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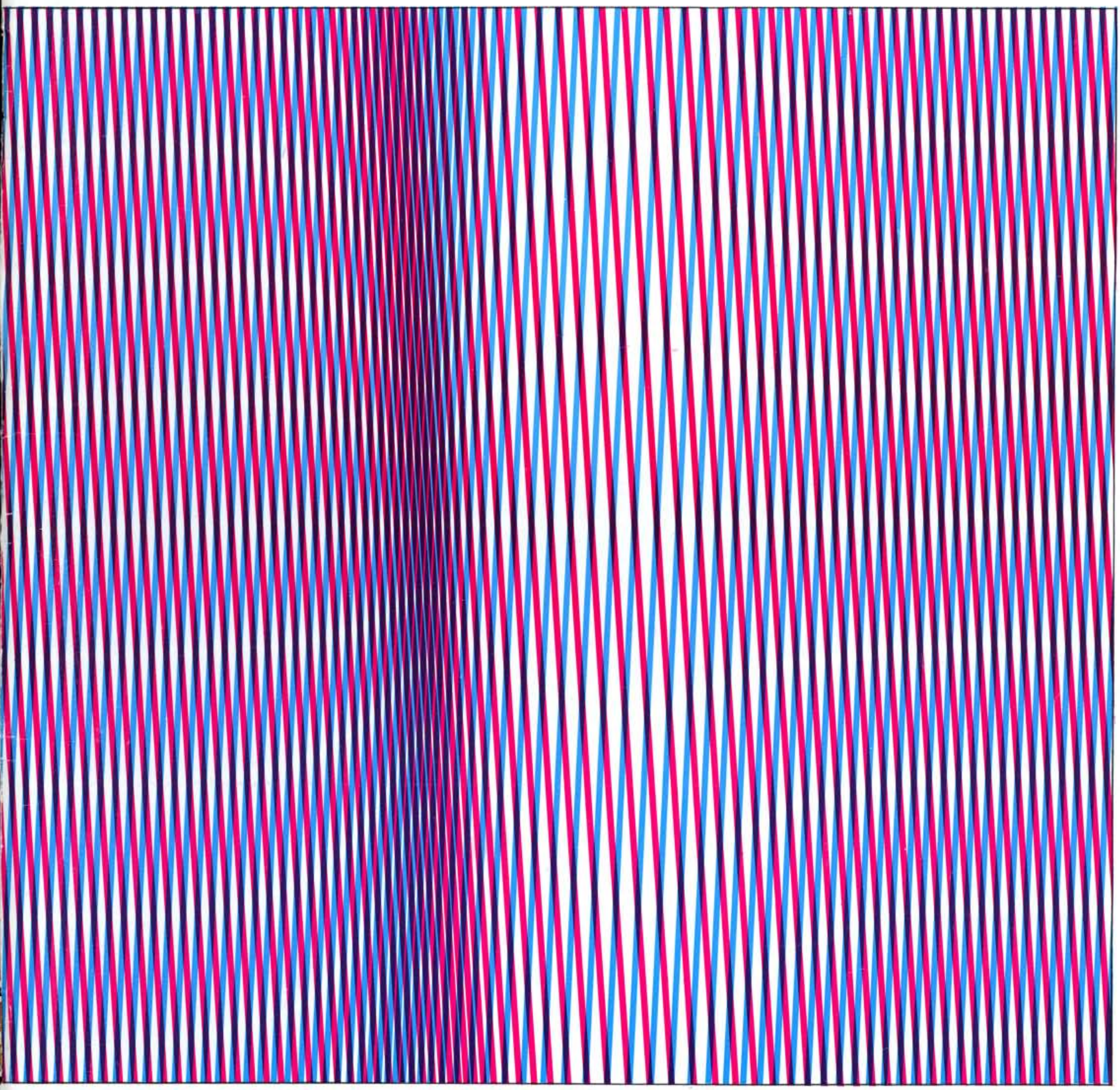
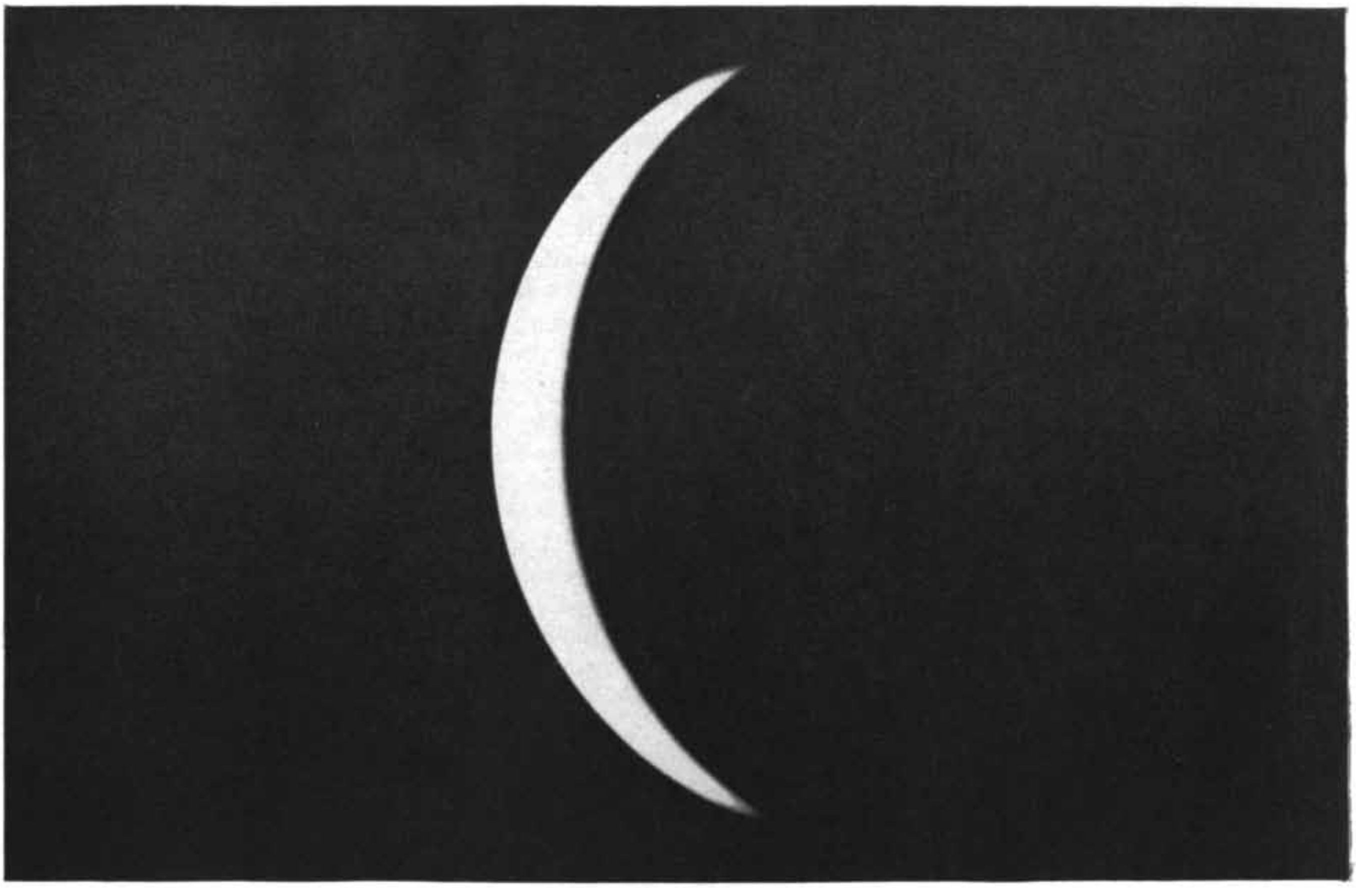


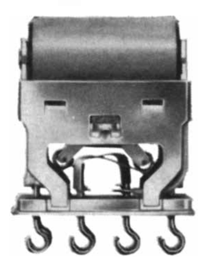
MOIRÉ PATTERN

FIFTY CENTS

May 1963



This is Venus



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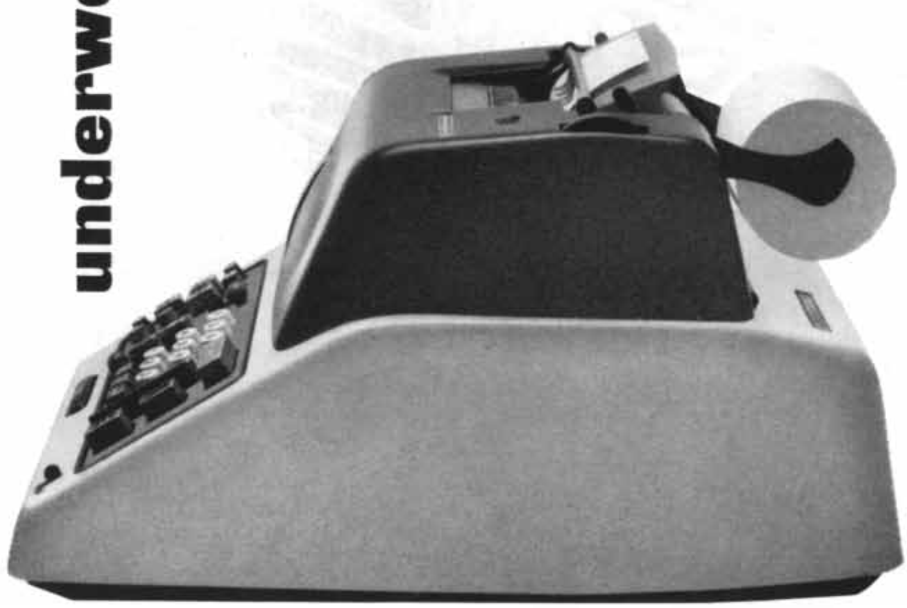

Established 1845 **SCIENTIFIC AMERICAN** May 1963 Volume 208 Number 5

ARTICLES

DEPARTMENTS

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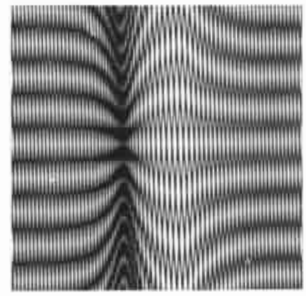

THE COVER

The design on the cover is a moiré pattern that appeared by chance during the shuffling of ruled figures being used to illustrate the article "Moiré Patterns" (*page 54*). The two components of the moiré are printed in different colors and can be clearly seen by holding the cover horizontal, at nearly eye level, and viewing the design obliquely. The two colors produce a secondary color moiré that ranges from red and blue through purple to black, where the two colors overprint. The ruled figures that create the moiré are derived from a Gaussian curve (*see illustrations on pages 56 and 57*).

