mottled (*photograph at right*).



infects a single bacillus. Most of the DNA replicas are of one type or the other, but occasionally recombination will produce either a double mutant or a standard recombinant containing neither mutation. When the progeny of the cross are plated on strain B (*top photograph at far right*), all grow successfully, producing many plaques. Plated on strain K, only the standard recombinants are able to grow (*bottom photograph at right*). A single standard recombinant can be detected among as many as 100 million progeny.



DELETION MAPPING is done by crossing an unknown mutant with a selected group of reference mutants (*four at top*) whose DNA molecules contain deletions—or what appear to be deletions—of known length in the *r*II region. Thus when mutant *X* is crossed with test mutants *A* and *B*, no standard recombinants are observed because both copies of the DNA molecule are defective at the same place. When *X* is crossed with *C* and *D*, however, standard recombinants can be formed, as indicated by broken lines and arrows. By using other reference mutants with appropriate deletions the location of *X* can be further narrowed.

it does not matter what defect the *r*II mutant has and both types are enabled to reproduce. Now suppose the intact structure of the standard type could be split into two parts. If this were to destroy the activity, the two parts could be regarded as belonging to a single functional unit. Although the experiment as such is not feasible, one can do the next best thing. That is to supply piece *A* intact by means of a mutant having a defect in piece *B*, and to use a mutant with a defect in piece *A* to supply an intact piece *B*. If the two pieces *A* and *B* can function independently, the system should be active, since each mutant supplies the function lacking in the other. If, however, both pieces must be together to be functional, the split combination should be inactive.

The actual experimental procedure is as follows. Let us imagine that one has identified two mutational sites in the *r*II region, *X* and *Y*, and that one wishes to know if they lie within the same functional unit. The first step is to infect cells of strain K with the two different mutants, *X* and *Y;* this is called the *trans* test because the mutations are borne by different DNA molecules. Now in K the decision as to whether or not the phage will function occurs very soon after infection and *before* there is any opportunity for recombination to take place. To carry out a control experiment one needs a double mutant (obtainable by recombination) that contains both *X* and *Y* within a single phage particle. When cells of strain K are infected with the double mutant and the standard phage, the experiment is called the *cis* test since one of the infecting particles contains both mutations in a single DNA molecule. In this case, because of the presence of the standard phage, normal replication is expected and provides the control against which to measure the activity observed in the *trans* test. If, in the *trans* test, the phage fails to function or shows only slight activity, one can conclude that *X* and *Y* fall within the same functional unit. If, on the other hand, the phage develops actively, it is probable (but not certain) that the sites lie in different functional units. (Certainty in this experiment is elusive because the products of two defective versions of the same functional unit, tested in a *trans* experiment, will sometimes produce a partial activity, which may be indistinguishable from that produced by a *cis* experiment.)

As applied to *r*II mutants, the test divides the structure into two clear-cut parts, each of which can function inde-

Objective: duplicate the cycle of life so man can sustain himself in space indefinitely

To leave the earth at all, man must take his environment with him. But no spaceship could hold all the air, food and water he'll need for any extended trip. His meager supplies will have to be constantly purified and renewed. There can be no waste. Every drop of moisture, every smidgeon of food must be reprocessed and reused.

This means that some substitute will have to be found for the fundamental cycle of life on earth. Northrop's Bioastronautics Laboratory is even now developing new strains of algae as a basic food source. They are investigating biological means of reclaiming waste and purifying air. Studying the effects of hard radiation on living matter unscreened by earth's atmosphere. Learning more about how life is affected by the absence of gravity. Coming to grips with all the interrelated problems of life support.

When men finally move out to occupy space, Northrop's foresight in research will have helped to make their long-term survival possible.

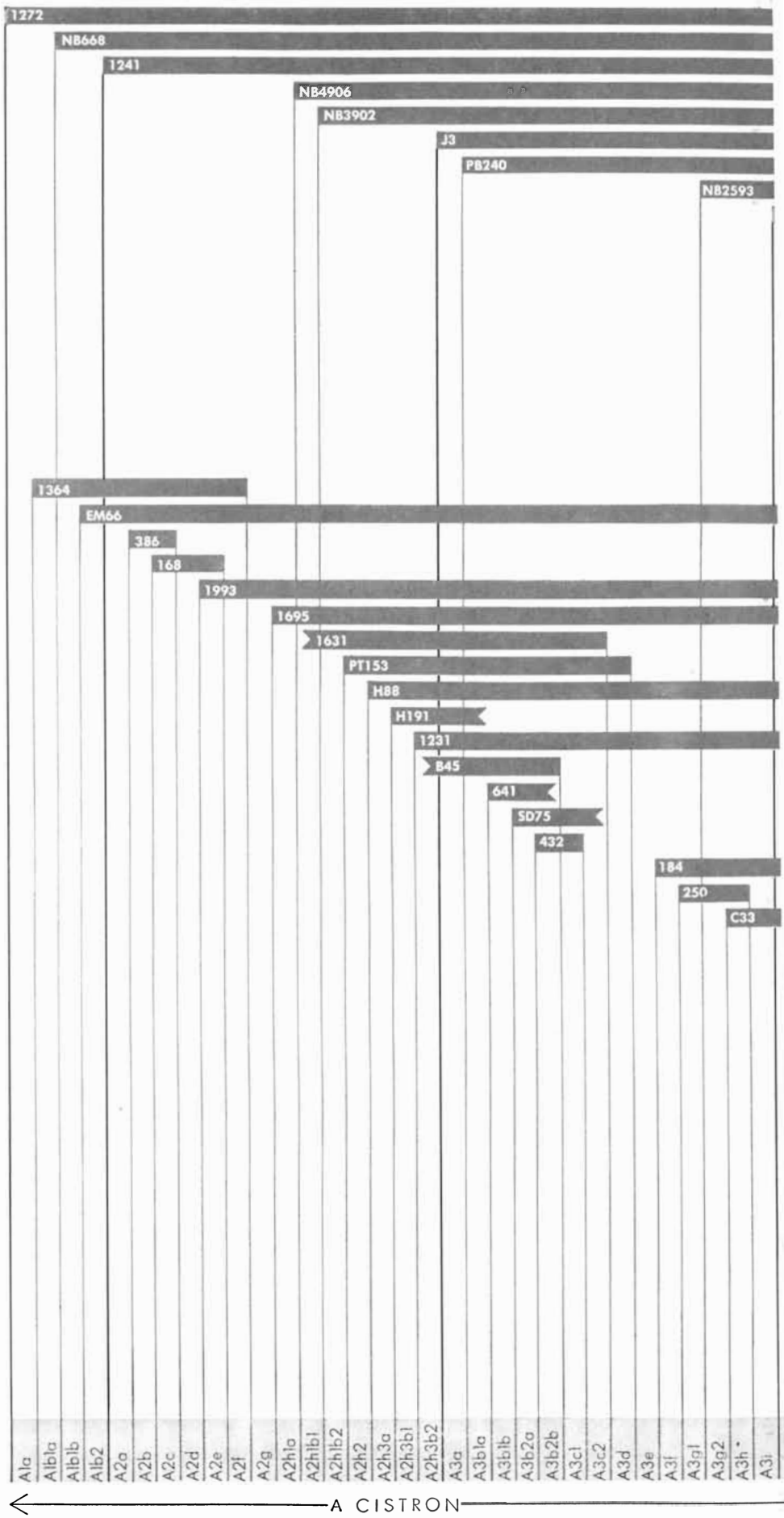
NORTHROP

pendently of the other. The functional units have been called cistrons, and we say that the *r*II region is composed of an A cistron and a B cistron.

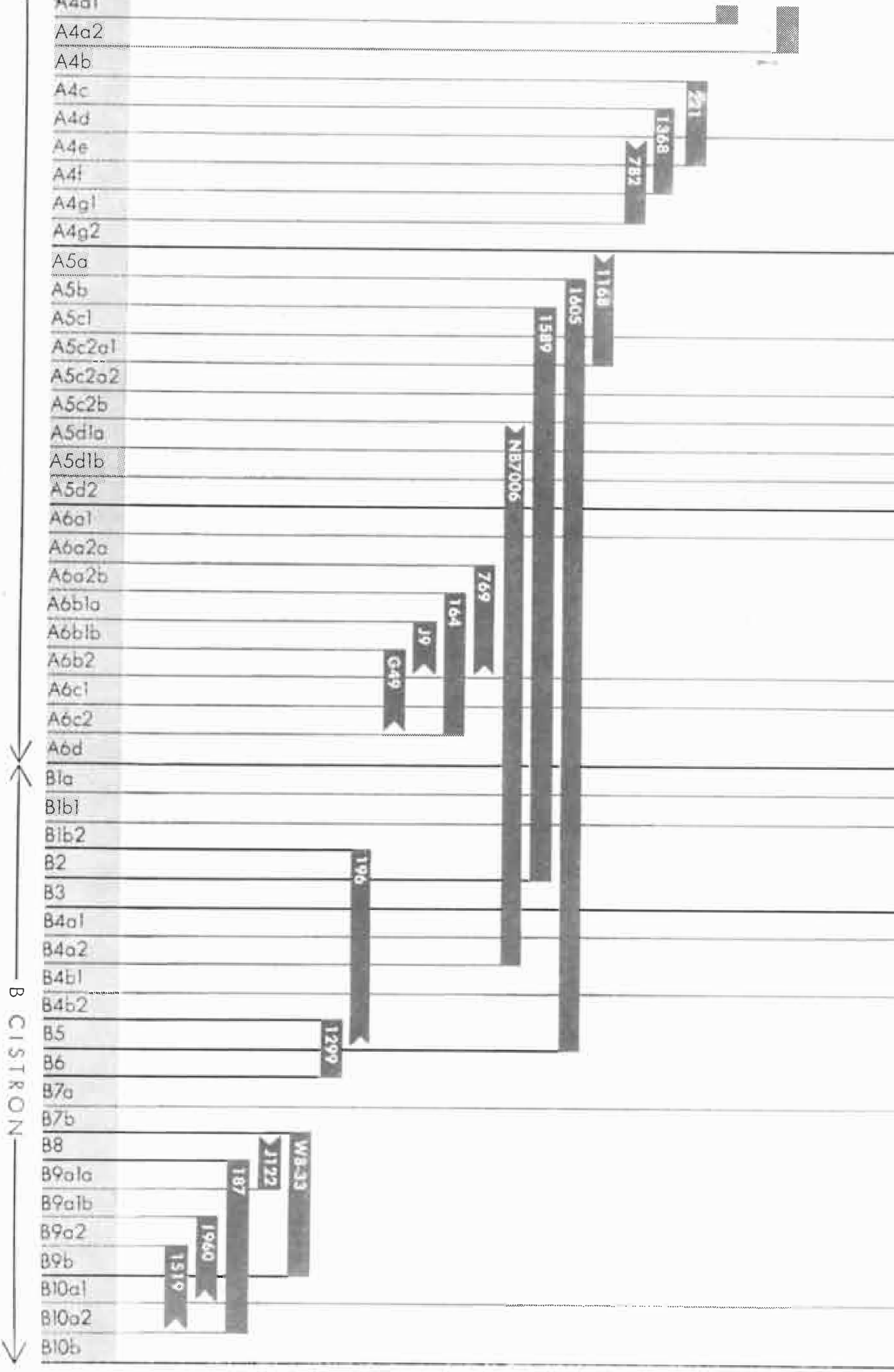
We have, then, genetic units of various sizes: the small units of mutation and recombination, much larger cistrons and finally the *r*II region, which includes both cistrons. Which one of these shall we call the gene? It is not surprising to find geneticists in disagreement, since in classical genetics the term "gene" could apply to any one of these. The term "gene" is perfectly acceptable so long as one is working at a higher level of integration, at which it makes no difference which unit is being referred to. In describing data on the fine level, however, it becomes essential to state unambiguously which operationally defined unit one is talking about. Thus in describing experiments with *r*II mutants one can speak of the *r*II "region," two *r*II "cistrons" and many *r*II "sites."

Some workers have proposed using the word "gene" to refer to the genetic unit that provides the information for one enzyme. But this would imply that one should not use the word "gene" at all, short of demonstrating that a specific enzyme is involved. One would be quite hard pressed to provide this evidence in the great majority of cases in which the term has been used, as, for example, in almost all the mutations in *Drosophila*. A genetic unit should be defined by a genetic experiment. The absurdity of doing otherwise can be seen by imagining a biochemist describing an enzyme as that which is made by a gene.

We have seen that the topology of the *r*II region is simple and linear. What can be said about its topography? Are there local differences in the properties of the various parts? Specifically, are all the subelements equally mutable? If so, mutations should occur at random throughout the structure and the topog-

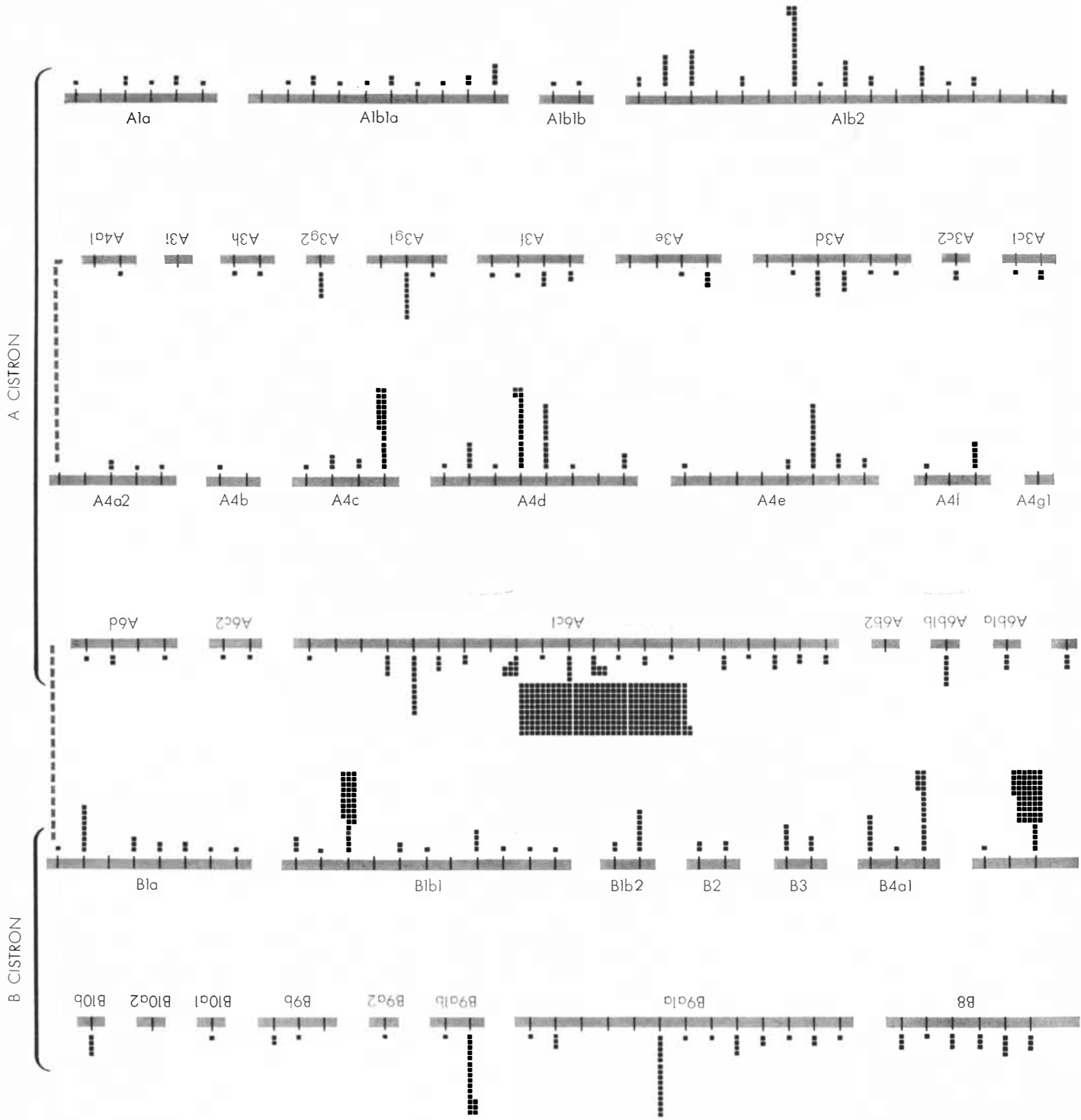


DELETION MAP shows the reference mutants that divided the *r*II region into 80 segments. These mutants behave as if various sections of the DNA molecule had been deleted or inactivated, and as a class they do not revert, or back-mutate, spontaneously to produce standard phage. Mutants that do revert usually act as if the mutation is localized at a single point on the DNA molecule. Where this point falls in the *r*II region is determined by systematically crossing the revertible mutant with these reference deletion mutants, as illustrated on page 76. The net result is to assign the point mutation to smaller and smaller segments of the map.



raphy would then be trivial. On the other hand, sites or regions of unusually high or low mutability would be interesting topographic features. To answer this question one isolates many independently arising *r*II mutants and maps each one to see if mutations tend to occur more frequently at certain points than at others. Each mutation is first localized into a main segment, then into a smaller segment, and finally mutants of the same small segment are tested against each other. Any that show recombination are said to define different sites. If two or more reverting mutants are found to show no detectable recombination with each other, they are considered to be repeats, and one of them is chosen to represent the site in further tests. A set of distinct sites is thereby obtained, each with its own group of repeats. The designation of a mutant as a repeat is, of course, tentative, since in principle it remains possible that a more sensitive test could show some recombination.

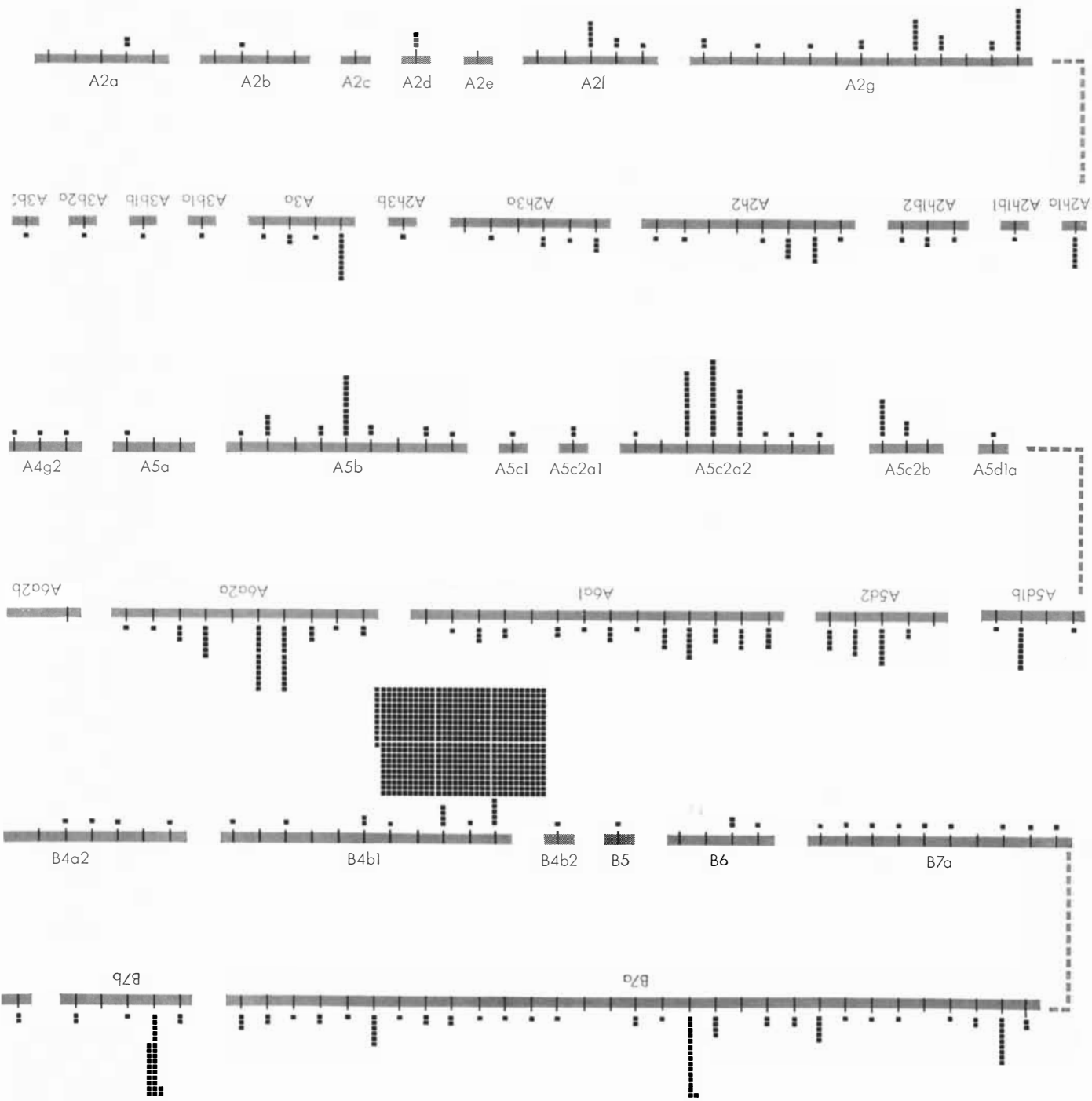
The illustration on these two pages shows a map of the *r*II region with each occurrence of a spontaneous mutation indicated by a square. These mutations, as well as other data from induced mutations, subdivide the map into more than 300 distinct sites, and the distribution of repeats is indeed far from random. The



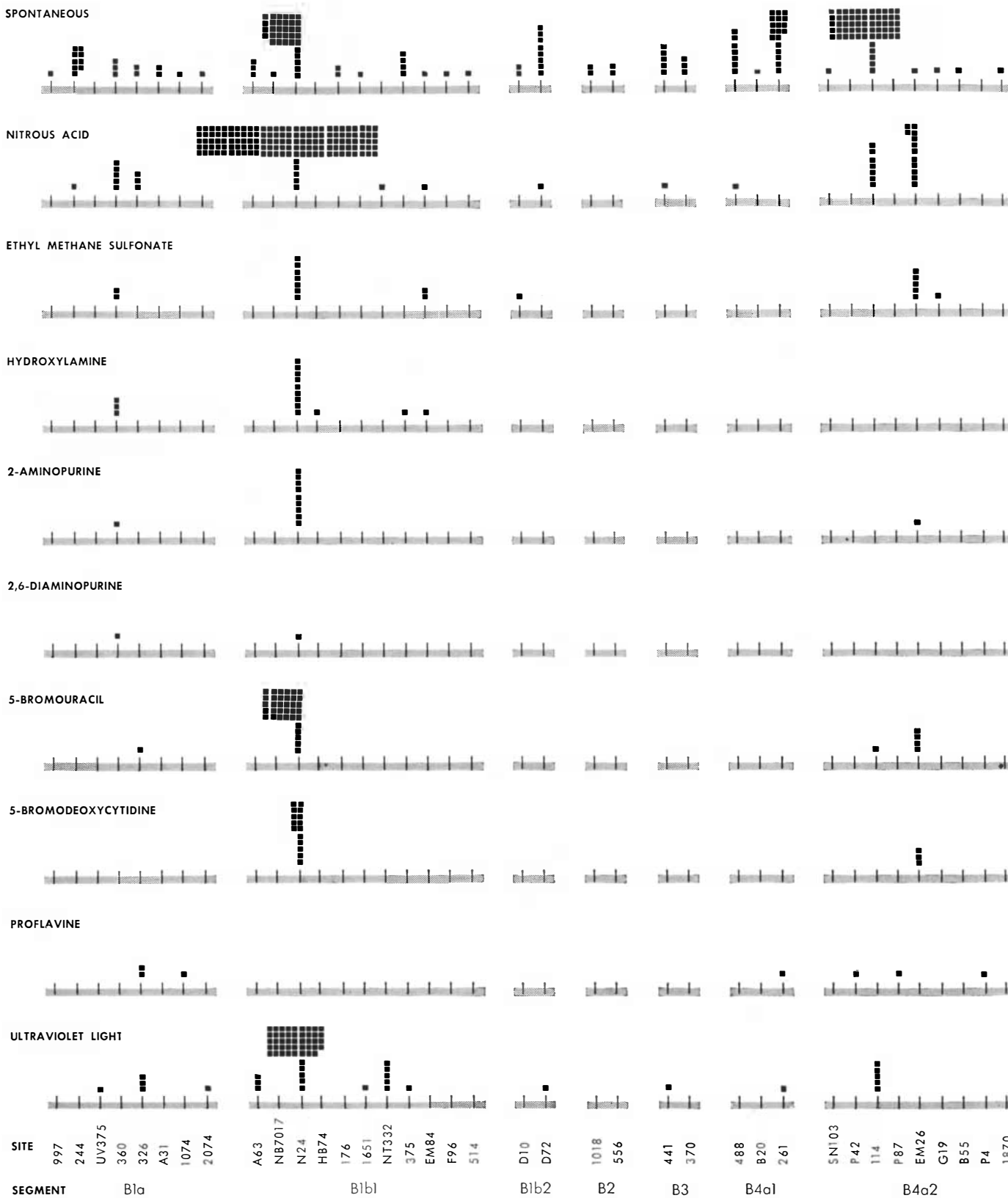
FREQUENCY OF SPONTANEOUS MUTATIONS at various sites is shown in this complete map of the *r*II region. Alternate rows have been deliberately inverted to indicate that the region is a continuous molecular thread. Each spontaneous mutation at a site

topography for spontaneous mutation is evidently quite complex, the structure consisting of elements with widely different mutation rates.

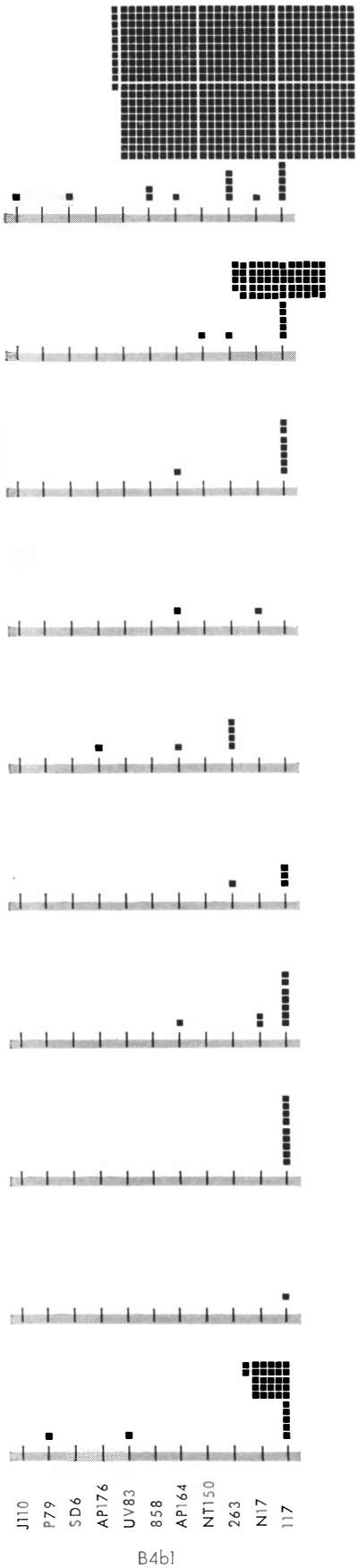
Spontaneous mutation is a chronic disease; a spontaneous mutant is simply one for which the cause is unknown. By using chemical mutagens such as nitrous acid or hydroxylamine, or physical agents such as ultraviolet light, one can alter the DNA in a more controlled manner and induce mutations specifically. A method of inducing specific mutations has long been the philosophers' stone of genetics. What the genetic alchemist desired, however, was an effect that could be directed at the gene controlling a particular characteristic. Chemical mutagenesis is highly specific but not in this way. When Rose Litman and Arthur B. Pardee at the University of California discovered the mutagenic effect of 5-bromouracil on phage, they regarded it as a nonspecific mutagen because mutations were induced that affected a wide assortment of different phage characteristics. This nonspecificity resulted because each functional gene is a structure with many parts and is bound to contain a number of sites that are responsive to any particular mutagen. Therefore the rate at which mutation is induced in various genes is more or less



is represented by a small black square. Sites without squares are known to exist because they can be induced to mutate by use of chemical mutagens or ultraviolet light (*see illustration on next two pages*), but they have not been observed to mutate spontaneously.



RESPONSE OF PHAGE TO MUTAGENS is shown for a portion of the B cistron. The total number of mutations studied is not the same for each mutagen. It is clear, nevertheless, that mutagenic action is highly specific at certain sites. Note that site 117 in



segment B4b1 is more apt to mutate spontaneously than in response to a mutagen.

the same. By fine-structure genetic analysis, however, Ernst Freese and I, working in our laboratory at Purdue University, have found that 5-bromouracil increases the mutation rate at certain sites by a factor of 10,000 or more over the spontaneous rate, while producing no noticeable change at some other sites. This indicates a high degree of specificity indeed, but at the level within the cistron. Furthermore, other mutagens specifically alter other sites. The response of part of the B cistron to a variety of mutagens is shown in the illustration on these two pages.

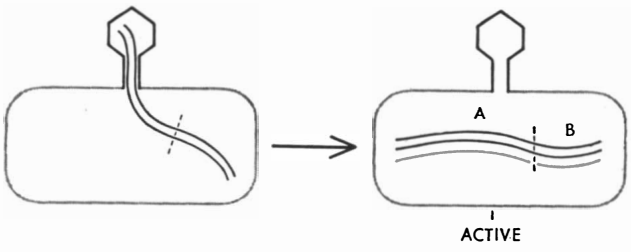
Each site in the genetic map can, then, be characterized by its spontaneous mutability and by its response to various mutagens. By this means many different kinds of site have been found. Some response patterns are represented at only a single site in the entire structure; for example, the prominent spontaneous hot spot in segment B4. This is at first surprising, because according to the Watson-Crick model for DNA the structure should consist of only two types of element, adenine-thymine (AT) pairs and guanine-hydroxymethylcytosine (GC) pairs. One possible explanation for the uneven reactivity among various sites is that the response may depend not only on the particular base pair at a site but also very much on the type and arrangement of neighboring base pairs.

Once a site is identified it can be further characterized by the ease with which a particular mutagen makes reverse mutations produce phage of standard type. Combining such studies with studies of the chemical mechanism of mutagenesis, it may be possible eventually to translate the genetic map, bit by bit, into the actual base sequence.

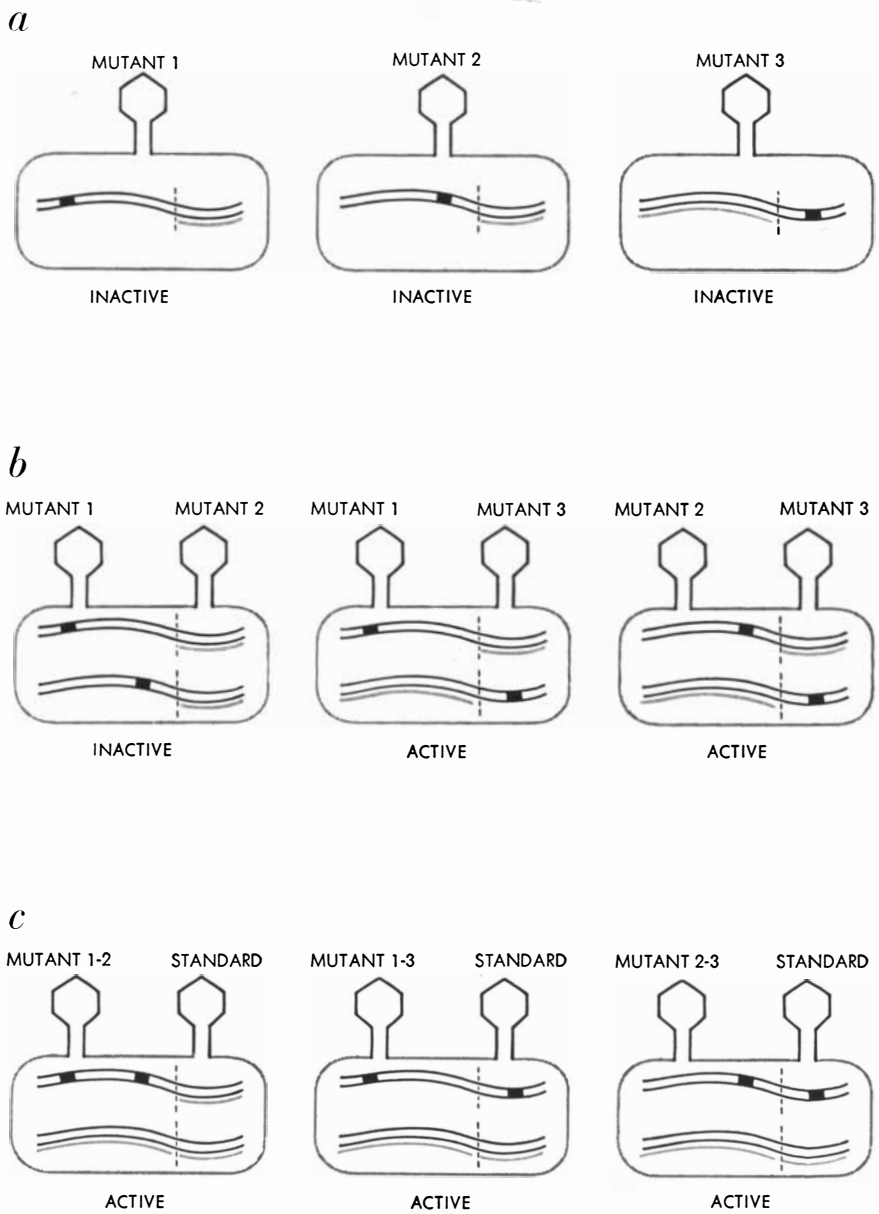
Saturation of the Map

How far is the map from being run into the ground? Since many of the sites are represented by only one occurrence of a mutation, it is clear that there must still exist some sites with zero occurrences, so that the map as it stands is not saturated. From the statistics of the distribution it can be estimated that there must exist, in addition to some 350 sites now known, at least 100 sites not yet discovered. The calculation provides only a minimum estimate; the true number is probably larger. Therefore the map at the present time cannot be more than 78 per cent saturated.

Everything that we have learned about the genetic fine structure of T4 phage is compatible with the Watson-Crick model of the DNA molecule. In



PHAGE ACTIVITY requires that the coded information inside functional units of the DNA molecule be available intact. The *r*II region consists of two functional units called A cistron and B cistron. When both are present intact (*right*), the phage actively replicates inside colon bacillus of strain K. Colored lines indicate effective removal of coded information.



***CIS-TRANS* TEST determines the size of functional units. In bacillus of strain K, T4 phage is active only if both A and B cistrons are provided intact; hence mutants *1*, *2* and *3* are inactive. (The sites of mutation have been previously established.) Tests with the three mutants taken two at a time (*b*) show that sites *1* and *2* must be in the same cistron. A test of each mutant with standard phage (*c*) provides a control; in this case all are active.**

this model the genetic information is contained in the specific order of bases arranged in a linear sequence. The four-letter language of the bases must somehow be translated into the 20-letter language of the amino acids, so that at least several base pairs must be required to specify one amino acid, and an entire polypeptide chain should be defined by a longer segment of DNA. Since the activity of the resulting enzyme, or other protein, depends on its precise structure, this activity should be impaired by any of a large number of changes in the DNA base sequence leading to amino acid substitutions.

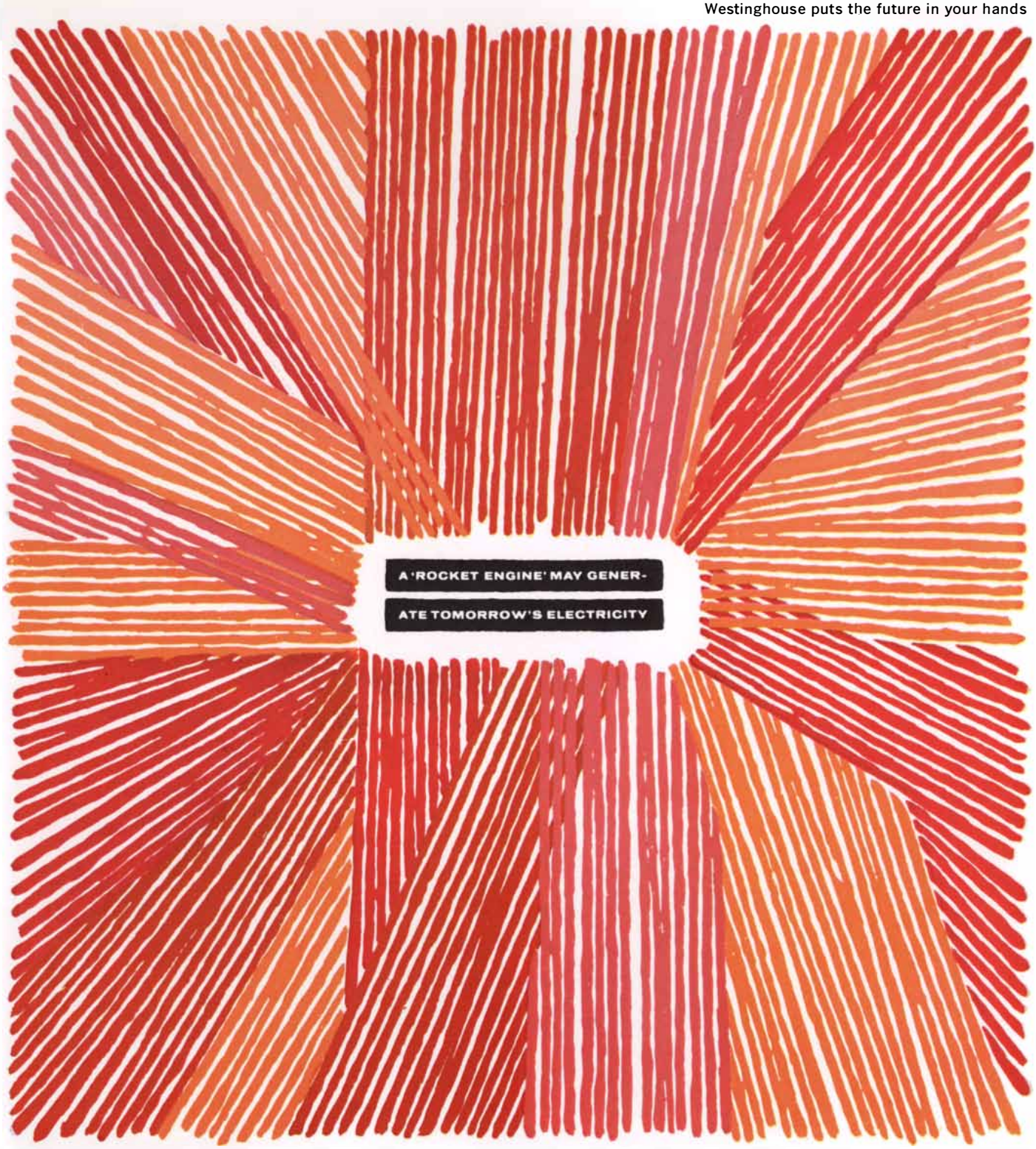
One can also imagine that certain changes in base sequence can lead to a "nonsense" sequence that does not specify any amino acid, and that as a result the polypeptide chain cannot be completed. Thus the genetic unit of function should be vulnerable at many different points within a segment of the DNA structure. Considering the monotonous structure of the molecule, there is no obvious reason why recombination should not be possible at every link in the molecular chain, although not necessarily with the same probability. In short, the Watson-Crick model leads one to expect that the functional units—the genes of traditional genetics—should consist of linear segments that can be finely dissected by mutation and recombination.

Mapping Other Genes

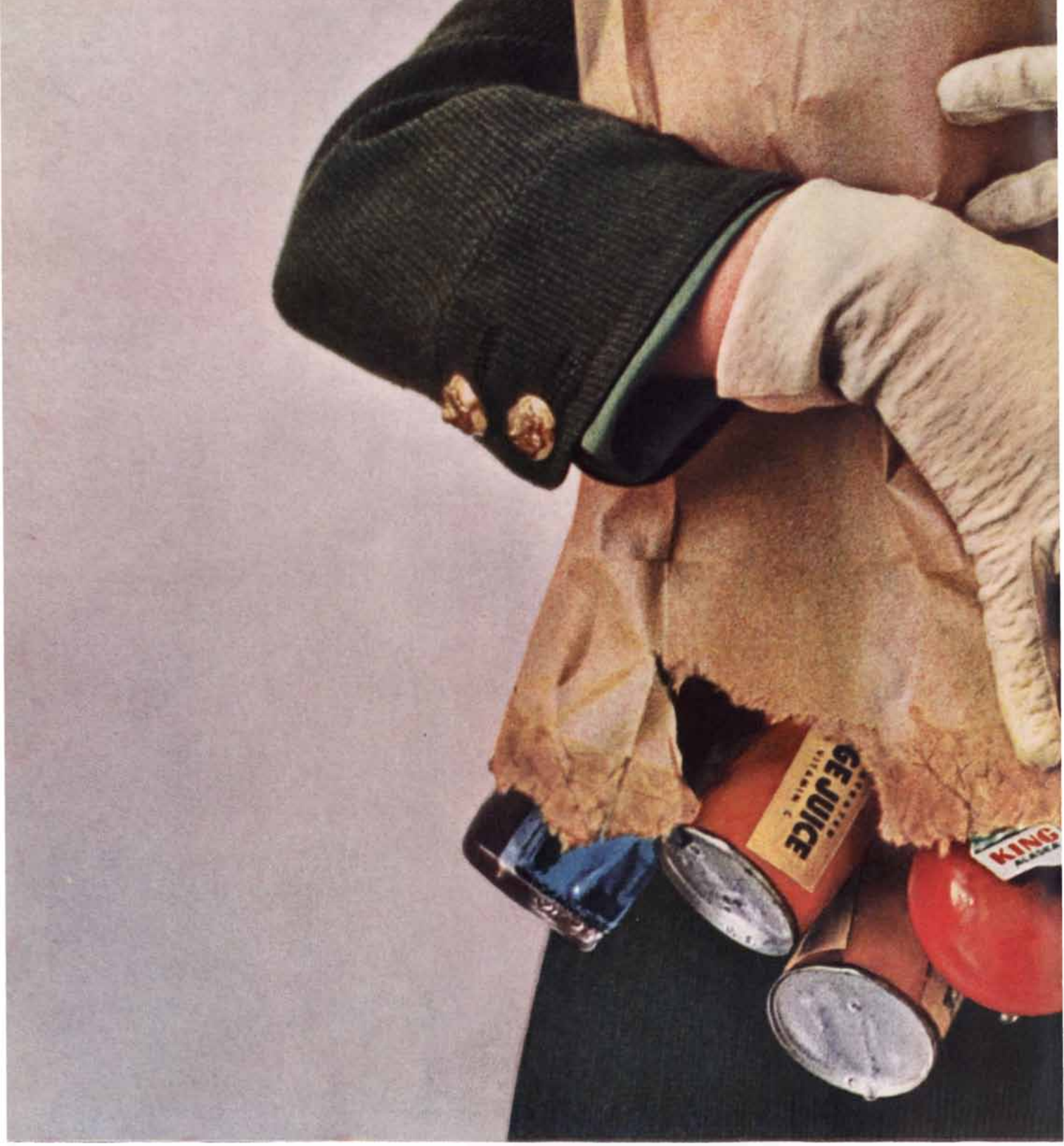
The genetic results fully confirm these expectations. All mutations can in fact be represented in a strictly linear map, the functional units correspond to sharply defined segments, and each functional unit is divisible by mutation and recombination into hundreds of sites. Mutations are induced specifically at certain sites by agents that interact with the DNA bases. Although the data on mutation rates are complex, it is quite probable that they can be explained by interactions between groups of base pairs.

In confining this investigation to *r*II mutants of T4, attention has been focused on a tiny bit of hereditary material constituting only a few per cent of the genetic structure of a virus, enabling the exploration to be carried almost to the limits of the molecular structure. Similar results are being obtained in many other microorganisms and even in higher organisms such as corn. Given techniques for handling cells in culture in the appropriate way, man too may soon be a subject for genetic fine-structure analysis.

Westinghouse puts the future in your hands



Today's electricity is produced in some of the biggest, most ingenious and precise equipment ever built. One part... the turbine... is as big as a locomotive, revolves at the speed of sound, is so hot it glows a cherry red, and its parts fit together like a fine watch. That's today's best method, and it's gone about as far as it can go. And so Westinghouse, which builds this equipment, is experimenting with completely new methods of producing electricity. Some of them are rather exotic. One method produces electricity by shooting a stream of gas between a set of magnets. Sounds simple, but this is like handling the roaring exhaust of a rocket. The gas travels 2,000 miles an hour at 5,000 degrees F. This method has a jawbreaker of a name... magnetohydrodynamics. Called MHD for short. It is a jawbreaker of a problem. But companies like Westinghouse are nearing a solution. A Westinghouse MHD generator has produced electricity for 52 minutes. That's five times as long as any other has ever run. If MHD "works," we will be in a new world of electric power. You can be sure... if it's **Westinghouse**



Who took the OOPS out of supermarket shopping?

Frozen food packages are wet. So are milk containers. Load a week's groceries on top of them and OOPS! Grocery clerks sometimes try to solve this problem by doubling up on bags. But two bags cost the grocer twice as much as one bag. ■ Olin has developed WaterBuff,® a water-resistant bag that can carry a load of soaking wet groceries for 45 minutes. That means one bag for the clerk to use. One bag for the grocer to pay for. One bag that carries the groceries all the way home. ■ Another creative solution to a problem . . . from the Packaging Division of Olin.

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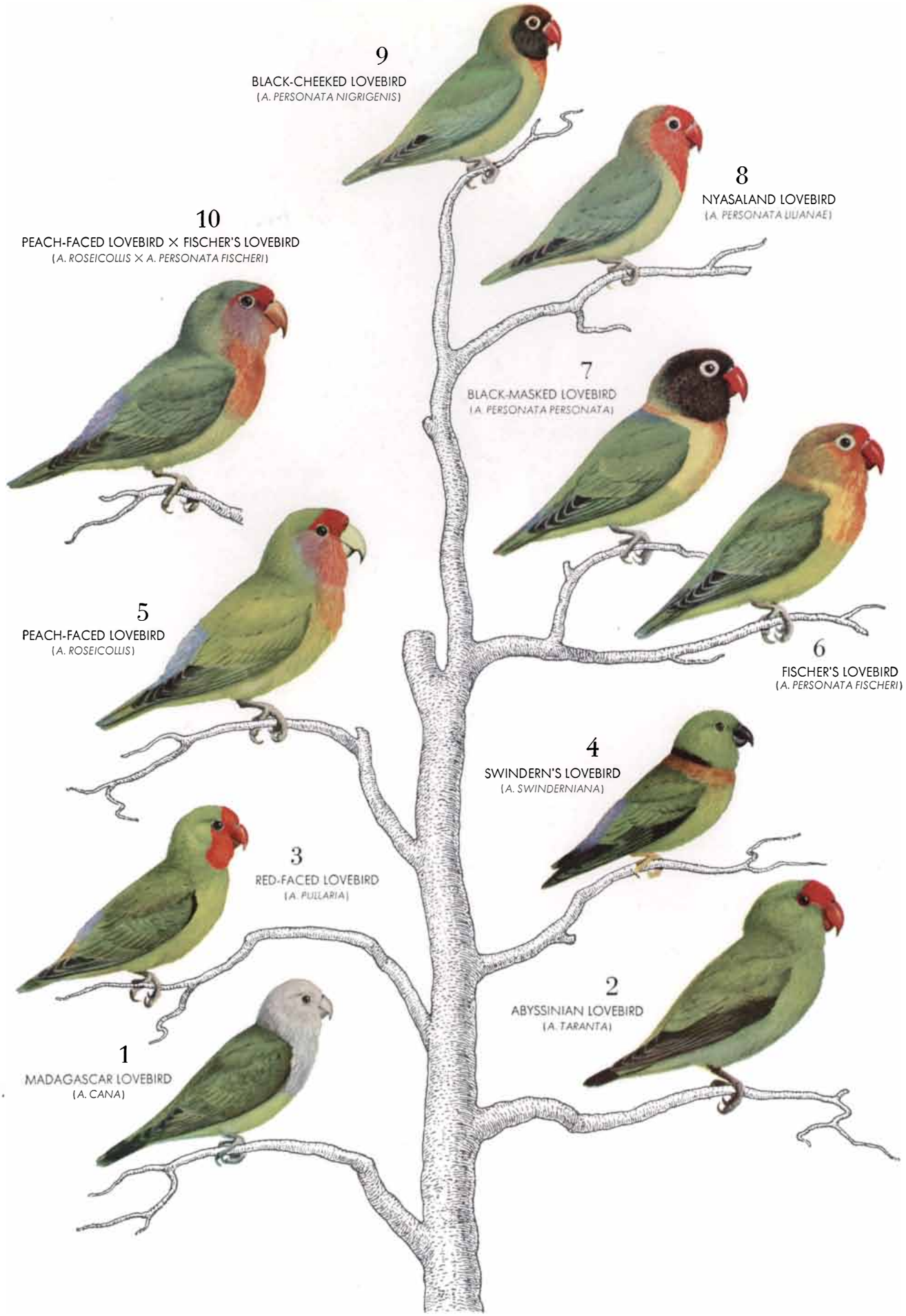


The Behavior of Lovebirds

The nine members of the genus Agapornis have different rituals for such activities as nest building. These differences shed light on the evolution of lovebirds and on the role of heredity in behavior

by William C. Dilger

All lovebirds display the behavior that gives them their anthropomorphic common name. They pair early, and once pairs are formed they normally endure for life. The partners exhibit their mutual interest with great constancy and in a variety of beguiling activities. For the student of the evolution of animal behavior the lovebirds have special interest. The genus comprises nine forms (species or subspecies). They show a pattern of differentiation in their behavior that corresponds to their differentiation in color and morphology. By comparative study of their behavior, therefore, one can hope to reconstruct its evolution and to observe how natural selection has brought about progressive variations on the same fundamental scheme.

Together with my colleagues in the Laboratory of Ornithology at Cornell University, I have been studying both the constants and the variables in lovebird behavior for the past five years. It is not too difficult to duplicate in the laboratory the basic features of the lovebirds' natural African environment, so the birds thrive in captivity. Our work has covered all the lovebirds except Swindern's lovebird; we have not been able to obtain any specimens of this species. Our findings in two areas—sexual behavior and the defense and construction of the nest—have been particularly fruitful, because in these areas the evolutionary changes in lovebird behavior stand out in sharp relief.

Lovebirds constitute the genus *Agapornis,* and are members of the parrot family. Their closest living relatives are the hanging parakeets of Asia (the genus *Loriculus*). Three species of lovebird—the Madagascar lovebird, the Abyssinian lovebird and the red-faced lovebird—resemble the hanging parakeets and differ from all other lovebirds in two major respects. The males and females of these three species differ in color and are easily distinguishable from each other. The male and female of the other lovebirds are the same color. In these three species the primary social unit is the pair and its immature offspring. The other lovebirds are highly social and tend to nest in colonies. In these respects, then, the Madagascar lovebird, the Abyssinian lovebird and the red-faced lovebird most closely resemble the ancestral form, and the other lovebirds are more divergent.

Our study of interspecies differentiation of behavior has begun to reveal the order in which the other species arrived on the scene. Next after the three "primitive" species is Swindern's lovebird. Then comes the peach-faced lovebird and finally the four subspecies of *Agapornis personata,* commonly referred to as the white-eye-ringed forms: Fischer's lovebird, the black-masked lovebird, the Nyasaland lovebird and the black-cheeked lovebird. There are significant differences in behavior between the peach-faced lovebird and the four white-eye-ringed forms.

Perhaps the sharpest contrasts in behavior are those that distinguish the three primitive species from the species that evolved later. Even the common generic characteristic of pairing at an early age shows changes between the two groups that must be related to their contrasting patterns of life—nesting in pairs as opposed to nesting in colonies. Among the primitive species pair formation takes place when the birds are about four months old. At that time they are entirely independent of their parents and have already developed adult plumage. In the more recently evolved species, the colonial nesting pattern of which offers them access to their contemporaries virtually from the moment of their birth, pair formation takes place even earlier: the birds are about two months old and still have their juvenile plumage.

Among all the lovebird species pair formation is a rather undramatic event. Unpaired birds seek out the company of other unpaired birds and test them, as it were, by attempting to preen them and otherwise engage their interest. Couples quickly discover if they are compatible, and generally it takes no more than a few hours to establish lifelong pairs.

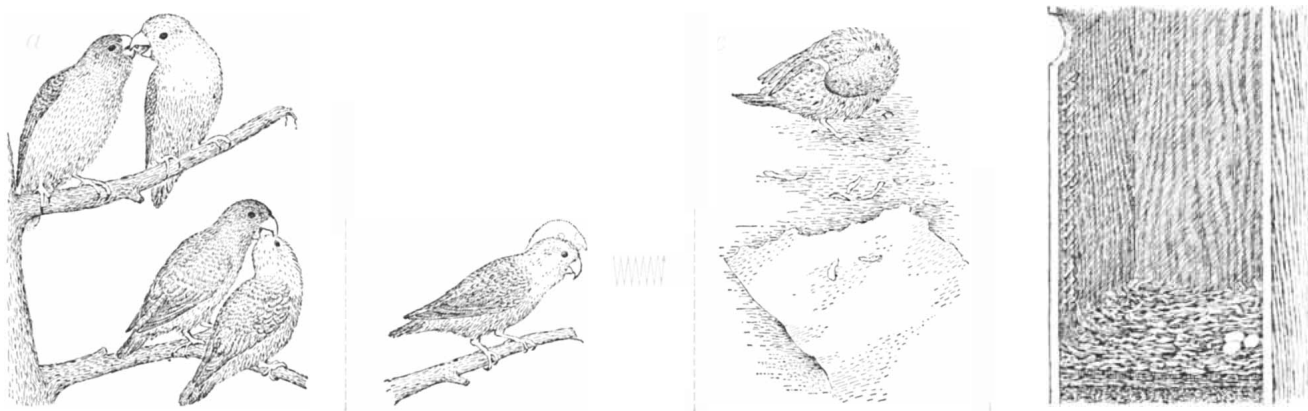
When the paired birds reach sexual maturity, their behavior with respect to each other becomes much more elaborate. This behavior as a whole is common to all lovebirds, and some activities are performed in the same way by all. Other activities, however, are not, and they show a gradation from the most primitive forms to the most recently evolved ones. One constant among all species is the female's frequent indifference to, and even active aggression against, the male each time he begins to woo her. Another is the essential pattern of the male's response—a combination of fear, sexual appetite, aggression and consequent frustration. Primarily motivated by both fear and sexual appetite, the male makes his first approach to his mate by sidling toward and then away from

NINE FORMS OF LOVEBIRD, as well as one hybrid (*top left*), are shown on the opposite page. They are arranged in their apparent order of evolution. The hybrid was bred in the laboratory for experiments on the inheritance of behavior. The letter *A.* at the beginning of each of the Latin species names stands for the genus *Agapornis.*

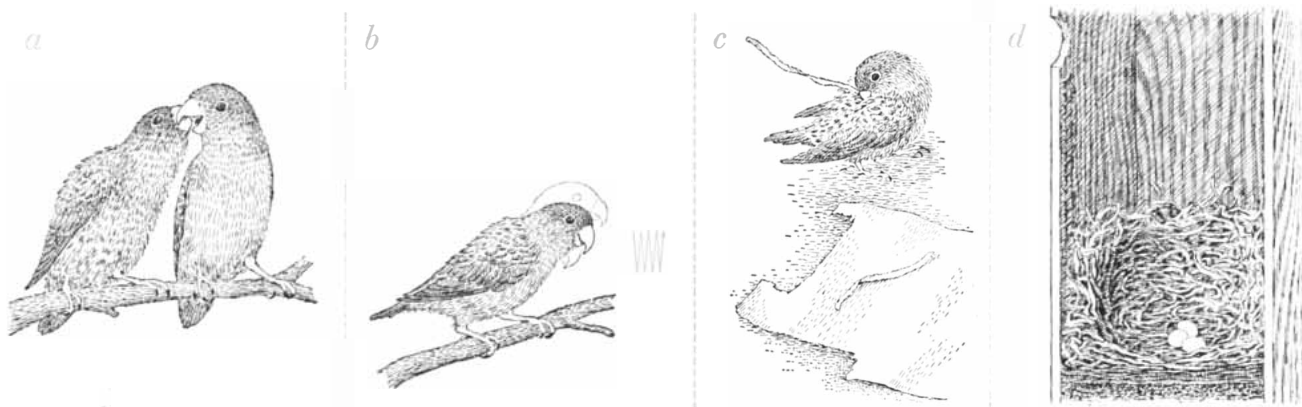
her while turning about on his perch. This switch-sidling, as it is called, is common to all species.

Two forms of male behavior initially associated with frustration, on the other hand, show a distinct evolutionary progression. The first of these activities is called squeak-twittering. Among the three primitive species—the Madagascar lovebird, the Abyssinian lovebird and the red-faced lovebird—the male utters a series of high-pitched vocalizations when the female thwarts him by disappearing into the nest cavity. The sounds are quite variable in pitch and purity of tone and have no recognizable rhythm. In the more recently evolved species—the peach-faced and the four white-eye-ringed forms—squeak-twittering is rather different. The sound is rhythmic, purer in tone and less variable in pitch. Nor does it occur only when the female has turned her back on the male and entered the nest cavity. The male usually vocalizes even when the female is present and gives no indication whatever of thwarting him. Squeak-twittering has undergone a progressive change not only in its physical characteristics but also in the context in which it appears.

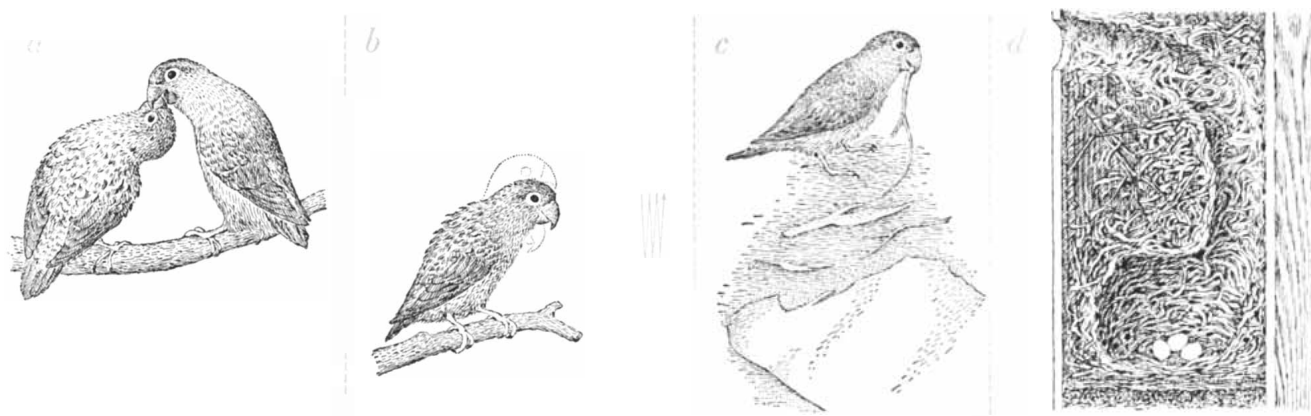
A similar evolution toward more highly ritualized behavior has occurred in another sexual activity, displacement



BEHAVIOR OF MADAGASCAR LOVEBIRD is outlined. Both sexes engage in courtship feeding (*a*). Accompanying head bobs are rapid and trace small arc (*b*). Nest materials, generally bark and leaves, are carried several pieces at a time and tucked among

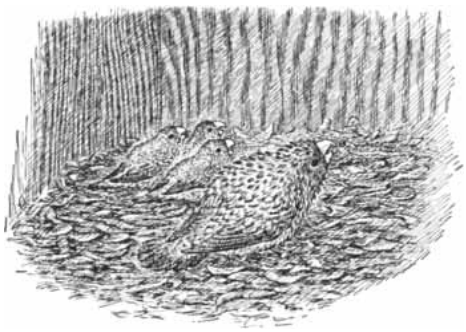


BEHAVIOR OF PEACH-FACED LOVEBIRD suggests higher evolutionary stage. Only males perform courtship feeding; females fluff their feathers during this ritual (*a*). Slower head bobs trace wider arc (*b*). Nest materials, also bark and leaves, are

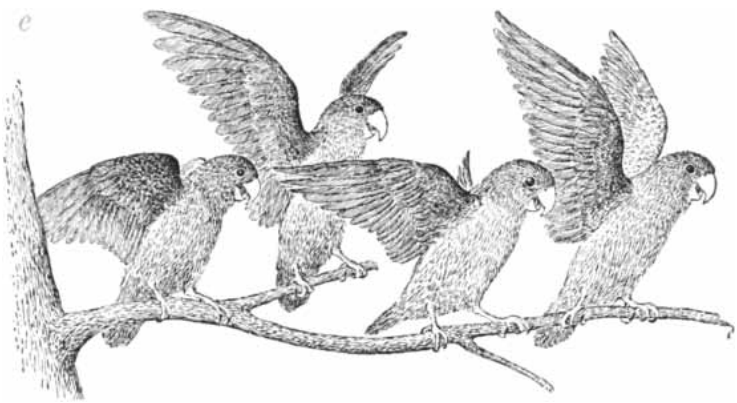


BEHAVIOR OF FISCHER'S LOVEBIRD indicates a further evolution. Courtship feeding (*a*), mobbing (*e*) and bill-fencing (*f*) are performed much as they are by the peach-faced lovebird. But other kinds of behavior are significantly different. Head bobs

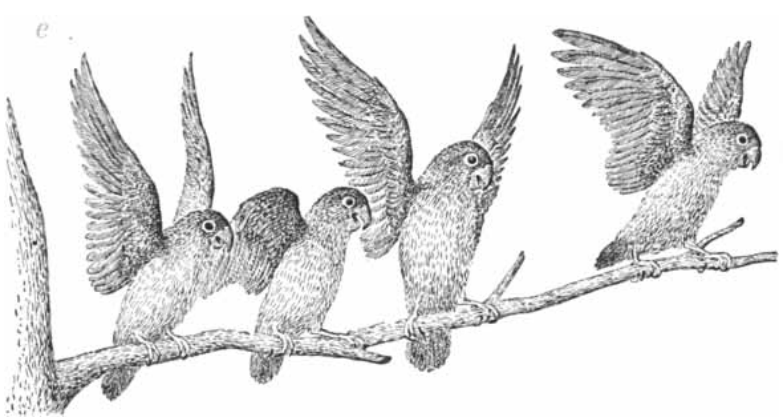
scratching. This response derives from the habit, common to all species, of scratching the head with the foot when frustrated. Among the three primitive species displacement scratching is still close to its origins. Only two things distinguish it from ordinary head-scratching: its context and the fact that it is always performed with the foot nearest the female. Purely practical considerations govern this behavior: the male already has that foot raised preparatory to mounting his mate. In the more recently evolved species, displacement scratching has become primarily a form of display. Its progressive emancipation from the original motivation with which it is associated becomes more and more apparent as one observes it in the species from the peach-faced lovebird through the white-eye-ringed forms. Among all these the scratching is far more rapid and perfunctory than it is among the primitive species. Nor is it uniformly directed at the feathered portions of the head. In the peach-faced lovebird it is sometimes directed at the bill instead, and among the Nyasaland and black-cheeked lovebirds it is nearly always so directed. Moreover, these species use the far foot as well as the near one in displacement scratching; among the Nyasaland and black-cheeked lovebirds one is



all feathers of the body (*c*). Short strips are used to make an unshaped nest pad (*d*). The young join the mother in cavity-defense display (*e*). In *f* birds show threat and appeasement display. It usually averts combat; if it fails, the birds fight furiously.



carried several at a time in back plumage (*c*); long strips are used to make a well-shaped nest (*d*). Birds join in "mobbing" to protect nest (*e*). Bill-fencing (*f*) has a display function. It never leads to real harm; the birds bite only their opponents' toes.



(*b*) are still slower and trace an even wider arc. Nest materials are carried in the bill, one piece at a time (*c*); twigs as well as strips of bark and leaf are used. This permits construction of an elaborate covered nest, entered through a tunnel (*d*).

used as often as the other. Finally, as in the case of squeak-twittering, which is often performed at the same time as displacement scratching among these species, the display occurs even when the female does not seem to be thwarting her mate.

All species engage in courtship feeding: the transfer of regurgitated food from one member of the pair to the other. In the three primitive species the female often offers food to her mate. This behavior has never been observed among the peach-faced and white-eye-ringed forms; here courtship feeding seems exclusively a male prerogative.

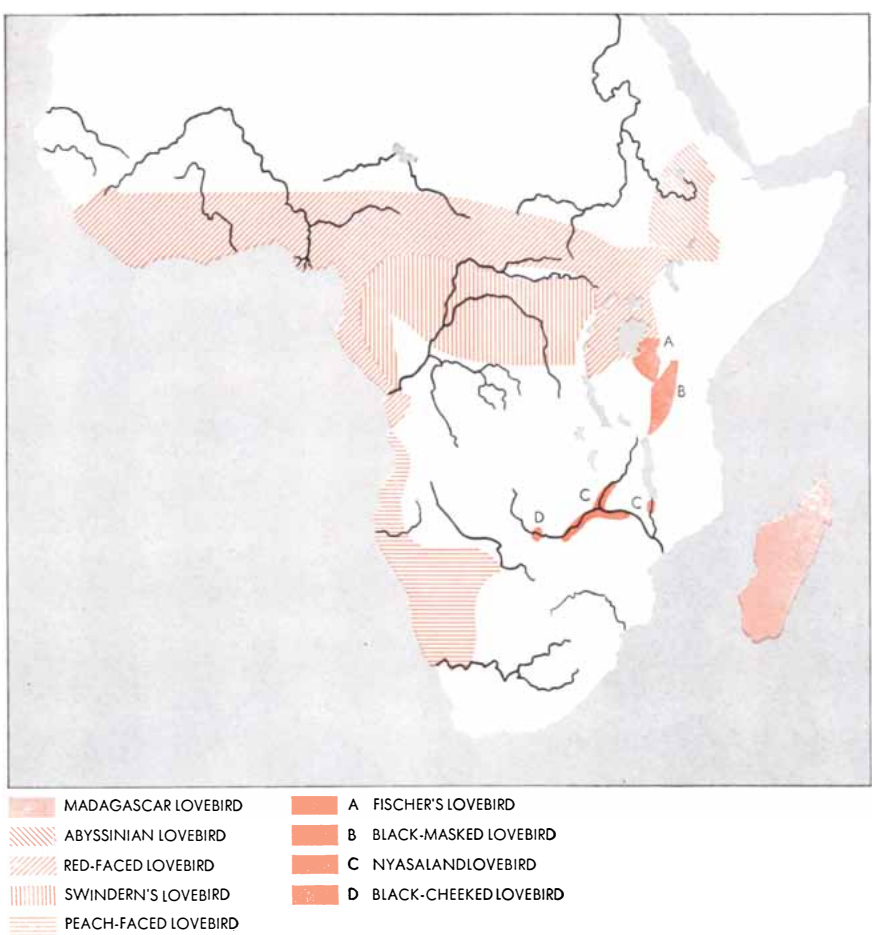
One can also discern an evolutionary progression in the manner in which the birds carry out the rather convulsive bobbing of the head associated with the act of regurgitation that immediately precedes courtship feeding. Among the primitive species these head-bobbings describe a small arc, are rapid and numerous and are usually followed by rather prolonged bill contacts while the food is being transferred. In the other forms the head-bobbings are slower, fewer in number and trace a wider arc; the bill contacts usually last for only a short time. Moreover, among the more recently evolved forms head-bobbing has become pure display; it is no longer accompanied by the feeding of the female. Unlike the females of the primitive lovebird species, which have no special display activity during courtship feeding, the females of the more recently evolved species play a distinctly ritualized role. They ruffle their plumage throughout the entire proceeding.

Females of all species indicate their fluctuating readiness to copulate by subtle adjustments of their plumage, particularly the feathers of the head. The more the female fluffs, the readier she is, and the more the male is encouraged. Finally she will solicit copulation by leaning forward and raising her head and tail. Females of the primitive species do not fluff their plumage during copulation; females of the more recently evolved species do. This is undoubtedly related to the morphological differences among the lovebirds. Since males and females of the more recently evolved species have the same coloring and patterning, the females must reinforce their mates' recognition of them, both in courtship and in copulation, by some behavioral means.

Although the forms of precopulatory behavior seem to be innate among all species, learning appears to play a major role in producing the changes that occur as the members of a pair become more familiar with each other. Newly formed pairs are rather awkward. The males make many mistakes and are frequently threatened and thwarted by their mates. After they have had a few broods, however, and have acquired experience, they become more expert and tend more and more to perform the right activity at the right time. As a result the female responds with aggression far less often, and the male engages more rarely in the displays that are associated with frustration and thwarting. Squeak-twittering and displacement scratching in particular become less frequent. Switch-sidling is still performed, but with a perceptibly diminished intensity. Altogether precopulatory bouts become less protracted. In spite of the male's reduced activity, the female seems to become receptive fairly quickly.

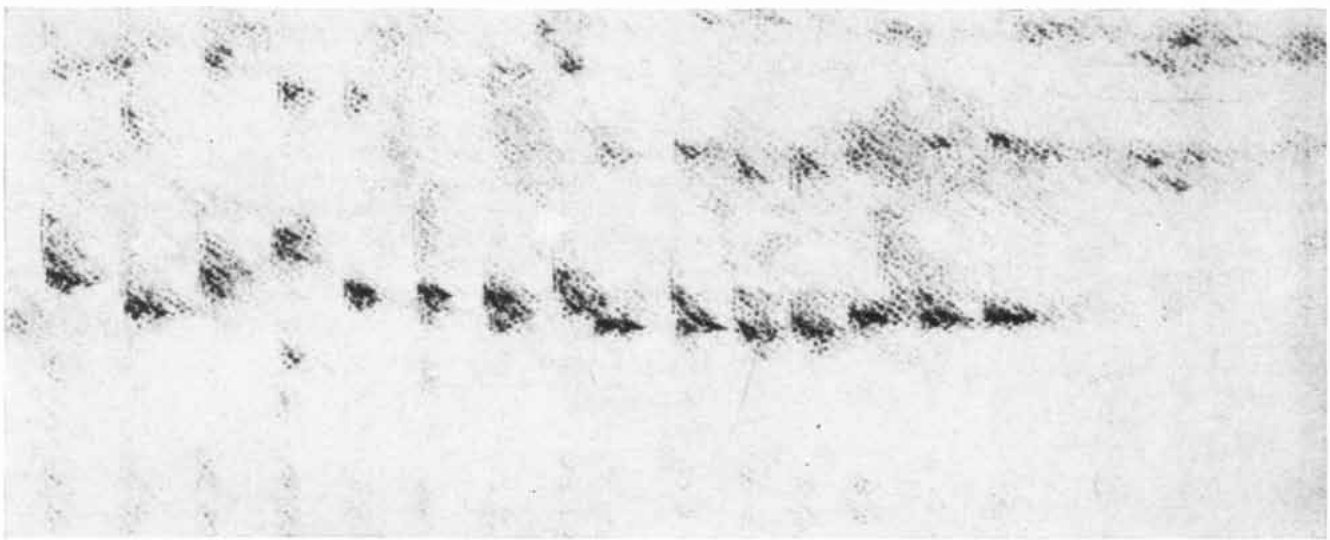
Disagreements among members of the same species are handled in quite different ways by those lovebirds that nest in pairs and those that nest colonially. Among the less social primitive species an elaborate pattern of threat and appeasement display has developed. For example, a formalized series of long, rapid strides toward an opponent signalizes aggression; a ruffling of the feathers, fear and the wish to escape. The loser in a bout of posturing may indicate submission by fleeing or by remaining quiet, turning its head away from its opponent and fluffing its plumage. By means of this code the birds can communicate rather exact items of information as to their readiness to attack or to flee. As a result actual fights seldom occur. When they do, however, the birds literally tear each other apart.

The peach-faced lovebird and the white-eye-ringed forms, which nest colonially, are thrown in contact with members of their own species much more often. This is undoubtedly related to the fact that they have developed a ritualized form of display fighting that goes far beyond a mere code of threat and appeasement and that replaces serious physical conflict. Display fighting among these more recently evolved species consists primarily of bill-fencing. The two birds parry and thrust with their bills and aim sharp nips at each other's toes.



DISTRIBUTION OF LOVEBIRDS is shown on this map of Africa and the island of Madagascar. All nine of the lovebird species and subspecies inhabit different areas.

SQUEAK-TWITTERING in male Madagascar lovebird is seen on sound spectrogram. The horizontal axis represents time; the vertical axis, frequency. Uneven distribution of spots along both axes shows an arhythmic quality and a wide variation in pitch.



SOUND SPECTROGRAM of squeak-twittering in peach-faced lovebird shows greater rhythmicity and less variation in pitch. In Madagascar lovebird behavior is displayed only when female thwarts male. In peach-faced lovebird this is not always the case.

FURTHER EVOLUTION in squeak-twittering is seen in behavior of Nyasaland lovebird. Sounds are very rhythmic and show almost no variation in pitch; wide vertical distribution of spots reflects the large number of harmonics contained in the monotonous note.

The toe is the only part the birds ever bite, and the inhibition against biting a member of the same species in any other place seems to be, like bill-fencing itself, an innate pattern. Though bill-fencing appears to be innate, it must be perfected by learning. The colonial nesting pattern offers young birds considerable practice with their contemporaries, and they quickly become skilled.

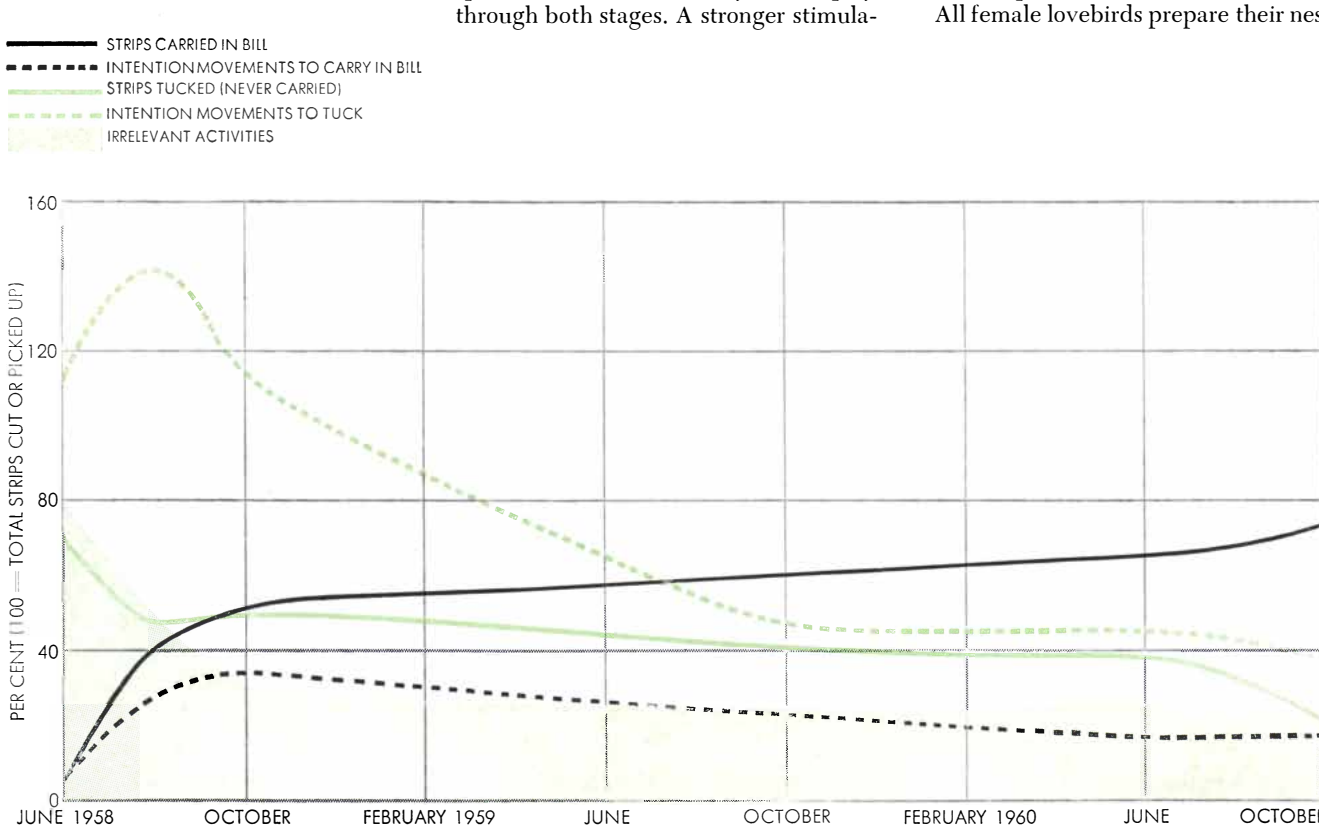
If lovebirds have had experience in rearing their own young, they will not rear the young of those other forms that have a natal down of a different color. On the other hand, a female that is given the egg of such a form at the time of her first egg-laying will rear the bird that emerges. Indeed, if a peach-faced lovebird has her first experience of motherhood with a newly hatched Madagascar lovebird, she will thereafter refuse to raise her own offspring. The down of the peach-faced lovebird's newly hatched young (like the down of the white-eye-ringed forms) is red, and the down of newly hatched Madagascar, Abyssinian and red-faced lovebirds is white.

Unlike most of the other members of the parrot family, which simply lay their eggs in empty cavities, all lovebird species make nests. The red-faced lovebird constructs its nest in a hole it digs in the hard, earthy nests certain ants make in trees. All other species, however, make their nests in pre-existing cavities, which are usually reached through small entrances. The nests of the Madagascar lovebird, the Abyssinian lovebird and the red-faced lovebird are quite simple, consisting essentially of deposits of soft material on the cavity floor. These three species have developed an elaborate cavity-defense display. The moment an intruder appears, the female ruffles her feathers, partly spreads her wings and tail and utters a rapid series of harsh, buzzing sounds. If the intruder persists, she will suddenly compress her plumage, utter a piercing yip and lunge toward it. She does not bite, but she gives every indication of being about to do so. Her older offspring may join her at this time, ruffling their feathers and making grating sounds.

The effect of this performance is quite startling; it can even give pause to an experienced investigator! The Madagascar lovebird, the most primitive of all the species, is the quickest to engage in the cavity-defense display and is the only species we have seen carry the display through both stages. A stronger stimulation is necessary before the Abyssinian lovebird engages in this behavior, and we have not seen the bird go any further than ruffling its body plumage and making the harsh, rasping sounds.

The white-eye-ringed lovebirds build rather elaborate nests, consisting of a roofed chamber at the end of a tunnel within the cavity. This fact and their strongly social nature combine to make their response to a threat to their nests different from the response of the primitive species. They have no cavity-defense displays at all. If a predator actually reaches the cavity, the birds within it will either cower or, if possible, flee through the entrance. But if the predator, encouraged by this show of fear, enters the cavity, it is likely to find that its troubles have just begun. It faces a journey down a narrow tunnel, defended at the end by a bird with a powerful and sharp bill. Moreover, a predator is seldom allowed to come close to the cavity. As soon as it is seen approaching, the entire colony engages in a form of behavior called mobbing: holding their bodies vertically, the birds beat their wings rapidly and utter loud, high-pitched squeaks. The sight and sound of a whole flock mobbing is quite impressive and probably serves to deter many would-be predators.

All female lovebirds prepare their nest



CONFLICTING PATTERNS of carrying nest-building materials are inherited by a hybrid lovebird, produced by mating the peach-faced and Fischer's lovebirds. The hybrid's behavior is charted here for a period of almost three years. As the bird progressively learns to carry nest materials as Fischer's lovebird does, the number of irrelevant movements and inappropriate activities decreases.

materials in much the same way: by punching a series of closely spaced holes in some pliable material such as paper, bark or leaf. The material is held between the upper and lower portions of the bill, which then works like a train conductor's ticket punch. The pieces cut out in this way vary in size and shape among the various lovebirds. So do the forms of behavior that now ensue.

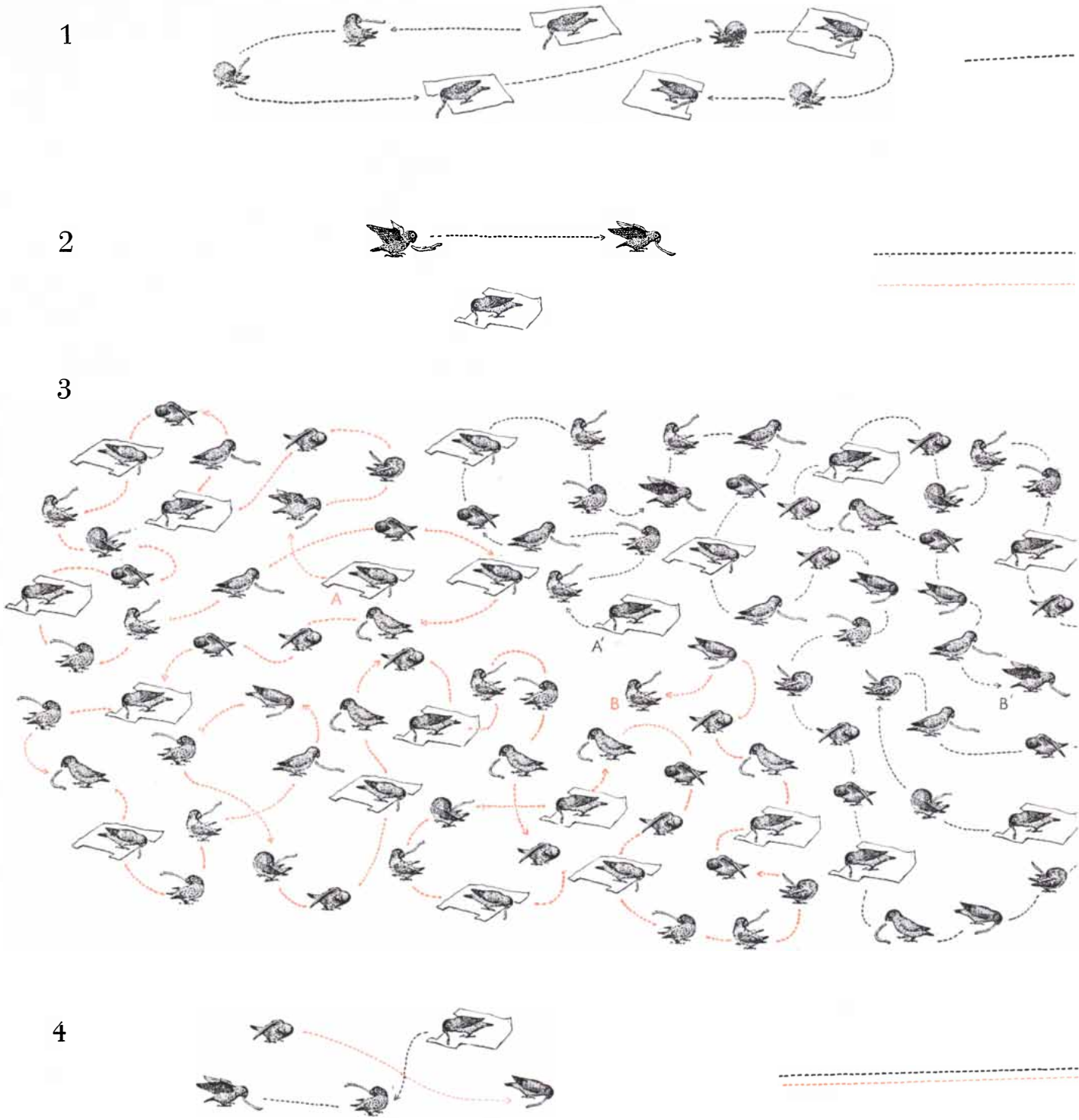
The three primitive species and the peach-faced lovebird tuck the pieces they have cut into the feathers of their bodies and fly off with them. The Madagascar lovebird, the Abyssinian lovebird and the red-faced lovebird use very small bits of material. (This is one of the reasons their nests are so unstructured.) The entire plumage of the bird is erected as it inserts the six to eight bits of material in place and remains erect during the whole operation. The peach-faced lovebird cuts strips that are considerably longer. (This permits the more elaborate structuring of its cuplike nest.) Indeed, the strips are so long that they can be carried only in the feathers of the lower back. These are the feathers erected when the strips are tucked in, and the feathers are compressed after each strip is inserted. The peach-faced lovebird loses about half of its cargo before it gets to its nest site; either pieces fall out while others are being cut or tucked in, or they fall out while the bird is flying. The lovebirds that use smaller bits of nest material are more successful in carrying them.

Carrying nest material in the feathers is unique to these birds and the related hanging parakeets. What is more, speculation about its origin must begin with the fact that no other parrots (with one unrelated exception) build nests at all. It is almost certain that this behavior arose from fortuitous occurrences associated with two characteristic parrot activities: chewing on bits of wood, bark and leaf to keep the bill sharp and properly worn down; and preening, which serves to keep the plumage clean and properly arranged. Some parrots that do not build nests will accidentally leave bits of the material in their feathers when they proceed directly from chewing to preening. Such oversights almost certainly initiated the evolution of the habit of carrying nest materials in the feathers.

The four white-eye-ringed forms are completely emancipated from this ancestral pattern. Fischer's lovebird, the black-masked lovebird, the Nyasaland lovebird and the black-cheeked lovebird all carry their nest materials as do most birds—in

their bills. They lose little material in the process of carrying, and they pick up twigs in addition to cutting strips of pliable material. With these materials, they can build their characteristically elaborate nests.

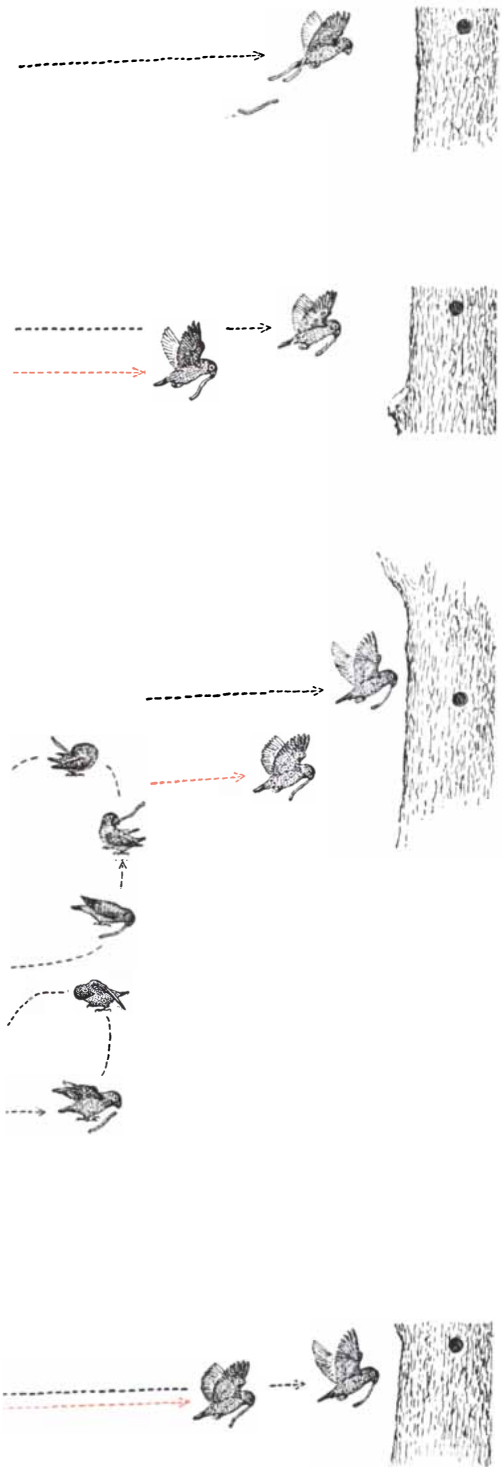
Although the peach-faced lovebird normally carries its nest-building material in its feathers, on about 3 per cent of its trips it carries material in its bill. This peculiarity suggested an experiment. We mated the peach-faced lovebird with Fischer's lovebird (the birds hybridize readily in captivity) to see what behavior would show up in the hybrids. In confirmation of the thesis that patterns of carrying nest materials are primarily innate, the hybrid displays a conflict in behavior between the tendency to carry material in its feathers (inherited from the peach-faced love-



HYBRID LOVEBIRD inherits patterns for two different ways of carrying nest-building materials. From the peach-faced lovebird (*1*) it inherits patterns for carrying strips several at a time, in feathers. From Fischer's lovebird (*2*) it inherits patterns for carrying strips one at a time, in the bill. When the hybrid first begins to build a nest (*3*), it acts completely confused. Colored lines from *A* to *B* and black lines from *A′* to *B′* indicate the number of activities necessary for it to get two strips to the nest site, a feat achieved only when the strips are carried singly, in the bill. It takes three years before the bird perfects its bill-carrying behavior (*4*),

bird) and the tendency to carry material in its bill (inherited from Fischer's lovebird).