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Cover design by Joan Starwood and Photo-Lettering

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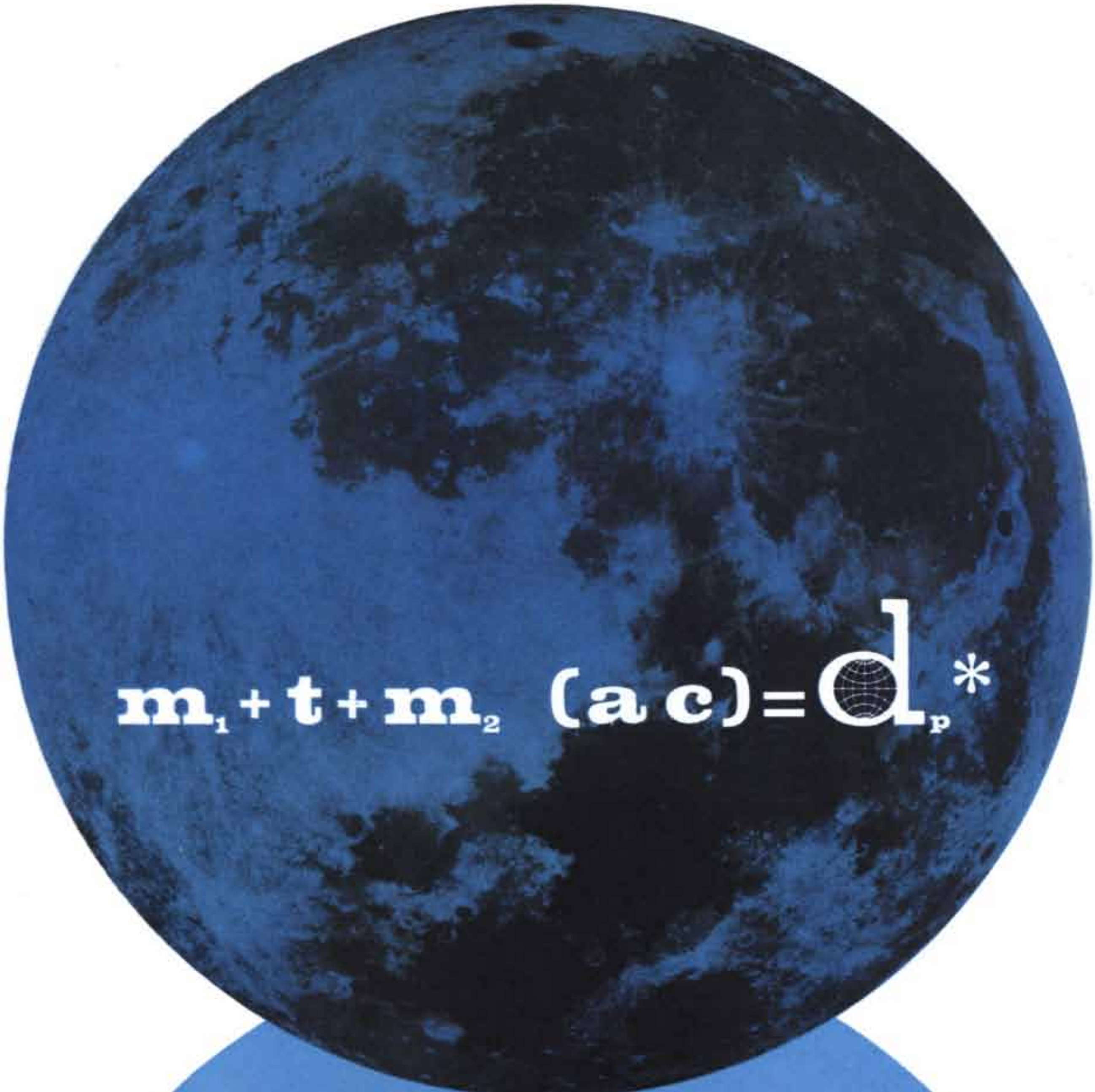

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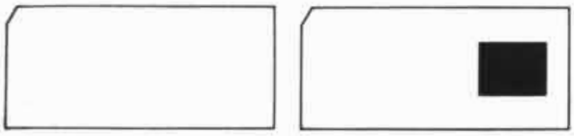

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ANACONDA COMMENTS

new facts about copper—man's oldest metal

NUMBER 9 OF A SERIES

ANACONDA RESEARCH AND TECHNICAL CENTER PROBES GAS CONTENT OF COPPER METALS

One of the new programs under way at Anaconda's Research and Technical Center involves gas analysis at new, lower levels of gas content. This fundamental exploration will attempt to improve existing products and to aid in the development of new products. The areas under study are so fine that once they were not even considered meaningful. The program, utilizing up-to-date analytical equipment, has one primary purpose: to develop methods for determining exact amounts of gas—infinitesimal as they may be—in copper metals.

Gases are unavoidably introduced into most metals during usual melting and casting operations, and often during process annealing and hot working. Because gases may have a harmful effect on the properties of metals, methods capable of analyzing gas content had to be developed. These methods, for the most part, are vacuum techniques in which metal samples are heated in a vacuum and extracted gases are collected and analyzed.

Lower Gas Content Meaningful Today

These standard vacuum techniques are meaningful for most metals. The effect of the gases present is sufficiently pronounced and the impurity level is sufficiently high to enable an analyst to determine gases present in the quantities which affect physical properties.

Anaconda research chemist Virginia Horrigan manipulates copper samples to release captive oxygen and hydrogen atoms for measurement of low level gas content of copper alloys.

Multiple specimens are enclosed in the glass system prior to evacuation. When the furnace is above the melting point of copper, one specimen at a time is caused to drop through the vertical tube into the furnace. The specimen is pushed to the opening by means of a ferrous rod (four can be seen in front of her hand) manipulated by a magnet through the glass.

Pressure increase from the evolution of gas is a measure of the quantity. Oxides are reduced by the graphite of which the furnace crucible is made, and the gas pressure is due to carbon monoxide from this source and from other gases present in the sample, such as hydrogen.

In copper metals, however, only very minute amounts of residual gases are present in acceptable castings. Copper metals have gas contents of the order of one-tenth of the amount found in ferrous metals and one-hundredth the usual level of oxygen and hydrogen found in titanium and other nonferrous metals. A copper currently characterized as oxygen-free, for example, contains too much oxygen for some of the newer requirements.

These low gas levels have made it extremely difficult for analysts to supply metallurgists with significant data on the gas content of copper metals.

Analytical Problems

Oxygen, one of the most frequently analyzed gases, can be extracted from copper metal samples without too much difficulty. The problems of analysis stem from the extremely low gas content, so small that the effects of gases held on the surface of the samples become important.

At high oxygen levels, surface effects are present but they are masked by the amount of oxygen held internally. When oxygen contents of less than 10 parts per million (the level of current specifications) are involved, gases held on the surface of the sample may completely obscure the amounts inside the metal—which alone are of prime concern to users of copper.

A truly oxygen-free copper material is required, for example, in hydrogen brazing and ultrahigh vacuum applications. Anaconda's current research on oxygen determination in low-oxygen copper is concentrated on evaluating the magnitude of surface gas effects on analytical values—so that meaningful data can be provided about the effects of various fabrication procedures on the oxygen content of mill products.

Frequently, alloys present special problems. Difficulties of hitherto unknown origin encountered during mill fabrication may well be related to small gas contents inherent in the metal. The ability to determine these small amounts will help the mill metallurgist pinpoint the cause of these difficulties and establish corrective measures to produce sounder products.

The determination of the gas content of copper alloys is made more difficult by the presence of lead and zinc, common alloying elements which volatilize both rapidly and explosively—complicating the gas evolution and making data assessment unreliable. To solve this problem, a considerable portion of present Anaconda work is being directed towards procedures for controlling the volatilization of low boiling metals while maintaining conditions suitable for the complete evolution of the gases in copper alloy samples.

Fundamental Anaconda research keeps copper-base metals modern and well suited to today's advanced needs. If analysis of the gas content of copper metals is of special interest to your own product development, we will be glad to keep you posted as new breakthroughs are made. Write, on your company letterhead, to: Anaconda Research and Technical Center, Anaconda American Brass Company, Waterbury 20, Conn.

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Whatever your next design may be—if you need a material that combines strength with conductivity or machinability—Think Copper. And think of Anaconda. As the world's largest supplier of copper metals in all mill forms, we can provide the high-performance alloy you need.

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When the CINCINNATI UNION TERMINAL was built 30 years ago, two types of piles were used for the foundation: steel piles with concrete cores, and pressure-creosoted timber piles. *Both types support 30 tons per pile.* Because permanent creosoted wood piles resist soil acids and alkalis and are not affected by moisture seepage, they were used in the fill areas. At that time these creosoted wood piles cost $.67 per lineal foot in place, compared to $1.62 per foot for the steel shell concrete piles; a savings of $.95 per lineal foot, for a total savings of $149,000 on the 156,840 feet driven.

That was 30 years ago. Today we know from longtime experience with many types of structures, as well as recent tests, that creosoted wood piles can safely support loads of *40 tons per pile.*

And pressure-creosoted wood piles are still saving money for building owners. At a recently completed shopping center in San Leandro, California, they saved $1.82 per lineal foot in place, as compared to concrete piles. Check the coupon for more facts from Koppers about money-saving creosoted wood piles.