When our hybrids first began to build their nests, they acted as though they were completely confused. They had no difficulty in cutting strips, but they could



and even then it makes efforts to tuck its nest materials in its feathers. As the bird gains experience it becomes more and more proficient in this activity, which, however, never results in successful carrying.

not seem to determine whether to carry them in the feathers or in the bill. They got material to the nest sites only when they carried it in the bill, and in their first effort at nest building they did carry in their bills 6 per cent of the time. After they had cut each strip, however, they engaged in behavior associated with tucking. Even when they finally carried the material in the bill, they erected the feathers of the lower back and rump and attempted to tuck. But if they were able to press the strips into their plumage—and they were not always successful in the attempt—they could not carry it to the nest site in that fashion. Every strip dropped out.

Two months later, after they had become more experienced, the hybrids carried many more of their nest strips in their bills—41 per cent, to be exact. But they continued to make the movements associated with the intention to tuck: they erected their rump plumage and turned their heads to the rear, flying away with material in their bills only after attempting to tuck.

After two more months had passed they began to learn that strips could be picked up in the bill and carried off with a minimum of prior abortive tucking. But it took two years for them to learn to diminish actual tucking activity to any great extent, and even then they continued to perform many of the movements associated with tucking.

Today the hybrids are behaving, by and large, like Fischer's lovebird, the more recently evolved of their two parents. Only infrequently do they attempt to tuck strips into their plumage. But it has taken them three years to reach this stage—evidence of the difficulty they experience in learning to use one innate pattern at the expense of another, even though the latter is never successful. Moreover, when they do carry out the activities associated with tucking, they perform them far more efficiently than they did at first. Evidently this behavior need not achieve its normal objective in order to be improved.

So far our hybrids have proved to be sterile and therefore unable to pass on their behavior to a second generation. Even in the first generation, however, one can see the ways in which nature interweaves innate and learned elements to produce the behavior characteristic of a species. Further comparative studies can add much to our understanding not only of the behavior of lovebirds but also of the behavior of all vertebrates, including man.

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THE PHYSIOLOGY OF AGING

The processes of aging operate during all of adult life. The decline in function that accompanies these processes is apparently due to the progressive loss of body cells

by Nathan W. Shock

With the virtual conquest of want and infectious disease in technologically advanced countries, men and women in increasing numbers are living out the promised Biblical life span of three score years and ten. The diseases of age and the fundamental process of aging are moving to the center of interest in the practice of medicine and in medical research. Few people die of old age. Mortality increases rapidly with age—in precise logarithmic ratio to age in the population as a whole—because the elderly become more susceptible to diseases that kill, such as cancer and cardiovascular disease. The diseases of old age are the province of the relatively new medical specialty known as geriatrics. A still younger discipline called gerontology deals with the process of aging itself. This is a process that continues throughout adult life. It goes on in health as well as in sickness and constitutes the primary biological factor underlying the increase in susceptibility to the diseases that are the concern of geriatrics.

Gerontology is still in the descriptive stage. Investigators have only recently developed objective standards for measurement of the decline in the performance and capacity of the body and its organ systems, and they have just begun to make such measurements on statistically significant samples of the population. The first general finding in gerontology is that the body dies a little every day. Decline in capacity and function over the years correlates directly with a progressive loss of body tissue. The loss of tissue has been shown to be associated in turn with the disappearance of cells from the muscles, the nervous system and many vital organs. To get at the causes of death in the cell gerontology has entered the realm of cellular physiology and chemistry.

The ideal way to study the aging of the human body would be to apply the same battery of tests to a large group of people at repeated intervals throughout their lives. Such a program would require dedicated subjects and a scientific staff organized for continuity of operation over a period of perhaps 50 years. Obviously some compromise must be made. Instead of starting observations on a group of subjects at age 30 and following them for 50 years, it is possible to begin with subjects of various ages and follow them for 20 years. At our laboratories in the Gerontology Branch of the Baltimore City Hospitals we started such a study on 400 men in 1958. Until this and similar undertakings have had time to yield results, gerontologists must rely on data accumulated from one-time tests of rather large numbers of different individuals ranging in age from 20 or 30 up to 80 or 90. Although subjects of any specific age differ widely, the average values for many physiological characteristics show a gradual but definite reduction between the ages of 30 and 90. Individual differences become quite apparent, for example, in studies of the amount of blood flowing through the kidneys. Whereas this function generally declines markedly with age, it is the same in some 80-year-old men as it is in the average 50-year-old man.

One of the most obvious manifestations of aging is the decline in the ability to exercise and do work. In order to measure the extent of the change it is necessary to set up laboratory experiments in which the rate of output and the amount of work done can be precisely determined along with the responses of various organ systems. Subjects may be put to walking a treadmill or climbing a certain number of steps at a specified rate. In our laboratory the subject lies on his back and turns the crank of an ergometer, an apparatus for measuring the work done. When our purpose is to measure the subject's maximum output in a given time, the crank can be adjusted to turn more stiffly or more easily. With the subject lying supine it is easier to make the necessary measurements of blood pressure, heart rate and heart output (blood pumped) and to collect the respiratory gases through a face mask for the measurement of oxygen consumption and carbon dioxide production. These measurements are customarily made before, during and after exertion in order to establish the subject's norms, his capacity and the rate at which vital functions recover their normal or resting rates.

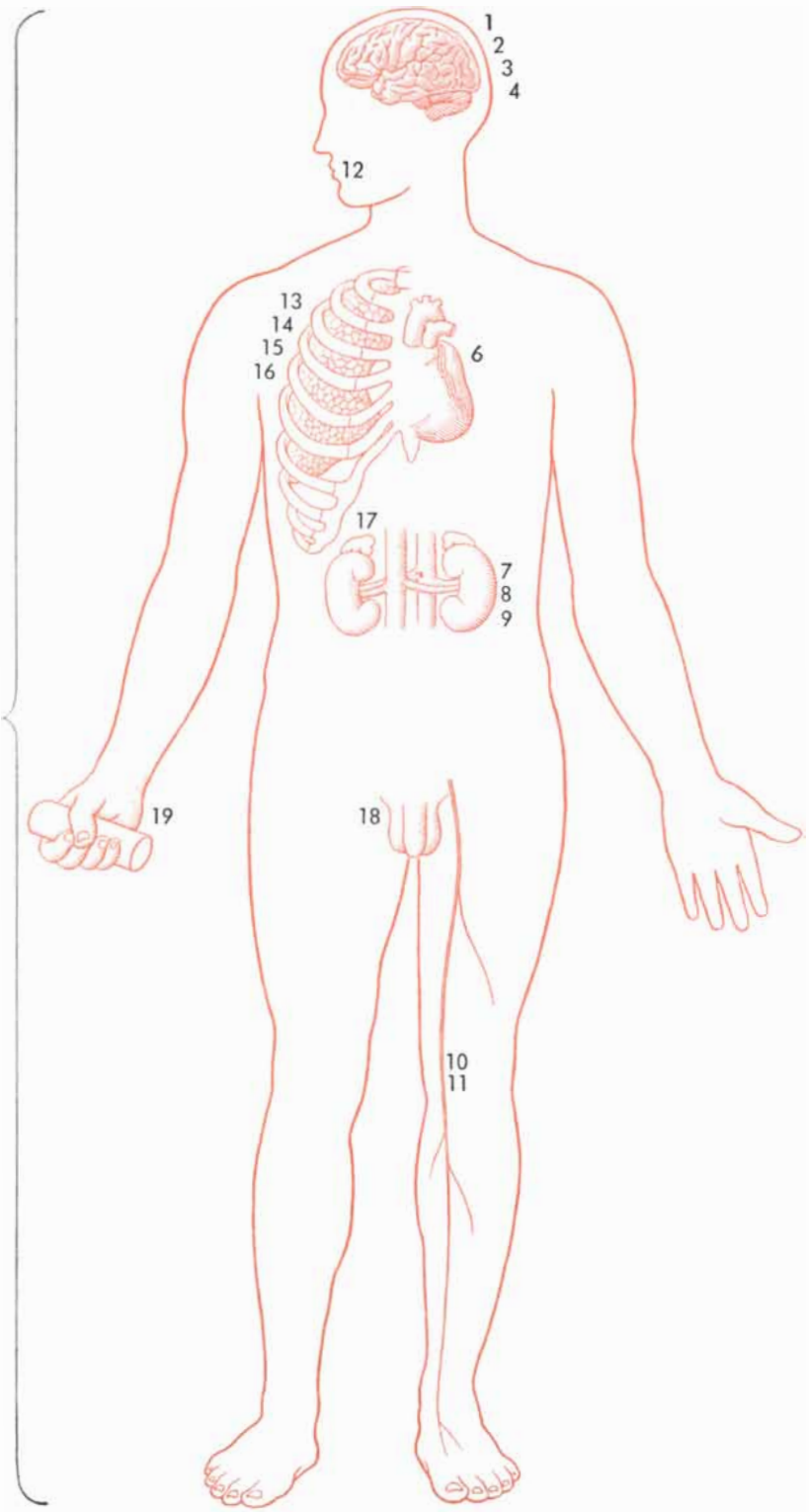
As a common denominator of capacity we seek to determine the maximum amount of work a subject can do and have his heart return to normal within two minutes after he stops working. Men 30 years old achieve an output of 500 kilogram-meters per minute (the equivalent of lifting 500 kilograms one meter in one minute), whereas 70-year-old men on the average reach only 350 kilogram-meters per minute. Thus at age 70 a man's physical capacity as defined by this test has declined by 30 per cent. Over the years from 35 to 80 the maximum work rate for short bursts of crank-turning falls almost 60 per cent, from about 1,850 kilogram-meters per minute for young men to 750 kilogram-meters for the 80-year-old.

Physical performance, of course, reflects the combined capacity of the different organ systems of the body working together. The ability to do work depends on the strength of the muscles, the co-ordination of movement by the nervous system, the effectiveness of the heart in propelling blood from the lungs to the working muscles, the rate at

which air moves in and out of the lungs, the efficiency of the lung in its gas-exchange function, the response of the kidneys to the task of removing excess waste materials from the blood, the synchronization of metabolic processes by the endocrine glands and, finally, the constancy with which the buffer systems in the blood maintain the chemical environment of the body. In order to determine the causes of the decline in overall capacity, it is necessary to assess the effects of aging on each of the organ systems.

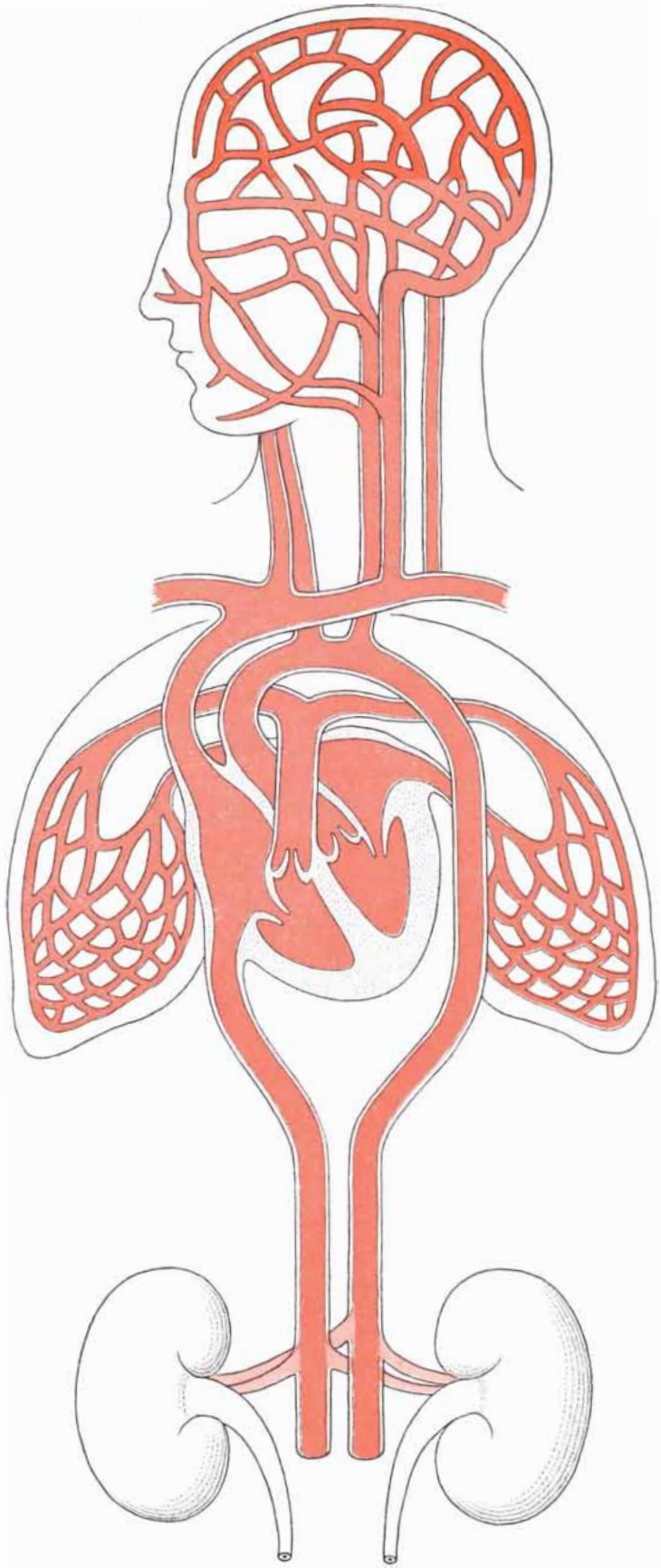
Tests of the strength of the hand serve in our laboratory to isolate one aspect of muscle function. The subject simply squeezes a grip-measuring device as hard as he can for a moment. In a group of 604 men the strength of the dominant hand dropped from about 44 kilograms of pressure at age 35 to 23 kilograms at age 90. Although the dominant hand is stronger at all ages, it loses more of its strength over the years than the subordinate hand. Endurance, measured by the average grip pressure exerted for one minute, drops from 28 kilograms at age 20 to 20 kilograms at age 75. That muscle performance is not the only factor involved in maximum work rates is indicated by the fact that the decrease in muscular strength over the years is less than the decline in work rates.

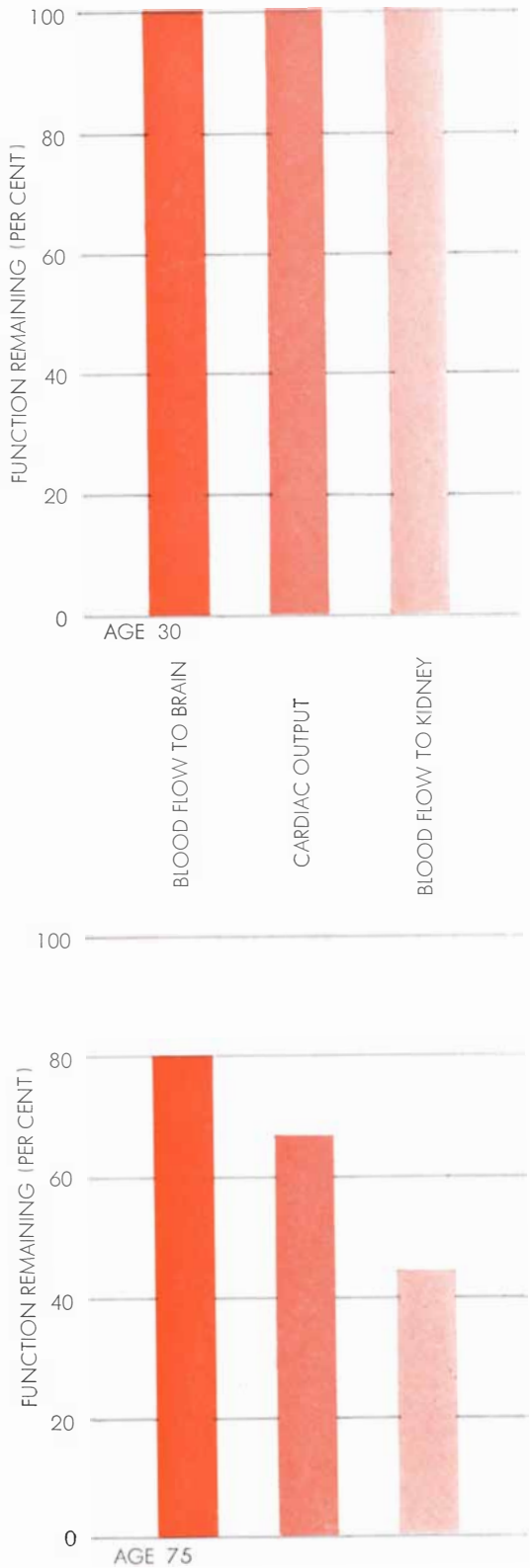
The nerve fibers that connect directly with the muscles show little decline in function with age. The speed of nerve impulses along single fibers in elderly people is only 10 to 15 per cent less than it is in young people. Simple neurological functions involving only a few connections in the spinal cord also remain virtually unimpaired. It is in the



1 BRAIN WEIGHT [56]
2 MEMORY LOSS
3 SLOWER SPEED OF RESPONSE
4 BLOOD FLOW TO BRAIN [80]
5 SPEED OF RETURN TO EQUILIBRIUM OF BLOOD ACIDITY [17]
6 CARDIAC OUTPUT (AT REST) [70]
7 NUMBER OF GLOMERULI IN KIDNEY [56]
8 GLOMERULAR FILTRATION RATE [69]
9 KIDNEY PLASMA FLOW [50]
10 NUMBER OF NERVE TRUNK FIBERS [63]
11 NERVE CONDUCTION VELOCITY [90]
12 NUMBER OF TASTE BUDS [36]
13 MAXIMUM OXYGEN UPTAKE (DURING EXERCISE) [40]
14 MAXIMUM VENTILATION VOLUME (DURING EXERCISE) [53]
15 MAXIMUM BREATHING CAPACITY (VOLUNTARY) [43]
16 VITAL CAPACITY [56]
17 LESS ADRENAL ACTIVITY
18 LESS GONADAL ACTIVITY
19 HAND GRIP [55]
20 MAXIMUM WORK RATE [70]
21 MAXIMUM WORK RATE FOR SHORT BURST [40]
22 BASAL METABOLIC RATE [84]
23 BODY WATER CONTENT [82]
24 BODY WEIGHT FOR MALES [88]

PHYSIOLOGICAL DECLINE ACCOMPANYING AGE appears in many measurements throughout the body. Changes are great in some cases, small in others. The figures in brackets following most of the labels in the key at left are the approximate percentages of functions or tissues remaining to the average 75-year-old man, taking the value found for the average 30-year-old as 100 per cent.





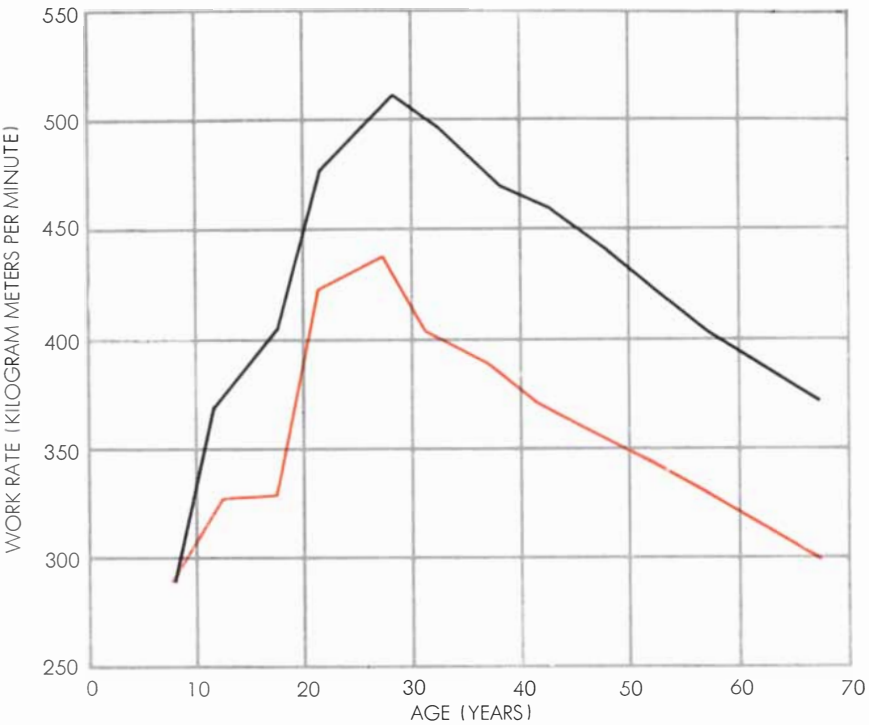
DECLINE IN HEART FUNCTION by age 75 means that both brain and kidney receive less blood than in the younger man. At age 75 the heart pumps only about 65 per cent as much blood as at age 30. The brain receives 80 per cent as much blood; the kidney, only 42 per cent as much. Large decrease in flow to kidney may be an adaptive mechanism permitting greater flow to brain.

central nervous system, where complex connections are made, that aging takes its toll. Memory loss, particularly for recent events, often plagues the elderly. The older person requires substantially more time for choosing between a number of possible responses to a situation, although with enough time he arrives at the correct decision. Certain routine mental activities, on the other hand, hardly change with age. Vocabulary comprehension, for example, remains strong in most people. Experienced proofreaders maintain a high degree of accuracy even at advanced ages.

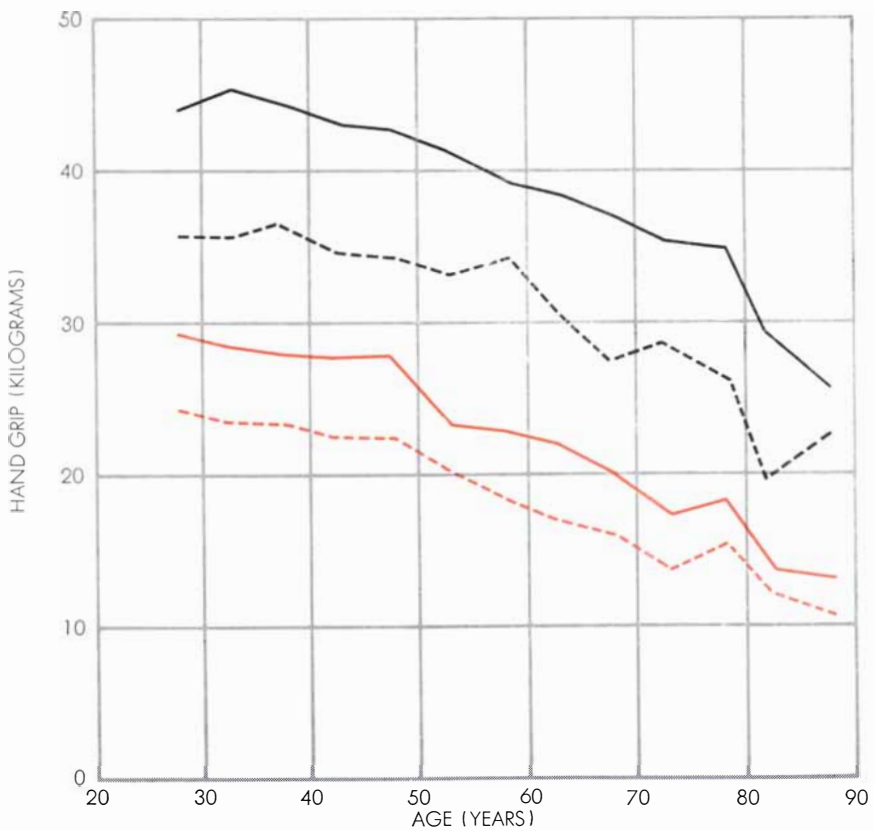
Because muscles engaged in sustained exercise require extra oxygen and other nutrients and produce more waste to be carried away, the heart must work harder to move more blood through the system. During exercise the heart pumps more blood at each stroke, at a faster rate and at higher pressure. Although the resting blood pressure in healthy individuals increases only slightly with age, a given amount of exercise will raise the heart rate and blood pressure in old people more than it will in young. And when subjects exert themselves to the maximum, the heart of the older person cannot achieve as great an increase in rate as that of the younger. During exercise, therefore, the cardiac output, or amount of blood pumped per minute, is less in the old than it is in the young. This, of course, imposes limits on the amount of work the elderly can do.

Cardiac output can be measured directly and, in subjects at rest, quite easily. (The measurements are difficult during exercise.) In one procedure a known amount of blue dye is injected into a vein of one arm and blood samples are then taken periodically from a small catheter in the large artery of the opposite leg. The dilution of the dye provides a measure of heart output. The amount of blood pumped falls from an average of 3.75 liters per minute (a liter is slightly more than a quart) per square meter of body surface in 20-year-olds to two liters per minute in 90-year-olds.

The lung plays as important a role in exercise as the heart. We have studied the two aspects of lung function—the maximum amount of oxygen that can be taken up from inspired air during exercise and the ability of the lung to move air in and out. The amount of oxygen that the blood takes up from the lung and transports to the tissues during exercise falls substantially with age. The blood of 20-year-old men takes up, on the average, almost four liters of oxygen



CHANGES IN WORK RATE with age are striking. The function reaches a peak at age 28 and declines steadily thereafter. Rate for males is shown in black, for females in color.



HAND GRIP GROWS WEAKER with age. Rate for men is shown in black, for women in color. Solid lines represent dominant hand; broken lines represent subordinate hand.

ABILITY TO DO WORK is measured by ergometer. Subject turns crank while breathing through face mask. Oxygen consumption, work rate and other functions can be measured.

TEST OF GRIP STRENGTH serves to isolate muscle function. The subject squeezes the grip and the dial registers the amount of pressure, in kilograms, that he is able to exert.

per minute, whereas at age 75 the rate is only 1.5 liters per minute. This function has been tested in several individuals over many years. D. Bruce Dill, a physiologist now at Indiana University, found that his own maximum oxygen uptake declined from 3.28 liters at age 37 to 2.80 liters at age 66.

Another measurement reveals that in order to double the level of oxygen uptake during exercise the older individual must move about 50 per cent more air in and out of his lungs. No doubt the decline in oxygen absorption reflects in part the reduced heart output, for less blood flows through the lungs of the older person in a given time. But the great difference in oxygen uptake between young and old shows that the lung tissue too has changed.

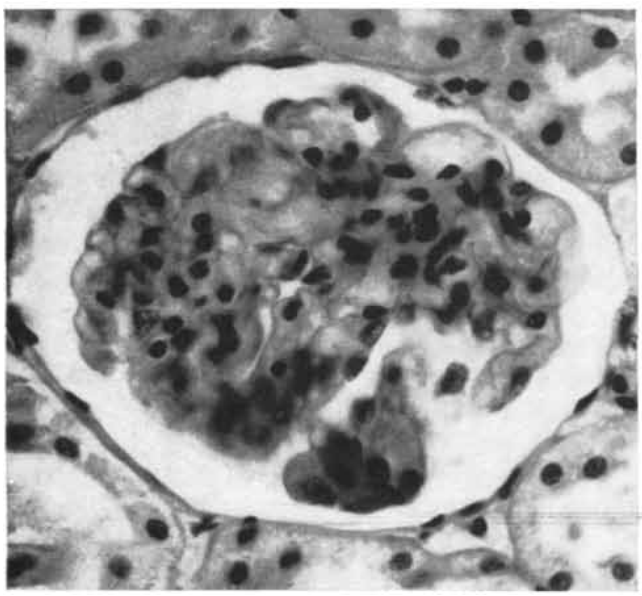
The decline in respiratory function also reflects a loss in simple mechanical efficiency. In normal respiration less air turns over and the amount of dead air space in the lungs increases, although total lung volume remains almost unchanged. Even the "vital capacity" (the amount of air that can be forcibly expired from the lung) diminishes with age. The nature of this impairment becomes clear when one measures the subject's maximum breathing capacity—the amount of air he can move through his lungs in 15 seconds. The chart for this test shows a decline of about 40 per cent between the ages of 20 and 80. Since the older person expels about as much air at each breath as the younger person does, it is clear that his capacity is less because he cannot maintain as fast a rate of breathing. The impairment is an expression of the general decline in neuromuscular capacity.

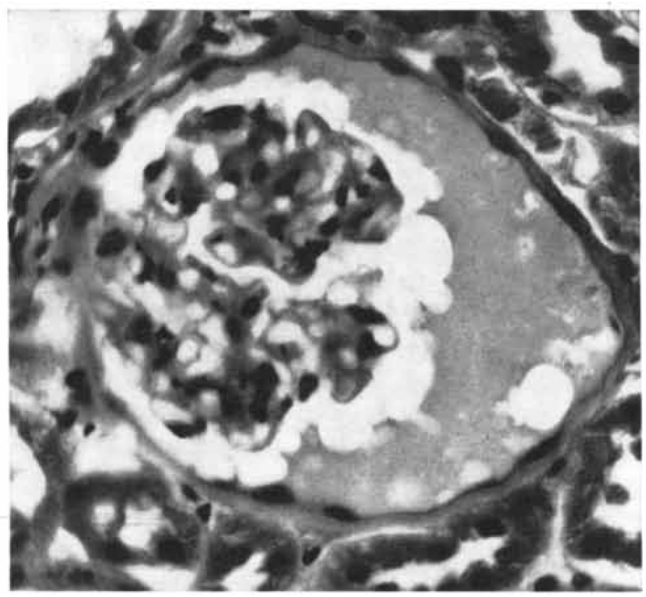
Exercise produces acids and other metabolic waste products that are excreted primarily by the kidney. Because the heart pumps less blood with advancing age, less blood flows through the kidney in a given time. Changes within the kidney itself further reduce the flow of blood as well as the efficiency with which the kidney processes the wastes. The kidney puts the blood through a delicate, multistaged process. First it filters the blood, flushing the waste products out of the bloodstream in a filtrate from which it withholds the red cells and larger molecules; then it processes this filtrate, recovering the smaller useful molecules, such as those of glucose, that get through the filter; and finally the kidney actively excretes waste molecules, some of them too large to pass through the filter. The active

functions take place in the tubular lining of the nephrons, the functional units of the kidney. A full test of kidney performance involves measurement of the amount of filtrate formed per minute, the quantity of blood plasma (the liquid portion of the blood) passing through the kidney per minute and the maximum excretory capacity of the nephrons. The measurements are made by infusing the blood with substances that the kidney removes in different ways; one substance, the metabolically inert polysaccharide inulin, goes out through the filter, whereas para-aminohippuric acid must be actively excreted. Analysis of blood samples and urine during the infusion shows how efficiently the kidney is working. Such tests show that between the ages of 35 and 80 the flow of blood plasma through the kidney declines by 55 per cent. The filtration rate and the maximum excretory capacity, as well as glucose reabsorption, decline to the same extent.

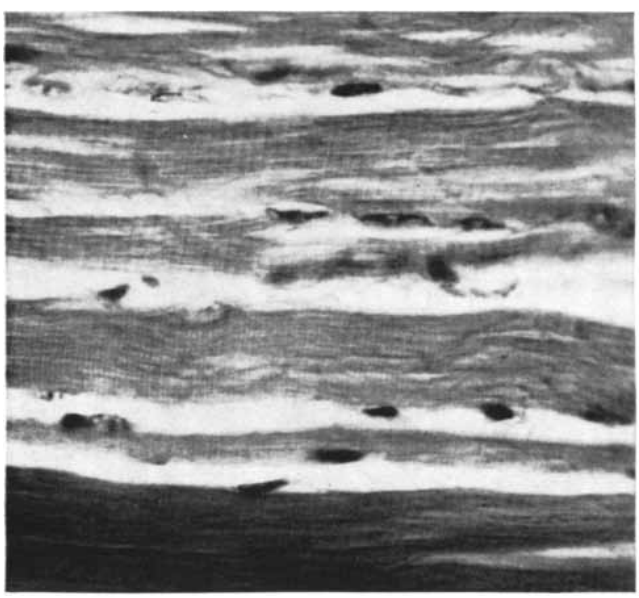
Intravenous administration of the substance pyrogen increases the flow of blood through the kidney in young and old. Apparently reduction in blood flow through the kidney is an adaptive mechanism of the aging body. It seems to result from constriction of kidney blood vessels, which makes more blood available to other organs. Because the kidney of the older person has less blood to work on it cleanses the blood of waste more slowly; given enough time, however, it will do the job.

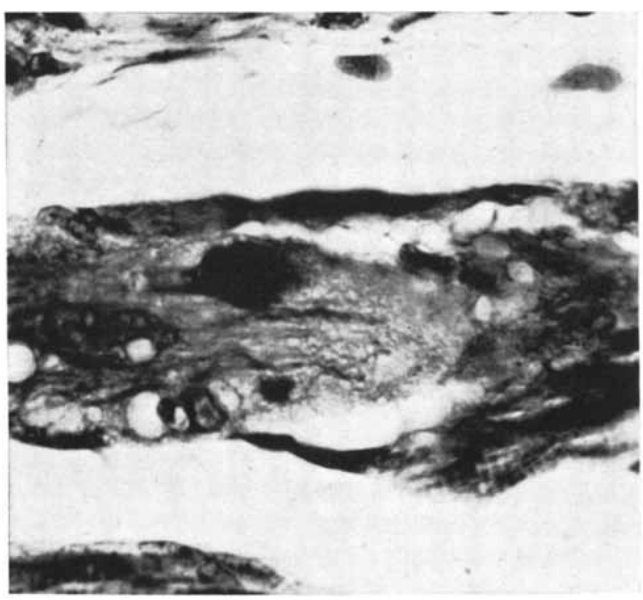
The endocrine glands regulate a wide variety of physiological processes, ranging from cellular metabolism to regulation of the diameter of small blood vessels and consequently the amount of





DEGENERATION OF KIDNEY accompanies aging in the rat. At left is a section through the kidney of a normal adult rat. Section at right is from senile rat. "Colloid" has stagnated in a glomerulus (filtration unit) of kidney, causing atrophy. Magnification is 570 diameters. These four photomicrographs were made by Warren Andrew of the Indiana University School of Medicine.





DETERIORATION OF LEG MUSCLE in rat shows plainly in these photomicrographs, each enlarged 710 diameters. Section at left is from normal adult rat, that at right from senile rat. Connective tissue has replaced many muscle fibers that have died.

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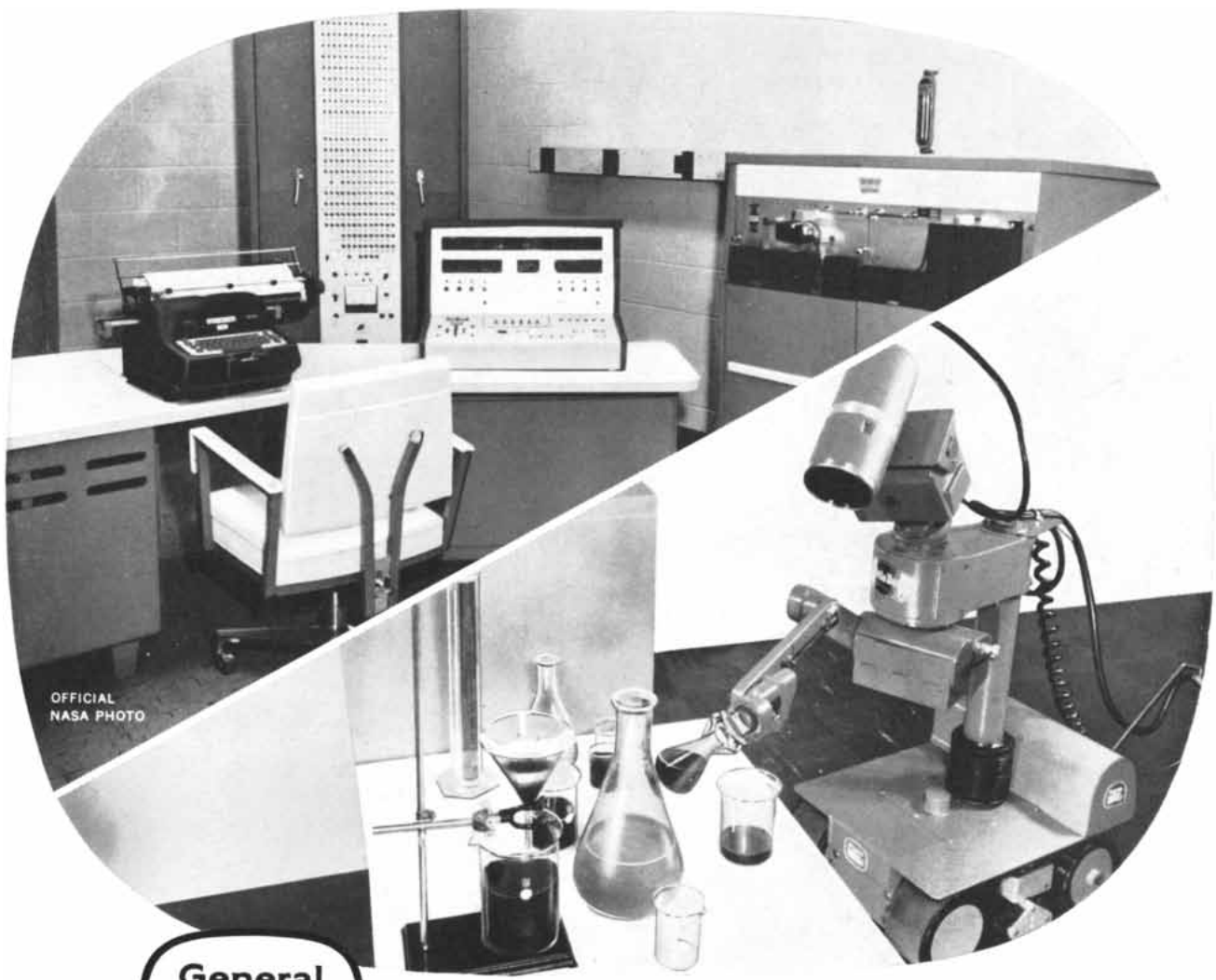

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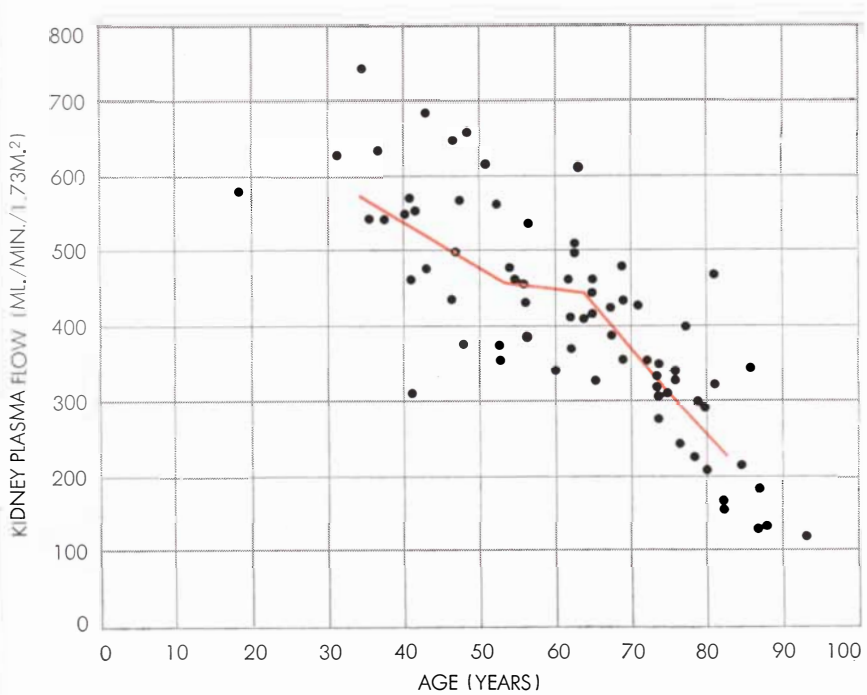
blood reaching various tissues. At the center of the endocrine system is the pituitary gland, which secretes hormones that stimulate the adrenal glands, the thyroid, the ovaries, the testes and other glands to release their hormones. There is no way to test the performance of the master gland in human subjects, but the responsiveness of other endocrine glands can be tested by administering the appropriate pituitary hormone. Sometimes the level of activity of a given gland can be estimated from the amount of its hormone or of the breakdown products of the hormone that appear in the urine. Adrenal activity is customarily measured by this means and shows a decline with age. Administration of the pituitary hormone that stimulates the cortex of the adrenals produces a smaller elevation of adrenal activity in older people. Since the adrenal hormones are the "stress" hormones, this indicates a reduction in the capacity to respond to stress. On the other hand, the pituitary hormone that stimulates the thyroid gland produces the same result in the old as it does in the young. Even at advanced ages the thyroid retains its ability to manufacture and release thyroxine, which regulates the basal metabolism, or the rate at which the resting subject consumes oxygen.

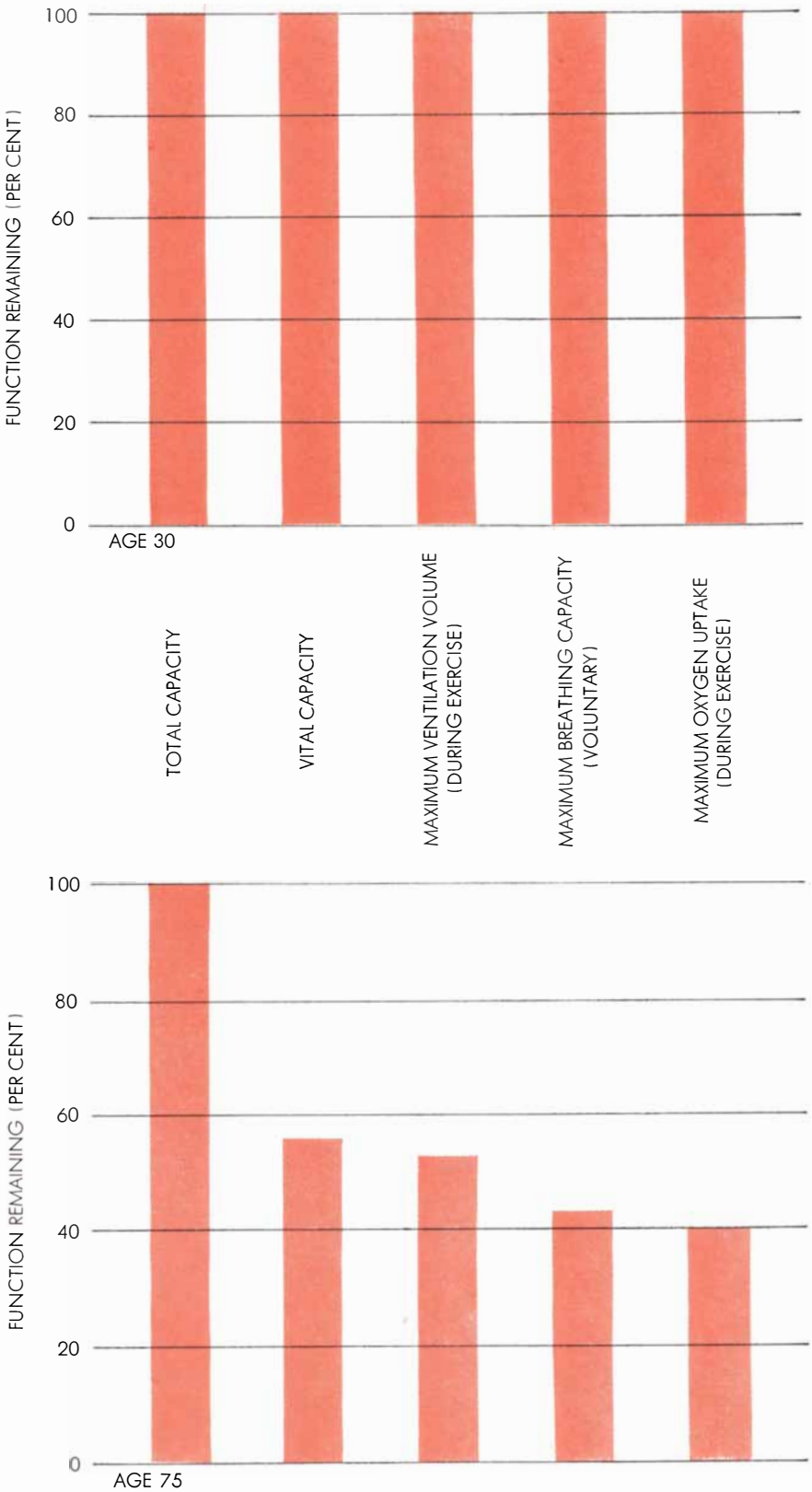
Normal function in the cells of the body requires that the chemical composition of the fluids surrounding them be closely regulated. Because the intercellular fluids cannot be sampled directly, estimates of the internal environment must come from analyses of the blood. Such factors as total blood volume, acidity, osmotic pressure, protein content and sugar content remain constant in both young and old subjects at rest. But when these variables are deliberately altered, the older person needs a much longer time to recover internal chemical equilibrium. The acidity of the blood, for example, can be increased by oral administration of ammonium chloride; a younger subject recovers normal acidity within six to eight hours, whereas the 70-year-old requires 36 to 48 hours to recover.

Although the average blood-sugar level remains quite constant even into advanced age, the rate at which the system removes extra glucose drops significantly in older people. Insulin, normally secreted by glands in the pancreas, greatly accelerates the removal of sugar from the blood. When we administer insulin intravenously along with extra glucose, the glucose disappears from the blood of the young person at a much higher rate than it does from the old.

It may well be that subtle changes in the chemical composition of the blood and other body fluids account for certain physiological changes in the elderly. So



LARGE INDIVIDUAL DIFFERENCES in aging show up when, for example, the rate of flow of blood plasma through the kidney is plotted against age for some 70 men. The plasma flow is measured in milliliters per minute per 1.73 square meters of body-surface area.



FUNCTIONS OF THE LUNG in man show marked decline with age. Total capacity is the amount of air lungs can hold; it does not decrease. Vital capacity is amount of air forcibly expelled in one breath. Maximum ventilation volume during exercise represents involuntary movement of air. Maximum breathing capacity is the amount of air that can be moved in and out of the lungs voluntarily in 15 seconds. Oxygen uptake is the quantity of oxygen absorbed by the blood from the lungs for transportation to the body cells.

far as the gross chemical characteristics go, however, the old animal or human easily maintains a constant, normal internal environment when completely at rest. But increasing age is accompanied by a definite reduction in the capacity to readjust to changes that accompany the stresses even of daily living. In other words, a key characteristic of aging is a reduction in the reserve capacities of the body—the capacities to return to normal quickly after disturbance in the equilibrium.

Another important element in the aging process shows up in those functions and activities that involve a high degree of co-ordination among organ systems. Co-ordination breaks down, in the first place, because the different organ systems age at different rates. Conduction of the nerve impulse, for instance, hardly slows with age, whereas cardiac output and breathing capacity decline considerably. Thus in those functions that involve the simultaneous output of several organ systems—sustained physical exercise, for example—the performance of the body shows marked impairment. Most of the debilities of age apparently result from a loss of tissue, particularly through the death and disappearance of cells from the tissues. The wrinkled and flabby skin so apparent in elderly people offers mute testimony to this loss. Body weight declines, especially after middle age. In a large sample of the male population of Canada average weight showed a decline from 167 pounds at ages 35 to 44 to an average of 155 pounds for men 65 and over. A sample of men in the U.S., all of them 70 inches tall, averaged 168 pounds in weight at ages 65 to 69 and 148 pounds at ages 90 to 94. Women 65 inches tall weighed, on the average, 148 pounds at ages 65 to 69 and 129 pounds at ages 90 to 94.

Individual organs also lose weight after middle age. For example, the average weight of the brain at autopsy falls from 1,375 grams (3.03 pounds) to 1,232 grams (2.72 pounds) between ages 30 and 90. The same striking loss in total weight and in the weight of specific organs shows up also in the senile rat: the total weight of certain muscle groups drops 30 per cent.

The microscope shows that in many tissues a decrease in the number of cells accompanies the weight loss. Connective tissue replaces the lost cells in some cases, so that the loss of cells is even greater than the reduction in weight would indicate. In the senile rat the

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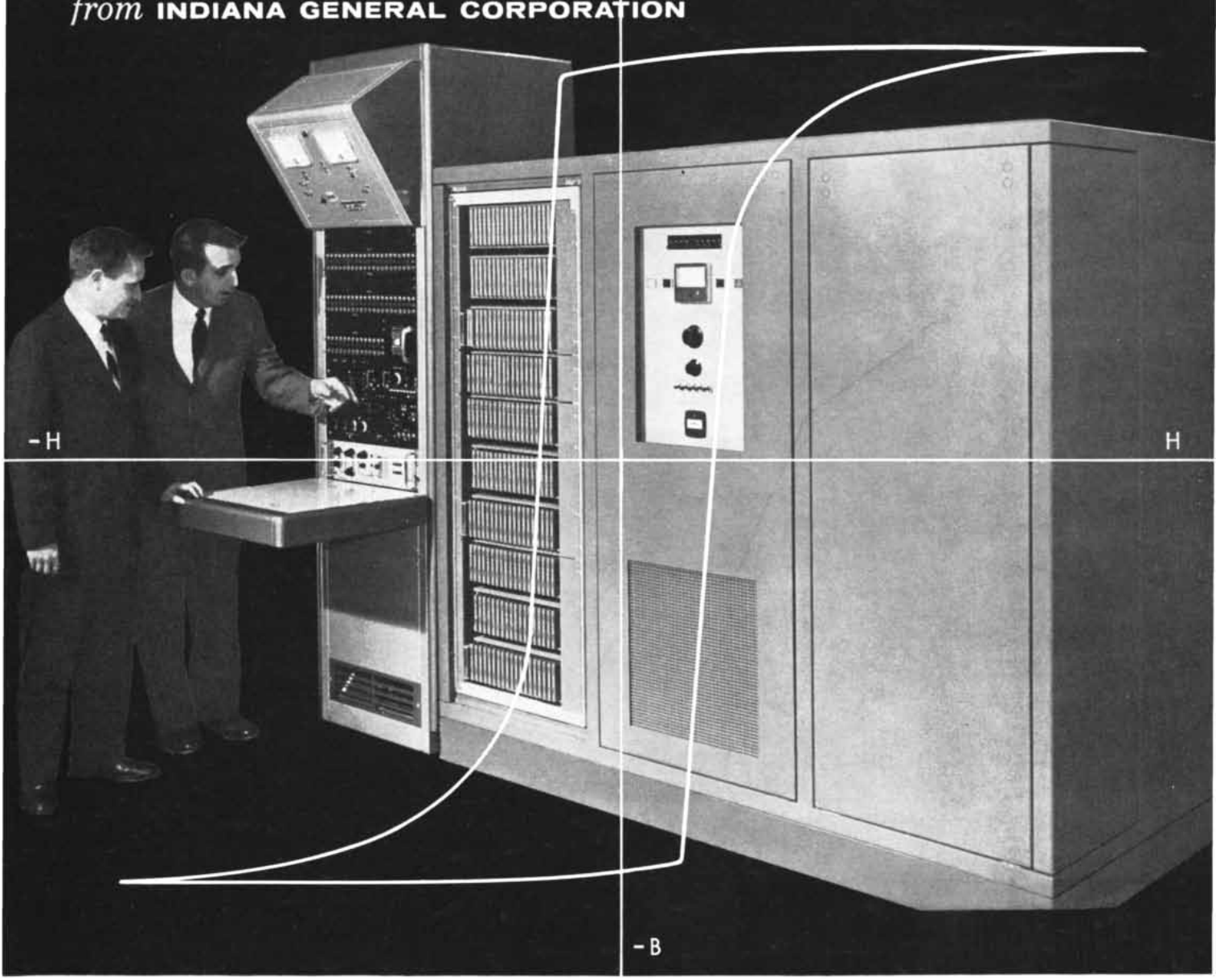

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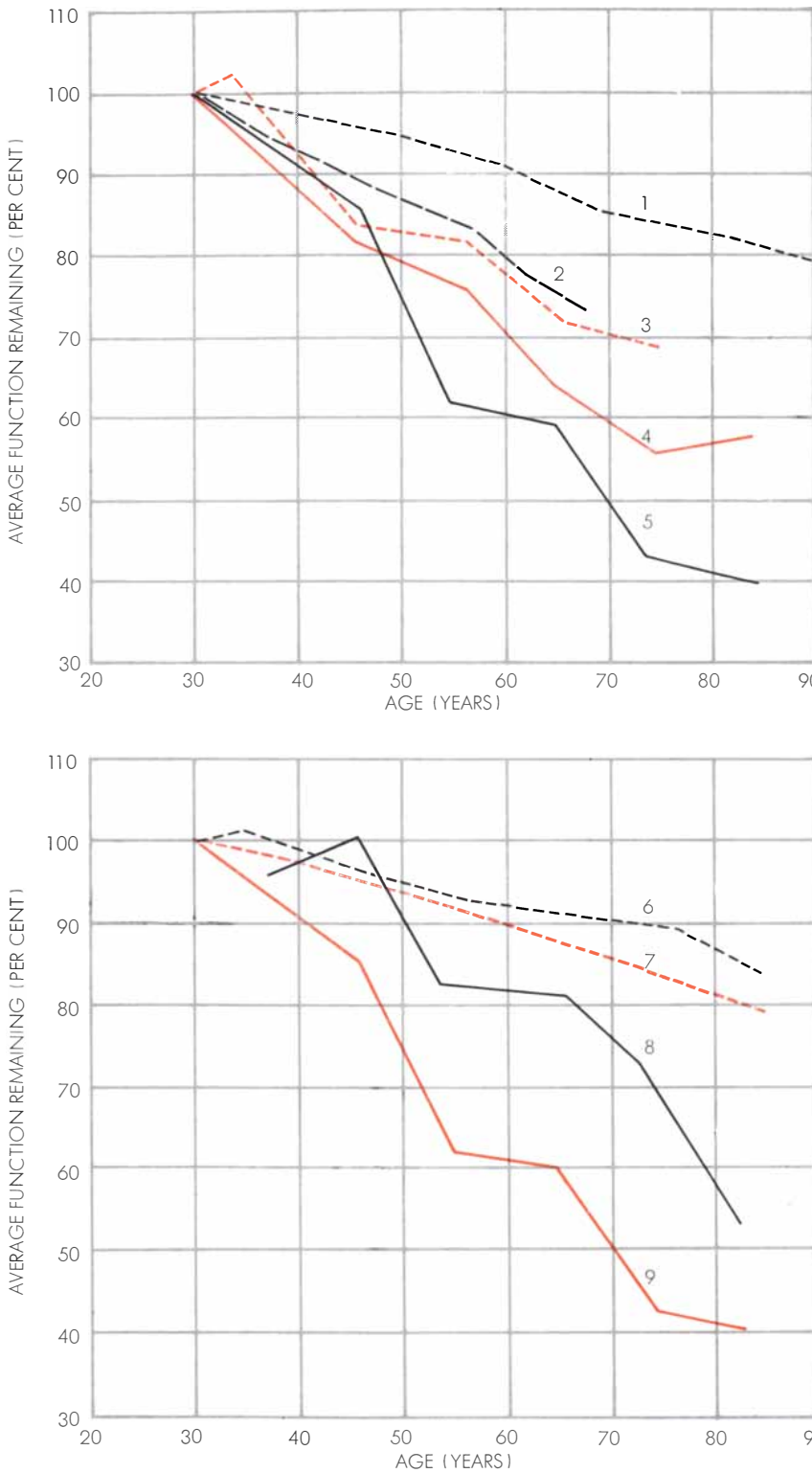
muscle fibers show degenerative changes with replacement by connective tissue and an increase in the spaces between fibers. Such loss of muscle fibers no doubt accounts in large measure for the lower muscular strength of elderly humans as well.

The nervous system shows a similar decline. The number of nerve fibers in a nerve trunk decreases by 27 per cent at advanced ages. In the kidney the disappearance of cells is accompanied by a reduction in the number of nephrons. According to counts made by Robert A. Moore of the State University of New York Downstate Medical Center, the number drops over the life span from 800,000 to 450,000. A final example: The number of taste buds per papilla of the tongue falls from an average of 245 in young adults to 88 in subjects aged 70 to 85 years.

In early life the body is endowed with tremendous reserve capacities. The loss of a few hundred or a few thousand cells hardly affects the performance of an organ. As age advances and losses accumulate, however, impairments develop; eventually the stress of daily living or disease imposes demands beyond the reserve capacity of the organism.

Understanding of the process of aging will ultimately require discovery of the factors that cause the death and disappearance of individual cells. It may be that the death of individual cells is merely a chance event that occurs on a statistical basis in most tissues. It is more likely that changes in the internal metabolism of a cell damage its capacity for self-repair and reproduction. Biochemical study of the life processes in tissue cells is in its infancy. Within the past few years investigation of tissues from the rat and lower organisms such as the hydra have begun to reveal the effects of age on enzyme activity in body cells.

One key to understanding aging and particularly to taking action that might extend the human life span can be found in the differences in the rate of aging observed in different individuals. These differences indicate that many factors play a role in aging. When we know why some people age less rapidly than others, we may be able to create conditions that will minimize the loss of functioning cells and tissues, thereby enabling many more people to live as long as those who live longest today.



1 BASAL METABOLIC RATE
2 WORK RATE
3 CARDIAC OUTPUT (AT REST)
4 VITAL CAPACITY OF LUNGS
5 MAXIMUM BREATHING CAPACITY (VOLUNTARY)
6 NERVE CONDUCTION VELOCITY
7 BODY WATER CONTENT
8 FILTRATION RATE OF KIDNEY
9 KIDNEY PLASMA FLOW

PERCENTAGE CHANGES WITH AGE for nine different physiological functions are shown in these two diagrams. The average value for each function at age 30 is taken as 100 per cent. Small drop in basal metabolism (*1*) is probably due simply to loss of cells.

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The Bering Strait Land Bridge

It is widely thought to have been a narrow neck of land over which man first came to America. Actually it was 1,300 miles wide and was traveled by large numbers of plants and animals

by William G. Haag

The New World was already an old world to the Indians who were in residence when Europeans took possession of it in the 16th century. But the life story of the human species goes back a million years, and there is no doubt that man came only recently to the Western Hemisphere. None of the thousands of sites of aboriginal habitation uncovered in North and South America has antiquity comparable to that of Old World sites. Man's occupation of the New World may date back several tens of thousands of years, but no one rationally argues that he has been here even 100,000 years.

Speculation as to how man found his way to America was lively at the outset, and the proposed routes boxed the compass. With one or two notable exceptions, however, students of American anthropology soon settled for the plausible idea that the first immigrants came by way of a land bridge that had connected the northeast corner of Asia to the northwest corner of North America across the Bering Strait. Mariners were able to supply the reassuring information that the strait is not only narrow—it is 56 miles wide—but also shallow: a lowering of the sea level there by 100 feet or so would transform the strait into an isthmus. With little else in the way of evidence to sustain the Bering Strait land bridge, anthropologists embraced the idea that man walked dry-shod from Asia to America.

Toward the end of the last century, however, it became apparent that the Western Hemisphere was the New World not only for man but also for a host of animals and plants. Zoologists and botanists showed that numerous subjects of their respective kingdoms must have originated in Asia and spread to America. (There was evidence also for some movement in the other direction.) These findings were neither astonishing nor wholly unexpected. Such spread of populations is not to be envisioned as an exodus or mass migration, even in the case of animals. It is, rather, a spilling into new territory that accompanies increase in numbers, with movement in the direction of least population pressure and most favorable ecological conditions. But the immense traffic in plant and animal forms placed a heavy burden on the Bering Strait land bridge as the anthropologists had envisioned it. Whereas purposeful men could make their way across a narrow bridge (in the absence of a bridge, Eskimos sometimes cross the strait in skin boats), the slow diffusion of plants and animals would require an avenue as broad as a continent and available for ages at a stretch.

The expansion of the Bering Strait land bridge to meet these demands is a task that has intrigued geologists for many years. Although their efforts have not completely satisfied zoologists and botanists, it is apparent that the Old and New worlds were once one world, joined by a land mass that now lies submerged beneath the seas on each side of the Bering Strait. The clues to the appearance and disappearance of this land mass are to be found both on the bottom of these waters and in such faraway places as the coral atolls of the South Pacific and the delta of the Mississippi River.

Today the maximum depth in the Bering Strait is about 180 feet. On a clear day from the heights at Cape Prince of Wales in Alaska one can look across the strait and see land at Cape Dezhnev in Siberia. St. Lawrence Island, Big Diomede Island, Little Diomede Island and smaller islands make steppingstones between. South of the strait is the Bering Sea. Its floor is one of the flattest and smoothest stretches of terrain on the entire globe. With a slope of no more than three or four inches to the mile, it reaches southward to a line that runs from Unimak Pass in the Aleutians to Cape Navarin on the Asiatic shore. Along this line—the edge of the continental shelf—the sea floor plunges steeply from a depth of about 450 feet down 15,000 feet to the bottom of the ocean. The floor of the Chukchi Sea, north of the Bering Strait, is not quite so smooth; the depth varies from 120 to 180 feet, and irregularities of the terrain bring shoals upward to depths of only 45 feet and lift the great granite outcrops of Wrangell and Herald islands above the surface of the sea. Along a line that runs several hundred miles north of the Bering Strait, from Point Barrow in Alaska to the Severnaya Zemlya off Siberia, the sea floor plunges over the northern edge of the continental shelf to the bottom of the Arctic Ocean.

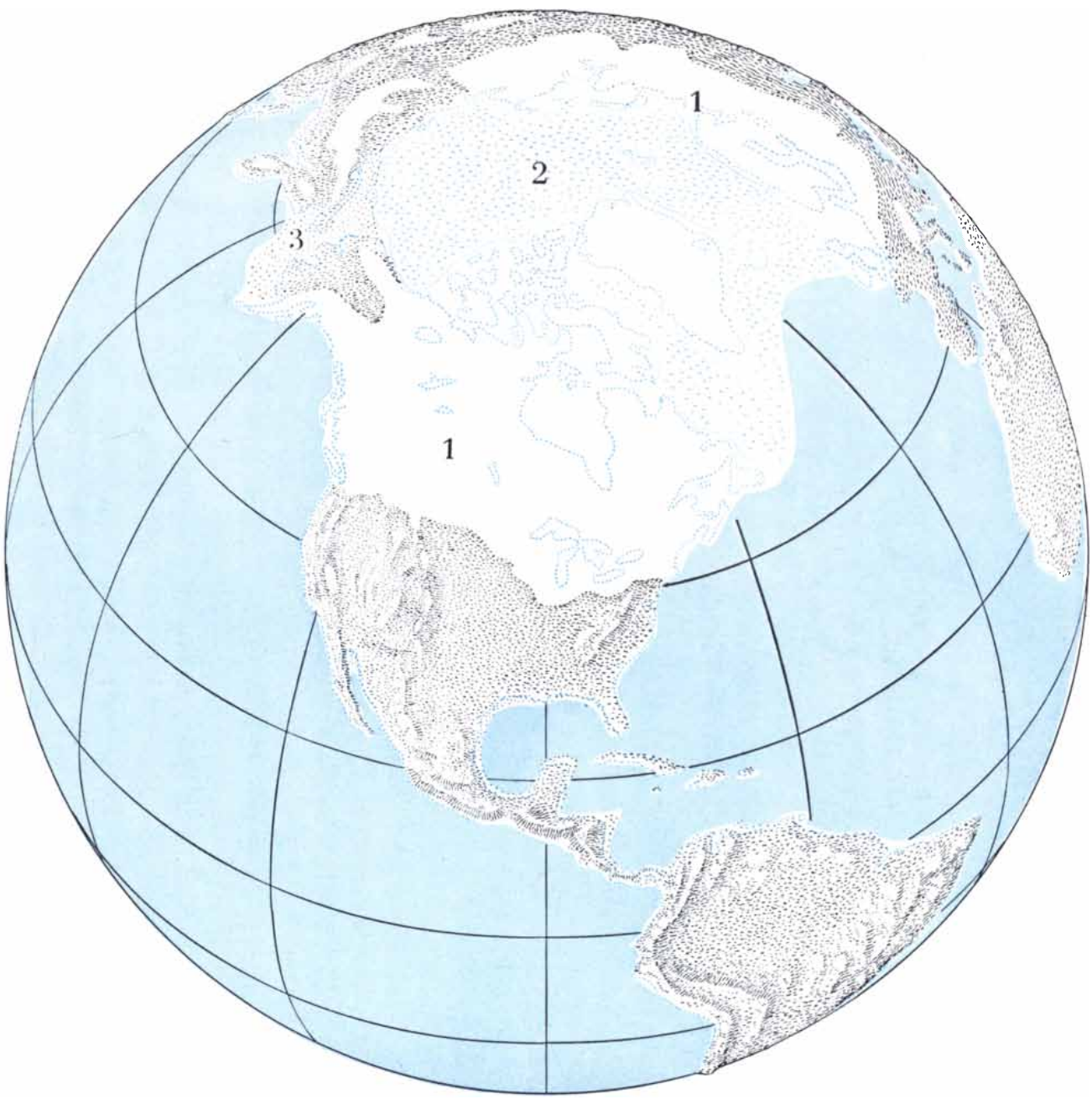
Sounding of the Bering and Chukchi seas thus depicts a vast plain that is not deeply submerged. At its widest the plain reaches 1,300 miles north and south, 600 miles wider than the north-south distance across Alaska along the Canadian border. The granitic islands that rise above the water testify that the plain is made of the same rock as the continents.

David M. Hopkins of the U.S. Geological Survey has shown that this great plain sank beneath the seas somewhat more than a million years ago as a result of the down-warping of the crust in the Arctic region that began with the Pleistocene epoch. Before that, Hopkins calculates, most of the area was above sea

level throughout most of the 50-million-year duration of the preceding Tertiary period.

The continuity of the land mass of Asia and North America during the Tertiary period helps to solve a major portion of the biologist's problem. The paleontological evidence indicates that numerous mammals, large and small, moved from Asia to America during that time. With the subsidence of the land, however, the flow must have stopped. Nor is there any chance that the land rose up again during the million-year Pleistocene period. It is true that the Pacific region along the Aleutian and Kurile island chains is geologically active. But by comparison the Bering Strait region is rather stable; studies of ancient beach terraces on the islands in the surrounding seas indicate that the vertical movement of the land could not have exceeded 30 feet in the course of the Pleistocene. The smoothness of the Bering Sea floor is another indication of prolonged submergence. Deep layers of marine sediment have smoothed out whatever hills and valleys it acquired when it was dry land and exposed to erosion.

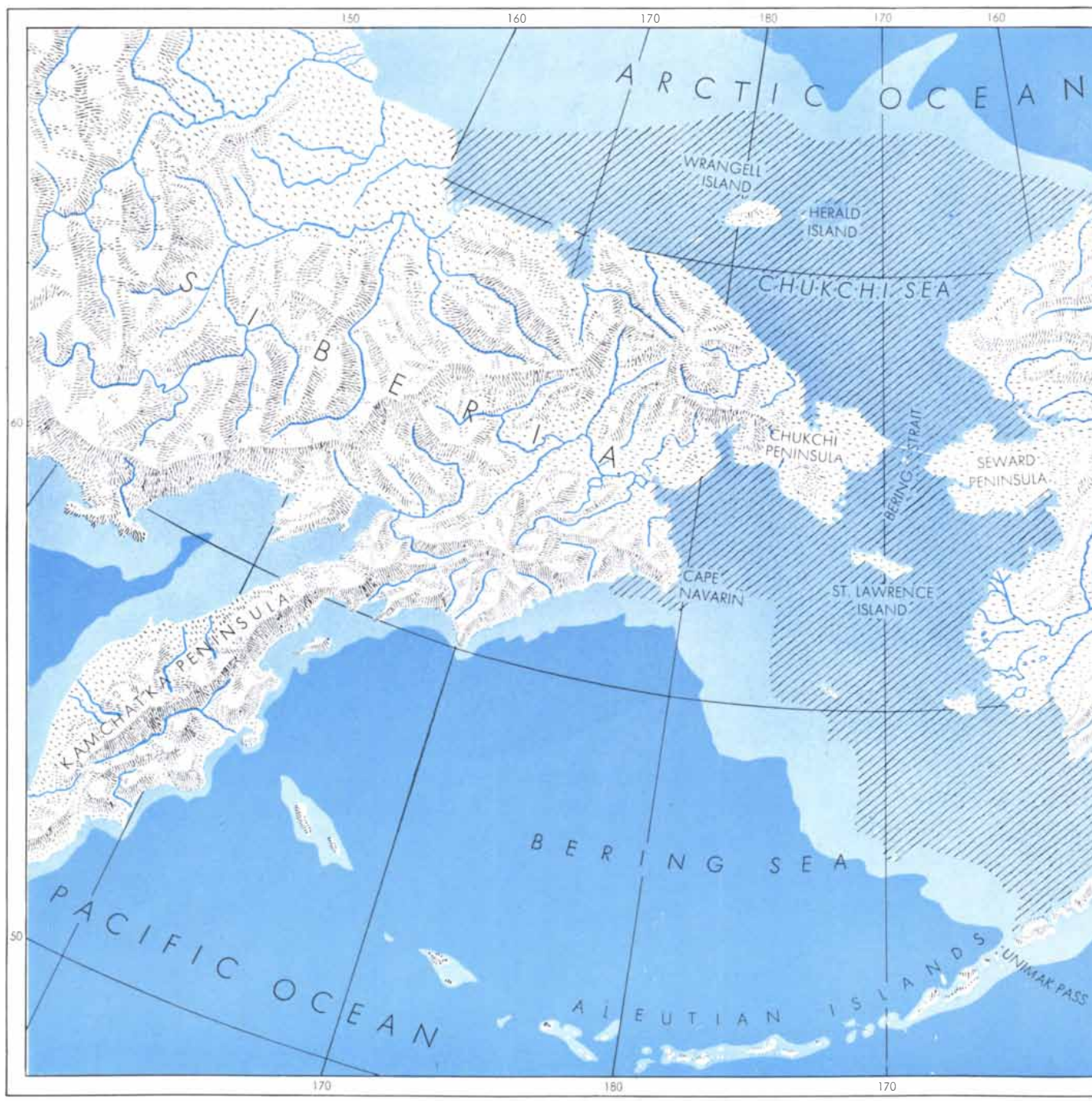
Fossil evidence for the origin and geographic distribution of North American mammals nonetheless shows that numerous animals, large and small, came from Asia during the Pleistocene. Beginning early in the Pleistocene, several genera of rodents arrived; such small mammals breed more rapidly than, say,



LAST GREAT GLACIATION, the Wisconsin, at its maximum covered about 30 per cent of the earth's land area. The glaciers (*1*) and accompanying pack ice (*2*) locked up vast quantities of sea water, lowering sea level by 460 feet and exposing a 1,300-mile-wide, ice-free land bridge in the region of Bering Strait (*3*). The broken colored line marks present-day seacoasts and lake shores.

elephants, and they spread far southward across North America, although not into South America. Later came the larger mammals: the mastodon and mammoth, musk oxen, bison, moose, elk, mountain sheep and goats, camels, foxes, bears, wolves and horses. (The horses flourished and then died out in North America; the genus was not seen again in the New World until the conquistadors brought their animals across the Atlantic.) Evidence from botany as well as from zoology requires a substantial dry-land connection between Asia and North America throughout the Pleistocene.

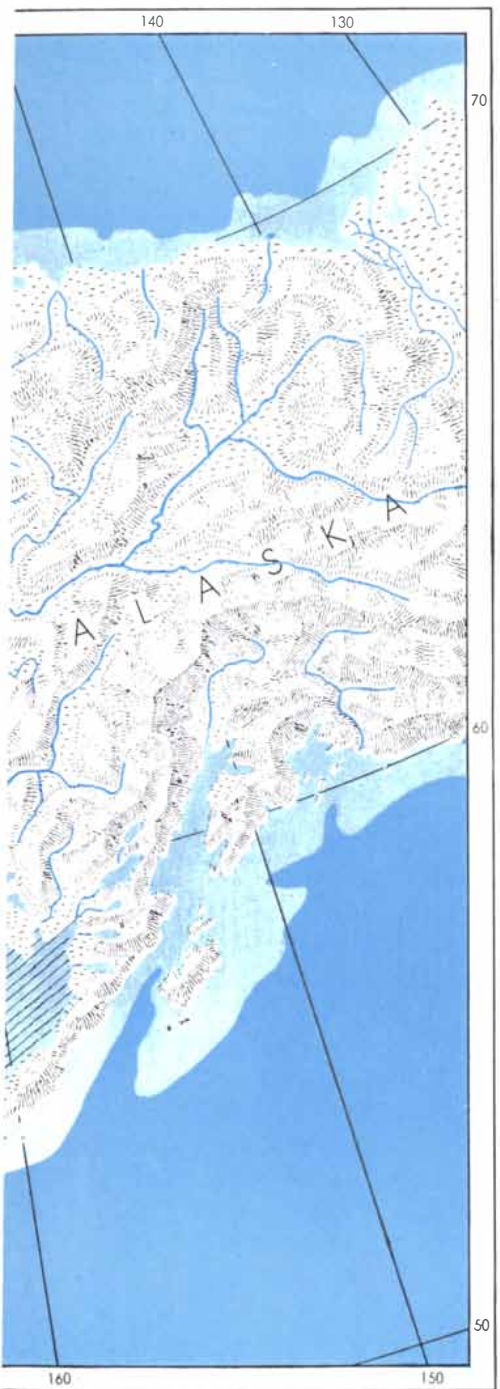
At this point it is well to remember that the sea level at any given place on the globe depends not only on the height of the land but also on the depth of the ocean. The depth of the ocean in this sense is a question of the volume of water in the ocean. With the Pleistocene began the ice age that has apparently not yet run its course. During this million-year period, for reasons subject to warm debate, at least four great ice sheets have built up, advanced and retreated on the Northern Hemisphere. That the ice can lock up considerable quantities of water on the land is evident even in the present interglacial period. The abrupt melting of the



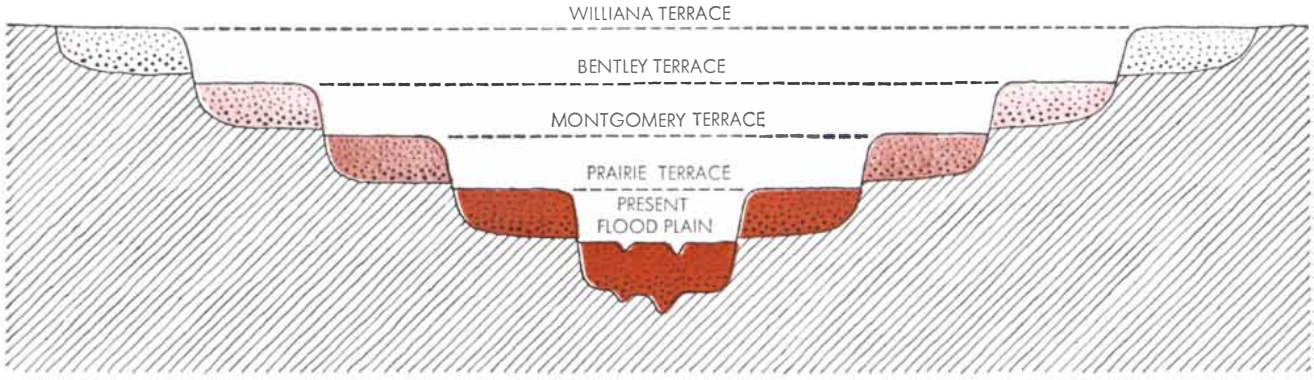
BERING STRAIT LAND BRIDGE during much of Wisconsin glaciation was at least as wide as hatched area, which marks present-day depths to 300 feet. The lighter color covers depths to 600 feet. The 600-foot contour roughly marks the margin of the continental

Greenland and Antarctic icecaps would, according to various estimates, raise the present world-wide sea level by as much as 300 feet.

To estimate the volume of water locked up on the land in the great continental glaciers of the Pleistocene one begins with the measurement of the land area covered by the glaciers. The great ice sheets gathered up sand, gravel and larger rubble and, when the ice pro-



shelf, with its sharp drop to the bottom of the deep ocean, several thousand feet lower.

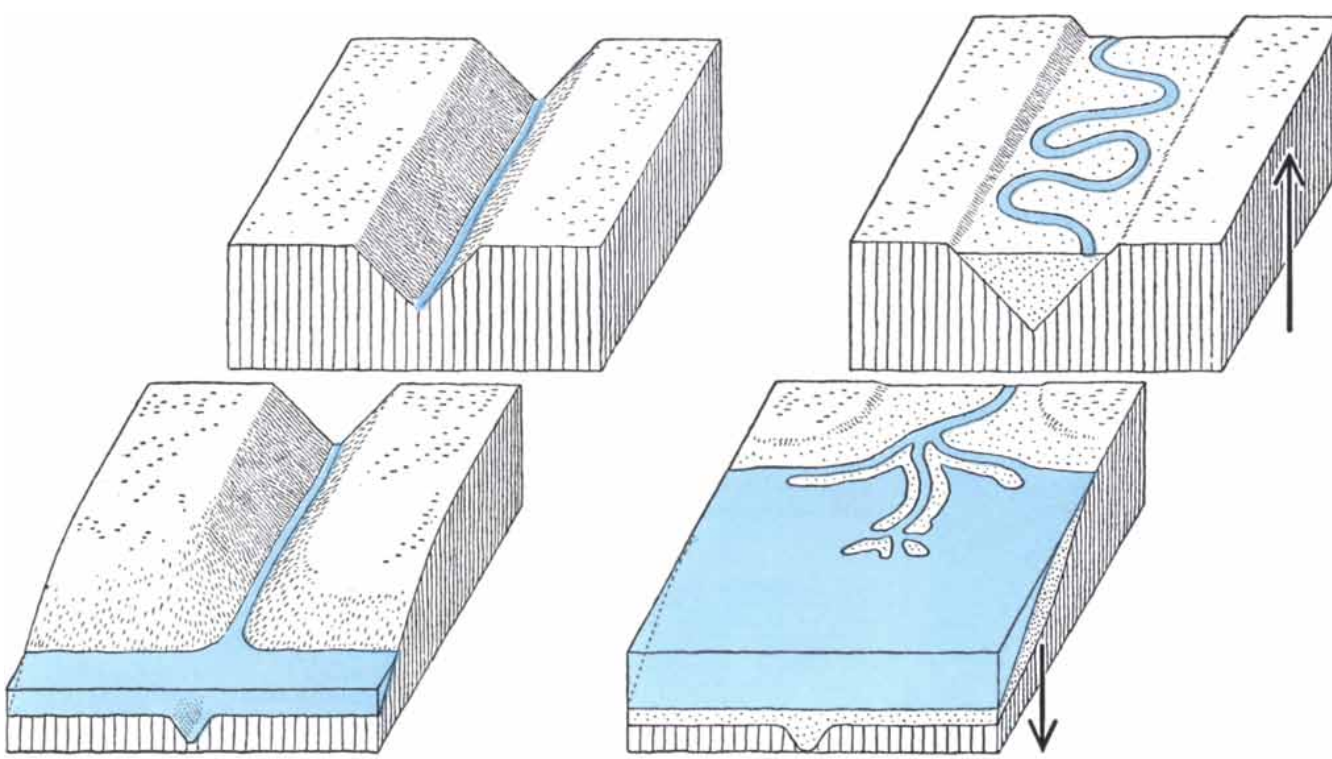


SUCCESSIVE TERRACES that formed in lower Mississippi Valley during the Pleistocene glaciations are shown in this highly schematic cross section. The terraces, with the oldest at the top, were flood plains laid down between glaciations. During each glacial period the river, rejuvenated by the fall in sea level and the consequent drop in its mouth, cut deeply into the preceding flood plain. The Prairie Terrace represents the flood plain that the river laid down between the early Wisconsin and the late Wisconsin glaciations.

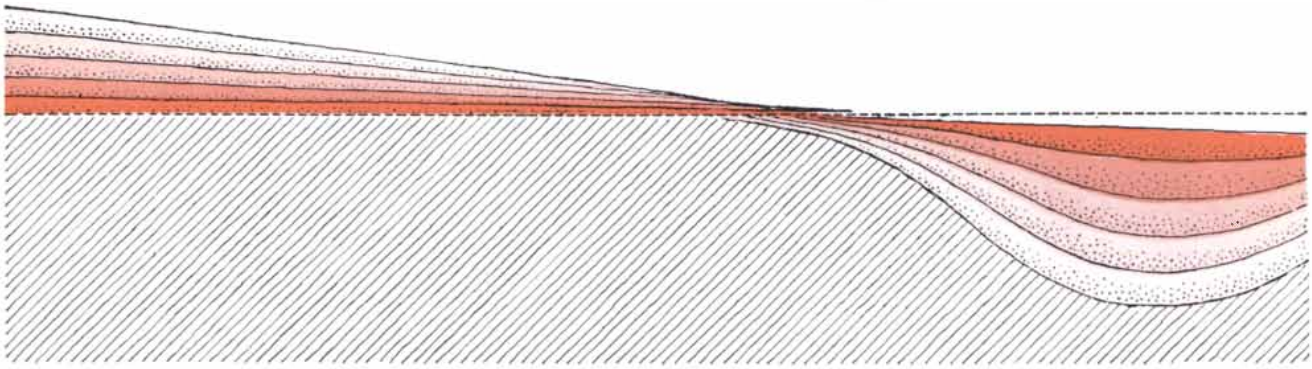
ceeded to melt, deposited a mantle of this "till" on the exposed ground. From such evidence it is calculated that ice covered 30 per cent of the earth's land area during the glacial maxima of the Pleistocene.

To arrive at the volume of water in the glaciers, however, one must have some idea of the thickness of the ice as well as the area it covered. The Greenland icecap is more than a mile deep, and in Antarctica the rock lies as much as three miles below the surface of the ice. It is clear that the Pleistocene glaciers could have been thousands of feet thick. Multiplication of the area of the glaciers by thicknesses predicated on various assumptions has shown that the freezing of the water on the land may have reduced the ancient sea level by 125 to 800 feet. Such calculations are supported by evidence from coral atolls in tropical seas. Since the organisms that build these atolls do not live at depths greater than 300 feet, and since the limy structures of such islands go down several thousand feet, a lowering of the sea level by more than 300 feet is necessary to explain their existence.

By all odds the best evidence for the rise and fall of the ancient sea level is offered by the Mississippi Valley, its delta and the adjoining shores of the Gulf of Mexico. In Pleistocene times about a dozen major streams entered the Gulf. As ice accumulated in the north, lowering the level of the sea, the streams followed the retreating shore line downward. On the steeper gradient the water flowed faster, cutting deeper and straighter valleys. Then, as the ice retreated, the sea rose and again moved inland, reducing the velocity of the streams and making them deposit their



EFFECTS OF GLACIAL ADVANCE AND RETREAT on rivers entering Gulf of Mexico are shown in these diagrams. Upper block of each pair is river valley, lower block is mouth of river. At left, glaciers have lowered sea level. River flows faster and cuts a deep,

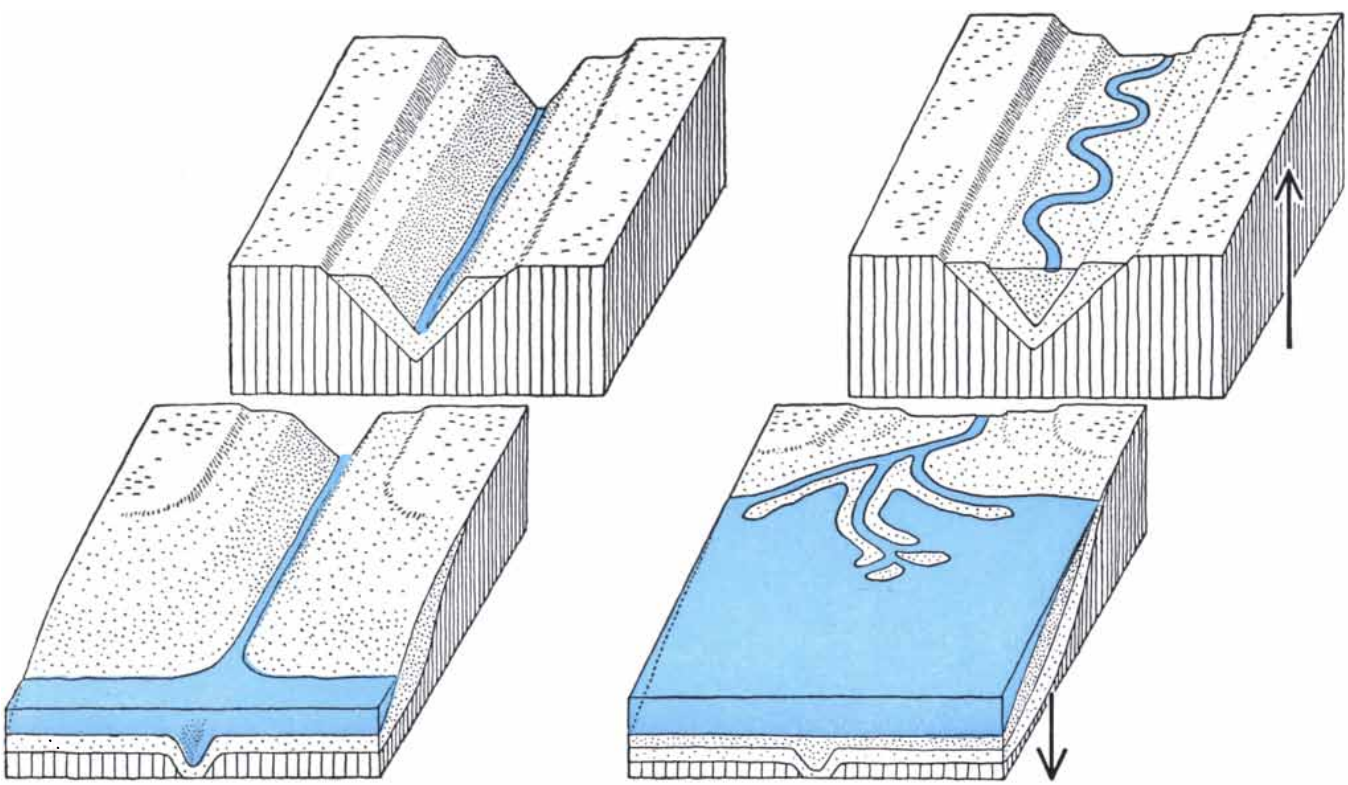


SLOPE OF TERRACES is illustrated in this schematic longitudinal section of lower Mississippi and Gulf region. The weight of the accumulated sediments (*right*), with the oldest deposit at the bottom, made the crustal rock sink and the adjacent land area rise like a great lever with the fulcrum near the coast. Because of this tilt the flood plains laid down during interglacial periods remained as terraces. The broken horizontal line marks present sea level. Hatched area is the older material of the continental crust.

burdens of gravel and silt at their mouths and farther inland. Consequently during the glacial minima the rivers built up great flood plains over which they wore meandering courses. Each glacial advance brought a withdrawal of the Gulf and quickened the rivers; each retreat raised the level of the Gulf and forced the rivers to build new flood plains.