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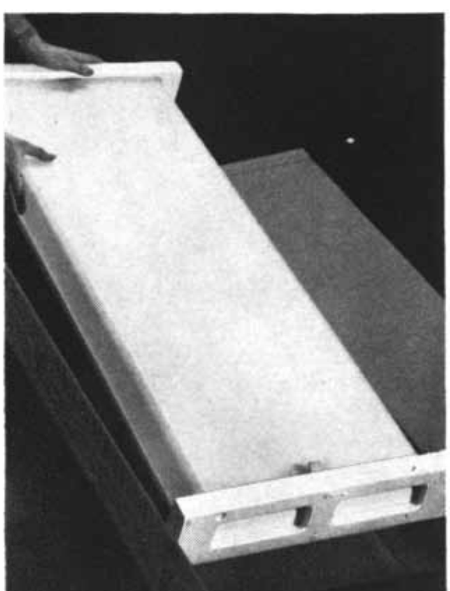

The WAKEFIELD LIGHTING DIVISION, WAKEFIELD CORPORATION, Vermilion, Ohio, ships its PRISMATIC® lighting fixtures in new single and double unit packages that consist of just two end pads of DYLITE expanded polystyrene which cushion the fixtures inside corrugated cartons. The old style package contained interior pieces of folded board. The rigid DYLITE pieces cut *material costs* $14.19/-hundred on the two-light package and $77.66/hundred on the four-light package. Based on their sales forecasts, the new packages will save WAKEFIELD $38,831 during the current year.

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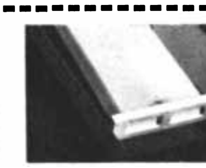

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LETTERS

Sirs:

In Martin Gardner's article about the paradox of the unexpected egg ["Mathematical Games," SCIENTIFIC AMERICAN, March] he seems to have logically proved the impossibility of the egg being in any of the boxes, only to be amazed by the appearance of the egg in box 5. At first glance this truly is amazing, but on thorough analysis it can be proved that the egg will always be in box 5.

The proof is as follows:

Let S be the set of all statements.

Let T be the set of all true statements.

Every element of S (every statement) is either in the set T or in the set C = S − T, which is the complement of T, and not in both.

Consider:

> (1) Every statement within this rectangle is an element of C.
> (2) The egg will always be in box 5.

Statement (1) is either in T or in C and not in both.

If (1) is in T, then it is true. But if (1) is true, it asserts correctly that every statement in the rectangle, including (1), is in C. Thus, the assumption that (1) is in T implies that (1) is in C.

Contradiction

If (1) is in C, we must consider two cases: the case that statement (2) is in C and the case that (2) is in T.

If (2) is in C, then both (1) and (2), that is, every statement in the rectangle, is an element of C. This is exactly what (1) asserts, and so (1) is true and is in T. Thus the assumption that both (1) and (2) are in C implies that (1) is in T.

Contradiction

If (2) is in T (and (1) is in C), then the assertion of (1) that every statement in the rectangle is in C is denied by the fact that (2) is in T. Therefore (1) is not true and is in C, which is entirely consistent.

The only consistent case is that in which statement (1) is in C and statement (2) is in T. Statement (2) must be true.

Therefore the egg will always be in box 5.

So you see that the discovery of the egg in box 5 is not so surprising after all.

GEORGE VARIAN
DAVID S. BIRKES

Stanford University
Stanford, Calif.

Sirs:

Martin Gardner's paradox of the man condemned to be hanged was read with extreme interest. I could not resist noting that had our prisoner been a faithful statistician he would have preferred hanging on Wednesday, the fourth day. For if the judge had picked at random one day out of seven, then the probability that the prisoner would be required to wait x days in order to receive exactly one hanging is $p(x) = 1/7$. That is, any number of waiting days between one and seven is equally probable. This observation is a simple case of the more general hypergeometric waiting-time distribution

$$p(x) = \frac{\left[\dfrac{(x-1)!}{(x-k)!\,(k-1)!}\right] \cdot \left[\dfrac{(N-x)!}{(N-x-h+k)!\,(h-k)!}\right]}{\dfrac{N!}{(N-h)!\,(h!)}}$$

where $p(x)$ is the probability that x independent trials must be performed in order to obtain k successes if there are h favorable events mixed randomly among N. In our case we have $N = 7$ and (assuming one hanging is more than adequate) $h = k = 1$. Thus the "expected," or mean, value of x is $1/7(1 + 2 + \ldots + 7) = 4$ days. However, I suppose we must always allow for that particularly tenacious reader who will rule out Wednesday on the grounds that it is "expected."

MILTON R. SEILER

Worthington, Ohio

Sirs:

The brief article entitled "Polarized Protons" ["Science and the Citizen," SCIENTIFIC AMERICAN, March] gives the erroneous impression that I am the sole inventor of the method of dynamic nuclear polarization. In actuality the achievement of polarized proton targets is due to the efforts of many scientists over the years, beginning a decade ago

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with the original idea of A. W. Overhauser and the experiments of T. R. Carver and C. P. Slichter on metals, which established that microwave pumping could enhance the nuclear polarization by two orders of magnitude. This concept was generalized to other nuclear-electron systems, notably by A. Abragam, and variations were developed by several groups. The particular idea utilized in the polarized targets (using forbidden microwave transitions to directly flip nuclei with electrons) apparently occurred independently to several people: myself; N. Bloembergen and P. P. Sorokin; A. Abragam and W. G. Proctor; E. Erb, J. L. Motchane and J. Uebersfeld; and probably others. Initial experiments on the target material, rare-earth hydrated salts, were done by M. Abraham, M. A. H. McCausland and F. N. H. Robinson. Extensive work on these crystals at Berkeley established that high proton polarizations (70 per cent) can be obtained.

Actual polarized targets have been developed by A. Abragam, M. Borghini *et al.* at Saclay for very thin targets suitable for low-energy scattering; and by O. Chamberlain, C. Schultz, G. Shapiro *et al.* at Berkeley for larger targets, designed for very-high-energy scattering.

These developments have been international, as so often happens in science.

CARSON JEFFRIES

Department of Physics
University of California
Berkeley, Calif.

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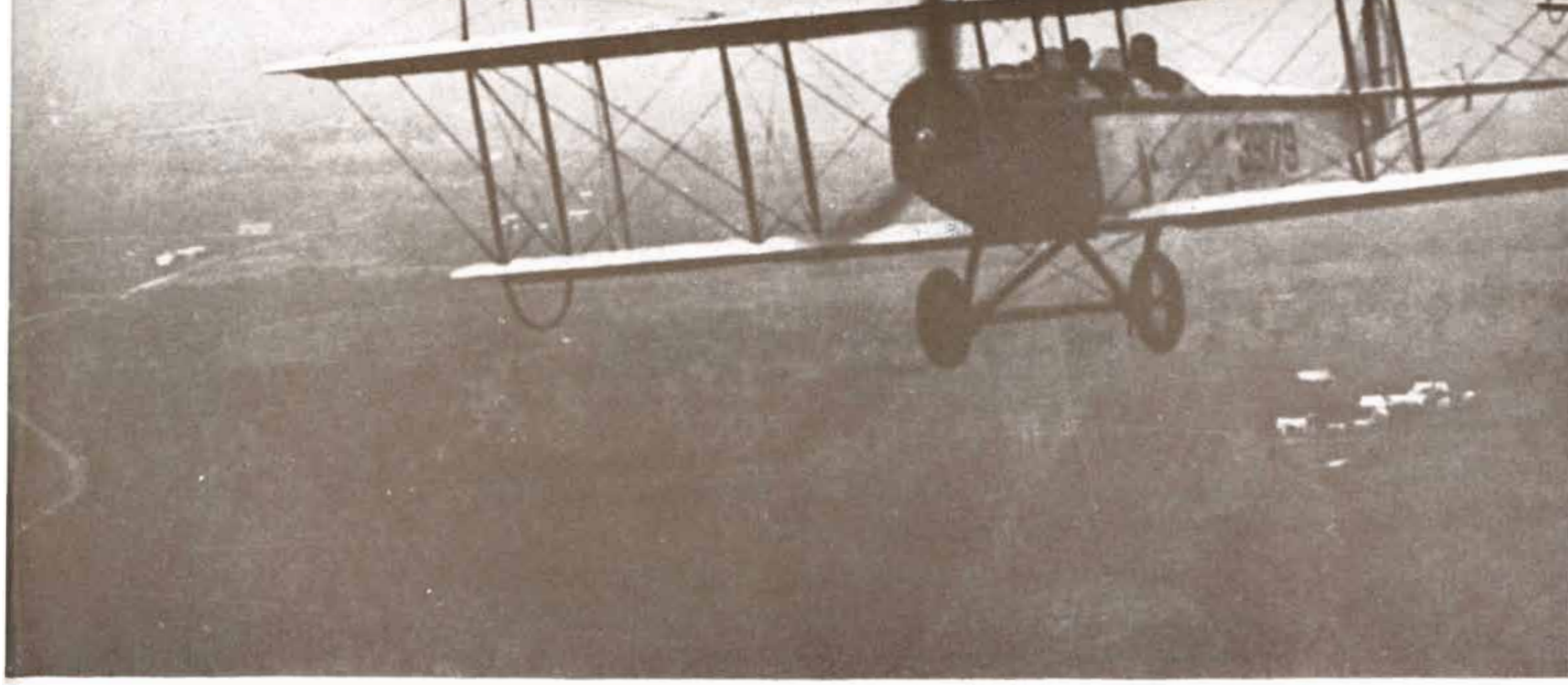

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UNITED

Why do more people save at Full Service Commercial Banks than anywhere else?

(BECAUSE IT HELPS THEM BUILD THEIR FINANCIAL FUTURE. READ HOW.)

Most people choose one of these three places for their savings:

A savings and loan association, which may pay a little *higher* return on savings, but is engaged mostly in making home loans.

A mutual savings bank (common in the East), which also may offer a little *higher* earnings but is—again—involved primarily in making home loans.

A Full Service commercial bank, which sometimes pays a little *less* on savings than the other two. (We'll talk about their loans later.)

Despite this apparent disadvantage, *Full Service banks are America's most popular place to save money. You have probably guessed why.*

People with plans prefer a Full Service commercial bank

Unlike other financial institutions, Full Service commercial banks are *not* restricted to making only a few types of loans. On the contrary, they can offer loans and other services that no other institution can duplicate: checking accounts, savings accounts, trust services, home loans, personal loans, auto loans, farm and business loans – full banking services and counsel, all under one roof.

How do you get established with a Full Service bank?

Just do three things:

1. Do all your banking business with a Full Service bank, both checking and savings accounts. Keep these accounts active and try to maintain fairly reasonable balances.