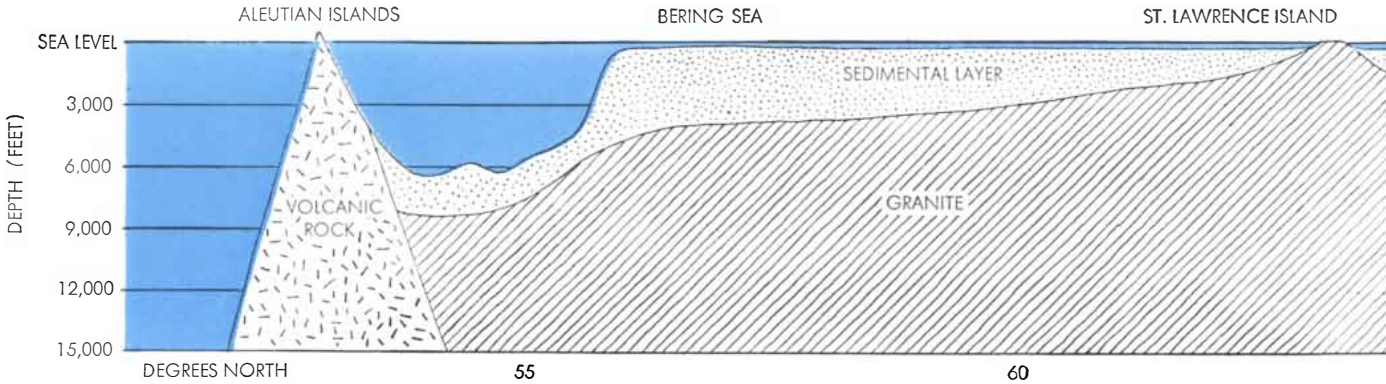
Had the earth's crust in this region remained stable, all traces of the preceding flood plain would have been erased by the next cycle of cutting and building. But the rivers, particularly the Mississippi, deposited vast quantities of sediment in their lower valleys, building "crowfoot" deltas like that of the Mississippi today. (Many large rivers, such as the Amazon, have never built such deltas because coastwise currents distribute their sediments far and wide.) The accumulating burden of offshore sediments tilted the platform of the continent, pressing it downward under the Gulf and lifting it inland. In succeeding cycles, therefore, the build-up of the flood plain started farther downstream.

Evidence of the succession of flood plains remains today in the terraces that descend like a flight of steps down both flanks of the Mississippi Valley toward the river. Near Memphis, Tenn., the highest and oldest terrace lies about 350 feet above the plain of the present river and slopes toward the Gulf with a gradient of about eight feet per mile. The terrace below lies 200 feet above the plain and slopes about five feet per mile; the third terrace lies 100 feet above the plain, with a slope of about 18 inches; the fourth, only 40 feet above, with a slope of only six inches. The present flood plain has a gradient of about three inches per mile. Out in the Gulf, where



straight valley. Then glaciers melt, mouth of river rises and river deposits sediments to make flood plain in valley and delta at mouth.

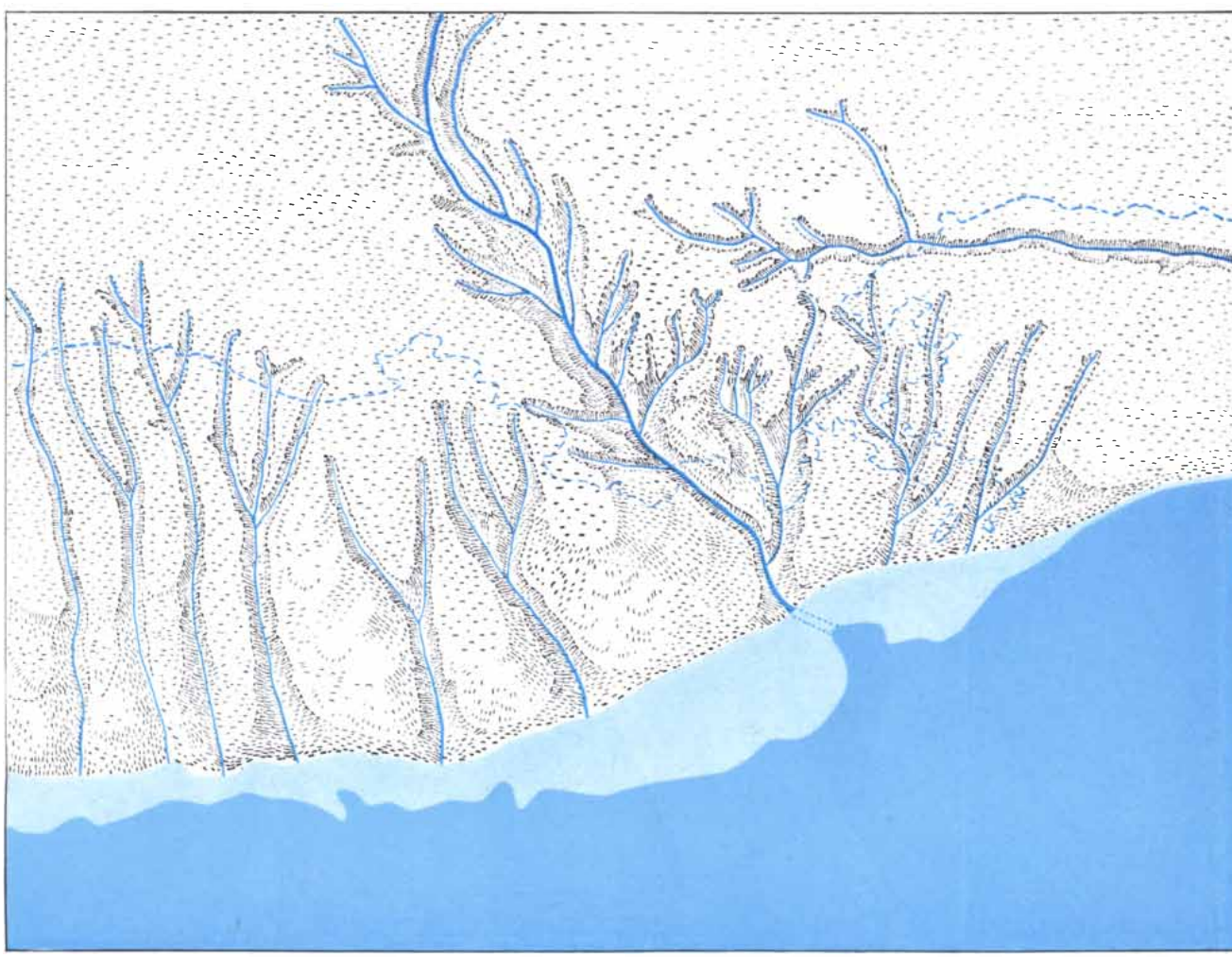
The crust under the Gulf sinks, raising the river valley (*second from left*). The cycle is repeated at next glaciation and interglacial.



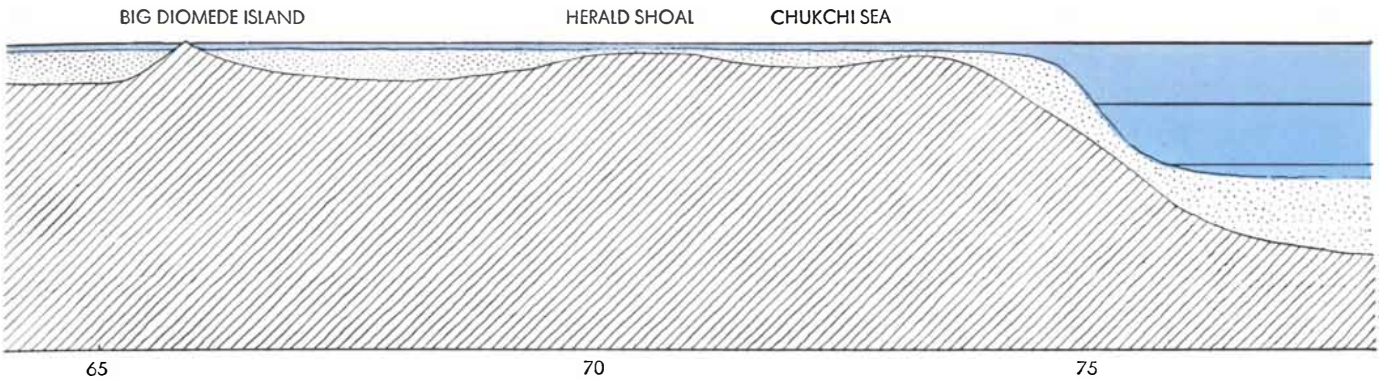
CROSS SECTION THROUGH BERING STRAIT along 169 degrees west latitude shows great breadth of shallow region. Earth's crust beneath strait is granitic and is part of continental shelf. Big Diomede Island lies in the narrowest part of the strait. The whole

the river has buried the older deposits under the younger, the successive slopes of the river bed are steeper.

In this setting geologists have been able to measure with great confidence the degree to which each of the glacial advances of the Pleistocene lowered the level of the sea. Borings along the axis of the old stream channels reveal the gradient of the bottom. The terraces show the slope of the alluvial plain associated with the successive streams. From these data the elevations of the earlier river mouths and consequently the sea level can be determined. The Rhine and Rhone rivers have yielded similar information, and on the Kamchatka Peninsula in Siberia it has been observed that the streams flowing into the Bering Sea are flanked by steeply sloping terraces.

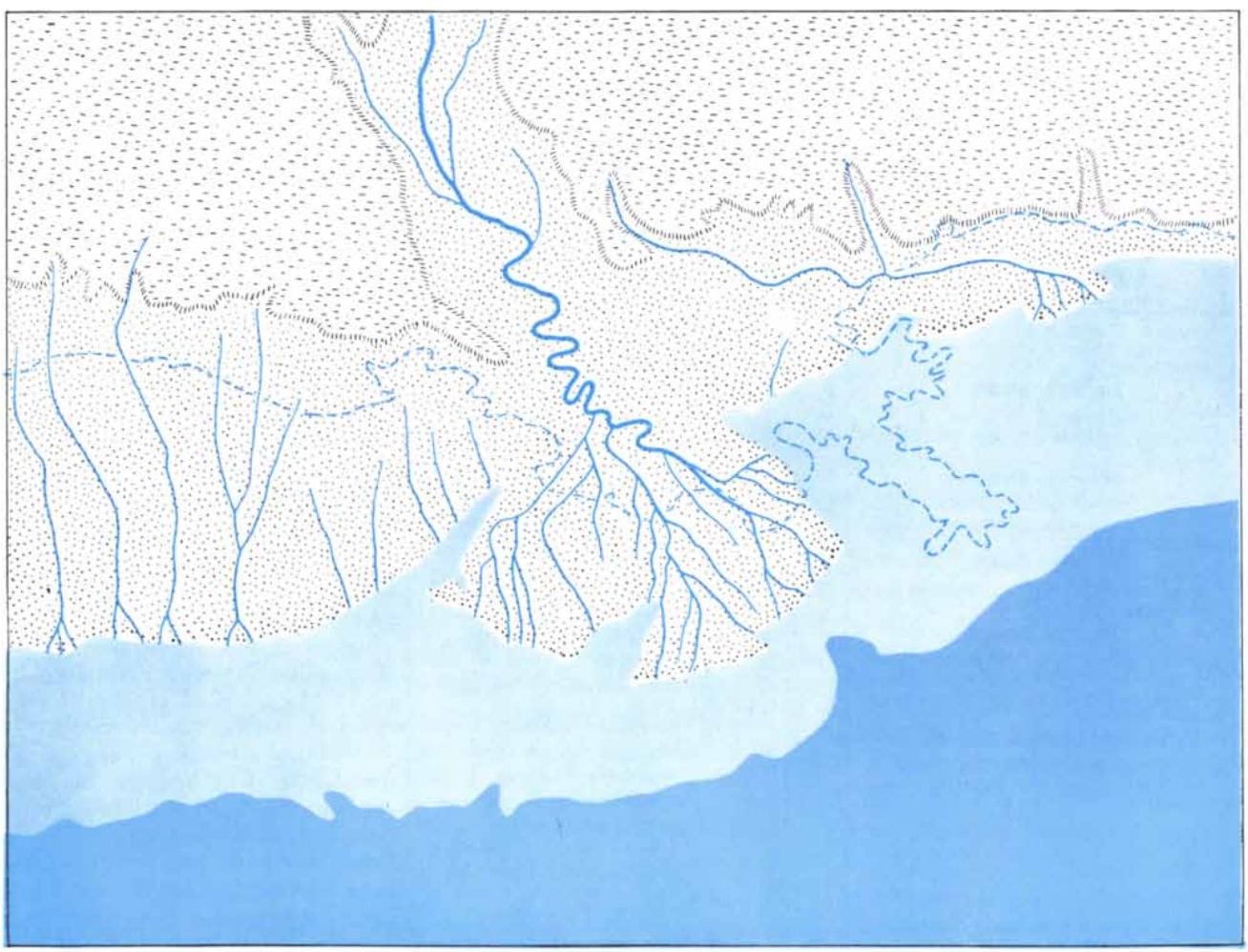


WITHDRAWAL OF WATER of the Gulf of Mexico at height of the Wisconsin glaciation exposed most of continental shelf. Edge of shelf is 600-foot-depth contour, where dark color starts. The rivers cut deep valleys and dumped their sediments in the deep water.



shallow area has been tectonically stable for the past million years. Glaciations rather than local uplift exposed its surface. The thickness of the sedimental layer is actually not definitely established for much of the region. Pacific Ocean is at left, Arctic Ocean is at right.

The Mississippi-Gulf region has provided especially secure and precise information about the course of the last great Pleistocene glaciation, the so-called Wisconsin stage of the Pleistocene. In no other area of the globe have oil prospectors drilled so many test holes through the recent sediments into the Pleistocene; the number of holes runs into the thousands, and they dot the map 30 miles out into the Gulf. In accordance with the law, the records of these wells show the types of material brought up by the drills at fairly evenly spaced intervals. The undersea sediments that were uncovered by the retreat of the sea at the maximum advance of the Wisconsin glacier mark a horizon familiar to all well drillers. Where these sediments were exposed to the air long ago they became oxidized and show as a bright



RISE IN WATER OF GULF at mouth of Mississippi accompanied retreat of glaciers. Sea level shown is only 100 feet lower than at present. Rivers flow slowly, building flood plains and deltas. Broken colored line marks today's coast and Mississippi delta.

reddish-orange zone. From the examination of many well records one can tell where, geographically, these sediments were exposed to air and where they remained underwater, and so fix the coast line at the time the sea reached its lowest level. In addition, numerous samples of formerly living matter have been recovered from well borings at known depths and from archaeological sites. The dating of these by carbon-14 techniques permits accurate plotting of the course of events in time.

From this rich supply of evidence it has been determined that the Wisconsin glacier reached its maximum 40,000 years ago and lowered the sea level by as much as 460 feet. As the glacier grew and the oceans receded, an ever broader highway was revealed at the Bering Strait. With a sea-level fall of only 150 feet, the bridge connecting the two continents must have been nearly 200 miles wide. Because the slope of the sea floor is so gentle, a further fall in the sea level uncovered much larger regions. At 450 feet the entire width of the undersea plain from one edge of the continental shelf to the other must have been exposed, providing a corridor 1,300 miles wide for the flow of biological commerce between the no longer separate continents. During the peak periods of the earlier glaciations the Bering Strait land bridge would have presented much the same appearance.

Because the maximum exposure of the land bridge necessarily coincided with a maximum of glaciation, one might think the bridge would have been blocked by ice. Geological evidence shows, however, that neither the Chukchi Peninsula in Siberia nor the westward-reaching Seward Peninsula of Alaska were glaciated during the Wisconsin period. Even large areas of central Alaska remained ice-free throughout the period. As for the now submerged plain on the floor of the Bering Strait and the adjoining seas, it seems clear that the rocky rubble, found where currents clear away the silt, was "rafted" there by icebergs; no part of this accumulation is attributed to glacial till deposited by the melting of glacial ice on the surface.

Conditions are made the more propitious for life on the bridge by the latest theory on the causes of glaciation. Paradoxically, this demands a warm Arctic Ocean over which winds could become laden with moisture for subsequent precipitation as snow deep in the Hudson Bay area, where the glacier had its center of gravity. Western Alaska would have had little snowfall and no accumulation of ice. This deduction is supported

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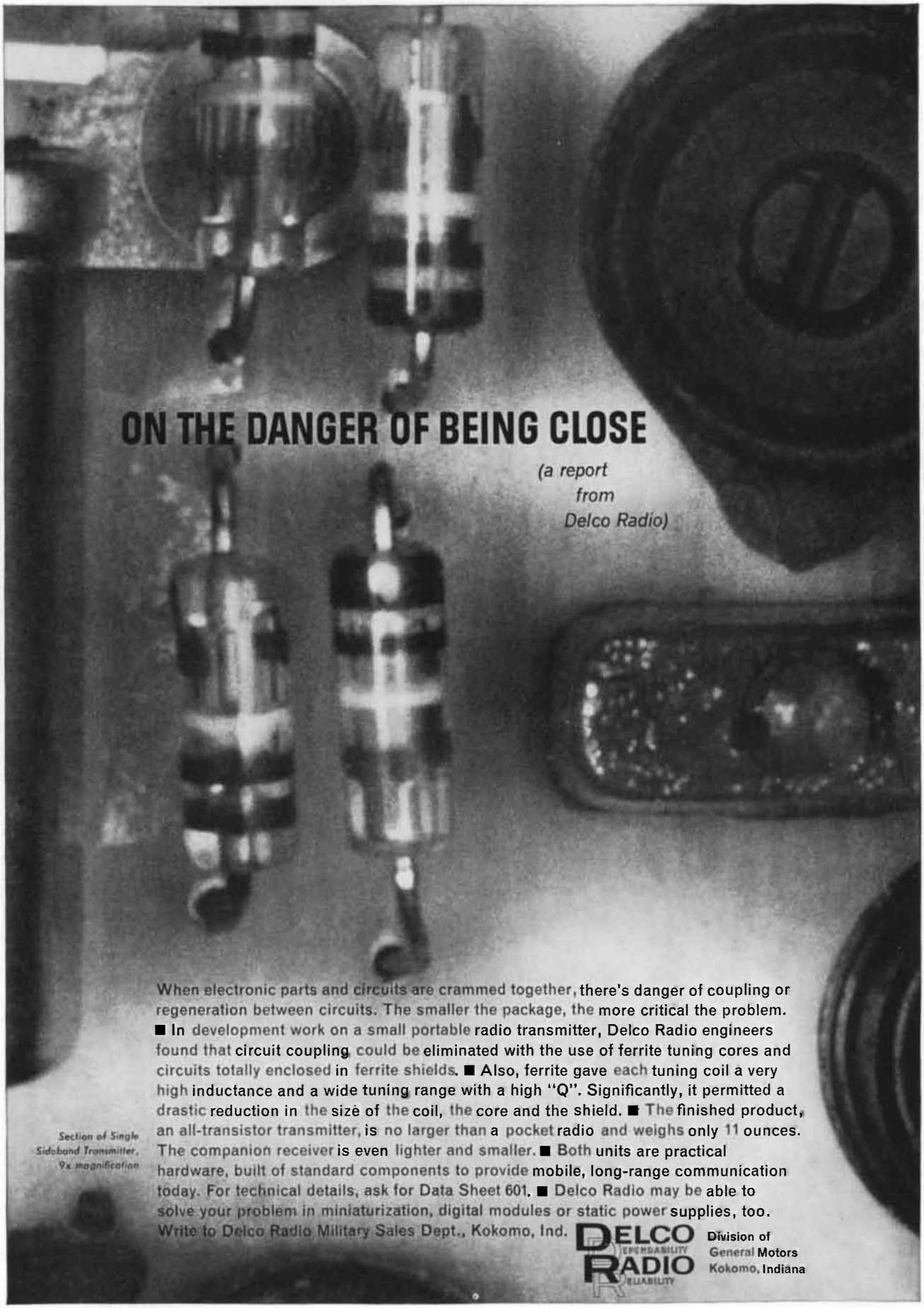

ON THE DANGER OF BEING CLOSE

(a report from Delco Radio)

When electronic parts and circuits are crammed together, there's danger of coupling or regeneration between circuits. The smaller the package, the more critical the problem. ■ In development work on a small portable radio transmitter, Delco Radio engineers found that circuit coupling could be eliminated with the use of ferrite tuning cores and circuits totally enclosed in ferrite shields. ■ Also, ferrite gave each tuning coil a very high inductance and a wide tuning range with a high "Q". Significantly, it permitted a drastic reduction in the size of the coil, the core and the shield. ■ The finished product, an all-transistor transmitter, is no larger than a pocket radio and weighs only 11 ounces. The companion receiver is even lighter and smaller. ■ Both units are practical hardware, built of standard components to provide mobile, long-range communication today. For technical details, ask for Data Sheet 601. ■ Delco Radio may be able to solve your problem in miniaturization, digital modules or static power supplies, too. Write to Delco Radio Military Sales Dept., Kokomo, Ind.

Section of Single Sideband Transmitter, 9x magnification

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Division of General Motors
Kokomo, Indiana

by the finding of trees in the Pleistocene deposits on Seward Peninsula. It is not thought, however, that the land bridge was ever anything but tundra.

It must be admitted that the Bering Strait land bridge of the geologist, appearing only intermittently above sea level, does not fully serve the purposes of the zoologist and botanist. Most zoologists find no evidence in the movement of animals that requires alternate opening and closing of the passage between the continents, and they argue for a broad bridge available throughout nearly all of the Pleistocene. What is more, the animals that came across the bridge were not typically cold-climate animals (none of the true cold-climate animals, such as the woolly rhinoceros, ever reached America). On the contrary, the animals were the ones that would prefer the warmer interglacial times for their spread. They may, of course, have made the crossing just as the climate was warming up and conditions on the American side were increasingly favorable to population increase and diffusion.

The botanists find even more compelling evidence for a broad land bridge throughout most of the Pleistocene. Eric Hultén of the University of Lund in Sweden recently calculated that a bridge 700 miles wide is necessary to account for the distribution of plants in Alaska and northeastern Siberia.

Giving full weight to the biological evidence, it seems amply demonstrated that a bridge wider than present-day Alaska joined the Old and New worlds during a large part of the Pleistocene. There is much to suggest that the land surface of this bridge was smooth and unbroken. And it appears that large animals moved freely across it during the 80,000 years of the Wisconsin stage and probably throughout much of the preceding interglacial stage.

Before the end of the Wisconsin period the first men must have crossed the bridge. It seems almost a truism that Asiatic man would have followed the slow spread of Asiatic animals into the New World. The men would most likely have come along the coastal margins and not across the interior that lies under the present-day strait. Their remains are covered, therefore, not only by 300 feet or more of water but also by as much as 100 feet of sediment laid down in the Recent period as the sea encroached on the continental shelf. Archaeologists need not be surprised in the future to discover evidence of man here and there in North America 50,000 years old and even older.

TWO-PHASE MATERIALS

The remarkable strength of glass fibers embedded in plastic focuses attention on the whole conception of materials in which a substance of high tensile strength is combined with one of greater elasticity

by Games Slayter

A new man-made material—glass fibers that are embedded in a plastic matrix—has come into wide and diverse use during the past two decades. The material is familiar in the one-piece boat hull and in structural panels employed in homes and factory buildings. It turns up also in high-specification functions in aircraft and space vehicles. The success of the material reflects a large catalogue of advantages: it is easy to fabricate and repair, light in weight, durable and so on. Above all, this success bespeaks a virtue inherent in the composite structure of the material: weight for weight it is the strongest material available for engineering purposes. Its specific strength (strength-to-weight ratio) is 2.5 times greater than that of any homogeneous material, such as a metal, glass or plastic.

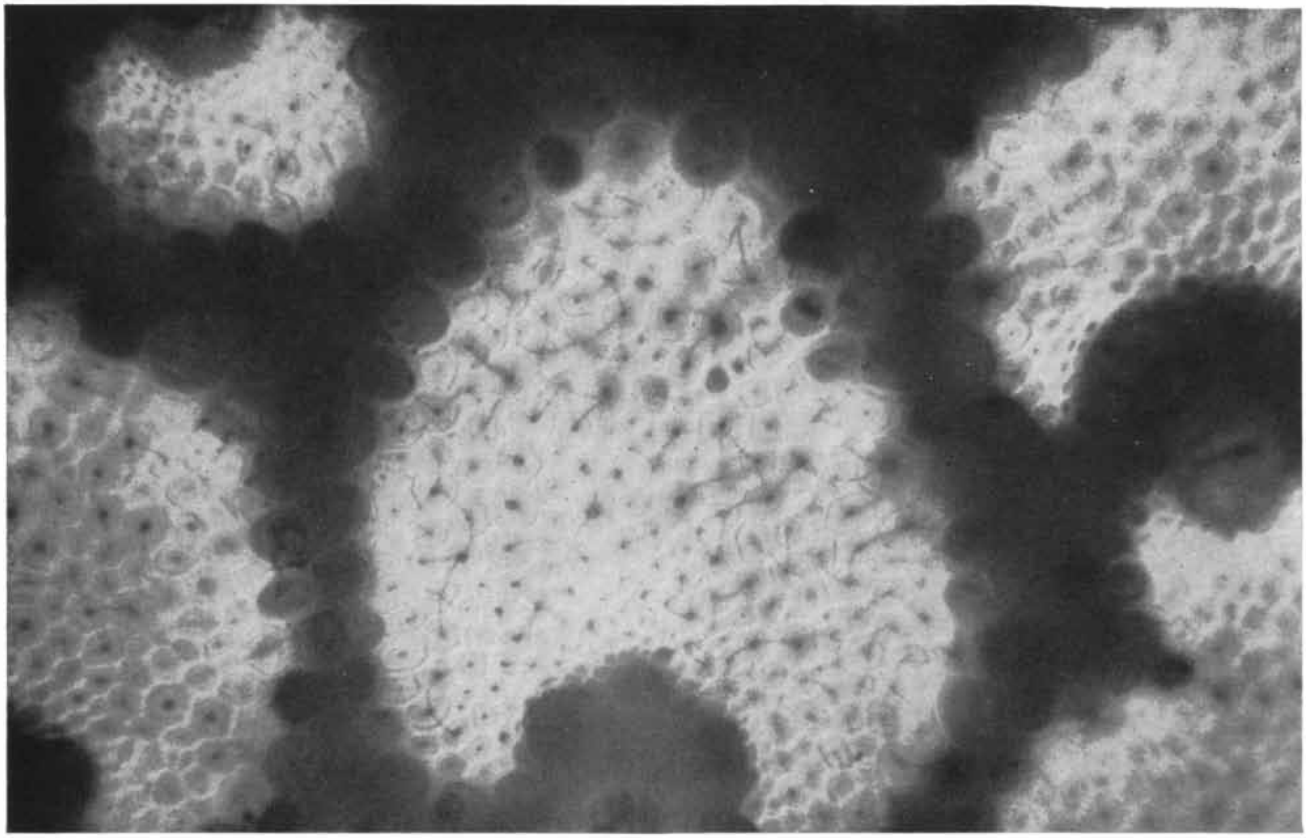
At the laboratories of the Owens-Corning Fiberglas Corporation in Granville, Ohio, where we have been working on the development and application of "Fiberglas" plastics, we have come to realize that their high specific strength derives from a fundamental principle in the science of materials that, to our knowledge, has never been formally recognized and defined. We call it the "two phase" principle of material structure and strength. As a little reflection and historical research shows, the strongest and most efficient materials created by nature over the ages and by man over the centuries have always been composite materials. Characteristically they are made up of two different substances with contrasting properties of strength and elasticity. By the combination of the properties of the component substances, it turns out, these materials realize a greater portion of the theoretical strength of the stronger component than that component exhibits in use and function by itself.

Metallurgists, polymer chemists and others who work with materials know the difficulty of preparing a dependably strong structure from a homogeneous, single-phase substance. In a block of glass or steel the bond between atoms is immensely powerful, something in excess of a million pounds per square inch. The materials never develop this remarkable strength in actual use because it is impracticable to manufacture glass, steel or any other material with perfect uniformity of structure or entirely free of defects. It is around defects that stresses accumulate. If the material is homogeneous in structure, cracks opened up by external stress propagate readily through the material, and a fracture results. The theoretical strength of certain materials has been approximated in "whiskers" of the materials; these are elongated single crystals grown under controls that minimize the occurrence of defects. In any piece of material massive enough to serve a structural function, however, defects reduce the realizable strength to a fraction of the theoretical.

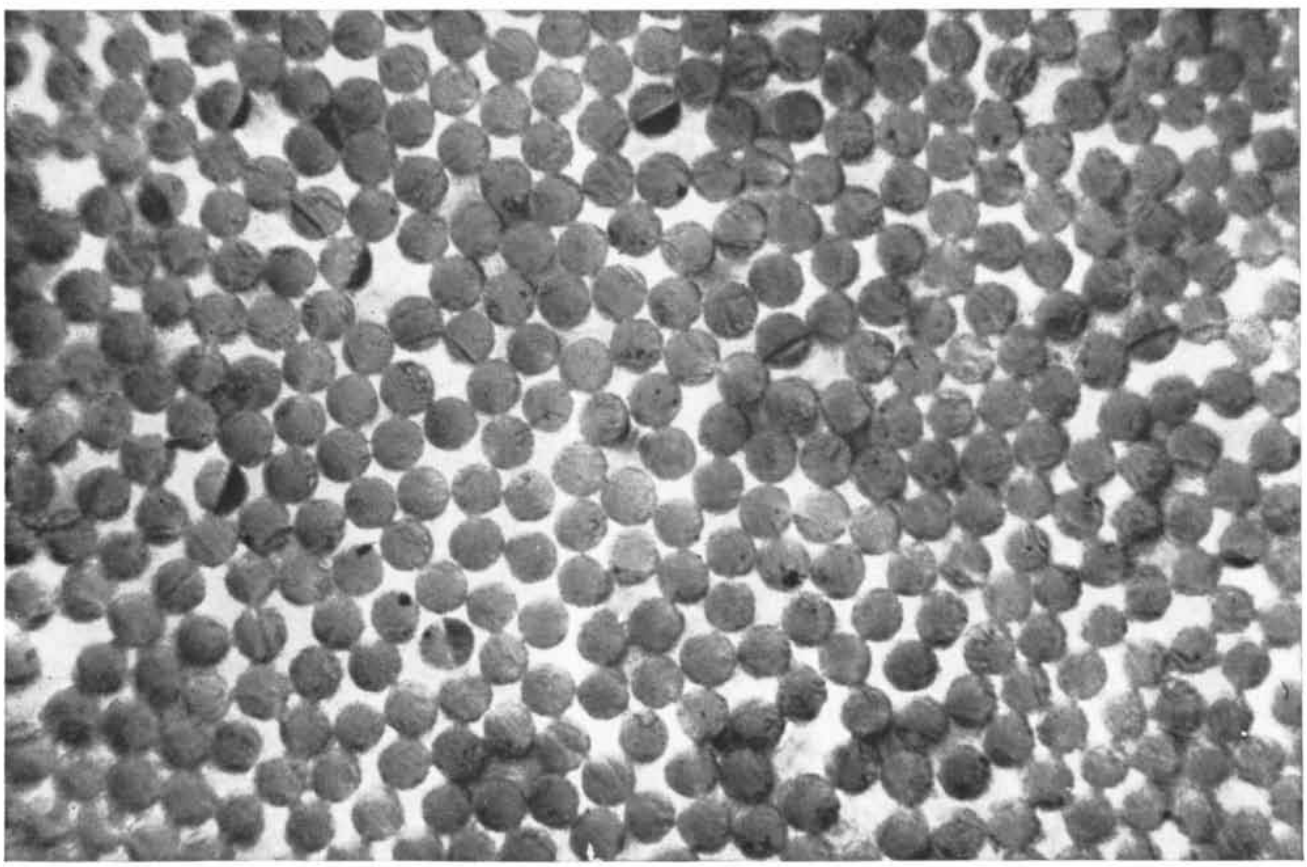
The behavior of a two-phase material under stress is a different story. The material must combine a substance of high tensile strength (strength at break) and high modulus of elasticity (resistance to stretch and deformation prior to break) with a substance of comparatively low modulus of elasticity. In the composite structure the high-strength substance usually constitutes the larger portion of the total mass and is more or less finely divided and dispersed in a matrix furnished by the low-modulus substance. Under an applied force the low-modulus substance stretches and deforms and so distributes the stress to the high-strength component. The total structure thereby absorbs a loading stress that would easily rupture the weaker component. At the same time the isolation of the imperfections present in the individual small units —crystals or fibers—of the high-strength substance prevents the propagation of cracks from these imperfections. Individual units may yield to stress, but the stress is thereupon redistributed through the low-modulus substance to other high-strength units in the structure. The composite structure thus enables the high-strength substance to perform closer to its theoretical limit.

There is ample evidence in nature and technology for the validity of this empirical description of the behavior of two-phase materials. But the two-phase concept seems to have escaped notice, even when men have produced materials that embody it. A general theoretical and quantitative expression of the concept remains to be developed. Our experience indicates, for example, that the high-strength substance should have a modulus of elasticity at least twice that of the low-modulus substance. Now that the concept is recognized, however, one cannot resist the urge to speculate on the tremendous possibilities that can be realized through its conscious application. It should be possible to design two-phase materials that will develop to a maximum the specific characteristics of their component substances and to produce materials with unprecedented impact resistance, great tensile, flexural and compressive strength, stability at high temperature and other properties.

In nature wood is a material that embodies the two-phase concept in a plainly apparent fashion. Wood combines a relatively high-strength, high-modulus fiber, cellulose, with a low-modulus plastic matrix, lignin. The advantages of this structure are admirably demonstrated in the bamboo pole. The long, high-strength fibers, arrayed longitudinally in parallel, have a modulus of elasticity of possibly



BAMBOO is a natural two-phase material. Magnified approximately 340 diameters in this cross-sectional view, the cellulose fibers appear as small, light gray, roughly circular areas with dark centers. The darker areas are gaseous cells in the dry bamboo. The fine light areas between the fibers contain lignin, the continuous phase of the material that cements the whole structure together.



FILAMENT-WOUND FIBERGLAS is an artificial two-phase material. Seen magnified approximately 415 diameters in this cross-sectional view, the glass fibers appear as small gray circles against the lighter background of epoxy resin, the supporting matrix.

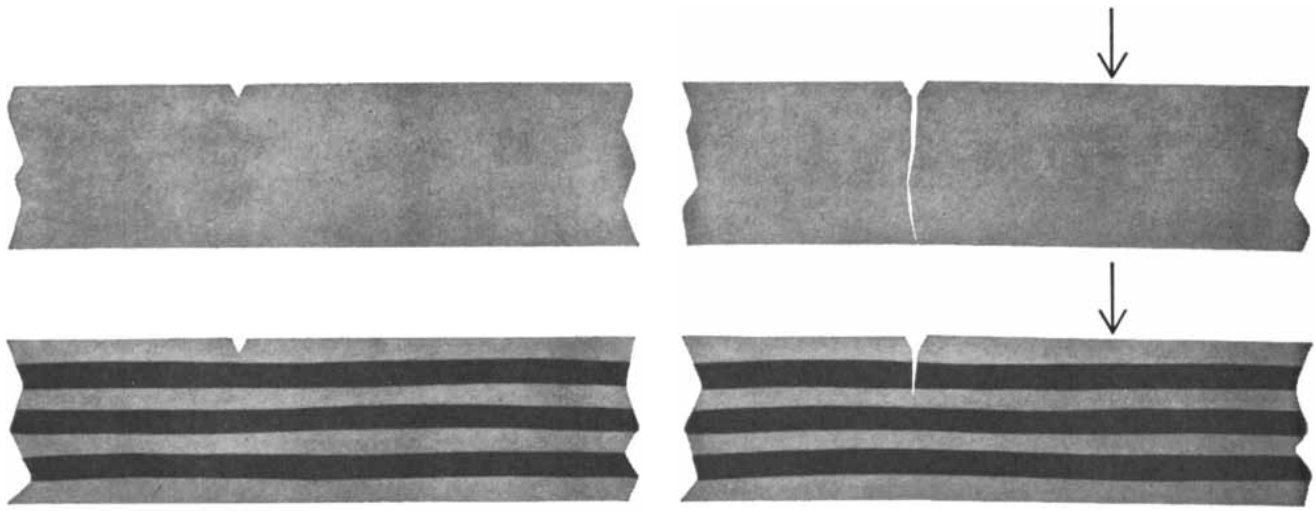
four million pounds per square inch (p.s.i.), whereas the containing matrix has a modulus of about one million p.s.i. In this highly organized structure any break in the fibers is isolated by the supporting matrix, and the yielding elasticity of the matrix transfers the loading stress to the other intact fibers. The result is a material with great resistance to scratches and bruises that would start fractures in homogeneous materials.

In the tropical and subtropical regions to which bamboo is indigenous this material serves in a great variety of functions, from poles for carrying purposes to furniture and dwellings. (The ancient Chinese disassembled the two-phase structure of bamboo by burying poles in mud until the lignin rotted away and then twisted the fibers into rope to support primitive but structurally sound suspension bridges made of bamboo poles.) In northerly climates the engineering virtues of bamboo are best known to anglers, who for generations have prized split-bamboo fly rods. These thin wands may weigh less than two ounces, and yet they show a tough, resilient "backbone" in action.

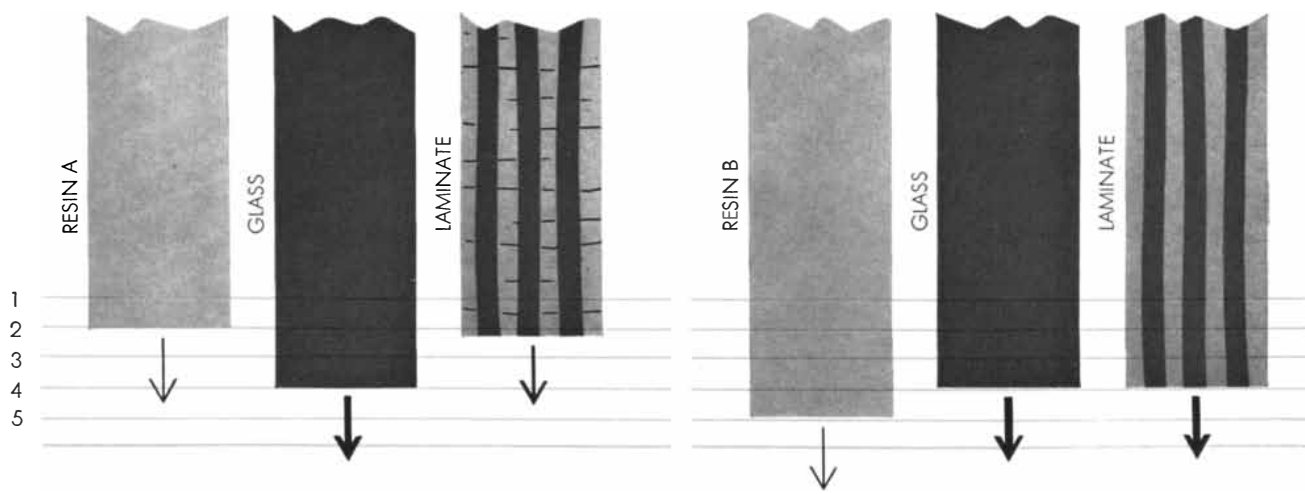
Investigation of the structure of various kinds of wood shows that the special properties exhibited in each case derive from the patterns in which the cellulose fibers are arranged. The gnarled and twisted grain of sycamore, for example, makes it the ideal material for the butcher's massive chopping block. On the other hand, the axial bundling of fibers in the Osage orange tree creates a structure of great flexural strength, needed in the making of a longbow.

I have found nothing in the historical record to suggest that man, in the course of his technological progress, read the lesson of nature's two-phase materials and deliberately set out to duplicate them. On the other hand, there are many instances, both ancient and modern, in which man has paralleled nature in the development of his strongest and most capable materials.

Students of medieval weaponry, for example, may now learn to appreciate

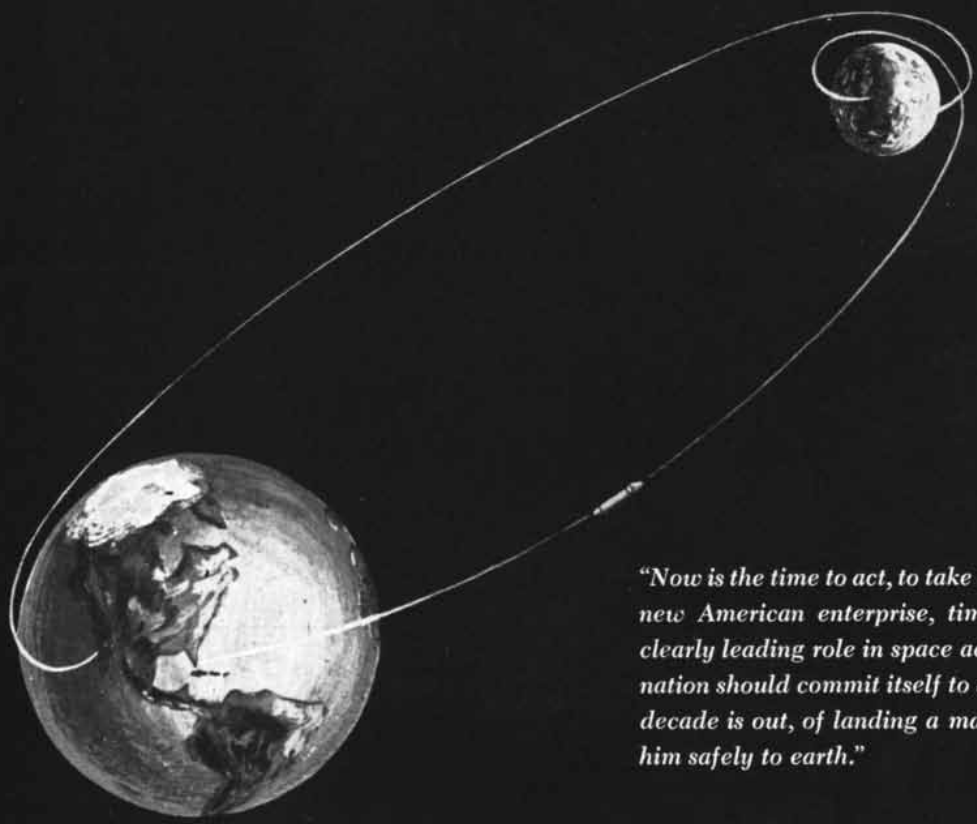


PROPAGATION OF A CRACK in a homogeneous material (*top*) is compared with that in a two-phase material (*bottom*). Any defect in the former, such as a surface scratch (*top left*), becomes the focus of any external stress (*arrow*). Once started, a crack propagates readily, resulting in a fracture (*top right*). Similarly, a defect in one of the fibers (*dark bands*) near the surface scratch can result in a fracture of that fiber. But because the fiber is isolated from the others, the crack cannot propagate throughout.



RELATIVE ELASTICITY of substances in a two-phase material largely determines the effective strength of the material. For example, if the resin ("*Resin A*") in a two-phase laminate is less elastic than the glass (*numbers at left represent per cent elongation at the breaking point*), it will rupture before the glass can absorb enough of the applied load (*arrow*). But if the resin ("*Resin B*") is more elastic, it deforms without breaking, allowing the glass to contribute its own strength fully to the laminate.

National Aeronautics and Space Administration



"Now is the time to act, to take longer strides, time for a great new American enterprise, time for this Nation to take a clearly leading role in space achievement. I believe that the nation should commit itself to achieving the goal, before the decade is out, of landing a man on the moon and returning him safely to earth."