2. Get acquainted with one or more of the bank's officers so that you know where you stand financially right now. A good way to do this is to fill out a Personal Financial Statement for the bank's file. Your banker can help you with this.

3. Use one of the bank's low cost loans whenever you need a little extra cash. Paying the loan back as promised will do wonders for your credit reputation.

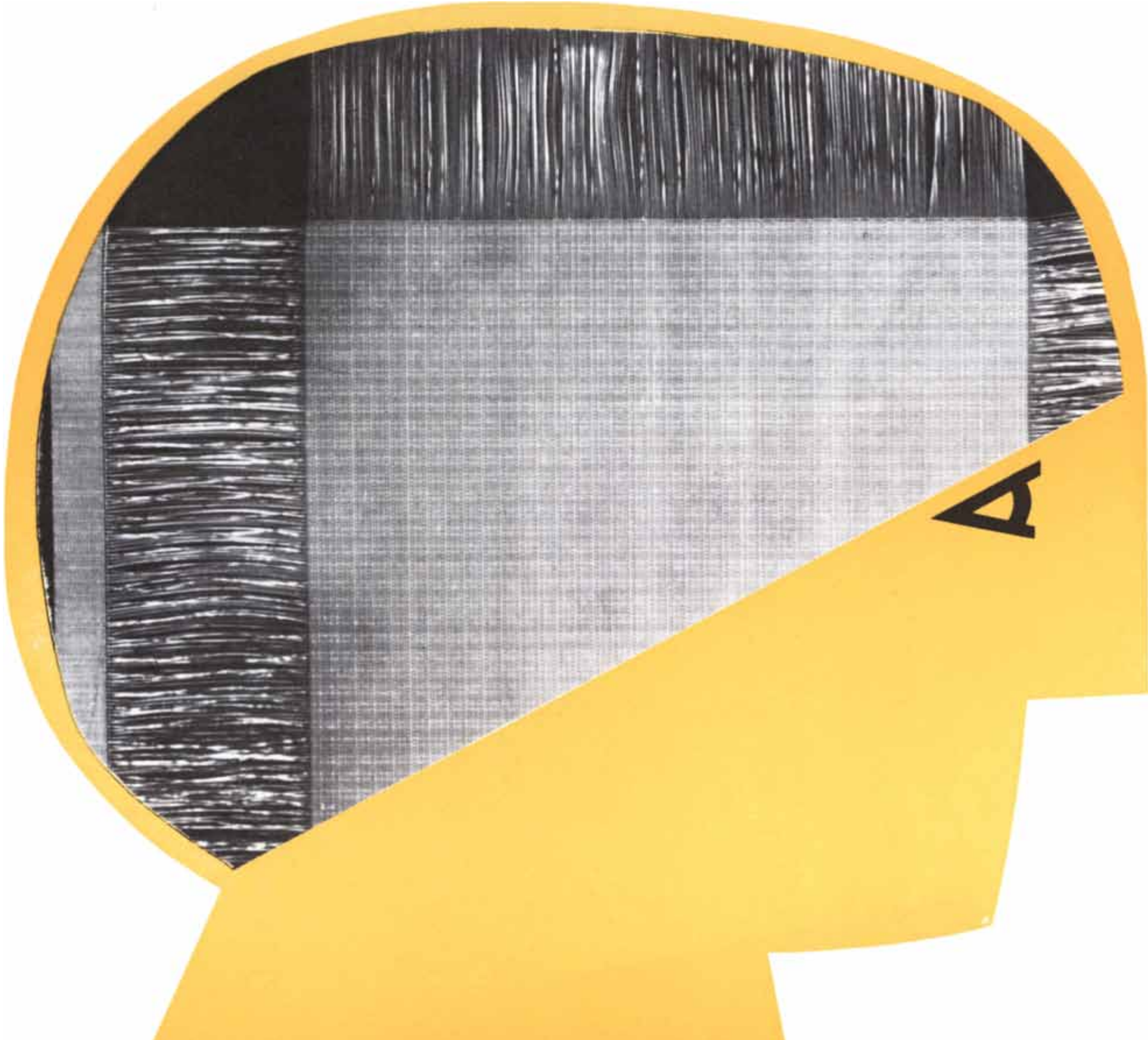
The rest comes naturally

Pretty soon, you'll find "they know you at the bank." And you'll find, too, that they're ready to help you grow financially in a dozen different ways – through advice on how to manage your income to credit references and a good credit rating.

Most important of all, they're ready to help you by lending you money at low bank rates for any useful purpose. The slightly lower earnings you may get on your savings are usually more than offset by lower rates on loans. In short, many people do their *saving* at a Full Service commercial bank so they can do their *borrowing* easier and less expensively from the same bank.

If you haven't already decided on a Full Service bank as your "financial partner," it isn't too early to start *right now.*

FULL BANK SERVICE®	*Your Full Service Commercial Bank*



In versatility, and in speed, one computer output device stands alone, challenged only by the imagination of its users

The S-C 4020 Recorder is the only proven equipment, available now, which converts and records digital output in combinations of curves, vectors and characters at speeds consistent with today's large-scale computers.

Users of the S-C 4020 have imagination. They are proving it in more than a score of data processing labs across the country. Some of the current applications of the S-C 4020 even surprise the designers of the equipment. But our users are willing to share their ideas, applications and programming techniques.

USERS SOCIETY

To do this, they have formed a society of users of the S-C 4020 named UAIDE for "Users of Automatic Information Display Equipment." UAIDE has already set up a software library to exchange programming and application data.

VARIETY OF OUTPUT

Tapes from a large-scale computer (typically a 7090 or 7094) are fed through the S-C 4020 which translates the numerical language by using an improved CHARACTRON® Shaped-Beam Tube. Directly opposite the tube face is a recording camera, either 35mm or 16mm. Another optically aligned camera is optional which gives you page-size paper copies. A slide projector allows standard formats to be superimposed on the frame or page automatically at the command of the computer program. The microfilm can be viewed through a standard viewer, reproduced into multiple reports, projected for group viewing, or placed into storage and retrieval systems.

SPEED

The S-C 4020 will accept data from magnetic tape at input rates up to 90,000 six-bit characters per second. The S-C 4020 will print this data at speeds in excess of 17,000 alphanumeric or symbolic characters per second. Frames combining characters, vectors and curves vary with the complexity of the drawing, but an average annotated graph can be recorded in fractions of a second.

ECONOMICS

The S-C 4020 can be leased by the month or purchased. We also operate a service bureau where you can lease 4020 time by-the-hour and try some of your own problems on the machine for evaluation. Prices on the 4020 have lifted some eyebrows of prospective users — but only at first glance. Used properly, the 4020 is paying its way many times over in labs throughout the U.S. For example, one user is doing a complex plotting job required daily by his engineering analysis group which was previously done in several days by more than 100 draftsmen. The S-C 4020 is producing the same annotated curves complete with grids, axis lines and titles in minutes for considerably less cost. The equipment's high density input tape adapter results in minimum use of valuable computer time for S-C 4020 tape preparation. Part of our lease or sales price includes trained customer engineers to install and maintain your S-C 4020.

The S-C 4020 is not "blue sky". There are more than 20 machines in use, and orders exist for many more.

APPLICATIONS

The S-C 4020 can be employed to record tabular and other alphanumeric information such as stock catalogs, program debugging, and other statistical data at speeds of 17,000 characters per second. The equipment's versatility, however, is best illustrated by applications involving combinations of both drawing and character recording.

SCIENTIFIC CURVES

In many scientific computer labs the 4020 is being used to plot highly accurate curves involving one or more parameters. All axis and grid lines, annotations and titles are included in the program. For curves requiring more than one frame length, a continuous graph may be plotted by butting the frames together under program control. Typical curves include flight tests, engine performance, missile trajectory simulation, etc.

BUSINESS GRAPHS

The recorder is proving its usefulness daily by plotting curves and other business charts for cost analysis, production control, manpower forecasts, projected sales, and other administrative tasks. The machine's ability to summarize the data in a visual form speeds decision making, saving time and money.

TOOL PATH DRAWINGS

Magnetic tapes programmed in APT language to guide machine tools can first be played on the S-C 4020 which makes a drawing of the part. The drawing can be checked for errors prior to making a part, and can also be used for final inspection. In addition to tool path drawings, the 4020 can be used for such computer drafting applications as logic and flow diagrams, ship and missile design.

SCHEDULE NETWORKS

PERT and other critical path charts can be produced and updated on the S-C 4020 in seconds.

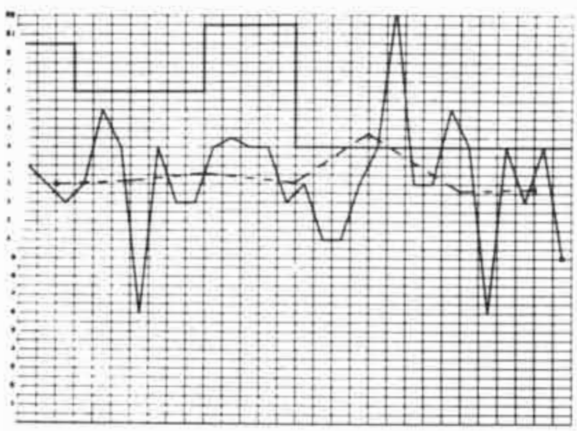
MAPPING

The 4020 is producing maps for such uses as weather patterns, satellite tracking and population studies. The map itself may be superimposed by the slide projector. The CHARACTRON Tube then displays the variable information, or the entire map may be drawn by the tube, allowing area expansion by computer command.

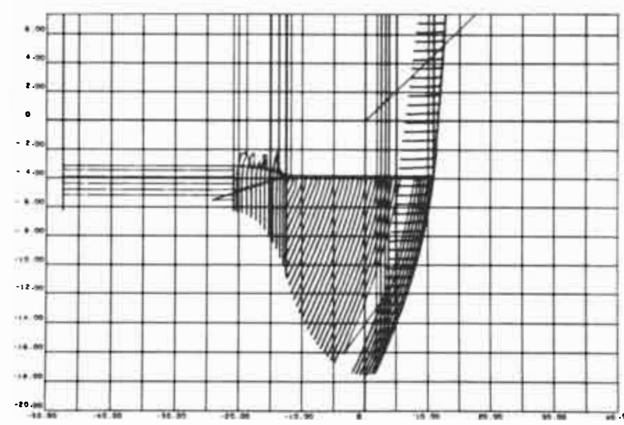
SEQUENTIAL EVENTS

One of the exotic uses of the equipment is the drawing of a series of slightly changing graphs for calculation of core reactor characteristics, simulation of shock waves and explosions, or for training aids. The series is then projected and viewed as a movie giving a time scale sequence.

Challenge the imagination and inventiveness of your programmers, engineers and managers to utilize your digital computer more fully in new ways through the S-C 4020. Write to Department D-29, General Dynamics| Electronics-San Diego, P.O. Box 127, San Diego 12, California.

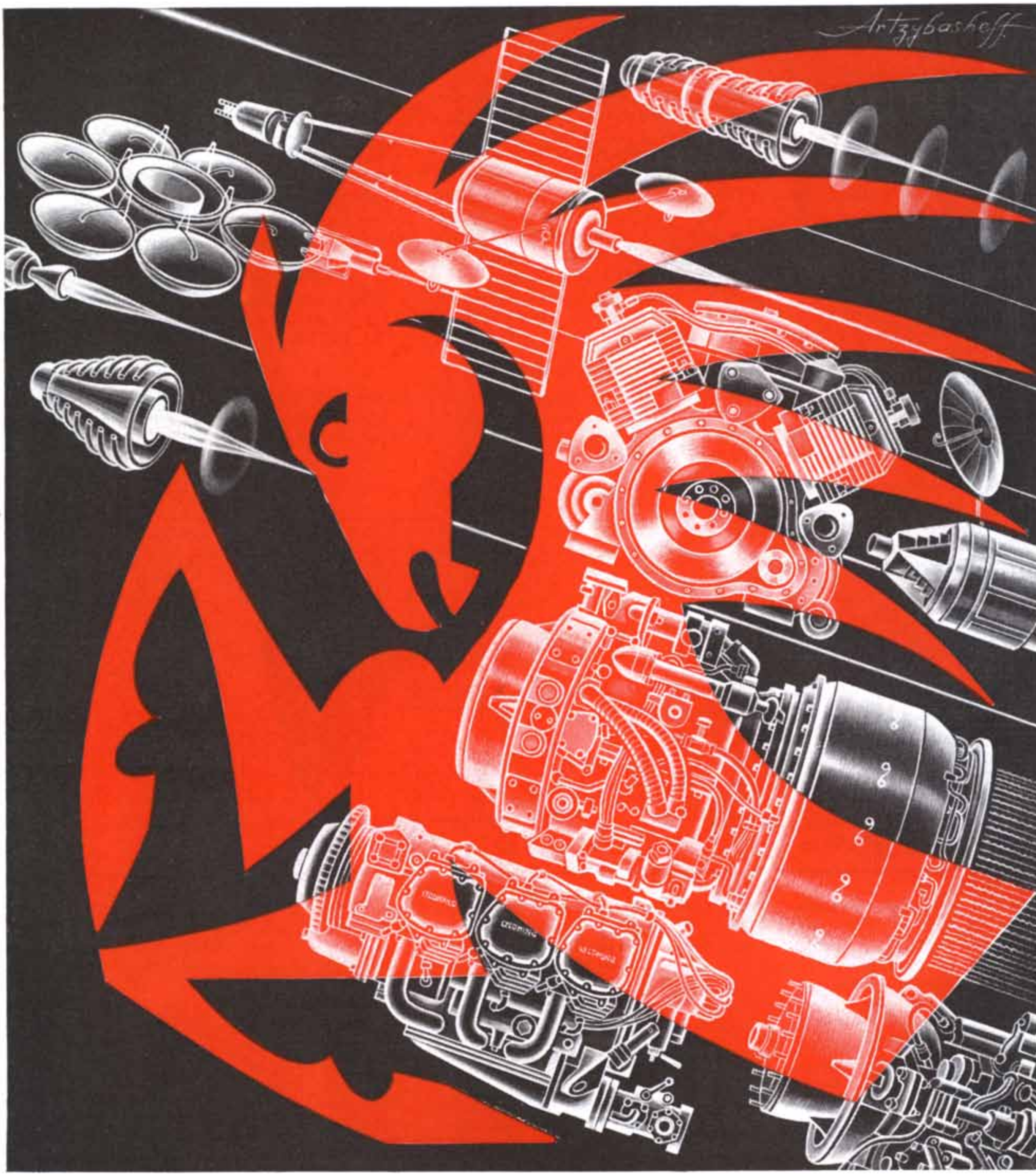


Business Graphs



Tool Path Drawings

GENERAL DYNAMICS | ELECTRONICS SAN DIEGO



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Mt. Wilson-Palomar Observatories Photos

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1913: "It is the opinion of many that the present development of the gasoline omnibus, which is now such a success, is to have quite an influence on the question of passenger traffic on roads. Heretofore we have been familiar with light electric or steam railroads for use in the country districts, but it often happens that there is comparatively little traffic on such lines. In some cases the estimated profits from such roads are not enough to warrant a great layout of capital, so that here the power wagon omnibus will fill the needs in the best manner. An example of this is seen in Italy, where the 'bus lines are developing considerably throughout the country."

"A new type of internal combustion engine, designed to run at the extraordinary speed of 4,200 revolutions per minute, has just been put on the market by a British manufacturer. Although it is chiefly intended for aeronautic use, a similar model for automobile use is in preparation. The engine has eight steel cylinders of 2½-inch bore and 2¼-inch stroke, arranged in V shape on a tubular steel crankcase. The cylinders are set on the crankcase in staggered fashion. The motor develops 50 horse-power at the normal speed of 4,200 revolutions per minute and weighs complete only 112 pounds; it works with a compression of 80 pounds per square inch."

"The recent radio-telegraphic tests conducted between the scout cruiser *Salem* and the Arlington station have demonstrated that waves produced by the electric arc are less modified by absorption than waves produced by spark apparatus. Up to a distance of about 900 miles there was very little to choose between the two types of waves. It was possible for the Arlington station to reach the *Salem* at a distance of 2,100 miles. But as the distance was increased beyond 2,000 miles, it was found that the waves produced by the electric arc showed a relatively increasing efficiency and possessed an energy much greater than those from the spark apparatus."

"On March 23, at San Diego, Cal., Lieutenant Harold Geiger and Lawrence Sperry, son of the inventor of the gyroscopic compass and the gyroscope for stabilizing ships, both of which inventions are at present being widely used in our Navy, made a preliminary test flight of 35 minutes' duration in a Curtiss flying boat equipped with Mr. Elmer A. Sperry's new gyroscopic control for aeroplanes. The flight was successful in every way. Experiments are still being continued, and the final test is to be a deliberate attempt to upset the machine while flying over the bay. The control consists of a small gyroscope weighing only 2¼ pounds, which operates the warping by means of a compressed-air motor the valves of which the gyroscope controls. We understand that Count Zeppelin, in Germany, has also just brought out a successful gyroscopic control for aeroplanes and applied it to a monoplane of his invention. In this case two large gyroscopes are used to operate the ailerons and the elevator."

Scientific American.

MAY, 1863: "Sir Charles Lyell, the distinguished geologist, infers from recent researches and discoveries of implements in various parts of Europe that man may have lived on the earth thousands of centuries before the era of his advent according to common belief. France, England, Denmark and Switzerland were once peopled by a race that used flint hatchets and arrow heads, like the old North American Indians. After them came a race that used implements of bronze; and again these were succeeded by a race that used implements of iron. In one case Lyell shows the section of an ancient hut that had been built on the Scottish seacoast. It had been submerged by the sea for so long a period that 60 feet of marine strata had formed over it, and after this, by some convulsion or gradual upheaval of the earth, it was elevated to its former position out of the sea. This hut affords evidence of having been erected in a far remote prehistoric period."

"A large barometer has been lately erected in the National Astronomical Observatory of Santiago de Chili. Humboldt had observed that the barometer rises and falls during the day in a peculiar manner, being at its maximum hight at 10 A.M. and 2 P.M., whilst the lowest readings are between 4 P.M. and 4 A.M.

NEW DEEP-SEA AMPLIFIER TRANSMITS 128 TELEPHONE CONVERSATIONS

Our engineers have developed a new amplifier which simultaneously transmits 128 telephone conversations in both directions over a single cable. It is designed to operate without repair or maintenance on the ocean floor for 20 years.

The new amplifier (illustration below) is an important advance in deep-sea communications technology.

To make a single amplifier operate in two directions, it was necessary to provide a precise, complex filter system to separate the signals. Signals traveling in one direction occupy a frequency band from 116 to 512 kc., and those traveling in the other direction, from 652 to 1052 kc.

The gain of each amplifier must accurately compensate for its share of cable loss. The total loss varies over the frequency band and, in a transatlantic system, reaches a maximum of 9000 decibels. Since there is no way to adjust an amplifier on the ocean floor, the performance of each one must be pre-established with extreme precision.

A 3600-mile cable link, with its 180 amplifiers, includes 36,000 electronic components. Each component has to be endowed with a reliability far in excess of the requirements of conventional land systems.

The casing and its seal to the cable must prevent minute water seepage at ocean bottom pressures. This could accumulate fatally over the years, and so production tests employing radioactive isotopes are used to search for any such microscopic leakage.

In bringing the new underseas system to production we worked closely with Western Electric, the manufacturing unit of the Bell System. Our joint objective was to create a system of high reliability that could be manufactured economically. The new amplifiers are being used first in the new deep-sea telephone link from Florida to Jamaica and Panama.

BELL TELEPHONE LABORATORIES

World center of communications research and development

View of deep-sea amplifier with casing cut away. The casing is of noncorrosive beryllium copper, tested to withstand pressures up to 11,000 psi.

The regularity of this periodic movement within the tropics is such during the year that Humboldt could tell the time within 15 minutes. But in the month of February the movement entirely ceases, showing then only the ordinary maximum and minimum hights in 24 hours. Señor Moesta (of the observatory) states that the oscillatory movement of the barometer is produced by the sun's power, analogous to that of gravitation, and that the said movement ought to disappear in the month of February, in consequence of the great variation of temperature during the course of the day. Thus the interesting result has been arrived at that, by virtue of the sun's power, a movement is manifested in the atmosphere analogous to the action of the tides, and it is this that causes the rise and fall of the barometric column in Santiago."