The President
of the United States
May 25, 1961

The nation has committed itself to accelerate greatly the development of space science and technology, accepting as a national goal, the achievement of manned lunar landing and return before the end of the decade. This space program will require spending many billions of dollars during the next ten years.

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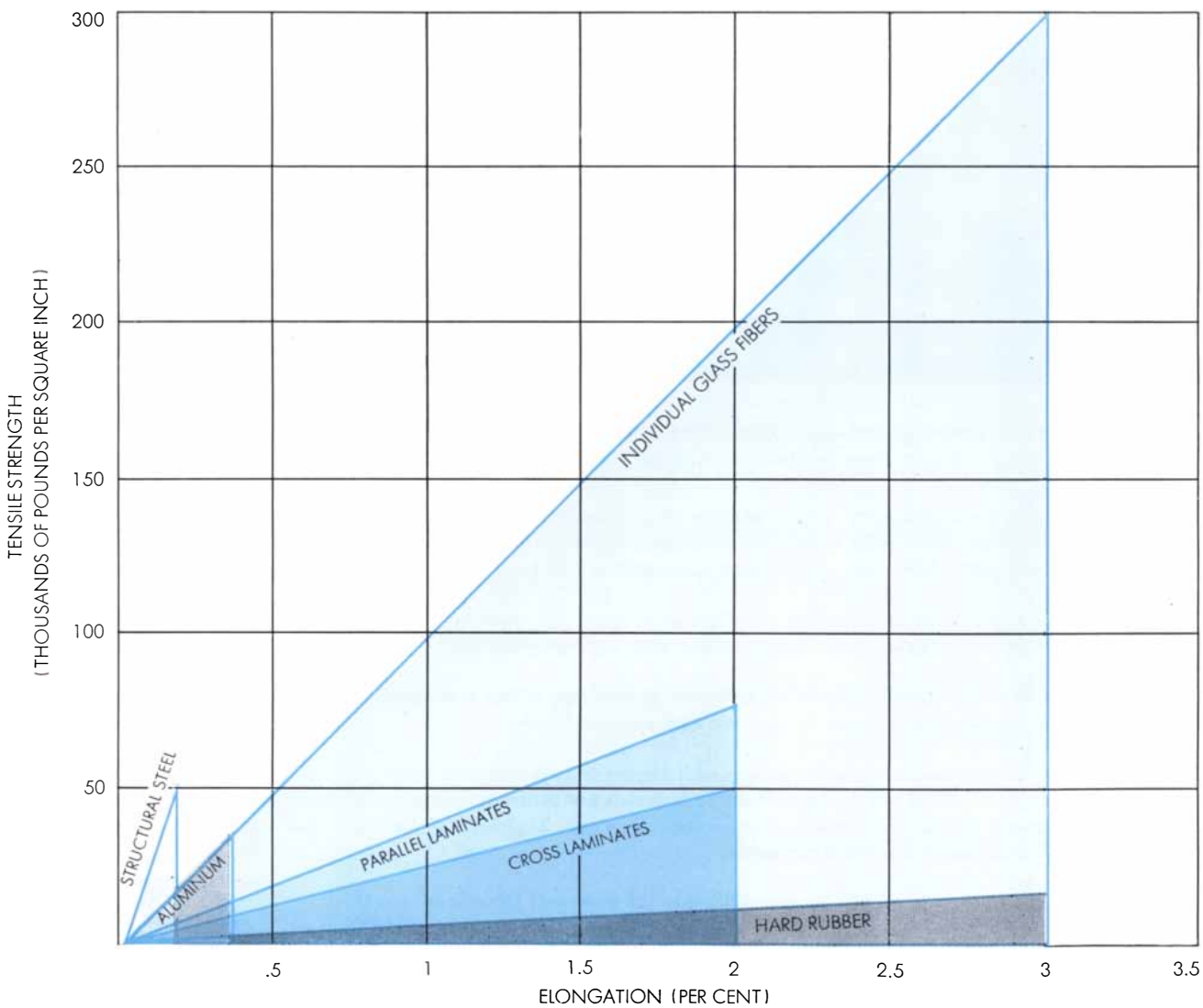
Positions are filled in accordance with Aero-Space Technology Announcement 252B.

All qualified applicants will receive consideration for employment without regard to race, creed or color, or national origin.

the full significance of the patterns they admire so much in the blades of swords made by the craftsmen of Damascus, Toledo and Japan. These blades possess a remarkable flexibility and toughness and yet they have a brittle hardness that enables them to hold a keen cutting edge. In Damascus and Toledo these results were obtained by combining soft wrought iron with an extremely hard nitrided steel. (The steel was nitrided by the addition of powdered fresh bone to the melt.) Strips of steel and iron were stacked on the anvil and hammered into a laminate, then the strips of the laminate were cut and stacked one on another, reheated and hammered out again until the iron and steel were drawn down to layers a mil (.001 inch) or a half-mil in thickness. In Japan the ritualistic forging process proceeded by almost the same methods to the same end. The beautiful patterns created by the differing grain of the component metals can now be comprehended as the visible evidence of a two-phase structure. Here is a classic example of a high-strength but brittle substance supported and contained in a matrix of a ductile substance; the one gave the blade its hardness and keenness, the other its flexibility and toughness.

In modern times instances of the creation of two-phase materials abound. But all seem to represent equally unconscious applications of the principle. Tough metal alloys can in general be regarded as two-phase materials. The literature, however, contains no explicit reference to the idea. The high-speed grinding wheel is made of a two-phase material composed of alumina granules with a modulus of elasticity of 50 million p.s.i. and a ceramic with a modulus of six million p.s.i. Next to diamond, the hardest cutting tools at the command of technology are a compound of tungsten carbide with a modulus of 80 million p.s.i. and a cobalt matrix with a modulus of 12 million p.s.i.

Nylon yarns represent the creation of a two-phase structure from an apparently homogeneous substance. As it is first drawn, the nylon filament is approximately 40 per cent by volume crystalline material. In the matrix formed by the otherwise amorphous plastic the crystals lie in a random jackstraw arrangement. Subsequent stretching of the material



ENERGY ABSORBED by a given material under stress is represented by the area under the curve obtained when the tensile strength of that material is plotted against per cent elongation. The peaks of the curves shown here mark the tensile strength at the yield point of structural steel and aluminum and at the breaking point of the other materials. Thus although steel has a much greater tensile strength than hard rubber, it cannot absorb as much energy under stress; thus it also has a lower impact resistance.

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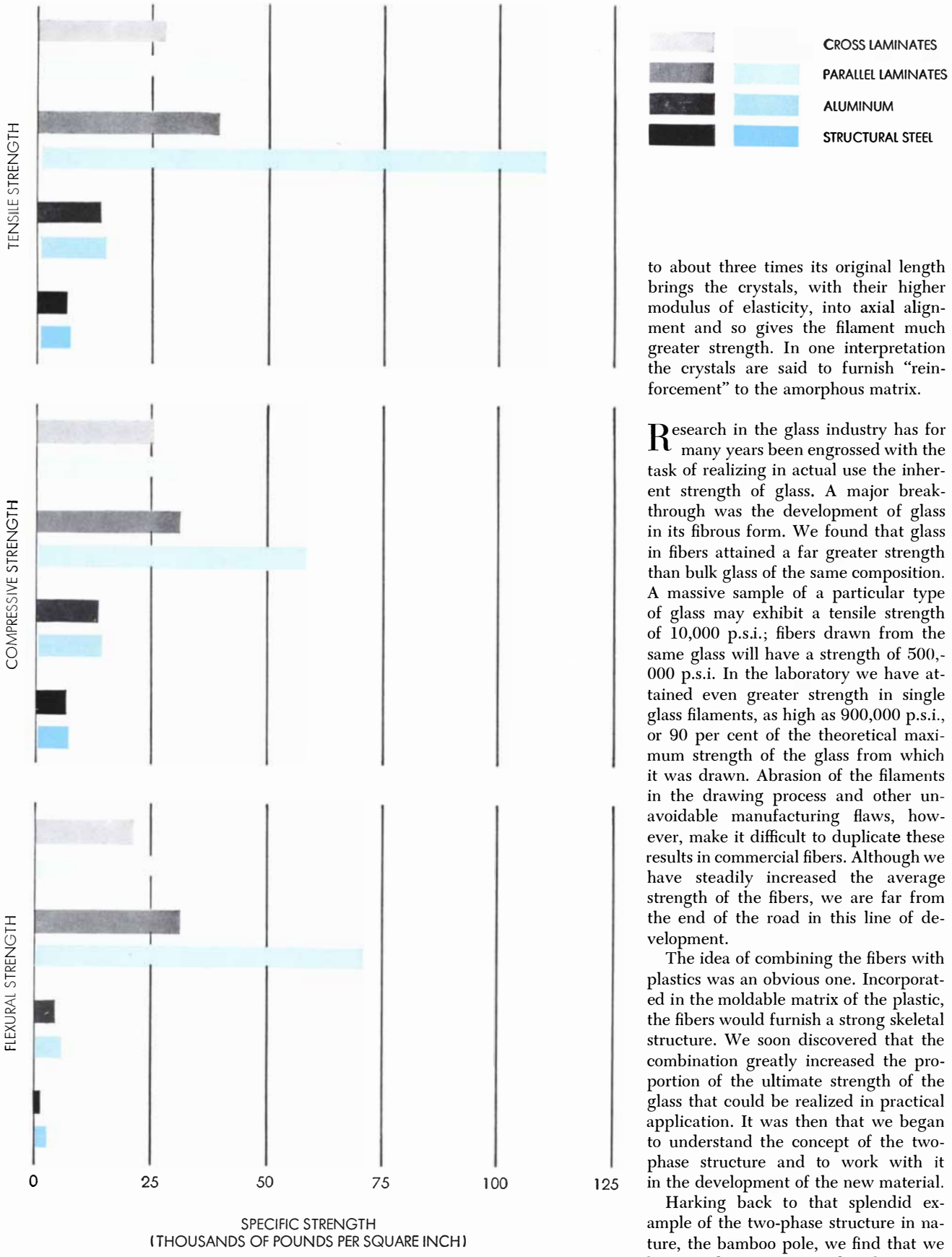


COMPARISON OF SPECIFIC STRENGTH (i.e., strength-to-weight ratio) of two-phase materials and aluminum and structural steel (*keyed to legend at top right*) shows the superiority of the former in terms of strength per unit weight. Upper bar of each pair is the strength of the material in commercial form; colored bar, that obtained in experiments.

to about three times its original length brings the crystals, with their higher modulus of elasticity, into axial alignment and so gives the filament much greater strength. In one interpretation the crystals are said to furnish "reinforcement" to the amorphous matrix.

Research in the glass industry has for many years been engrossed with the task of realizing in actual use the inherent strength of glass. A major breakthrough was the development of glass in its fibrous form. We found that glass in fibers attained a far greater strength than bulk glass of the same composition. A massive sample of a particular type of glass may exhibit a tensile strength of 10,000 p.s.i.; fibers drawn from the same glass will have a strength of 500,000 p.s.i. In the laboratory we have attained even greater strength in single glass filaments, as high as 900,000 p.s.i., or 90 per cent of the theoretical maximum strength of the glass from which it was drawn. Abrasion of the filaments in the drawing process and other unavoidable manufacturing flaws, however, make it difficult to duplicate these results in commercial fibers. Although we have steadily increased the average strength of the fibers, we are far from the end of the road in this line of development.

The idea of combining the fibers with plastics was an obvious one. Incorporated in the moldable matrix of the plastic, the fibers would furnish a strong skeletal structure. We soon discovered that the combination greatly increased the proportion of the ultimate strength of the glass that could be realized in practical application. It was then that we began to understand the concept of the two-phase structure and to work with it in the development of the new material.

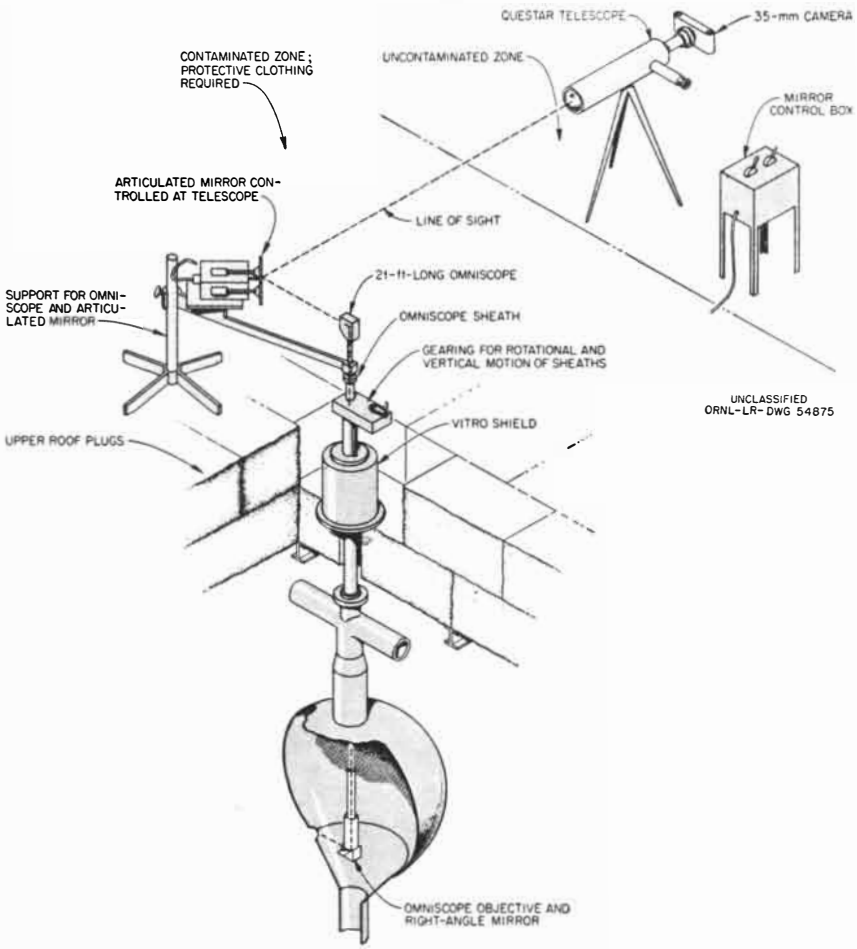
Harking back to that splendid example of the two-phase structure in nature, the bamboo pole, we find that we have outdone nature. Today the manufacture of fly rods and other fishing rods is dominated by fibrous glass in plastic. A typical rod may contain 70 per cent

glass fibers by volume and 30 per cent resin. The glass fibers have a modulus of elasticity of 10 million p.s.i., the resin a modulus of 500,000 p.s.i. In combination these components make a rod that develops a tensile strength of 250,000 p.s.i., or a large fraction of the inherent strength of the fibers used in this application and a strength far greater than that of a comparable bamboo rod. The rods are not sensitive to scratches or bruises; they can be bent almost double without a break even when notched. Because the glass fibers are perfectly elastic, the rods will not warp after being stored in a curved position for a prolonged period. For this and other uses the glass-plastic combination produces a material with high dimensional stability.

Another application that dramatizes the character of the glass-plastic material is the lightweight body armor with which foot soldiers in the U.S. armed forces have been equipped. Ordinary plastics have an impact resistance of less than one foot-pound per inch. Glass-plastic materials show an impact resistance of 15 to 30 foot-pounds. By arranging the fibers in parallel configurations this figure can be increased to 50 to 70 foot-pounds. The material apparently derives its shock-absorbing qualities from the fact that the fibers have about the same tensile strength as steel but a lower modulus of elasticity, about 10 million p.s.i. compared with 30 million, and so a greater stretch at break. Glass-plastic body armor can withstand the force of a bullet or shell fragment that would penetrate a comparable weight per square foot of steel.

In the development of glass plastics to meet specific engineering specifications the fineness to which the fibers may be drawn offers one avenue of design. Although the diameter of the fiber does not significantly affect the strength of the filaments and strands themselves, greater fineness allows greater subdivision and wider distribution of the high-strength component in the matrix and corresponding reduction of the probability of fault propagation.

The arrangement of the fibers in the matrix can also be adapted to develop maximum strength for particular applications. By using the fibers as separate filaments, by weaving them into fabrics or laying them at random or in whorls in felted mats, the materials can be endowed with structural patterns in accordance with the economic, thermal or other considerations imposed by the end use. An important recent development



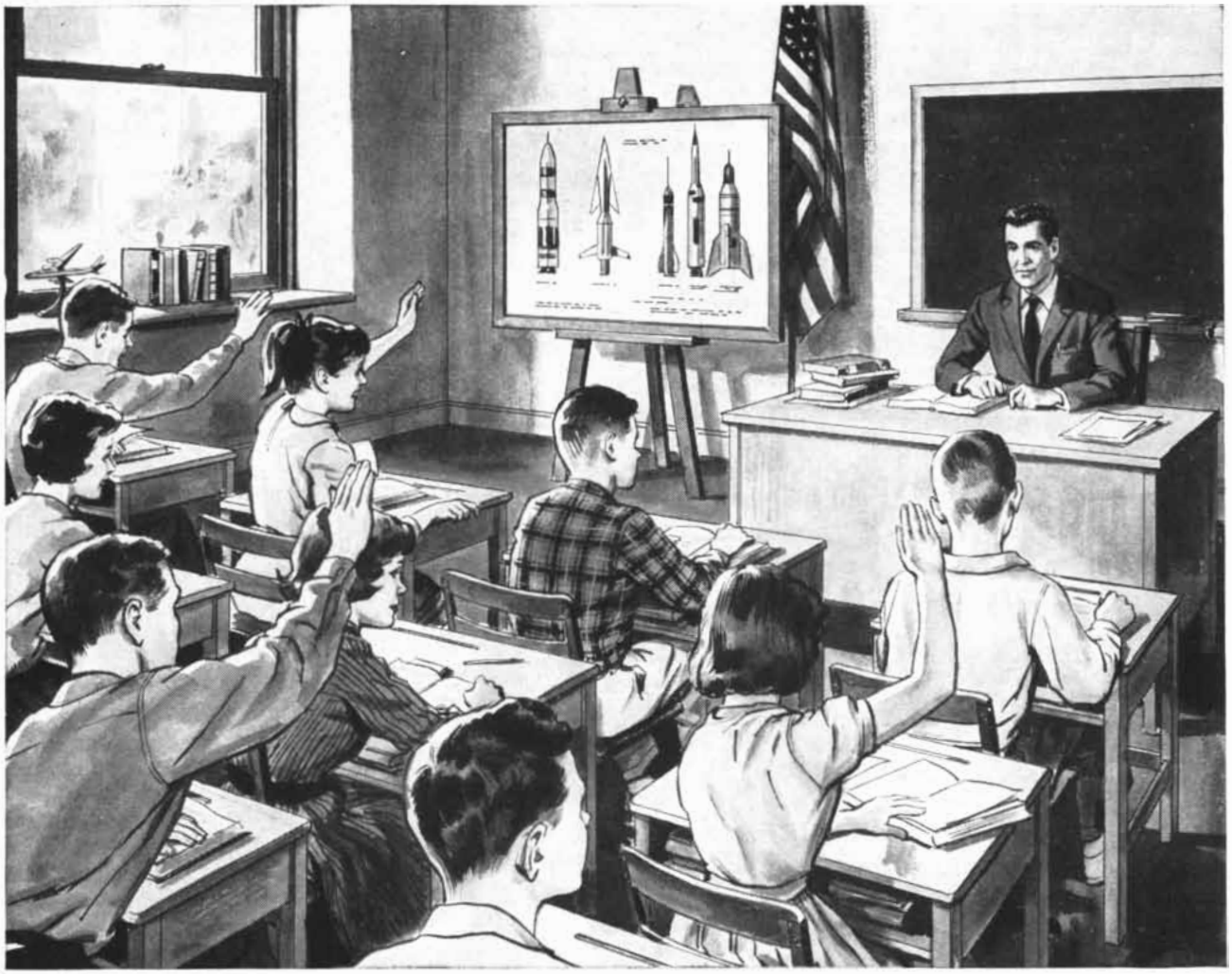
This schematic diagram was sent to us by Oak Ridge National Laboratory at Oak Ridge, Tennessee, operated by Union Carbide Corporation for the U.S. Atomic Energy Commission. It shows how the versatile Questar telescope, in the uncontaminated zone at top right, permitted metallurgists to work, without protective clothing, in comfort and safety while examining the interior of a radioactive core vessel twenty feet below the 5-foot-thick concrete shield. By means of a remotely controlled mirror, the operator could direct light rays from a 21-foot periscope, called an Omniscope, into the Questar, where visual or photographic images were formed at will. Inside the empty tank the radiation level sometimes reached 100,000 roentgens per hour, a small fraction of which would be lethal. With a 35-mm. camera attached to Questar's optical axis, 5 x 7 prints were secured giving magnifications of 4 and 16x, while the standard Questar eyepieces allowed visual inspection at 4, 8, 16 and 32 diameters magnification. We are told that the metallurgists were highly pleased with Questar and optimistic about its possible use in other difficult applications. The examination proved that powers to 60 diameters are feasible with improved lighting, that stereophotography is possible, and that mapping of the entire inner surface of the vessel may be done with a motion picture camera attached to Questar.

has been made possible by the drawing of the glass into continuous fine filaments. With these filaments laid in parallel, the material can be designed for stresses that impose extremely high loading on the glass. In the fabrication of a pressure vessel, for example, the fibers can be arranged in patterns to withstand maximum circumferential and axial stresses. This development reflects one of the major advantages of two-phase materials: the opportunity to design required properties into the material.

The choice of resin is restricted only by the requirement that this low-modulus element must have a greater elongation at break than the glass. If the elongation at break in the glass fiber is about 4 per cent, then the resin must have an elongation of 5 per cent or more. The resin can otherwise be selected for thermal stability, impermeability to moisture or other considerations imposed by the task at hand.

The importance of the relative degree of elongation at break in the two components of a two-phase material can be illustrated by a negative example. Glass fibers cannot be used to reinforce Portland cement, even though the two materials can be made compatible by protecting the fibers against the action of lime. The reason is that the modulus of elasticity of both glass and cement are on the order of 10 million p.s.i.—too close together to permit distribution of stress to the fibers. (Steel, with a modulus of 30 million p.s.i., or asbestos, with a modulus of 24 million p.s.i., makes an excellent two-phase material in combination with cement.) On the other hand, plaster of Paris, which has a modulus of two million p.s.i., works well in combination with glass fibers. By itself it has the fragile, brittle character of an empty eggshell. In combination with glass fibers it becomes, without any significant increase in weight, a tough, relatively flexible material with much-improved impact resistance. William D. Kingery and his associates at the Massachusetts Institute of Technology have produced a composite of glass fibers and ice, not as a laboratory stunt but in a serious effort to create an inexpensive, practical building material for use in the Arctic and Antarctic.

Even in its present, not yet precise formulation the two-phase concept charts an approach to the design of entirely new materials. They may be made of improbable combinations of substances. In our laboratory, for example, we have produced samples of a temperature-resistant material in which glass



ANYONE FOR MARS?

Chances are there's more than one budding astronaut in this bright-eyed group. As in any other classroom in the land, there are probably several potential teachers, too . . . along with a sprinkling of doctors, scientists, linguists, engineers and poets.

Let's hope so.

Let's hope that all the bright-eyed youngsters in all the classrooms in this great country of ours will have every opportunity to make the most of their God-given talents. Let's hope they go to first-rate colleges and universities, where they will be trained to be useful and productive citizens. We're going to need them all in the critical years that lie ahead.

Yet what are their chances?

Today the college classroom, the place where future brainpower is generated, is being seriously weakened by two alarming trends: (1) Low faculty salaries are driving great numbers of gifted teachers into other fields, and doing little to attract talented young people to the teaching profession. And (2) physical facilities, in some cases already inadequate, are not being expanded to take care of mushrooming enrollments. (College applications are expected to *double* within ten years!)

This is a serious situation, and we must do something about it *now!* Our future as a nation depends on it. Won't you help? Support the college of your choice. Help it to pay teachers decent salaries and the respect they so richly deserve. Help it to build the classrooms, laboratories and libraries that will be so desperately needed by 1970. The rewards will be greater than you think.

It's important for you to know what the college crisis means to you. Write for a free booklet to: HIGHER EDUCATION, Box 36, Times Square Station, New York 36, New York.

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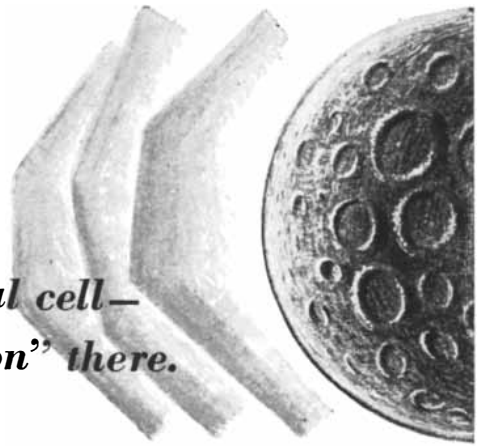
fibers are embedded in an aluminum matrix. Aluminum begins to lose strength at 300 degrees Fahrenheit, but the combination remains stable up to 800 degrees F., the yield point of glass. The two-phase concept has even given glass technologists a strategy for realizing the strength of glass in bulk. Over the years the aim has been to produce glass of high transparency and so of high homogeneity in structure. Glass that meets these specifications is, of course, highly susceptible to fractures that can be started by the merest surface scratch. We can write the specifications for two-phase glasses, combining glasses of different properties, that would overcome this deficiency. If we could design industrial processes to make such glasses cheaply, we could greatly expand the uses of this material.

The greatest promise in the application of the two-phase concept lies in the prospective utilization of oxides as structural materials. Technology operates in an atmosphere of oxygen; it expends much energy to win metals from their oxides and then must lavish great effort on the control of rust and corrosion in order to keep the metals from returning to their original state. Oxides, being already oxidized, would need no such protection. These materials have many other interesting properties. The oxides of such metals as zirconium and titanium, for example, are light in weight, maintain their strength at temperatures above the melting point of metals and have a modulus of elasticity in the range of 40 to 50 million p.s.i. Because these oxides are brittle and scratch-sensitive, however, their virtues have yet to be used in engineering functions. With the two-phase concept in mind, it becomes possible to design new materials that will put these substances to work.

In the laboratory we have combined whiskers of titanium oxide and zirconium oxides with glasses of special formulation. The glass, itself an oxide, serves as the low-modulus matrix in these prototypes of a new family of two-phase materials. They appear to offer a combination of strength, hardness, insensitivity to scratches, lightness in weight and stability at high temperature not found in any other materials. Composed entirely of nonoxidizable substances, these materials would also resist weathering and corrosion. Although we are just learning to make deliberate application of the two-phase concept, it is already teaching us how to employ the useful properties of many neglected materials.

When it Comes to Colonizing the Moon...



Chances are the regenerative liquid metal cell—developed by Allison—will be "on location" there.

This revolutionary new power source could serve as the vitally important power plant for lunar colonization.

Fantastic?

We don't think so.

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Theoretical and experimental studies of magnetofluidynamics, electron emission, and other physical processes involved in plasmas for power generation and space flight propulsion.

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Design and development of nuclear and solar solid state energy conversion systems.

Studies of nuclear power system design.

Study and preliminary design of advanced power systems for space and terrestrial use.

Heat transfer research for missiles, space and nuclear systems.

Reactor analysis for various reactor design studies.

Design and evaluation of fluidynamics problems in three dimensional supersonic flow.

Two-phase liquid metal technology.

MISSILES AND SPACECRAFT

Analytical support and engineering analysis of hot gas dynamics, combustion, interior ballistics and grain design, structural design, control system synthesis, missile dynamics and overall systems performance.

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MATHEMATICAL GAMES

An adventure in hyperspace at the Church of the Fourth Dimension

by Martin Gardner

"Could I but rotate my arm out of the limits set to it," one of the Utopians had said to him, "I could thrust it into a thousand dimensions."

—H. G. Wells, MEN LIKE GODS

Alexander Pope once described London as a "dear, droll, distracting town." Who would disagree? Even with respect to recreational mathematics, I have yet to make an imaginary visit to London without coming on something quite extraordinary. Last fall, for instance, I was reading the London *Times* in my hotel room a few blocks from Piccadilly Circus when a small advertisement caught my eye:

WEARY OF THE WORLD OF THREE DIMENSIONS? COME WORSHIP WITH US SUNDAY AT THE CHURCH OF THE FOURTH DIMENSION. SERVICES PROMPTLY AT 11 A.M., IN PLATO'S GROTTO. REVEREND ARTHUR SLADE, MINISTER.

An address was given. I tore out the advertisement, and on the following Sunday morning rode the Underground to a station within walking distance of the church. There was a damp chill in the air and a light mist was drifting in from the sea. I turned the last corner, completely unprepared for the strange edifice that loomed ahead of me. Four enormous cubes were stacked in one column, with four cantilevered cubes jutting in four directions from the exposed faces of the third cube from the ground. I recognized the structure at once as an unfolded hypercube. Just as the six square faces of a cube can be cut along seven lines and unfolded to make a two-dimensional Latin cross (a popular floor plan for medieval churches), so the eight cubical hyperfaces of a four-dimensional cube can be cut along 17 squares and "unfolded" to form a three-dimensional Latin cross.

A smiling young woman standing inside the portal directed me to a stairway. It spiraled down into a basement auditorium that I can only describe as a motion-picture theater combined with a limestone cavern. The front wall was a solid expanse of white. Formations of translucent pink stalactites glowed brightly on the ceiling, flooding the grotto with a rosy light. Huge stalagmites surrounded the room at the sides and back. Electronic organ music, like the score of a science fiction film, surged into the room from all directions. I touched one of the stalagmites. It vibrated beneath my fingers like the cold key of a stone xylophone.

The strange music continued for 10 minutes or more after I had taken a seat, then slowly softened as the overhead light began to dim. At the same time I became aware of a source of bluish light at the rear of the grotto. It grew more intense, casting sharp shadows of the heads of the congregation on the lower part of the white wall ahead. I turned around and saw an almost blinding point of light that appeared to come from an enormous distance.

The music faded into silence as the grotto became completely dark except for the brilliantly illuminated front wall. The shadow of the minister rose before us. After announcing the text as Ephesians, Chapter 3, verses 17 and 18, he began to read in low, resonant tones that seemed to come directly from the shadow's head: "... that ye, being rooted and grounded in love, may be able to comprehend with all saints what is the breadth, and length, and depth, and height...."

It was too dark for note-taking, but the following paragraphs summarize accurately, I think, the burden of Slade's remarkable sermon.

Our cosmos—the world we see, hear, feel—is the three-dimensional "surface" of a vast, four-dimensional sea. The ability to visualize, to comprehend intuitively, this "wholly other" world of higher space is given in each century only to a few chosen seers. For the rest of us, we must approach hyperspace indirectly, by way of analogy. Imagine a Flatland, a shadow world of two dimensions like the shadows on the wall of Plato's famous cave [*The Republic*, Chapter 7]. But shadows do not have material substance, so it is best to think of Flatland as possessing an infinitesimal thickness equal to the diameter of one of its fundamental particles. Imagine these particles floating on the smooth surface of a liquid. They dance in obedience to two-dimensional laws. The inhabitants of Flatland, who are made up of these particles, cannot conceive of a third direction perpendicular to the two they know.

We, however, who live in three-space can see every particle of Flatland. We see inside its houses, inside the bodies of every Flatlander. We can touch every particle of their world without passing our finger through their space. If we lift a Flatlander out of a locked room, it seems to him a miracle.

In an analogous way, Slade continued, our world of three-space floats on the quiet surface of a gigantic hyperocean; perhaps, as Einstein once suggested, on an immense hypersphere. The four-dimensional thickness of our world is approximately the diameter of a fundamental particle. The laws of our world are the "surface tensions" of the hypersea. The surface of this sea is uniform, otherwise our laws would not be uniform. A slight curvature of the sea's surface accounts for the slight, constant curvature of our space-time. Time exists also in hyperspace. If time is regarded as our fourth co-ordinate, then the hyperworld is a world of five dimensions. Electromagnetic waves are vibrations on the surface of the hypersea. Only in this way, Slade emphasized, can science escape the paradox of an empty space capable of transmitting energy.

What lies outside the sea's surface? The wholly other world of God! No longer is theology embarrassed by the contradiction between God's immanence and transcendence. Hyperspace touches every point of three-space. God is closer to us than our breathing. He can see every portion of our world, touch every particle without moving a finger through our space. Yet the Kingdom of God is completely "outside" of three-space, in a direction in which we cannot even point.

The cosmos was created billions of years ago when God poured (Slade paused to say that he spoke metaphorically) on the surface of the hypersea an enormous quantity of hyperparticles with asymmetric three-dimensional cross sections. Some of these particles fell into three-space in right-handed form to become neutrons, the others in left-

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handed form to become antineutrons. Pairs of opposite parity annihilated each other in a great primeval explosion, but a slight preponderance of hyperparticles happened to fall as neutrons and this excess remained. Most of these neutrons split into protons and electrons to form hydrogen. So began the evolution of our "one-sided" material world. The explosion caused a spreading of particles. To maintain this expanding universe in a reasonably steady state, God renews its matter at intervals by dipping his fingers into his supply of hyperparticles and flicking them toward the sea. Those which fall as antineutrons are annihilated, those which fall as neutrons remain. Whenever an antiparticle is created in the laboratory, we witness an actual "turning over" of an asymmetric particle in the same way that one can reverse in three-space an asymmetric two-dimensional pattern of cardboard. Thus the production of antiparticles provides an empirical proof of the reality of four-space.

Slade brought his sermon to a close by reading from the recently discovered Gnostic Gospel of Thomas: "If those who lead you say to you: Behold the kingdom is in heaven, then the birds will precede you. If they say to you that it is in the sea, then the fish will precede you. But the kingdom is within you and it is outside of you."

Again the unearthly organ music. The blue light vanished, plunging the cavern into total blackness. Slowly the pink stalactites overhead began to glow, and I blinked my eyes, dazzled to find myself back in three-space.

Slade, a tall man with iron gray hair and a small dark mustache, was standing at the grotto's entrance to greet the members of his congregation. As we shook hands I introduced myself and mentioned this department. "Of course!" he exclaimed. "I have some of your books. Are you in a hurry? If you wait a bit, we'll have a chance to chat."

After the last handshake Slade led me to a small elevator, which quickly carried us up to his study in the top cube of the church. Elaborate models of three-space projections of various types of hyperstructure were on display around the room.

"Tell me, Slade," I said, "is this doctrine of yours new or are you continuing a long tradition?"

"It's by no means new," he replied, "though I *can* claim to have established the first church in which hyperfaith serves as the cornerstone. Plato, of course, had no conception of a geometrical fourth dimension, though his cave analogy clearly implies it. In fact, every form of Platonic dualism that divides existence into the natural and supernatural is clearly a nonmathematical way of speaking about higher space. Henry More, the 17th-century Cambridge Platonist, was the first to regard the spiritual world as having four spatial dimensions. Then along came Immanuel Kant, with his recognition of our space and time as subjective lenses, so to speak, through which we view only a thin slice of transcendent reality. After that it is easy to see how the concept of higher space provided a much needed link between modern science and traditional religions."

"You say 'religions,' " I put in. "Does that mean your church is not Christian?"

"Only in the sense that we find essential truth in all the great world faiths. I should add that in recent decades the Continental Protestant theologians have finally discovered four-space. When Karl Barth talks about the 'vertical' or 'perpendicular' dimension, he clearly means it in a four-dimensional sense. And of course in the theology of Karl Heim there is a full, explicit recognition of the role of higher space."

"Yes," I said. "I recently read an interesting book called *Physicist and Christian*, by William G. Pollard [executive director of the Oak Ridge Institute of Nuclear Studies and an Episcopal clergyman]. He draws heavily on Heim's concept of hyperspace."

Slade scribbled the book's title on a note pad. "I must look it up. I wonder if Pollard realizes that a number of late 19th-century Protestants wrote books about the fourth dimension. A. T. Schofield's *Another World*, for example [it appeared in 1888], and Arthur Willink's *The World of the Unseen* [subtitled "An Essay on the Relation of Higher Space to Things Eternal"; published in 1893]. Of course modern occultists and spiritualists have had a field day with the notion. Peter D. Ouspensky, for instance, has a lot to say about it in his books, although most of his opinions derive from the speculations of Charles Howard Hinton, an American mathematician. Whately Carington, the English parapsychologist, wrote an unusual book in 1920—he published it under the by-line of W. Whately Smith—on *A Theory of the Mechanism of Survival*."

"Survival after death?"

Slade nodded. "I can't go along with Carington's belief in such things as table tipping being accomplished by an invisible four-dimensional lever, or clairvoyance as perception from a point in higher space, but I regard his basic hypothesis

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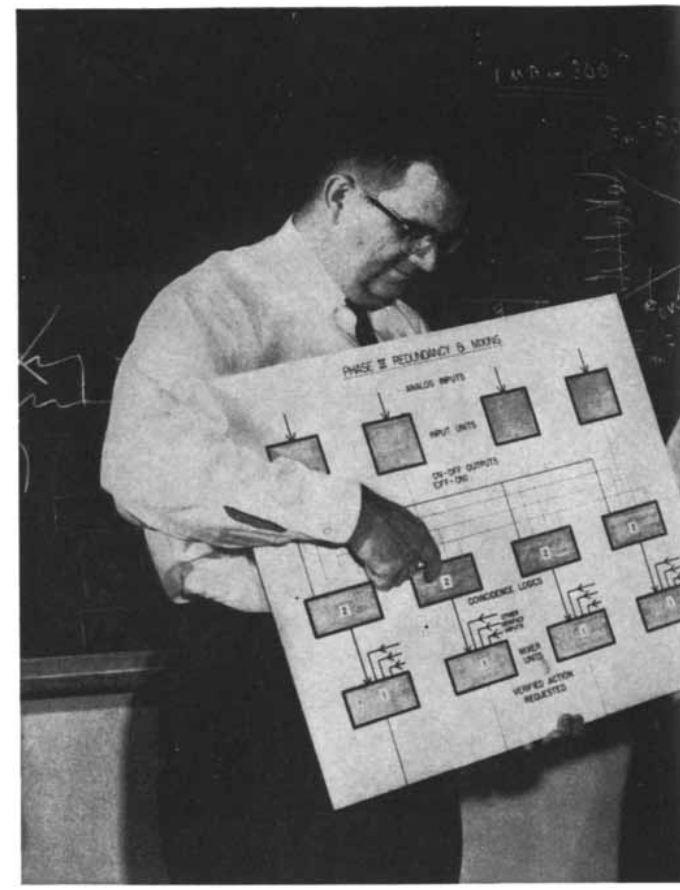
V. S. Underkoffler, J. L. Cockrell and J. H. Magee are three of the scientists who are pioneering new systems reliability concepts at L&N's R&D Center, North Wales, Pa.



His problem:

To boost reliability of process control systems

Name of this scientific American:
V. S. Underkoffler
Leeds & Northrup Company

As the capabilities and complexity of electronic process control systems increase, over-all systems reliability becomes an increasingly important consideration. For example, nuclear reactor operators are now asking for protective systems which will operate ten times longer—even a hundred times longer—between system failures.

In order to meet this requirement, a Leeds & Northrup R&D team has developed a self-monitoring protective system—an assembly of electronic components which, when properly coordinated with sensors and actuators, permits a many-fold increase in the mean-time between system failures. This team, consisting of V. S. Underkoffler, James Magee, James Cockrell and supporting personnel, is now looking at the possibility of applying this ingenious protective system to other processes.

The Inevitable Component Failure

At the outset of the project, Underkoffler and his men reasoned that even with the best components and craftsmanship, component failures would be inevitable. The problem, therefore, was to find some way of ensuring uninterrupted system operation from the time a component fails —until it has been detected, identified and replaced.

To do this, they proceeded to design separate circuit cards for each of the essential functions of a protective system: input, logic and output. By making identical copies of each of these three cards, they were able to build modular systems which continued to operate despite the failure of any one component.

With this arrangement, a number of identical cards can be made to accept the same signal. In the event that one of these cards fails to produce the correct signal in its output, the outputs of the remaining cards prevail. The system can be arranged on a two-out-of-three basis, three-out-of-four—or any other combination which gives the required probability of uninterrupted service.

Thus, for a system to fail, it would be necessary to have simultaneous failure of at least two cards in a given functional stage.

Self-Checking Feature

As a safeguard against this unlikely event, the system is equipped with a dynamic monitoring unit which auto-

matically informs the operator when any component fails either completely or intermittently. This unit produces a test signal which scans every card periodically (every 32 seconds in the typical system). If any card in the system develops performance not in accordance with the customer's specifications, the operator is alerted so that the defective circuit card can be immediately identified and replaced —by untrained personnel if necessary. System operation remains normal during both monitoring and repair.

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as sound. Our bodies are simply three-dimensional cross sections of our higher four-dimensional selves. Obviously a man is subject to all the laws of this world, but at the same time his experiences are permanently recorded—stored as information, so to speak—in the four-space portion of his higher self. When his three-space body ceases to function, the permanent record remains until it can be attached to a new body for a new cycle of life in some other three-space continuum."

"I like that," I said. "It explains the complete dependence of mind on body in this world, at the same time permitting an unbroken continuity between this life and the next. Isn't this close to what William James struggled to say in his little book on immortality?"

"Precisely. James, unfortunately, was no mathematician, so he had to express his meaning in nongeometrical metaphors."

"What about the so-called demonstrations of the fourth dimension by certain mediums," I asked. "Wasn't there a professor of astrophysics in Leipzig who wrote a book about them?"

I thought I detected an embarrassed note in Slade's laugh. "Yes, that was poor Johann Karl Friedrich Zöllner. His book *Transcendental Physics* was translated into English in 1881, but even the English copies are now quite rare. Zöllner did some good work in spectrum analysis, but he was supremely ignorant of conjuring methods. As a consequence he was badly taken in, I'm afraid, by Henry Slade, the American medium."

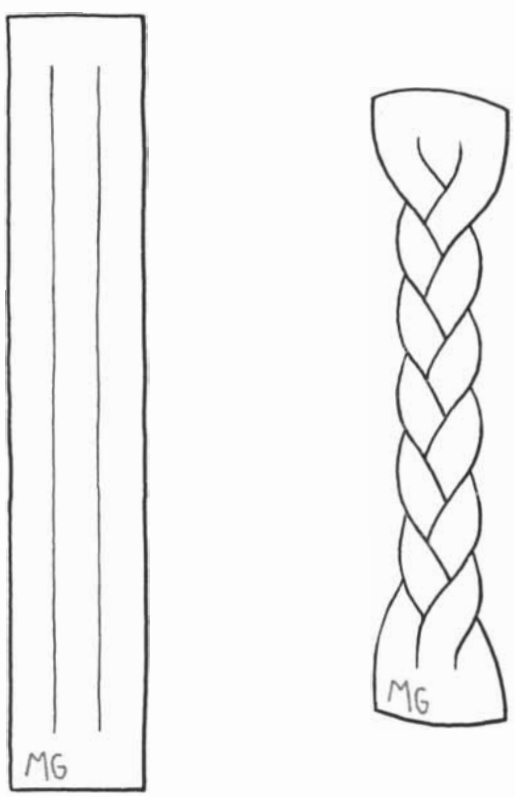
"Slade?" I said with surprise.

"Yes, I'm ashamed to say we're related. He was my great-uncle. When he died, he left a dozen fat notebooks in which he had recorded his methods. These notebooks were acquired by the English side of my family and handed down to me."

"This excites me greatly," I said. "Can you demonstrate any of the tricks?"

The request seemed to please him. Conjuring, he explained, was one of his hobbies, and he thought that the mathematical angles of several of Henry's tricks would be of interest to my readers.

From a drawer in his desk Slade took a strip of leather, cut as shown at the left in the illustration below, to make three parallel strips. He handed me a ball-point pen with the request that I mark the leather in some way to prevent later substitution, and I initialed a corner as shown. We sat on opposite sides of a small table. Slade held the leather under the table for a few moments, then brought it into view again. It was braided exactly as shown at the right in the illustration! Such braiding would be easy



Slade's leather strip—braided in hyperspace?