"At the late session of Congress an act was passed for the formation of a National Academy of Sciences, and 50 corporators, mostly members of the American Association for the Advancement of Science, were included in the bill. A preliminary meeting of the corporators was held in New York City last week and 50 members were present; Prof. Joseph Henry of the Smithsonian Institution was chosen president."

"Up to the 13th of last April no less than 7,402,339 gallons of petroleum had been shipped from New York to foreign ports. London and Liverpool are the two great receiving ports of American petroleum—over 1,000,000 of gallons having been sent to each of these places at the date stated. In addition to the above, 3,353,608 gallons have been shipped from Portland, Boston, Philadelphia and Baltimore, making a total of 10,755,947 gallons. Our petroleum trade with foreign nations has already attained to gigantic proportions."

"Sir H. Davy, in his important and interesting experiments, found that light carbureted hydrogen, the most powerfully explosive of the gases, required about seven times its bulk of atmospheric air to be mixed with it to produce the greatest explosive effect. Practically, it can be calculated that from eight to nine times its bulk of air will produce the most explosive mixture of coal-gas; but the air and gas must be mixed previous to inflammation. No matter how rapidly the air may be supplied when the gas is burning, it will merely increase the fierceness of combustion; there will be no explosion."

HOOKER RESEARCH REPORTS

- On Chlorobenzotrifluorides
- Triallyl phosphate
- Dechlorane®

. . . of fins and fluorides

Shaped like an 18-inch section of garden hose, and looking as harmless, a sea lamprey stalks a trout.

The doomed fish is unaware, unhurried and unworried—a perfect victim for the lamprey's suction mouth that presently reaches out and drains him of his blood.

In a single year in the Great Lakes the evil pests have sucked the life from 20,000,000 pounds of game fish.

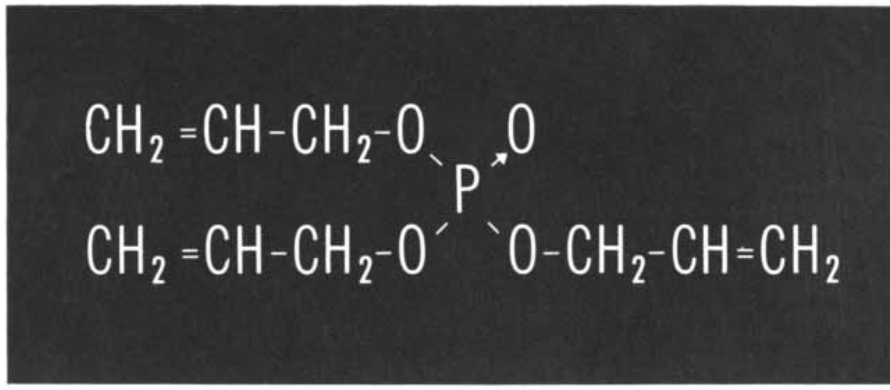
While fishermen were beginning to wonder where their next trout was coming from, imaginative scientists were closing in on a discovery to stop the slaughter.

Their starting point was the *meta*-chloro isomer of benzotrifluoride. From it, they developed a lampricide so potent a cupful in 100,000 gallons (around 2 to 3 parts per million) of water kills all lamprey larvae in tributary streams. Miraculously, it leaves all other life unharmed.

Now, we can't offer you the lampricide. We don't make it. But we can provide you with a bulletin full of information on benzotrifluoride and its *ortho-*, *meta-*, and *para-*chloro isomers.

It gives physical and chemical properties, suggested applications, typical chemical reactions, toxicity, and bibliography.

Just check the coupon.



A structure to whet your curiosity

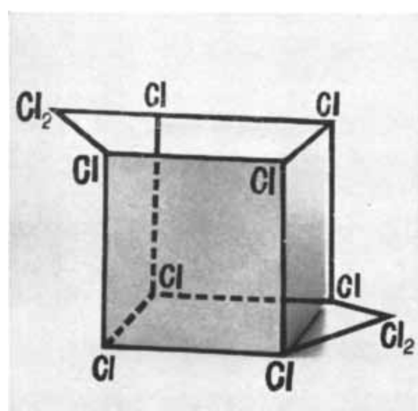
The double bonds of triallyl phosphate frankly invite you to the blackboard and the search for useful derivatives. Work done with these three *open sesames* hasn't begun to exhaust their possibilities.

Should you care to look for opportunity beyond the double bonds, triallyl phosphate offers still other means to interesting ends. It is inherently capable of being polymerized or copolymerized with almost any other monomer.

One way or another, it may lead you to new products for textile, plastics, paper, and petroleum applications.

Reassurance for the reluctant. Our triallyl phosphate is made by a patented process that provides a product of high purity and good storage stability.

It's available in semi-commercial quantities. For more information, please check the coupon.



The shape of fire retardance

A glance at the unique structure of our new molecule, Dechlorane—and you see the latest shape of fire retardance.

Boxlike, it's the most stable configuration possible. Chlorine makes up 78.3% of its composition, with only carbon to fill out the formula.

The content and contour of Dechlorane make no empty promise. Dechlorane won't melt or decompose until you get it up around 485° C.

Consequently, it is suggested as a non-plasticizing fire-retardant additive in thermoplastic and thermosetting resins where stable chlorine is desirable because of electrical properties or corrosion.

Other possible applications are in the area of fire-retardant elastomers. Pyrotechnic formulations, such as in tracer shells and flares, are being investigated.

Dechlorane is available in semi-commercial quantities.

For information on physical properties, solubility and other data, please check and mail the coupon.

FOR MORE INFORMATION, CHECK HERE AND MAIL WITH NAME, TITLE AND COMPANY ADDRESS:

- ☐ BULLETIN 12-A. BENZOTRIFLUORIDE AND ITS ORTHO-, META-, AND PARA-CHLORO ISOMERS
- ☐ TRIALLYL PHOSPHATE
- ☐ DECHLORANE®

For complete product listing, see Chemical Materials Catalog or Chemical Week Buyers' Guide.

Sales Offices: Boston Buffalo Chicago Detroit Los Angeles New York Niagara Falls Philadelphia Tacoma.

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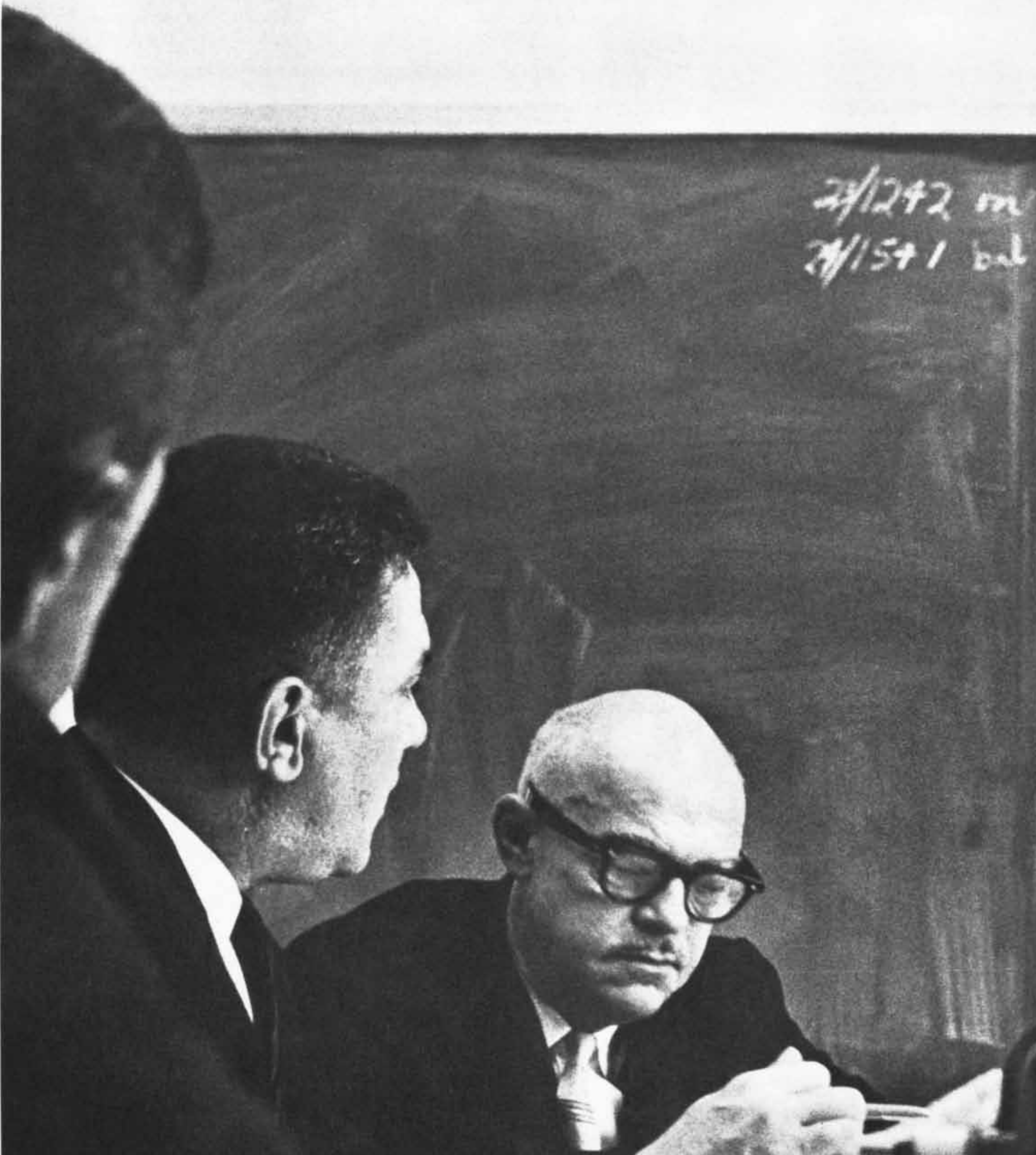
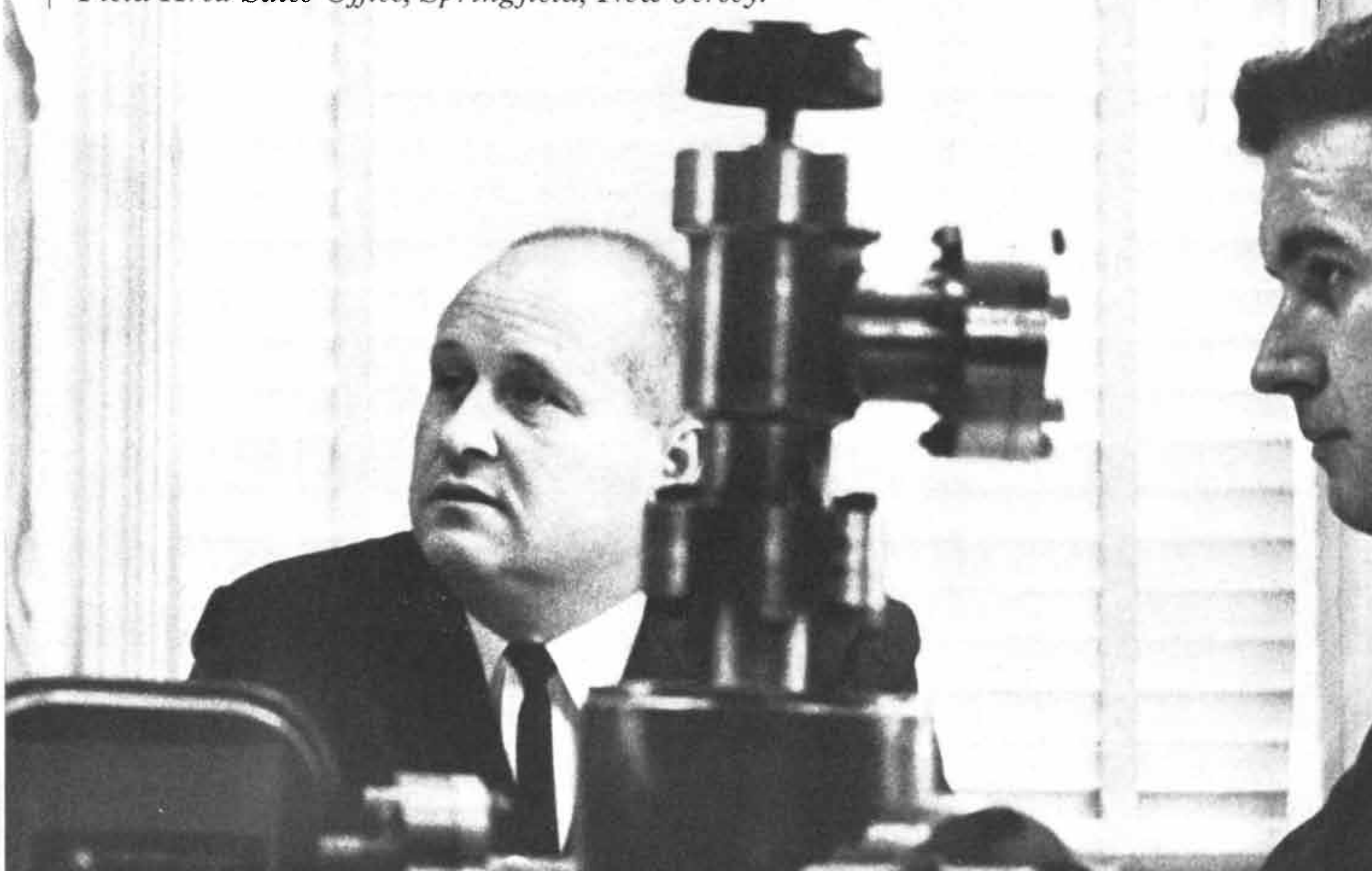
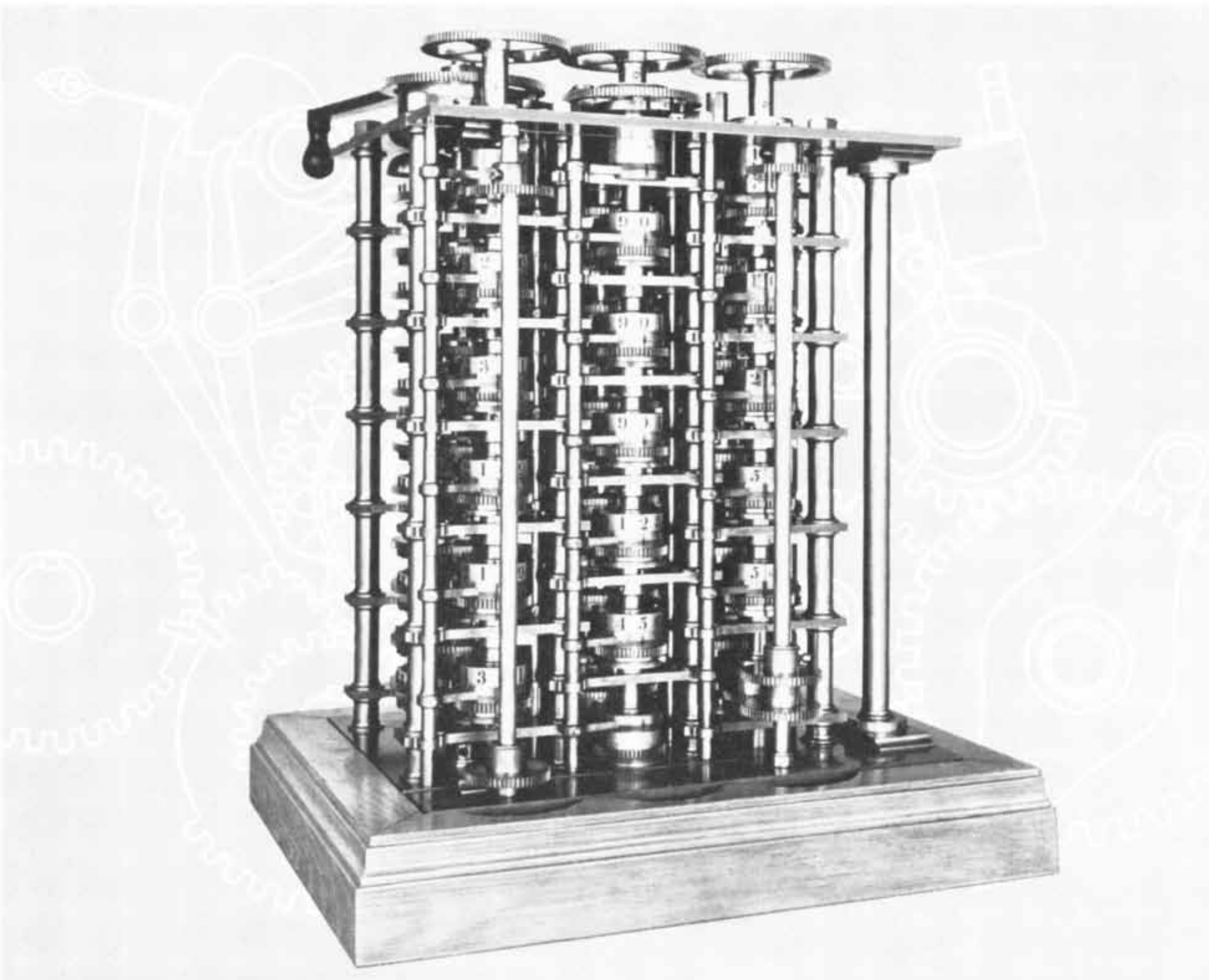


"When you've got a microwave tube problem and want technical information, you want it fast. That's why we've set up 12 field offices around the country—so that we can put a top technical man, or a whole team, in your office within 24 hours. We want to be sure you get information that's complete, accurate, and current. And this service pays off. Just the other day, as a matter of fact, another customer of ours told me he had freed one of his expediters for other work because of the efficiency of our local marketing team. It's the same kind of service we'll be giving you." *Tom Curtis (below), District Sales Manager, New York Field Area Sales Office, Springfield, New Jersey.*



MICROWAVE TUBE GROUP **VARIAN associates**

FROM DIFFERENCE ENGINE TO COMPUTER



Part of BABBAGE'S DIFFERENCE ENGINE (circa 1830) which was designed to calculate functions through finite differences. Since it had the disadvantage of a "fixed program," Babbage devoted the rest of his life to a "universal" analytical machine. (British Crown Copyright, Science Museum, London)

AC NAVIGATION SYSTEMS— ACCURATE, RELIABLE, LOW COST, DELIVERED ON SCHEDULE

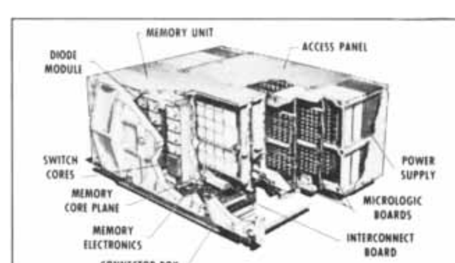
AC's highly qualified research, development and production team includes scientists, engineers, technicians, management and staff personnel. In addition, AC has two fully integrated research laboratories and modern production facilities with over 1½ million square feet of floor space. Result: Inertial guidance systems for MACE, THOR, TITAN II and III; a navigational-guidance system for project APOLLO; Bombing Navigational System Integration for the B-52C&D; a new stellar inertial guidance system for mobile missiles and spacecraft; precision inertial components for these products and computers for sea, land, air or space navigation. To take these people and facilities, and to develop these systems and capabilities required organization—AC organization.

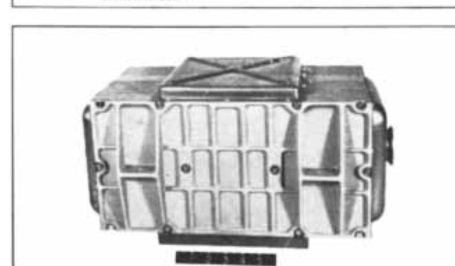
This same organization is available to you. Let us solve your navigation and guidance problems with our proven capability for low-cost development, best time to first flight with outstanding accuracy. Contact Director of Sales, AC-Milwaukee.

MASTER NAVIGATORS THROUGH TIME AND SPACE

AC SPARK PLUG • THE ELECTRONICS DIVISION OF GENERAL MOTORS
7929 South Howell, Milwaukee 1, Wisconsin

MAGIC—The first lightweight general purpose airborne digital computer to use molecular electronics—was introduced recently by AC. The function of the airborne computer is to handle computations and actuate vehicle controllers for guidance and control of the missile, space vehicle or aircraft. In a popular sense, the MAGIC computer serves as the brains of the total airborne guidance system.