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Hughes systems, developed to meet the most advanced fighter mission problems, have paced airborne systems development. They have flown with the F-86, the F-89, the F-102, the F-106, and other U.S. Air Force, U.S. Navy and Canadian aircraft.

The new Hughes Tactical Attack System in its own right achieves new levels of capability, reliability and over-all economy. Highly flexible in design, this new system will be as modern in the late 1960's as it is today. It integrates three major functions—high resolution radar, weapon control auxiliaries and a navigational subsystem. Each function incorporates the latest state-of-the-art developments.

Coolant Problems which could be encountered in aircraft flying at multiples of sonic speeds and at high altitudes have been solved. New techniques are being applied which provide for more efficient cooling of the thousands of electronic parts and assemblies, promising greater reliability.

New "encapsulation" packaging techniques permit more work to be done in smaller space, saving weight and, again, vastly increasing reliability. This technique packages complex circuits in small "blocks" of plastic material. Each contains scores of diodes, transistors, relays and other electronic components. These units are vibration-free. They can be plugged in and out as easily as a toaster—facilitating trouble-shooting and cutting maintenance time.

These kinds of advancements are the "norm" at Hughes. For they are the result of over 16 years of prime experience in the design and building of airborne systems. The new Hughes Tactical Attack System has grown out of a special, company-funded program which has been active for three years.

Creating a new world with electronics

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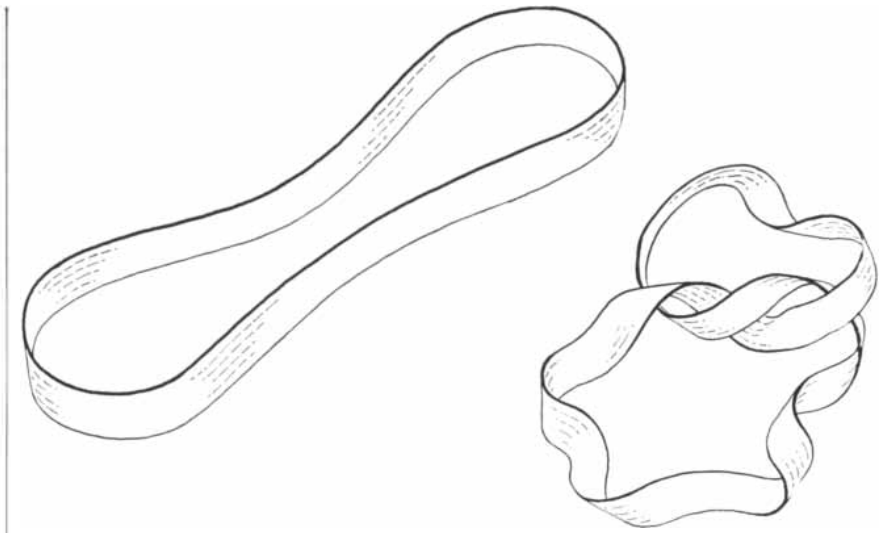

Slade's elastic band—knotted in hyperspace?

to accomplish if one could move the strips through hyperspace. In three-space it seemed impossible.

Slade's second trick was even more astonishing. He had me examine a rubber band of the wide, flat type shown at the left in the illustration above. This was placed in a matchbox, and the box was securely sealed at both ends with Scotch tape. Slade started to place it under the table, then remembered he had forgotten to have me mark the box for later identification. I drew a heavy *X* on the upper surface.

"If you like," he said, "you yourself may hold the box under the table."

I did as directed. Slade reached down, taking the box by its other end. There was a sound of movement and I could feel that the box seemed to be vibrating slightly.

Slade released his grip. "Please open the box."

First I inspected the box carefully. The tape was still in place. My mark was on the cover. I slit the tape with my thumbnail and pushed open the drawer. The elastic band—*mirabile dictu*—was tied in a simple knot as shown at the right in the illustration.

"Even if you managed somehow to open the box and switch bands," I said, "how the devil could you get a rubber band like this?"

Slade chuckled. "My great-uncle was a clever rascal."

I was unable to persuade Slade to tell me how either trick was done. The reader is invited to think about them until next month, when I shall give the best explanations I can.

We talked of many other things. When I finally left the Church of the Fourth Dimension, a heavy fog was swirling through the wet streets of London. I was back in Plato's cave. The shadowy forms of moving cars, their headlights forming flat elliptical blobs of light, made me think of some familiar lines from the Rubáiyát of a great Persian mathematician:

We are no other than a moving row
Of magic shadow-shapes that come and go
Round with the sun-illumined lantern held
In midnight by the Master of the Show.

Readers were asked last month to spot the fallacy in a roulette system that recently swept the casinos of South America. Here is John Scarne's analysis, from his new book, *Scarne's Complete Guide to Gambling:*

"The joker is in the statement that 'when the 8 red numbers in the third column appear, you win 2 chips on each for a total win of 16 chips.' This is incomplete. When those 8 numbers win and pay off 16 chips, *you also lose 8 chips on Black,* making the net payoff only 8 chips. Since you lost 20 chips on the red numbers in the first and second columns, your net loss on Red is not 4 chips, as stated, but 12 chips. Having lost 12 chips on Red, won 12 chips on Black, and lost 4 chips on the zero and double zero, you end up losing 4 chips. And that washes that system out completely. The house still has its favorable edge of 5 and 5/19 per cent, as usual, and the casino operator is the guy who is going to get rich—not you."

The Christmas greeting obtained by sliding those four paper strips is: JOLLY CHEER.

LOST IN THOUGHT

The dedicated research scientist, engrossed in an important project, might be described as "lost in thought." . . . Of course, he is *not lost.* He is systematically (and sometimes intuitively) tracking down the truth . . . the truth which—once found—represents significant accomplishment in basic and applied research.

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THE AMATEUR SCIENTIST

How to make an electrocardiogram of a water flea and investigate other bioelectric effects

Conducted by C. L. Stong

"Have you ever made a really good electrocardiogram of a *Daphnia*?" This question, an example of the irresistible teasers that occasionally reach this department, came a few months ago from George Camougis, assistant professor of physiology at Clark University. As things worked out, the challenge usurped several of my otherwise lazy summer weekends.

I had not made a good electrocardiogram of a *Daphnia* or of any other kind of water flea, and I so informed Camougis. "Neither has anyone else," he replied, "but it's a lot of fun to try. All you need is a *Daphnia* plus a high-fidelity amplifier, a recorder of some sort and a few accessories. With this apparatus you can do the flea experiment and others involving the electrical effects associated with animal behavior, including those of various muscle actions that are otherwise hidden from the eye. I will mail a description of the general procedure in a few days and you can take it from there." He did, and I did.

Camougis pointed out that the electrical phenomena associated with the active tissues of animals have been known for a long time. Perhaps the most startling examples are the shocks of electric fishes, which Aristotle first described more than 2,000 years ago. It was not until the latter part of the 18th century, however, that the existence of animal electricity was definitely established. With the 19th century and the development of electrical instruments, many experiments were performed to investigate the physical basis of animal electricity, especially in nerve and muscle.

With the advent of modern electronic equipment, electrical phenomena associated with nerve and muscle action have come in for intensive study. The basic inquiries, according to Camougis, center on the functions of the receptive, integrative and response mechanisms underlying animal behavior. They include studies of vision and hearing, the functioning of the brain and the contraction of muscle. The behavior of an animal reflects the complex interaction of great numbers of nerve and muscle fibers. To isolate a single event the experimenter must often attach a number of electrodes and ingenious sensing devices to the animal. Indeed, many discoveries in physiology can be traced to the development and use of just such clever devices. It is possible, on the other hand, to study the electrical responses of the whole animal by means of a somewhat simpler and less delicate apparatus. Such an apparatus usually includes a mechanism that writes a record whenever the animal moves or shifts a limb. Of necessity some part of the apparatus must touch the animal and so to some extent restrict or impede its movements. This drawback is avoided in the very simple apparatus described by Camougis and used to study animals that live in water. The bioelectric potentials are picked up merely by placing a pair of electrodes in the water.

Camougis says that a number of materials can be used for electrodes. Heavy copper wire about ⅛ inch in diameter works well for picking up currents from frogs and small fishes. (Brass, lead, soft iron and carbon can also be used.) The wire is cut into convenient lengths of about six inches. The ends can be flattened to provide a greater surface area. The wires are then insulated with several layers of quick-drying nail polish, except for the flattened part and about half an inch at the opposite end, where the leads are to be attached. Sleeves of plastic or rubber tubing are slipped over the wires as mechanical protection against the iron clamps used to support the electrodes in the water. A glass dish or other nonconducting vessel of appropriate size can be used as the container for the animal and water. The bare upper ends of the electrodes are connected by alligator clips to the input leads of the recording system, as shown in the illustration on the next page.

The electrical potentials normally picked up are so small that high-gain amplification is required. Stray fields set up by alternating-current power lines, by appliances and even by nearby radio stations can induce currents in the input leads almost as strong as the desired signal. Shielded cages that house the electrodes, the water container and a preamplifier have therefore become standard equipment for electrophysiological work. The shielded cage can be a plywood box covered on all sides with bronze or copper screening. It should have a hinged door on one side for access to the specimen and apparatus inside. It is essential that the door screening make good electrical contact with the rest of the shielding. Convenient dimensions are 30 by 20 by 20 inches, the door being 30 by 20 inches [*see illustration on page 149*]. The cage must be grounded, preferably to a nearby water pipe.

The characteristics of the amplifier and instrument required for displaying the electrical potentials are determined by the electrical phenomena to be investigated. When observing the action potentials of aquatic arthropods, a high-quality preamplifier capable of multiplying the input signal 10,000 times is essential. Capacitance-coupled, battery-operated preamplifiers are satisfactory, although direct-current preamplifiers must be used in the case of signals of very low frequency. A cathode-ray oscilloscope can be used to display the potentials and, along with the amplifier, should be grounded to the shielded cage. Any good oscilloscope will work, including the better kit models.

The technical problems of recording animal electricity vary inversely with the amplitude of the potential picked up by the electrodes. The potentials developed by some fishes, for example, can be fed directly into an oscilloscope of only moderate sensitivity, and the specimen need not be shielded.

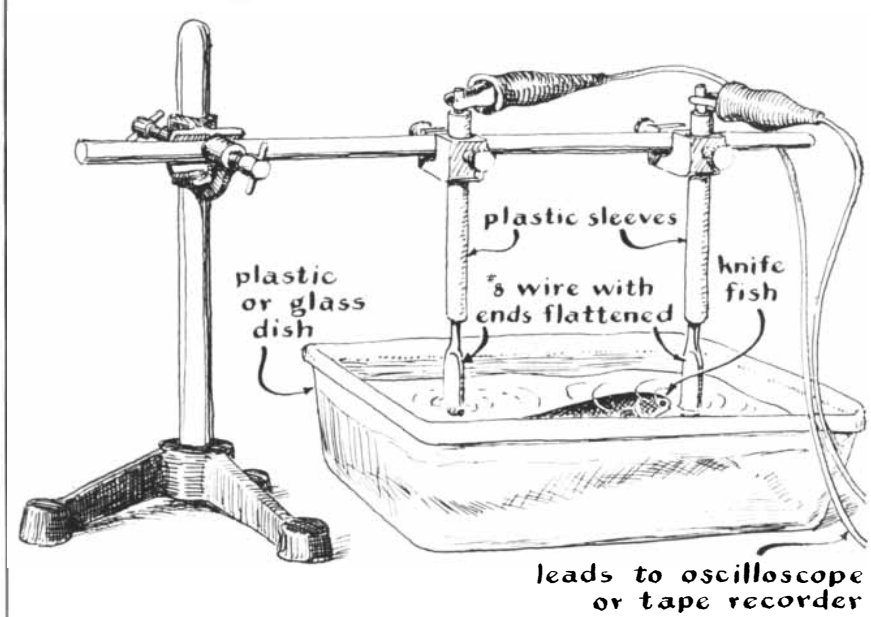
When the experimental animal in the

container remains still, the horizontal trace of the oscilloscope is a steady, straight line. When the animal moves, peaks of varying form and amplitude appear that correspond to variations in the electrical field induced in the water by the animal. These potentials are caused mainly by muscle action. When the crayfish is used as an experimental animal, for example, the amplitude of the action potentials is on the order of 50 to 100 microvolts. The amplitude of the deflections increases when an animal moves close to the recording electrodes. Surface oscillations of the water also induce spurious excursions in the trace, but these are normally of low amplitude and do not confuse the observations, particularly in the case of animals that move slowly. Since most of the electrical phenomena recorded are fast transients that span no more than a few thousandths of a second, ordinarily no difficulty arises from electrochemical reactions between the electrodes and the water. When observing animals that develop substantial direct currents, however, it is advisable to use silver electrodes that have been immersed in salt water for a few minutes while connected to a six-volt source. The process coats the electrodes with a protective film of silver chloride.

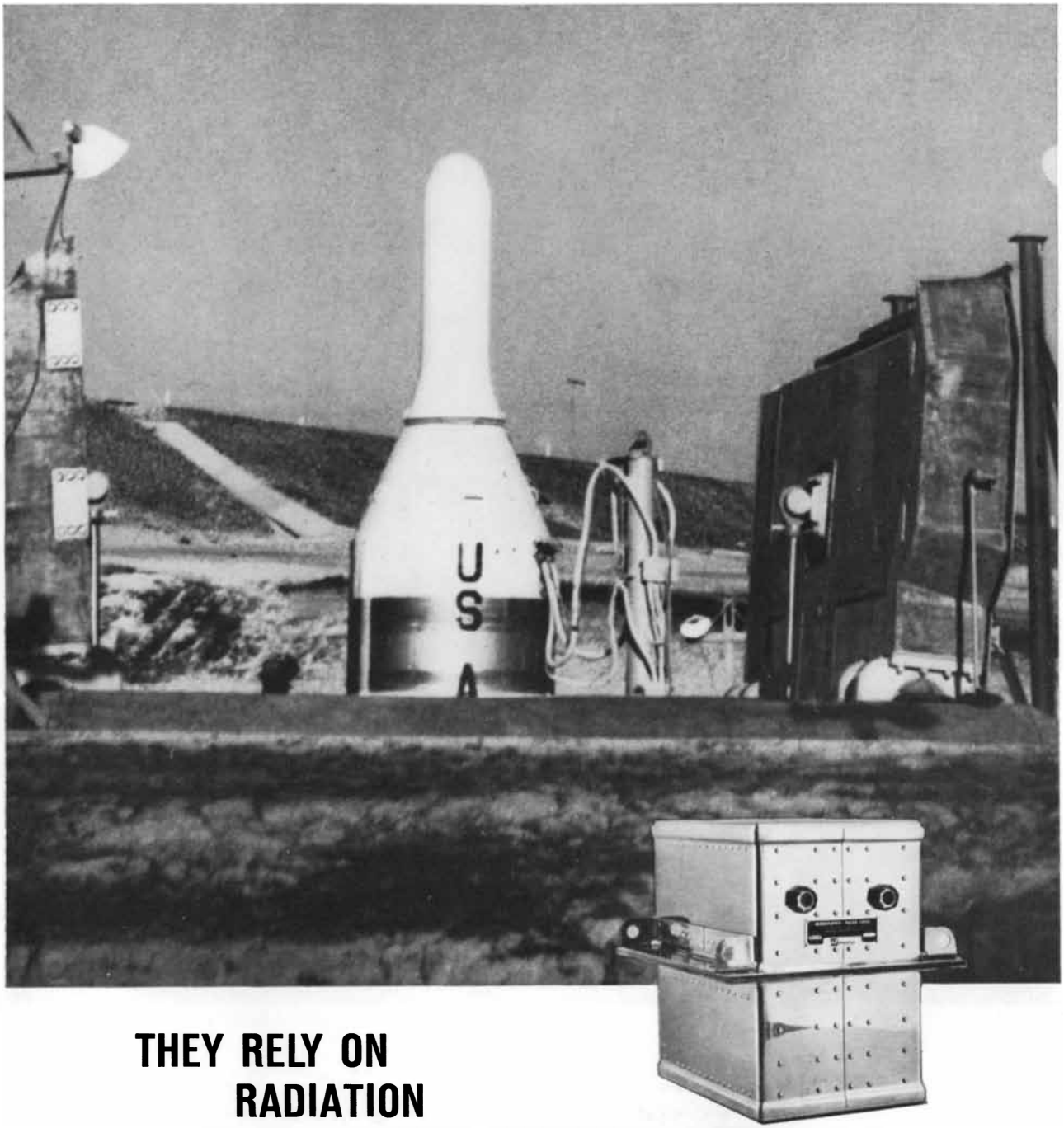
The voltage that appears across the electrodes varies with the resistance, and hence the purity, of the water. Impure water, which contains ions, provides a good path for the currents and tends to "short-circuit" the animal. This presents no problem in the case of large potentials, such as the electric discharges from knife fishes. But if one is to record muscle action potentials from crayfish and smaller creatures, the specimen must be in distilled or deionized water.

A variety of bioelectrical phenomena can be recorded by this method. Muscle action potentials are readily detected. Crayfish, for example, react as if startled when a bright light is suddenly turned on them. How much time elapses between the instant when the light comes on and the response of the crayfish? The interval is difficult to time accurately by eye. But it shows plainly on the oscilloscope. Experiments of this sort are made easier and still more interesting by the addition of an audio system so that the action potentials can be heard as well as seen. Just hook any good audio amplifier across the output of the preamplifier (in parallel with the input to the oscilloscope) and feed the amplified signal into a loudspeaker.

Aquatic insects such as the corixids (water boatmen) also make interesting subjects. Periodic bursts of electrical activity are clearly noted, synchronized with readily observable movements of the locomotory appendages. Such swimming movements have not been extensively investigated because heretofore the available techniques of observing the movements required bright lights, mechanical attachments and related apparatus that tended to modify natural behavior. Any muscle that contracts in the water generates a signal that can be detected with the aid of an amplifier having sufficiently high gain and not so noisy that the signal is masked. Incidentally, convenient test signals for checking



Electrode assembly for picking up bioelectric signals



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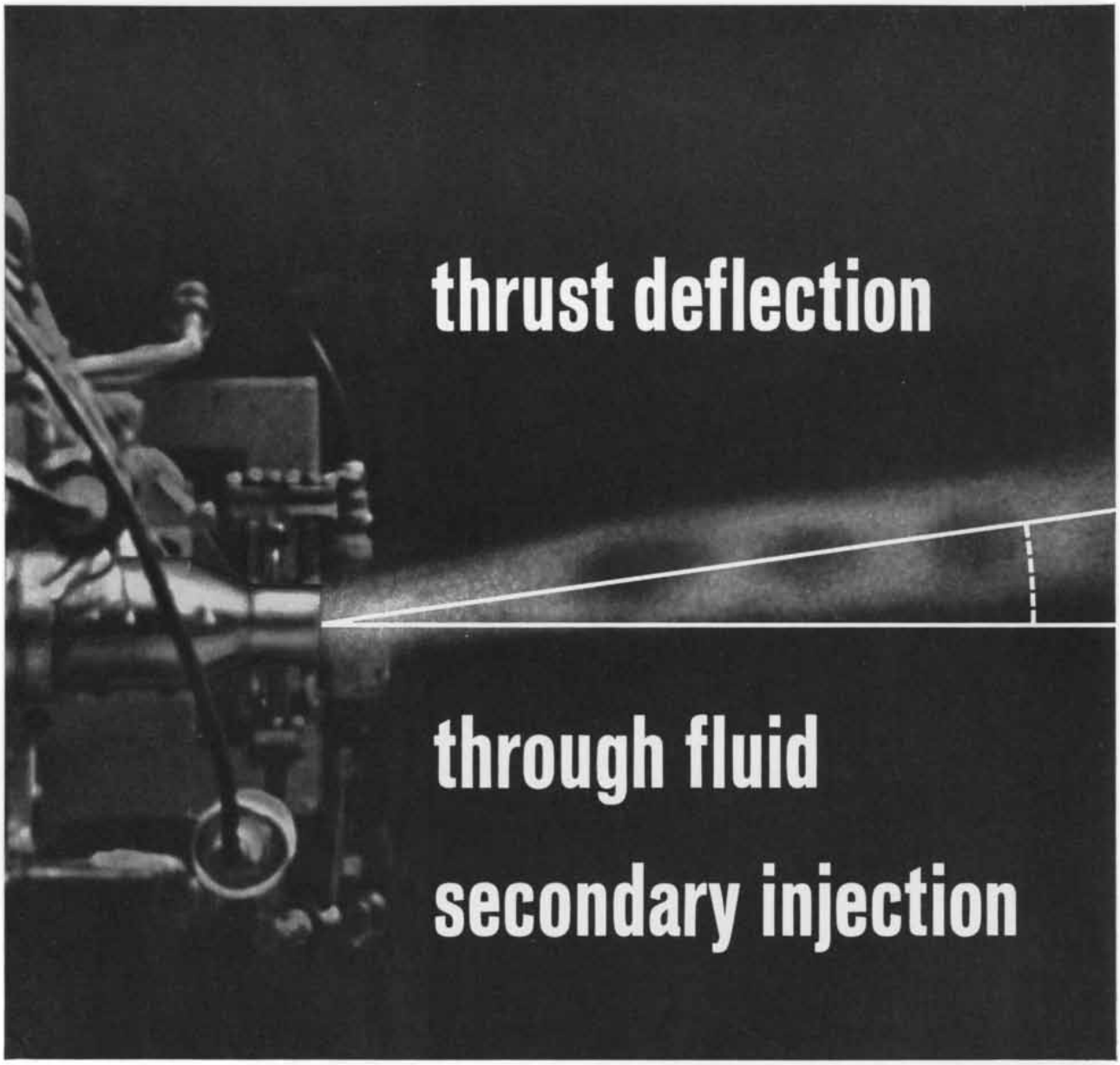

Photo of test conducted at AiResearch

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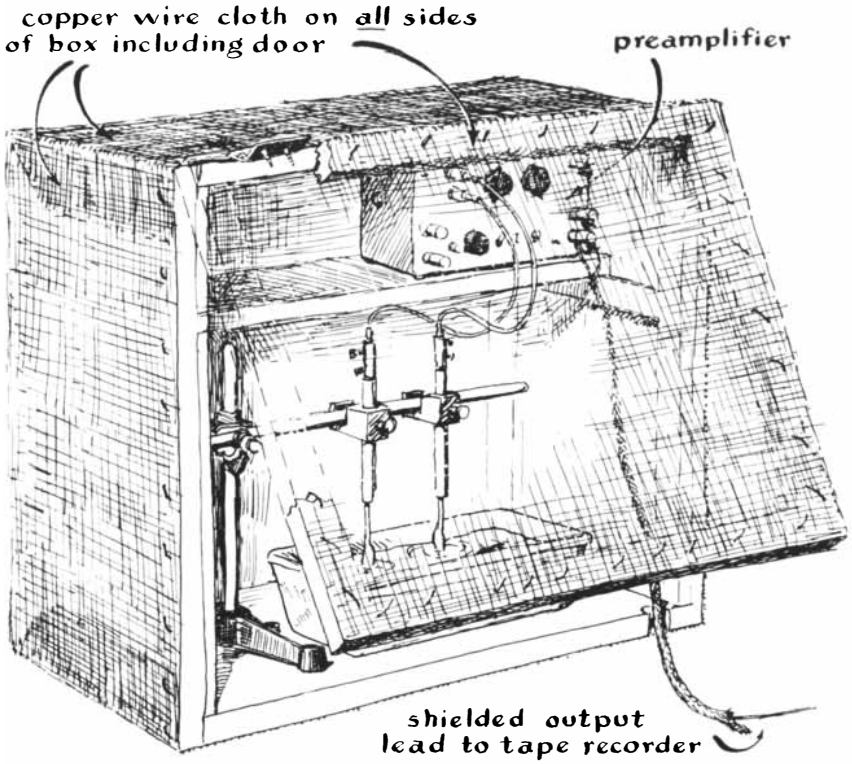


Shielded cage and apparatus for detecting bioelectricity

the apparatus can be generated merely by submerging your hand in the water and clenching your fist.

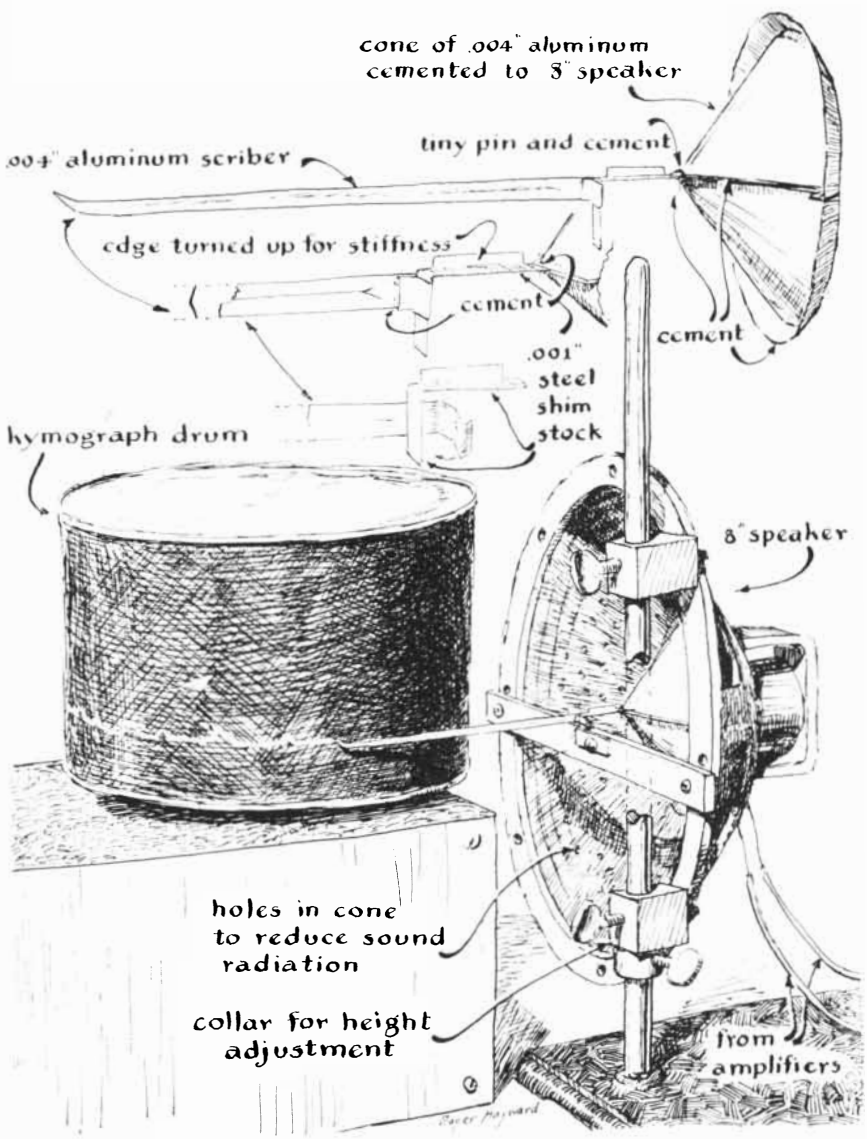
Electrocardiograms can be made by arranging the electrodes in a special configuration for each kind of animal. It is not always possible to detect every component of the complex curve. For example, sometimes the so-called P wave may be small or missing. The method has not yet been developed to the point where it is suitable for making a detailed study of the whole electrocardiogram complex, but it is a highly accurate method of recording the frequency of the heartbeat. In the case of larger animals, such as frogs, potentials generated by limb movements and other major parts of the body are superimposed on the electrocardiogram. This is not a serious problem; even the most active animals are still for brief intervals. Movements can be eliminated by anesthetics, of course, but then the technique of using remote electrodes does not offer much advantage over surface electrodes. Other expedients to compensate for movements, or to confine the observations to a part of the animal, include specially shaped containers, electrical wave filters and multiple electrode arrangements connected in compensating arrays. Some have been tried, but Camougis feels that all merit further investigation and refinement.

The nerve and muscle cells of animals the size of a lamprey and even much smaller normally develop potential differences on the order of a tenth of a volt, a potential substantially greater than the output of a high-quality phonograph pickup. Offhand, it might seem reasonable to suppose that an amplifier of relatively low gain could boost signals of this amplitude enough for display on an oscilloscope. A high-gain amplifier must ordinarily be used, however, because an electrical field that exists in a conducting medium such as water is strongest along the path of least resistance—the path closest to the animal. As the field curves outward from the animal it grows progressively weaker, much as the field that surrounds a horseshoe magnet weakens with distance. As a result electrodes in contact with the medium at points remote from the specimen pick up only a small fraction of the signal voltage. For this reason an electric field that amounts to as much as a tenth of a volt in the immediate vicinity of an excited cell can fall to as little as a few millionths of a volt between the remote electrodes.

Animal tissue is capable of developing potentials much greater than a tenth of a volt. A potential difference of about .06 volt normally exists across a layer of skin freshly removed from a frog. But when two dozen such layers are stacked

with the inside of one layer in contact with the outside of the next, a potential of 1.5 volts is measured across the stack. Through an analogous process one species of electric fish can develop a potential of 500 volts and more. The cells of electric fishes have evolved in a pattern of alternate positive-to-negative interconnections that is precisely comparable to the battery that emerged from Alessandro Volta's experiments with frogs and led to man's harnessing of electricity. Certain South American knife fishes that develop potentials of several volts are often available from dealers in tropical fishes. The discharges from these animals can be observed easily without amplification or shielding. Just touch the tips of the oscilloscope probes to the surface of the water in the aquarium or use the probes for the input of a hearing aid.

In Camougis' opinion the range of animals that can be investigated by the remote electrode technique and the kind of information it can reveal appear to be limited only by the ingenuity and imagination of the experimenter. He mentions one investigator, working at a medical school, who has looked into the matter of recording the electrocardiogram of an alligator. There seems to be no theoretical reason why the project should not succeed if he can catch the animal when it is not moving or learn how to make it remain motionless. At another extreme in animal size, Camougis suggests, it should be possible to pick up the potentials that accompany the beating movements of the antennae of the water flea *Daphnia*. "This has, in fact, been tried," he writes, "but with only limited success. The problem appears to be merely one of refining techniques. High-gain, low-noise recording methods,



Loudspeaker modified to act as pen recorder

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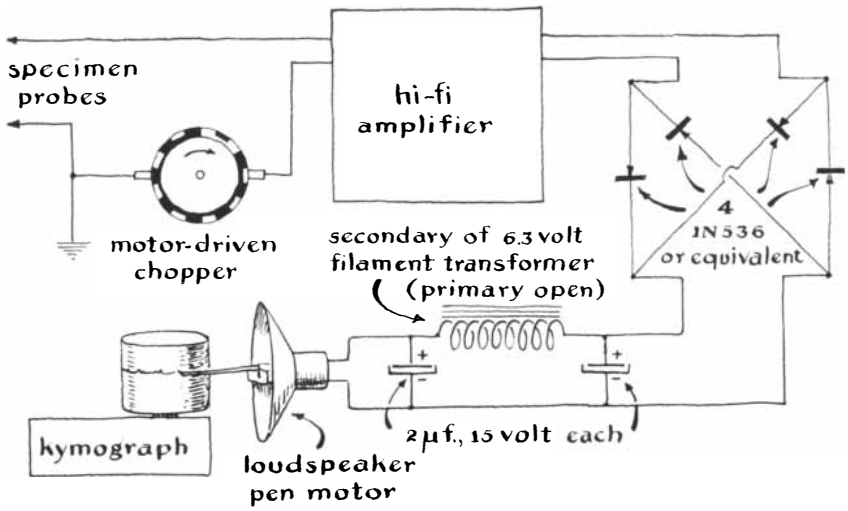


Schematic diagram of loudspeaker pen recorder

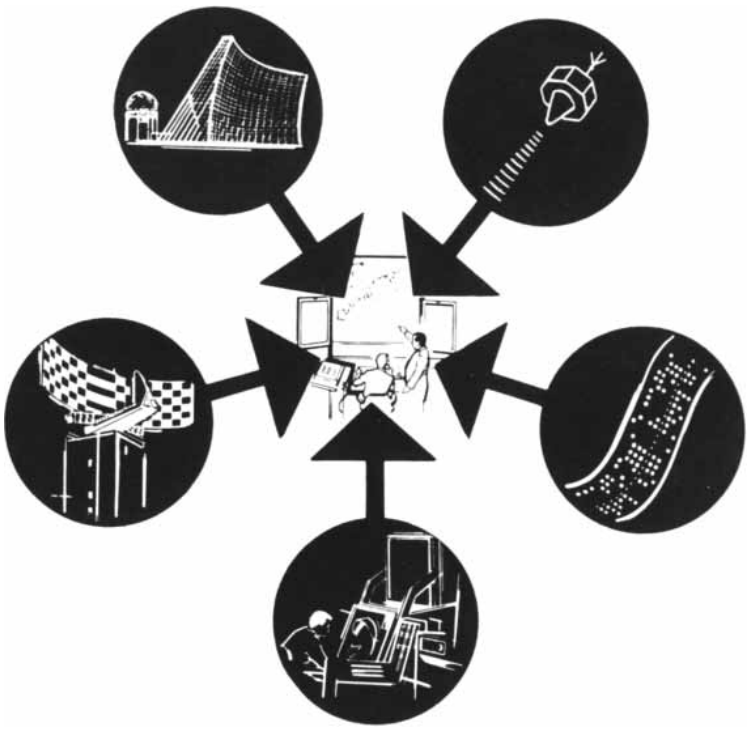
as well as an appropriate container and the right electrodes, should result in recordings free of distortion but with good resolution. In the case of minute organisms, remotely placed electrodes appear to represent the only practical method of picking up the action potentials. It is difficult to imagine how one could attach electrodes directly to a delicate creature of microscopic size without injuring it or modifying its natural behavior."

The oscilloscope and loudspeaker limit the investigator to instantaneous visual and auditory monitoring of the electrical potentials. As one progresses with a problem, permanent records for leisurely study are usually wanted. One apparatus for making permanent records is the tape recorder. Signals from the preamplifier can be fed simultaneously to the tape machine, oscilloscope and audio system. Tapes can then be played back and displayed on the oscilloscope or other apparatus at will. A number of photographic techniques are also available for making permanent records. Various cameras can be easily adapted for use in photographing the screen of a cathode-ray tube.

Automatic pen recorders are also available that write on a rotating drum or paper strip. The paper moves at a constant speed and therefore provides a horizontal time axis, with voltages or currents appearing as vertical excursions of the pen. The inertia of these pens limits their frequency response. Accordingly they can distort or even fail to record the fast transients. Within limits, fast events can be recorded on magnetic tape at high speed and then, at low tape speed, reproduced as a graph by a pen recorder. Camougis often finds it desirable to integrate the bioelectric energy for driving an ink writer. He accomplishes the integration by feeding the muscle action potentials into a large capacitor, which then powers the pen recorder. The smoother excursions of the pen are thereby brought well within the frequency limits of the recording system, although at some sacrifice of fine detail in the variations of the signal.

"In summary," Camougis writes, "the method of observing the bioelectric effects associated with aquatic animals has the obvious advantage of simplicity and provides perhaps the only practical method of studying motor responses of animals that must not be mechanically impeded because of their behavior, delicate structure or small size. A disadvantage of the method is that it doesn't localize the electrically active site. In this respect it is not intended to replace the techniques that involve inserting a fine electrode directly into the tissue being studied. It is a method of investigation at an entirely different level —studying the behavioral responses of intact animals by means of simple apparatus."

The stagnant pond in back of my home teems with *Daphnia*, and last summer our hi-fi set was not fully engaged. So I dug up a packing box big enough to hold a preamplifier and a microscope and covered it with old copper screening. A hole was made in the screening to admit a microscope eyepiece for examining specimens through a 90-degree prism. My plan was to place a single *Daphnia* in a drop of water on a microscope slide and pick up the action potentials by inserting a pair of small copper wires into the drop from opposite sides. These electrodes would feed the battery-powered preamplifier inside the



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cage. I decided to try out the arrangement by means of a loudspeaker before connecting the oscilloscope. The construction went smoothly enough, and when the amplifiers were switched on, ample power appeared at the output—all noise, consisting mostly of 60-cycle hum.

The cage leaked noise like a sieve. Still more was picked up by the circuits because I had neglected to ground the main amplifier and had failed to solder the screening where it came together at the corners. The tarnished wire would not take solder, so I re-covered the box with new screening. I found that the door screening must make good electrical contact with the box screening every few inches around the edge, and that all ground connections must come together at a single point. These corrections eliminated the 60-cycle hum, but the character of the random noise did not change although I tried every available kind of water—distilled, deionized, tap, rain and pond.

Finally I hit on the idea of reducing the size and shape of the specimen container. I softened a glass tube in a gas flame and pulled it into a capillary with a bore just slightly larger than the animal. Then I put a drop of distilled water containing a single *Daphnia* on a microscope slide and "speared" it with the glass tubing. Capillary attraction made the drop rush into the tube and carry the specimen along with it. Snapping off a half-inch length of tubing containing the specimen, I pushed fine wires into the ends far enough to make contact with the water. The junctions between the wires and the ends of the glass were sealed by dabs of silicone grease and the assembly was pressed against the sticky side of Scotch tape to secure the leads. It worked! The oscilloscope displayed the heartbeats clearly during instants when they were not obscured by other muscle action.

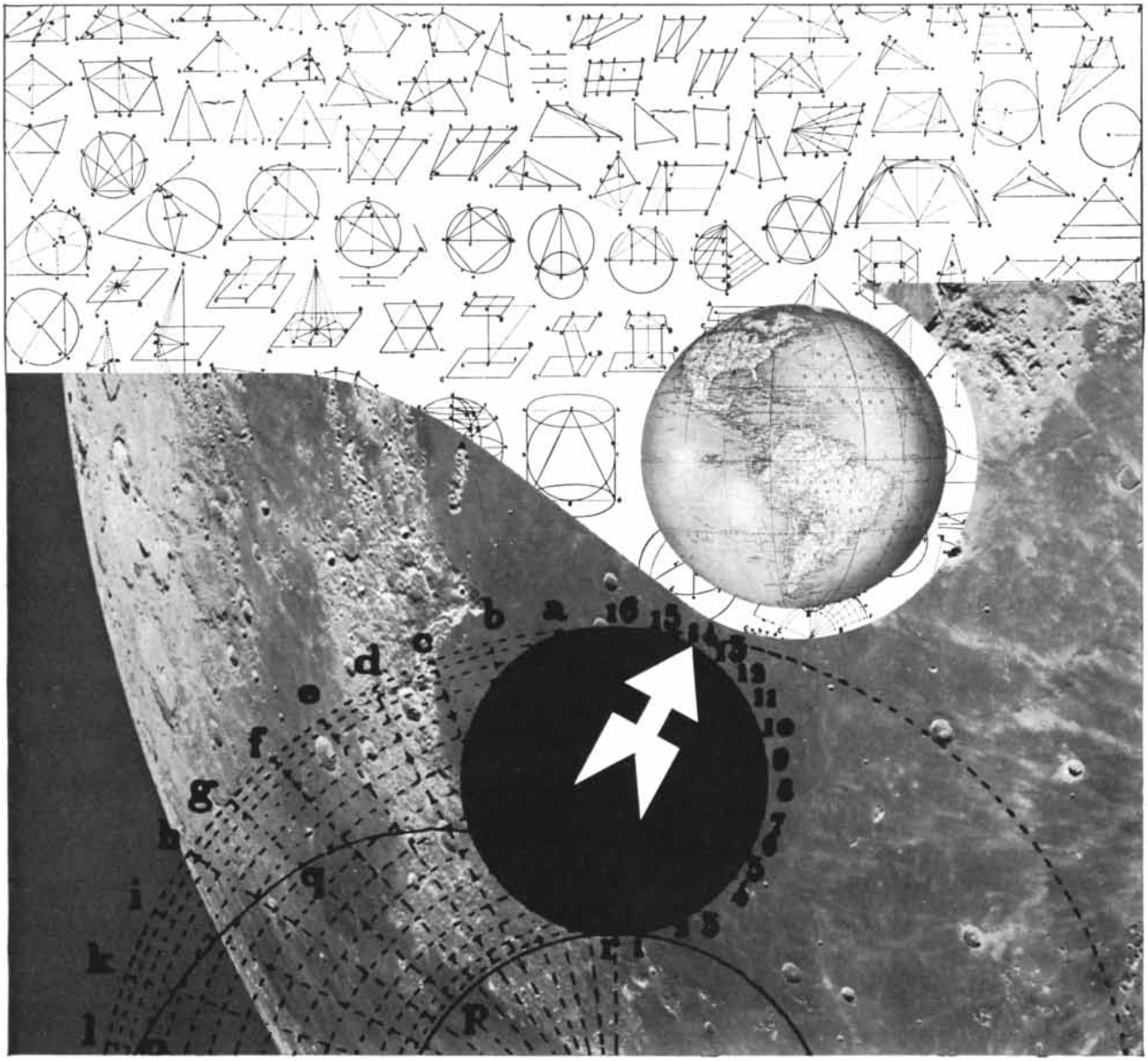
I wanted to make a permanent record of the oscilloscope display. Like most other amateurs, however, I do not own a pen recorder. It occurred to me that perhaps a loudspeaker could be modified to act as a pen motor if a lightly hinged arm was simply attached to the driving coil of the cone. Roger Hayward, who illustrates this department, fashioned a pen lever from heavy aluminum foil and equipped it with a hinge in the form of a steel reed cut from shim stock about .001 inch thick, as shown on page 150. The reed was clamped between the head of a machine screw and a piece of strap aluminum that was bolted across the face of the metal frame that supports the cone assembly. The pen lever was driven from the side opposite the hinge by a second length of shim stock that was attached by epoxy cement to the apex of a cone made from heavy aluminum foil. The base of the aluminum cone was cemented to the paper cone of the loudspeaker over the driving coil.

The first model was promptly wrecked. The violent vibration of the cone broke the hinge attachment. A full-wave rectifier and a smoothing filter were then inserted between the output of the amplifier and the loudspeaker pen recorder [*see illustration on page 152*]. The arrangement worked nicely at frequencies between 20 and 30 cycles per second, the lower frequency limit of the amplifier.

To record still lower frequencies, I then inserted a chopper—a motor-driven switch—between the output of the preamplifier and the hi-fi amplifier. The chopper was a modified motor generator of the type used to step up the voltage of storage batteries for powering radio sets used in military aircraft. The armature windings of the generator were cut loose from the commutator, and alternate bars of the commutator were connected together. The commutator of my unit, which was picked up on the surplus market for a dollar, had 39 bars. The odd bar was not connected. The circuit to be chopped was simply connected in series with the brushes on the generator side. I found that copper-impregnated brushes introduced less noise in the chopper circuit than the graphite brushes with which the unit was originally equipped. At its normal operating speed of 6,400 revolutions per minute, the chopper converted direct current to alternating current at a frequency of about two kilocycles.

The end of the pen lever was bent at a right angle to act as a stylus and was supported against the smoked cylinder of a motor-driven drum recorder, or kymograph, by an apparatus stand. (For data on constructing a homemade kymograph see "The Amateur Scientist"; SCIENTIFIC AMERICAN, April, 1960.)

With this apparatus I succeeded in making a number of electrocardiograms of *Daphnia* and of other small animals, including frogs. At least I call them electrocardiograms. Actually they are rather smooth waves that appear in step with the heartbeats of the animal. I do not know what a really good electrocardiogram of a *Daphnia* should look like, and it is probable that a true one would require greater refinements in technique than this department managed to contrive. But, as Camougis predicted, the attempt was good fun.



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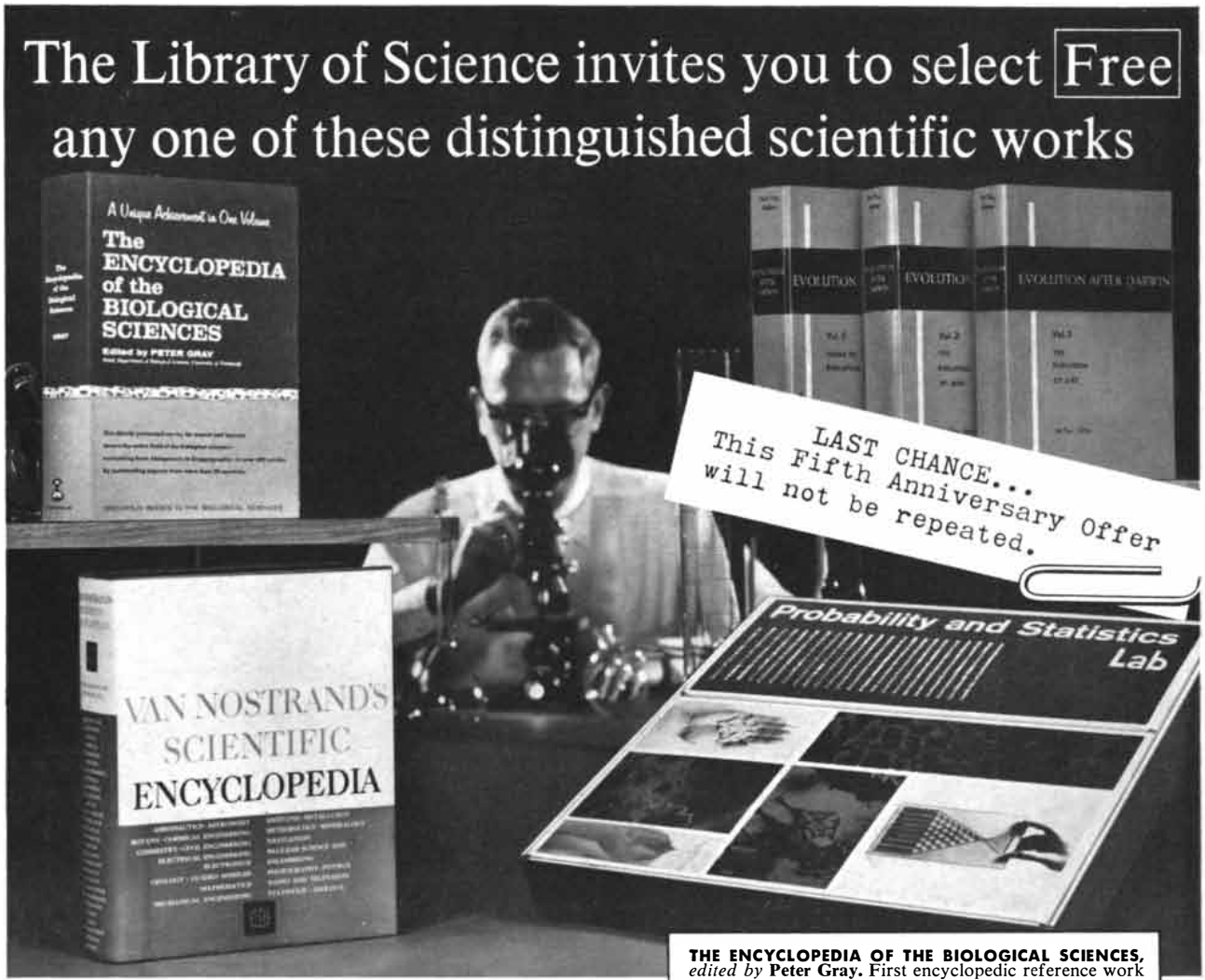

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by Morris Kline

THE LORE OF LARGE NUMBERS, by Philip J. Davis; WHAT IS CALCULUS ABOUT? by W. W. Sawyer; GEOMETRIC INEQUALITIES, by Nicholas D. Kazarinoff; AN INTRODUCTION TO INEQUALITIES, by Edwin Beckenbach and Richard Bellman; NUMBERS: RATIONAL AND IRRATIONAL, by Ivan Niven; THE CONTEST PROBLEM BOOK, by Charles T. Salkind. Random House ($1.95 each).

Concern for exposition, the central problem faced by this new series of monographs, has never been among the hallowed traditions in mathematics. The great Greek works of Euclid, Apollonius and Archimedes were splendid in conception but are models of impoverished rendition. Descartes's *La géométrie,* in which he presented the creation we now call analytic, or coordinate, geometry, was difficult reading for his contemporaries. Descartes excused this failing on the ground that others should have the pleasure of working out the details. He added acidly: "I have foreseen that certain persons who boast that they know everything would not miss the opportunity of saying that I have written nothing that they did not already know, were I to make myself sufficiently intelligible for them to understand me." The complexity of Newton's *Principia,* which was the foundation of celestial mechanics and the inspiration for several major branches of mathematics, baffled his colleagues, and for 100 years after its publication in 1687 mathematicians struggled to clarify and elaborate what Newton wrote. Lagrange, when he finished his monumental *Mécanique analytique,* boasted that he had not used one geometrical diagram in the whole work of over 800 pages. Although Lagrange was trying to show that algebra and analysis were no longer logically dependent on geometry, it was not necessary to dispense with diagrams, and as a consequence his book was not easy to read. Laplace, in his five-volume classic *Mécanique céleste,* another landmark in the development of mathematics, brushed off the weightiest mathematical steps with the phrase "It is obvious that...." This obstacle to understanding provoked the famous comment from Nathaniel Bowditch, the American who translated and annotated Laplace's masterpiece, that every time he encountered the phrase he knew he had hours of work ahead of him. Gauss's papers were neat and polished but barely understandable to his fellow mathematicians. When he was criticized, Gauss rejoined that no architect leaves the scaffolding after the building is erected. The brilliant Évariste Galois was so frustrated in trying to master mathematical papers that he denounced the hypocritical mathematicians who concealed the origins of their discoveries. Only a few men—for example, Gaston Darboux, Felix Klein and Émile Borel—have been capable of writing mathematical works with a charm that invites rereading. Perhaps the saddest commentary on mathematical literature is that hardly one mathematician in a hundred reads the older works for pure enjoyment.

The quality of mathematical writing has become even poorer in this century. Because the pace and pressure of research has increased, mathematicians spend less time on how they say what they say. Readability is scarcely an objective. To make matters worse, because journals are flooded with manuscripts editors ask authors to make their papers as brief as possible. Mathematicians are quite willing to accede to this request; it is really no trouble. The author can always replace a long proof that may have taken weeks to devise with Laplace's phrase "It is obvious that..." and should repetition of this phrase become too obvious he can say instead: "It follows immediately that...." Modern papers and texts strive for generality, compactness and rigor. As a result professional mathematical literature has become forbidding. One might even say that mathematical writing has very positively developed some decidedly negative qualities: crabbedness, excessive symbolism and obtuseness. The unintelligibility of current research articles has become accepted as standard.

When the clarity of his writing is challenged, many a mathematician acts supercilious and condescending. The challenger is made to feel either naïve or stupid. The author asks whether or not the proofs are correct, and if the answer is yes, he walks away completely satisfied.

Against this background, and with full awareness of it, the School Mathematics Study Group has undertaken to produce a series of brief monographs that should stimulate and inform laymen and bright high school students and attract talent to mathematics. Because the material of these monographs is to be elementary and so does not require highly original mathematics, the essential contribution of the works is to be exposition. The six monographs reviewed here are the first of what is intended to be a continuing series under the embracing name of the New Mathematical Library.

One of the six should certainly appeal to students and laymen. Davis' *The Lore of Large Numbers* covers for the most part familiar topics: the writing of numbers in other bases; the occurrence of small and large numbers in scientific measurement; the use of exponents to express small and large numbers; division by zero; the properties of prime numbers; the growth of numbers when squared, cubed and so forth; the properties of pi, including its connection with squaring the circle; and the occurrence of large numbers in the solution of ordinary first-degree equations in several unknowns. This material has been treated in popularizations, and some of it is commonly found in textbooks, but Davis' presentation has a fresh and lively style. The language is down to earth—even friendly. For instance, Davis' table of properties of the first 100 whole numbers is entitled "Who's Who among the Integers." He demonstrates how the disposition of a basic problem of physics, the flow of heat in a piece of metal, can

be reduced to the solution of a system of first-degree equations in several unknowns. This is a fine and original explanation of what the mathematician would call the finite-difference method of solving a partial differential equation. It should convince readers that the process of solving simultaneous equations, dreary as it appears in the schoolbooks, really has a point.

What Is Calculus About? is very well executed, considering that Sawyer apparently intends his book to be a first step. He wants to introduce young people to the calculus, and he presupposes that this introduction will be followed by further study of the subject. Hence he adopts a gradual, careful pace and succeeds in being intuitive and clear in what he has presented. In a short book one cannot get too far into the calculus; the layman who may be expecting a bird's-eye view with some attention to the range and power of the calculus and its place in mathematics and science may find the perspective a bit limited. Sawyer is capable of addressing sophisticated laymen, as readers of his books in the Penguin series well know, but the interests of such an audience seem to have been secondary in the present exposition.

Kazarinoff's *Geometric Inequalities* will appeal to those who are already inclined toward mathematics. It proves a number of interesting inequalities. For example, of all triangles with the same perimeter, the equilateral triangle has the greatest area; of all quadrilaterals with a given area, the square has the least perimeter; the circle has more area than any other plane figure with the same perimeter. The writing is honest. The author labels difficult what is difficult and does not pretend that all things are simple. The text suggests guessing, conjecturing and then proving. The author does not hesitate to offer a proof of his own that, he points out, he later found to be incorrect. The device of putting a proof of a general theorem in one column and a concrete case alongside could be more widely employed by others.

Although the book has a number of attractive pedagogical features, it is not for laymen. It requires close reading and is in fact difficult to follow in spots. The first chapter will be forbidding even to students. Its proofs of some theorems about arithmetic and geometric means are heavy. Moreover, the complexity that results from proving theorems about n numbers is unnecessary because the inequalities used in the geometric proofs require only the simplest cases of these algebraic inequalities.

An Introduction to Inequalities by Beckenbach and Bellman, both fine mathematicians, pursues the subject of inequalities far beyond the needs of young students and laymen and is difficult reading for the purported level of the series. In addition, little is done to show where even mathematicians use such inequalities. The few applications to geometry overlap those of Kazarinoff's, but here the reliance is on arithmetic and algebraic proof, and so the applications are less perspicuous. Analytic geometry is presupposed. The final chapter, which discusses concepts of distance between two points, may serve to demonstrate the use of the inequalities, but it sheds no light on what one does with various concepts of distance.

The first three chapters are intended to teach the axiomatic method, but if the form is axiomatic, the substance is confused. In their treatment of inequalities the authors allow themselves the use of all properties of the ordinary real numbers. Hence they presuppose far more than they state explicitly in their axioms and call freely on the properties of real numbers whenever they need them. Just how the idea of the axiomatic method can emerge from such a presentation is not clear. Some of the confusion is illustrated in the following. From their axioms the authors prove that the product of a positive and a negative number is negative—but the proof appeals to "the usual algebraic rules for interchanging parentheses and minus signs: $-[a(-b)] = -[-(ab)] = ab$." Where do all these rules come from? This presentation shows once again that any attempt to be axiomatic about the real numbers (except on the professional mathematician's level) produces axioms, definitions, theorems and obscurity.

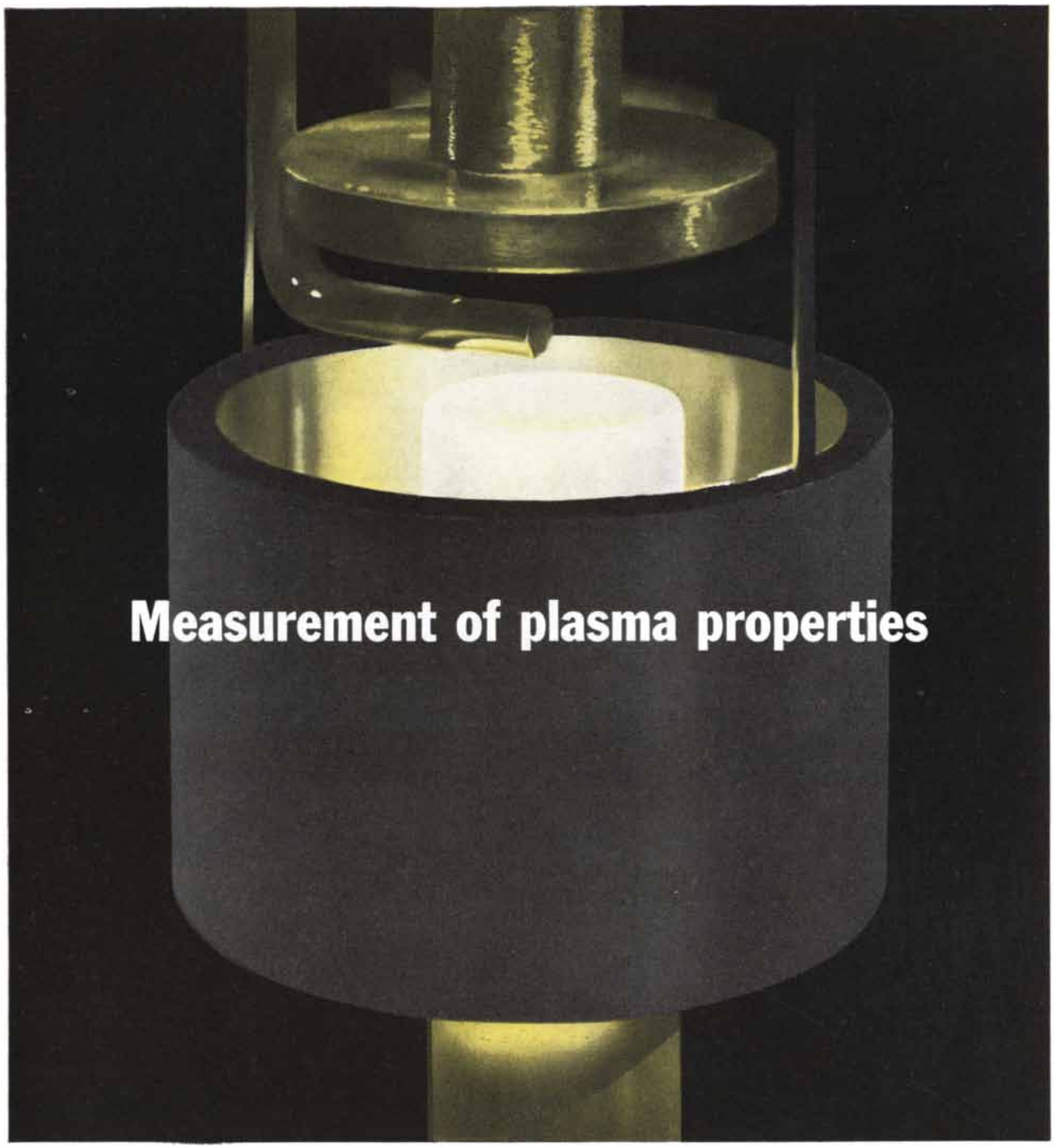
Equally annoying are frequent references to advanced ideas such as "the limiting processes that are used in defining irrational numbers" and "the completely ordered field of real numbers." The treatment of absolute values of numbers through inequalities is a complex distortion of a simple idea.

Niven's monograph *Numbers: Rational and Irrational*, like Kazarinoff's, will win the approval of mathematicians. It presents a lot of the basic material on the types of number in our number system, the distinction between rational and irrational numbers (e.g., 5/2 as opposed to $\sqrt{2}$), the classification of irrational numbers into algebraic ones such as $\sqrt{2}$ and transcendental ones such as pi, the decimal representation of numbers and the irrational character of logarithms and of the trigonometric ratios. The basic facts are there and the style is informal and clear.

But to the student as well as the layman the book offers little enlightenment. Why are the distinctions between rational and irrational numbers or between algebraic and transcendental numbers important? Would the course of mathematics have been different if these distinctions had never been recognized? Do they serve any purpose other than to provide problems for idle mathematicians? Such questions may seem absurd and even heretical to the mathematician, but until he recognizes that these questions must be answered if mathematics is to be meaningful to others he will not succeed in broadening the appeal of his subject.

The story of the real number system could have been enlivened and the nature of mathematics clarified by some relevant history. Negative numbers, created about A.D. 600, were rejected by all mathematicians until A.D. 1600 and even thereafter were only grudgingly accepted. Irrational numbers, discovered about 500 B.C., failed to gain acceptance, except by the "naïve" Hindus and Arabs, until A.D. 1600; and even after that date Blaise Pascal and Isaac Barrow denounced them. This history is highly instructive. It teaches us that some of the greatest mathematicians were unable to broaden their concept of number. Moreover, it was not any sudden inspiration, however long in coming, that enabled the mathematicians to see the light. Rather, when they were forced to use negative and irrational numbers to make progress in scientific problems, they ungraciously conceded the usefulness of these numbers. It took a couple of centuries more for the mathematicians to supply the proper logical foundation for these numbers and to grasp the higher truth that numbers are human creations, which we can introduce almost at will if they can be made to serve significant purposes. The explanation usually given for introducing negative numbers—that they permit us to answer such questions as what is 3 minus 5—fails to answer the question of why anyone wants to know what 3 minus 5 is. Similar remarks apply to the introduction of other mathematical concepts.

Salkind's *The Contest Problem Book* is, through no fault of the author, poor. It is a collection of the problems set in the past 10 years by the Mathematical Association of America in its national high school mathematics contests. The problems are typical of those in the high school texts: dull and pointless except as sheer drill in technique. Of course the



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examiners themselves cannot be criticized, since the problems test what is actually being taught.

It is a pleasure to note that the subjects chosen for the first six monographs fall within the bounds of the basic mathematical fields—standard algebra, Euclidean geometry, trigonometry, analytic geometry and the calculus—as opposed to such fields as sets, groups, matrices and Boolean algebra, which are erroneously being thrust into the public eye as superseding the older fields. In this respect, at least, the editors of the monographs, unlike their brethren in the allied curriculum project, are putting first things first.

There is, however, one major problem of exposition that these monographs have not faced. A great deal of mathematics, especially elementary mathematics, is vacuous when presented as an isolated discipline. What point is there in learning in and for itself the simplification of radicals, factoring, the addition and multiplication of fractions, inequalities and a dozen other processes taught in the standard algebra? The same criticism applies to the trigonometric identities and to the techniques of differentiation and integration that consume a good deal of time in the calculus. As a matter of fact, the resistance that the best mathematicians offered over centuries to negative, irrational and complex numbers was caused by the fact that these concepts lacked significance. Still more meaningless as solely mathematical themes are some of the newer topics such as the theory of sets, Boolean algebra, groups, symbolic logic and matrices. Of course pure formalism, clothed in a jargon that would be worthy of the emptiest sociologist and in a symbolism that would strain the mind of an Einstein and surely offend his aesthetic sense, can be made to seem profound. Even the purported beauty of mathematics may not appeal to many people. The diverse reactions to beauty in mathematics are analogous to the reactions to modern painting.

The point, then, is that most of the mathematics taught to young people has no readily discernible significance to them. And in fact this significance is not to be found in the mathematics itself. The greatest mistake made by the professional mathematician is to assume that his subject is self-justifying. Good exposition for students and laymen involves more than clear statements, sufficient detail to enable the reader to follow the proof, correct grammar and an engaging style. What must be added are motivation for study of the topics undertaken, the intuitive and physical significance of those topics and applications which would show that the concepts and theorems accomplish something for mankind. As Alfred North Whitehead put it, mathematicians must shun the communication of inert ideas. They should of course be concerned with proof—proof of the worth of what they teach. A warning may be in order with respect to applications. The use of complex numbers to represent vectors is not an "application" for the student or layman, for he will undoubtedly ask what one does with vectors. Nor are matrices "applied" when they are used to represent transformations. The tree of mathematics has its roots in the physical world, and the many branches have no independent life of their own.

Another way in which significance can be imparted is to introduce some historical material. Such material is sometimes regarded by disdainful minds as pure fill-in or a sop to the lazy reader. But this is hardly the case. Mathematics is not produced by machines, even with today's electronic computers. It is produced by human beings living and working in real situations, and good mathematics is produced by great minds responding to vital intellectual or practical problems. In addition, the most enlightening explanation one can give of the meaning of a mathematical achievement is often the historical reason for having undertaken it.

The mathematician has not begun to meet the need to show the larger significance of his subject. He tries to avoid this need by telling his audience that mathematics is good mental discipline, but this argument is only hearsay. He also tells students that the mathematics they are being asked to learn will be useful to them in later life. This argument is dishonest because 95 per cent of high school students will never use any appreciable amount of technical mathematics later in life. Not even the concept of deductive structure, which is stressed on all sides today as being the essence of mathematics, serves much in later life, for the most important decisions humans must make cannot be deduced from axioms. Moreover, all the preaching and rhapsodizing by mathematicians about the beauty of mathematics will not make such ugly ducklings as the quadratic formula more attractive.

When all such arguments fail to arouse interest, the mathematician concentrates on those students who, for whatever reason, accept and pursue the subject avidly. With unconscious immodesty the mathematician labels these

students keen and bright, whereas in many cases they have merely been uncritical and have blindly followed the commands or exhortations of their teachers. No doubt some of the students who are willing to plunge into mathematics without concerning themselves with ultimate purpose or meaning are bright, but the "less intelligent" students (quantitatively about 98 per cent) and laymen do want to know why they should absorb seemingly useless material. On the basis of what they know about the subject it is no more attractive than ceramics or philately.

It may not be amiss to point out that even for their own sake and for the sake of the future of their own field mathematicians should be asking why they are pursuing particular themes. The great mathematicians of the past, either because they were themselves outstanding physical scientists or because they were at least keenly interested in science, possessed sound reasons for pursuing mathematical investigations. But most currently active mathematicians have forgotten the unity of the sciences. In the halls of mathematics today one dare not ask for meaning and purpose. Apparently research in mathematics must not be tainted by reality. The ivy has grown so thick that the scholars within can no longer see through it to the world outside. A few discerning mathematicians have seen the danger in creations of the sequestered mind and have put in print a direful prediction: The significant mathematics of the future may be created by scientists and engineers, whereas professional mathematicians will be a body apart, living for a while in the reflected brilliance supplied by mathematicians of the past but doomed ultimately to grope futilely in darkness.

The present monographs offer some values, albeit on different levels. Consideration of the monographs by Sawyer, Niven and Kazarinoff in particular, which do serve the convinced mathematics student, raises the question of whether or not the same monographs can appeal to laymen and students. The editors of the monographs say that "the best way to learn mathematics is to *do* mathematics." This may well apply to students, but it is not realistic for laymen. Must a mathematician, if he seeks to appreciate painting, architecture and poetry, actually paint, design and write poetry? Certainly the specialists in these fields would say that one who merely appreciates must be shallow. Yet can human beings do more? The same limitation applies to mathematics. In view of the intense specialization required today

of creative mathematicians, should the expert in partial differential equations remain ignorant of topology or can he acquire some inkling of what that field is about without being obliged to *do* topology? If the argument seems strained for the expert in question, it surely applies to the physicist, the chemist and the engineer. In the meantime it may be well to keep in mind that books addressed to laymen that prove too difficult or pointless for them will kill latent interest and do more harm than good to mathematics.

The continuing search for authors will undoubtedly produce books more pertinent to the objectives of the series, and the present ones will fall into place as useful works, if not the key ones needed today. One member of the monographs' editorial board recently pointed out that because the challenge to explain, to motivate and to write attractively is now being made by good mathematicians, expository writing may finally be respected by creative workers in the field. Perhaps, rather belatedly, the professed cultivators of an art will come to recognize that exposition is as vital in their medium as it is in painting, music and literature.

Short Reviews

CYBERNETICS, by Norbert Wiener. The M.I.T. Press and John Wiley & Sons, Inc. ($6.50). First published in 1948, and since then exceeded in its very considerable influence only by the overblown claims which have been made for the "new science" it broaches, *Cybernetics* now appears in a second, revised edition, with two additional chapters, one on learning and self-reproducing machines, the other on brain waves and self-organizing systems. Wiener's philosophy with respect to the problems raised in the first of these chapters deserves brief comment. Can a machine learn and can it have issue like itself? The author has no doubt that it can do both. Machines have been made that play wizard games of ticktacktoe and a "fair amateur" brand of chess. This, however, is no true example of learning. Such machines have rigid personalities, and if they make characteristic blunders, they make them over and over again. Yet there are machines which do not have this idiot cast; they can be programed to behave reflectively, to look back on their mistakes and profit from them. A machine of this kind might play a series of chess games, be outwitted by its opponent, and then take time off to examine the games recorded on its memory "to determine what weighing of the different evaluations of the worth of pieces, command, mobility, and the like, will conduce most to winning." This procedure, which involves a hierarchy of programing—the higher orders studying segments of the past to determine future policies for the lower orders—could fairly be called learning. What is involved here is nothing less than scrutinizing one's opponent's (and one's own) habits and making use of these patterns in future contests. It is easy to see that this type of learning from experience occurs in almost every department of human activity, and it has therefore been argued that the theory of games has much to teach us about prudent strategy in a wide variety of contests, from stud poker to war. Moreover, it is said that machines which can learn can take over certain planning tasks and execute them more thoroughly and speedily than we can. This obviously raises a specter: the danger exists, in Wiener's opinion, that learning machines will begin to live lives of their own, and that as we come increasingly to rely on their "thoughts" and "decisions," they will commit us to courses of action, such as launching a war, which may destroy us. We can, to be sure, turn off the machines if we don't like their counsel or regard it as dangerous, but this presupposes that we will immediately recognize the danger point—a precarious presupposition. The magic broom in Goethe's *The Sorcerer's Apprentice* does such an admirable job in fetching water for the lazy apprentice that, when he forgets the incantation to make it stop, it almost drowns him. Luckily the sorcerer appears in time to speak the "words of power" and stop the diligent broom. An even more apt moral is to be found in W. W. Jacobs' famous horror story of the monkey's paw. This wizened object, endowed by an Indian holy man with the power of granting three wishes, brings nothing but disaster to those who use it. Although warned against it, its possessor wishes for 200 pounds. Soon there is a knock at the door and the possessor of the paw is given this sum as a "solatium" for the death of his son, who has just been killed in a factory accident. Grief-stricken, the father uses his second wish to get his son back. A horrifying apparition—evidently the son's ghost—promptly appears. And now there is no better use for the third wish than to have the ghost return to the dead. If we let machines plan a war for us, and let them decide by a kind of maniac arithmetic that x million dead and y million survivors represent an acceptable cost for "vic-

tory," then, as Wiener says, "we shall find the ghost knocking at our door."

THE NIGHT HAMBURG DIED, by Martin Caidin. Ballantine Books, Inc. (50 cents). On the night of July 24, 1943, some 800 British heavy bombers attacked the German city of Hamburg. This was the first of a number of raids that were part of an operation known by the code name Gomorrah, the object of which was to cripple this industrial and shipping center of nearly two million people. The raids continued until the morning of August 3, by which time more than 6,000 square acres of homes, factories and office buildings had been destroyed, 750,000 people were homeless and more than 70,000 had been killed. On the first night some 2,300 tons of high explosives and incendiary bombs were dropped; in succeeding raids some 6,000 tons were dropped. But it was the conflagration started on the first night which was largely responsible for the prodigious ruin. The main destructive agent, which had never been seen before, was an immense "fire storm," a phenomenon which recurred in the raid against Dresden in 1945 and in the atomic bomb attack on Hiroshima. The bombing pattern at Hamburg was carefully designed to set a large number of fires in a densely populated and densely built-up area, and the results were beyond all expectation. After high explosives had been dropped to knock out water mains and cripple fire fighting, a great number of incendiaries were used. The fires they set spread rapidly, joined each other and gave rise to a disaster on a meteorological scale. As the individual fires combined and the hot gases from them rose, cool air rushed into the partial vacuum below and acted on the flames like a huge bellows. The temperature in the Hamburg streets encompassed by the fire storm rose to between 1,400 and 1,800 degrees Fahrenheit. Flames were swept along by winds exceeding 150 miles per hour. One of the results of the fire storm was that tens of thousands of people in shelters, safe enough against the effects of blast, were suffocated or slowly roasted to death. Caidin's account is luridly written. But it is based on careful official studies made after the war by British and American teams of investigators, and the horrifying facts speak for themselves.

ENCYCLOPEDIA OF WORLD ART: VOL. I, AALTO—ASIA MINOR; VOL. II, ASIATIC PROTOHISTORY—BYZANTINE ART; VOL. III, CALDER—COSMOLOGY. Edited by Massimo Pallottino and others.

McGraw-Hill Book Co., Inc. ($39.80 per volume). To the date of this writing three volumes have appeared of this lavishly illustrated 15-volume set intended to cover the subject of world art in three major categories of monographic articles: historical, conceptual and systematic, and geographical. The historical entries deal with great cycles of art civilization, such as baroque art or classic art, or with individual artists. The conceptual monographs study general problems of art "from the viewpoint of theory or methodology." The geographical articles, essentially documentary in nature, treat such subjects as Arabia, Polynesia and Tibet. Leading authorities from 45 countries have contributed the monographs, which have all been translated into English from the original language. Each article is preceded by a summary, and there are extensive bibliographies. Some of the monographs are many tens of thousands of words long. The complete work is to comprise nine million words of text, 5,600 pages of black-and-white reproductions and 1,400 pages of color reproductions. The books are printed and illustrated in Italy, and the execution of the illustrations is on the whole of high quality. No extensive comment can be made in these pages on an undertaking of such magnitude, except to advise readers of its progress and to express the hope that the volumes still to appear will be worthy of those at hand.

A HISTORY OF PLATINUM, by Donald McDonald. Johnson Matthey & Co. Limited (35 shillings). It is doubtful that the ancients recognized platinum as a distinct substance. Traces of it, mixed with gold, have been found occasionally among the relics of the early civilizations of Egypt; Pliny may have referred to it in his *Natural History* when he described a heavy black sand which he called *plumbum candidum* or *cassiteros*. Other evidence relating to early recognition is equally conjectural. Around the middle of the 18th century the metal began to reach Europe in quantity from the Spanish colonies in South America. Scientific inquiries then began into its properties and nature; research in Sweden, England, Spain, Germany and France developed in a relatively short time the facts about platinum—such as its imperviousness to corrosion, how it can be separated from iron and gold, its melting point, its nonmagnetic and malleable properties—necessary for later advances toward its fabrication. This scholarly, attractive and handsomely illustrated volume concentrates on the technology of the metal:

how supplies are obtained, the refining of the raw material, the manufacture of the product. It does not concern itself with "the recondite parts of the geology of the deposits" or with the complex chemistry of platinum components. The story is carried to about 1890, leaving later developments to a "historian of the future." A worthy contribution to the history of science.

THE SALMON, by J. W. Jones. Harper & Brothers ($4.50). "For many years past," wrote the naturalist Frank Buckland in 1880, "I have scarcely done anything else either officially or privately, except to attend to and carefully watch the interests of the King of Fish, the Salmon, the great *Salmo salar*." The author of this book, a zoologist at the University of Liverpool, can make the same claim for himself. His readers, as well as many others interested in natural history, from anglers to conservationists, will derive pleasure and enlightenment from his survey. He describes the remarkable life cycle of the salmon and presents a fascinating account of spawning based on his own long observations, which included film studies made in a specially constructed tank. He explains how much of the present knowledge of this fish is based on "reading" its scales; he considers the amazing homing instinct which guides the salmon back to the river where it was born, and suggests it may be based on the distinctive smell of the particular waters. Photographs, diagrams and a bibliography.

JOKES AND THEIR RELATION TO THE UNCONSCIOUS, by Sigmund Freud. W. W. Norton & Company, Inc. ($4.50). An entirely new translation by James Strachey of Freud's well-known essay, previously published under the title *Wit and Its Relation to the Unconscious.* Freud discusses the technique and purposes of jokes, the mechanism of pleasure and the psychogenesis of jokes, jokes as a social process and their relation to dreams and the unconscious. The theoretical part is orthodox Freud, having been first published in 1905, and will certainly not appeal to heretics and others who have parted from the master. But many of the jokes are still funny, and it is always intellectually exciting to watch Freud taking apart an intricate problem, whether or not one agrees with his hypotheses, his methods or his conclusions. Strachey's translation is first-rate; considering the typical difficulties of translating jokes from one language to another without destroying their funniness, he has achieved a tour de force.

LUEGER LEXIKON DER TECHNIK: VOLS. I AND II. Edited by Alfred Ehrhardt, Hermann Franke and others. Deutsche Verlags-Anstalt (135 Deutschemarks per volume). These volumes, the first two of a work which on completion will run to 17 volumes, initiate the fourth wholly revised edition of a respected German encyclopedia of technology. The first volume deals with all aspects of the construction of machines, the second with the technology of electricity and atomic energy. This is an impressive enterprise, comprehensive in scope, well printed and illustrated.

THE GREAT MATHEMATICIANS, by Herbert Westren Turnbull. New York University Press ($3.50). A reissue of the best work of its kind, a brief biographical history of mathematics from the early beginnings to the present day. The late H. W. Turnbull, a distinguished mathematician who in his last years edited the first three volumes of the Royal Society's great work *The Correspondence of Isaac Newton,* was a clear and agreeable writer. In this volume he succeeded in showing "how a mathematician thinks, how his imagination, as well as his reason, leads him to new aspects of the truth."

RADIOACTIVE WASTES: THEIR TREATMENT AND DISPOSAL, edited by J. C. Collins. John Wiley & Sons, Inc. ($8). A technical symposium on a problem which presents increasing (and in some respects perhaps unsolvable) difficulties. The articles deal with such topics as the nature of radioactivity, the sources of radioactive wastes, the treatment and disposal of radioactive liquid effluents and solid wastes.

ABUNDANCE OF CHEMICAL ELEMENTS, by V. V. Cherdyntsev. The University of Chicago Press ($10). A revised translation of a book, first published in Moscow in 1956, which deals with the abundance of chemical elements—that is, their quantitative content in the individual systems of the cosmos. Physics, geochemistry, astronomy and other scientific disciplines are pressed into service for this inventory of the occurrence and distribution of the elements in nebulae, stars, planets, cosmic rays, the earth's crust and so on, and of the formation of elements in nuclear processes in the sun and stars and in supernova explosions.

THE LAKE REGIONS OF CENTRAL AFRICA, by Sir Richard F. Burton. Horizon Press, Inc. ($15). A two vol-

ume reprint of a 19th-century classic of exploration, Burton's story of his 1,000-mile march to Lake Tanganyika. Burton was a fine writer with enormous energy—colorful, imaginative, witty and sardonic. He both loved and hated the vicissitudes and dangers of travel, the climate, the people, the country—above all, the mystery of Africa. His descriptions are superb, his enthusiasms, no less than his fury and frustrations, infectious.

THE DAGUERREOTYPE IN AMERICA, by Beaumont Newhall. Duell, Sloan & Pearce, Inc. ($12.50). An illustrated history of the beginnings of photography, from the introduction of Daguerre's process in America in 1839 to the perfection of the art some 20 years later. An informative text and 83 facsimile reproductions, many of which are marvelous.

Notes

MEN OF MATHEMATICS, by E. T. Bell. Simon and Schuster, Inc. ($2.25). A paperback of Bell's widely known and highly readable account of the lives and achievements of great mathematicians, from Zeno and Archimedes to Henri Poincaré and Georg Cantor.

SCIENCE IN THE CAUSE OF MAN, by Gerard Piel. Alfred A. Knopf ($5). Essays and lectures by the publisher of SCIENTIFIC AMERICAN on a broad variety of topics, mostly concerned with the social bearings of science.

RECORDS OF THE AMERICAN-AUSTRALIAN SCIENTIFIC EXPEDITION TO ARNHEM LAND: VOL. II, ANTHROPOLOGY AND NUTRITION. Edited by Charles P. Mountford. Cambridge University Press ($19.50). The second volume of this admirable report of the 1948 expedition to Arnhem Land deals with the health and nutrition of the aborigines, and with several aspects of their art and material culture, such as tools, weapons, pottery, cave paintings and string figures.

GEROLAMO CARDANO: THE BOOK ON GAMES OF CHANCE. Holt, Rinehart and Winston, Inc. ($1.50). This booklet gives Sydney Henry Gould's English translation of Cardano's *Liber de ludo aleae,* which marked the beginning of the theory of probability. The translation first appeared in Oystein Ore's *Cardano, the Gambling Scholar,* reviewed in these pages in 1953.

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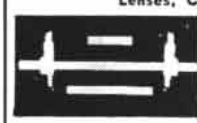

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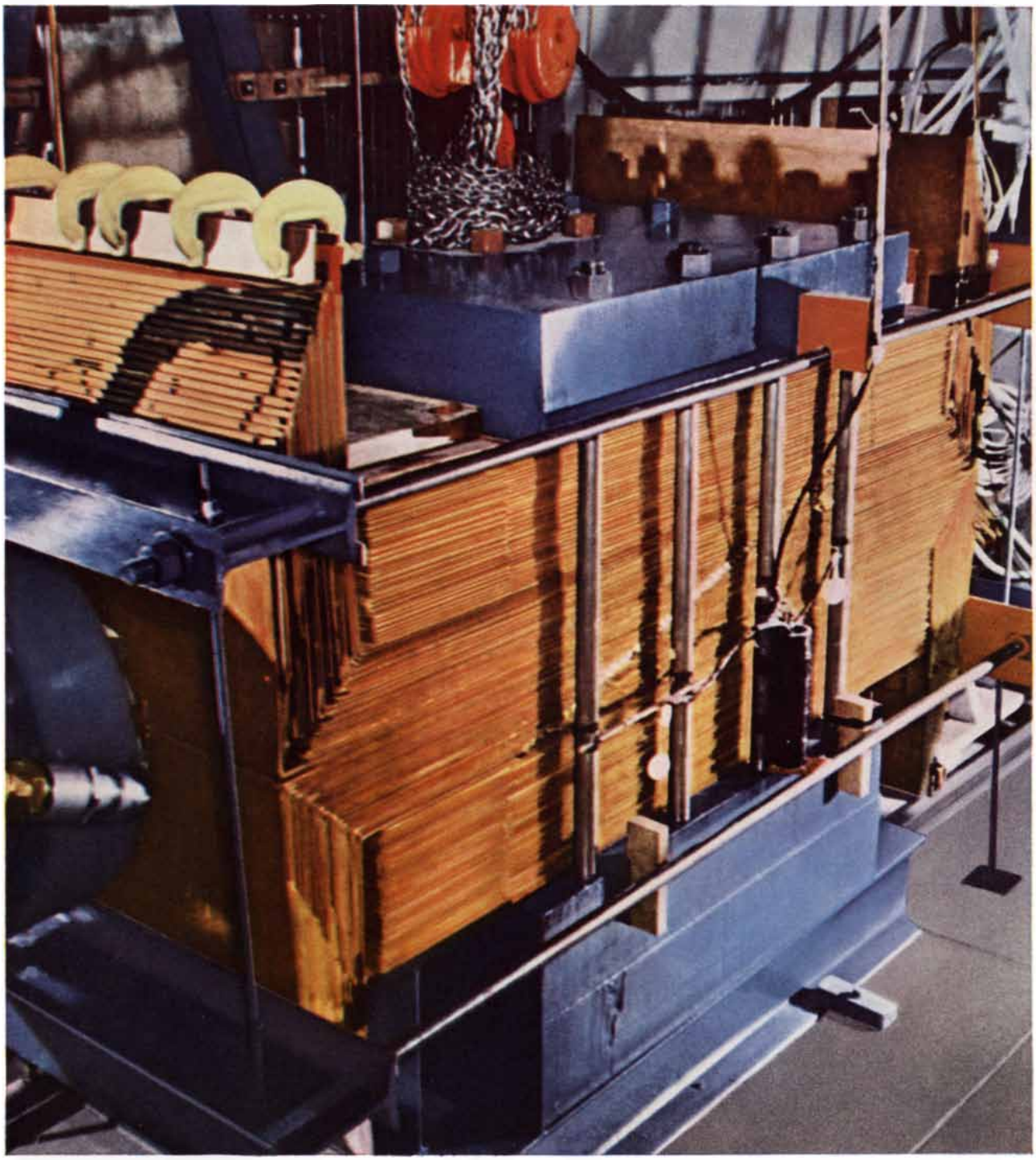

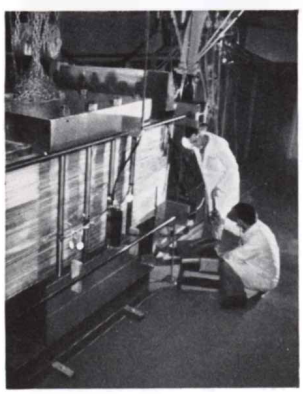

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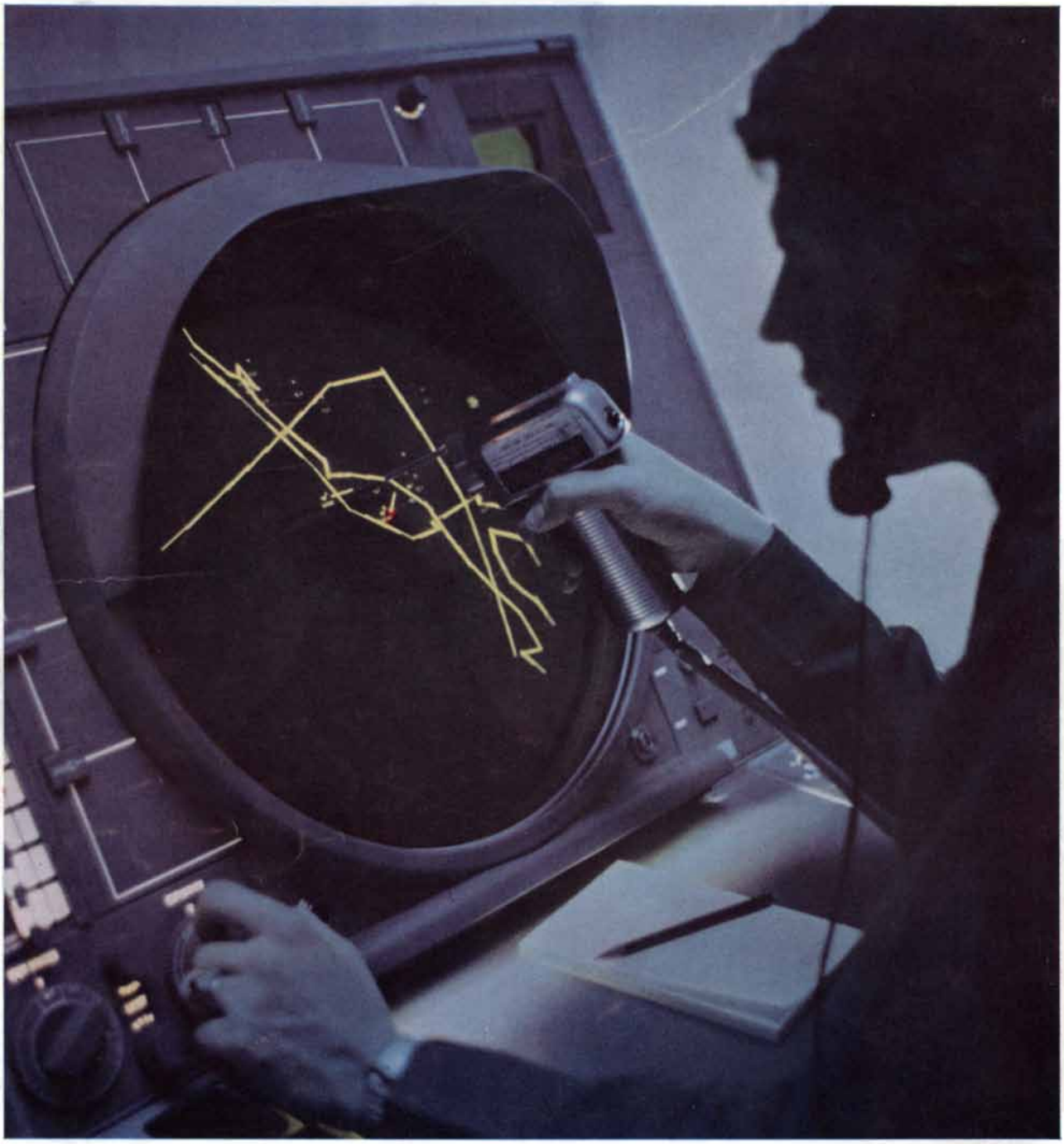

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