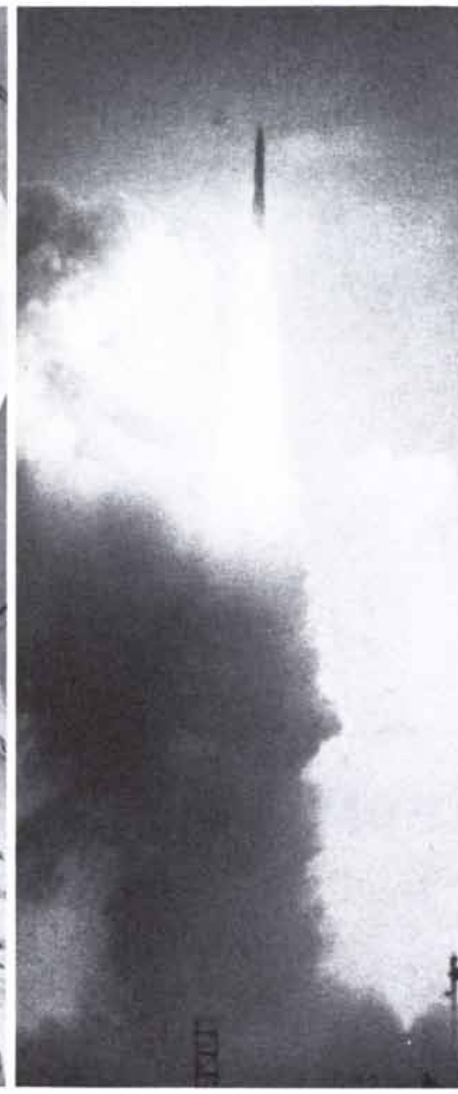
10
6
5
3.3
2
1.5
1

1 μs

we probed switching speed . . . developed the first practical 1 μ sec. memory system

Anticipating the demand for faster digital systems, IGC engineers developed terminal switching — a new, faster, method of memory core operation. Terminal switching techniques allow IGC to produce memory systems capable of a full read/write cycle in 1,000,000th of a second . . . and faster. Most important, IGC's new high speed memory systems utilize reliable, time-proved FERRAMIC® core elements. Result: Fast cycle speed is combined with very stable operation and high amplitude output signals. ■ IGC's new 1 μ sec. memory system is available with capacities in multiples of 2,048 words of 60 bits per word in all standard access modes. ■ **Magnetic Storage Systems Are Our Business** ■ In addition to our 1 μ sec. word organized memory system, IGC engineers have recently developed a 2 μ sec. coincident current memory system. ■ For information on all IGC memory systems, write to Indiana General Corporation, Electronic Division, Keasbey, N. J. Ask for brochure MS-1.

INDIANA GENERAL



MINUTEMAN, U.S. Air Force's solid-fuel ICBM, is now operational at Malmstrom AFB, Montana. Missiles, after assembly in a Boeing-operated plant, are delivered to sites and lowered into silos (above left and center), for link-up with support and launch-control equipment. Picture, right above, shows earlier test firing from Cape Canaveral. The Minuteman program, on which Boeing is weapon system integrator, has achieved success unprecedented in the history of intercontinental missiles, in terms of low-cost missile production, economical maintenance and operation, and ahead-of-schedule performance from drawing board to final installation.

Capability has many faces at Boeing

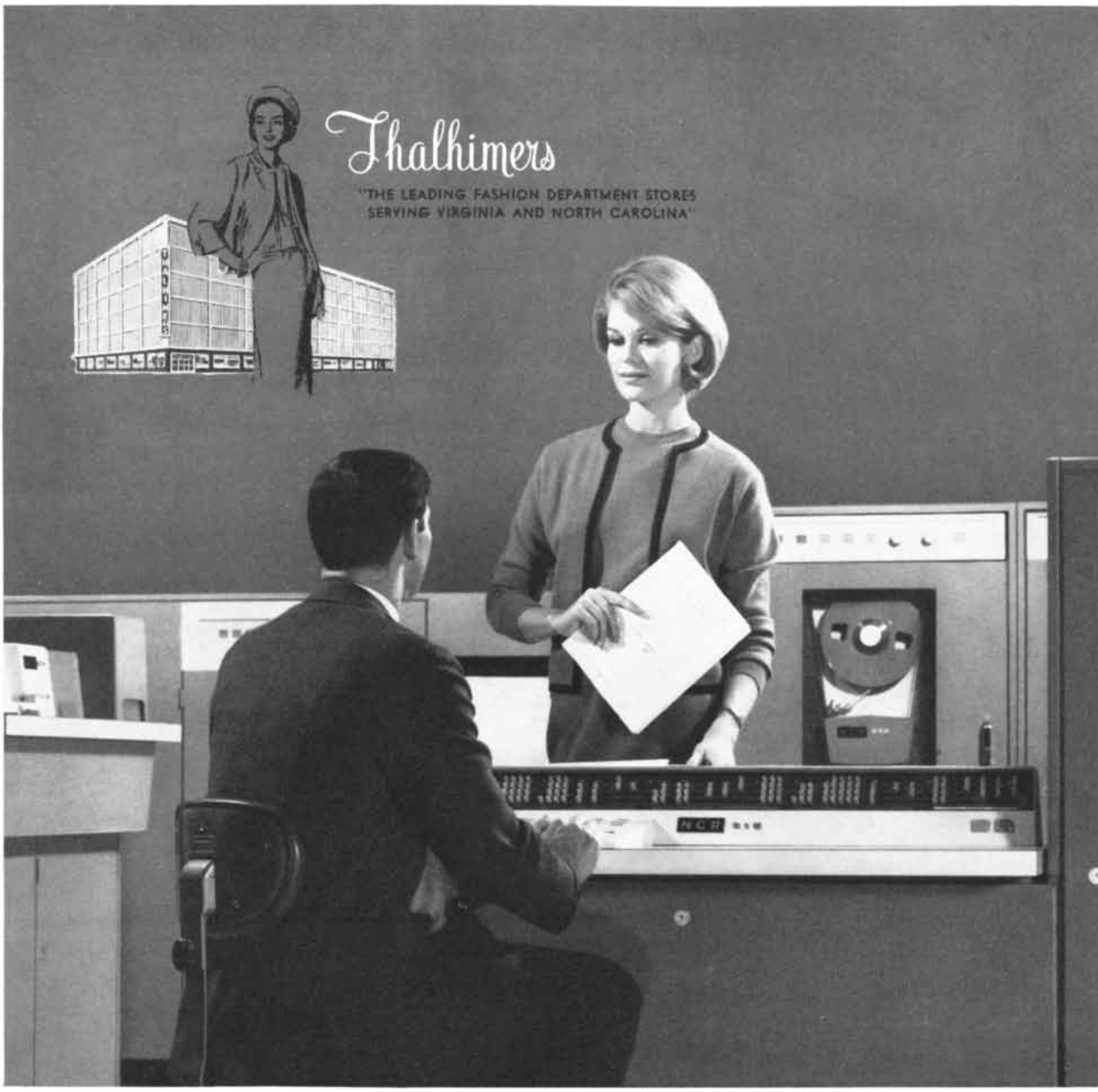
OPTICAL pyrometer, one of precision instruments in Boeing's new Metrology Laboratory devoted to space-age requirements for extreme accuracy of electrical, physical, mechanical measurements.

DASH, U. S. Navy's Drone Anti-Submarine Helicopter, operates by remote control from destroyers. Built by Gyrodyne Company of America, DASH is powered by Boeing gas turbine.

CARGO JET. Boeing -320C can carry 45 tons of cargo or 188 passengers. Ordered by American, Pan American and World Airways, -320C cargo jets offer lowest ton-mile costs of any transport.

BOEING

Space Technology • Missiles • Military Aircraft Systems • 707, 720 and 727 Jetliners • Systems Management • Helicopters • Marine Vehicles • Gas Turbine Engines • Also, Boeing Scientific Research Laboratories



"Why we chose the NCR 315 Computer."—THALHIMER BROTHERS, INC. Richmond, Va.

"Our interest in computers dates back to the early 1950's when we participated in an extensive computer research and testing project. Backed with this experience, we began a study to design our system, and this led to our choice of the NCR 315 Computer as the one best suited to our specific needs.

"Our 315 was delivered in May 1962 and we made the first customer billings for our Danville store one month later. Each month we added one or more stores to our computer system, and are now completely processing all the customer accounts for our 12 stores in Richmond and Danville, Virginia; Greensboro, Winston-Salem and Durham, North Carolina.

"Essentially, our choice of the NCR 315 stemmed from the fact that we have had a long association with NCR—they know the problems of retailing. With the 315, we were able to install just those pieces of equipment needed today, yet the system can be expanded as our future needs demand. And additionally, the 315 gives us a strong foundation upon which to grow and expand in the trading areas which we serve."

William B. Thalhimer, Jr.

William B. Thalhimer, Jr., President
Thalhimer Brothers, Inc.

NCR PROVIDES TOTAL SYSTEMS — FROM ORIGINAL ENTRY TO FINAL REPORT —
THROUGH ACCOUNTING MACHINES, CASH REGISTERS OR ADDING MACHINES, AND DATA PROCESSING
The National Cash Register Co.•1,133 offices in 120 countries • 79 years of helping business save money

NCR

THE AUTHORS

P. A. M. DIRAC ("The Evolution of the Physicist's Picture of Nature") is Lucasian Professor of Mathematics at the University of Cambridge. His article is based on a lecture given at the Conference on the Foundations of Quantum Mechanics, which took place at Xavier University in Cincinnati in October of last year. The editors especially wish to thank John B. Hart, chairman of the department of physics at Xavier University, for his assistance in preparing the article for publication. In 1928 Dirac proposed his theory of the electron, which led him to predict, three years later, the existence of an antiparticle of the electron. The antiparticle, or positron, was discovered in 1932 by C. D. Anderson of the California Institute of Technology. For this work Dirac shared (with the Austrian theoretical physicist Erwin Schrödinger) the 1933 Nobel prize for physics. He was elected Fellow of the Royal Society in 1930.

GERALD OSTER and YASUNORI NISHIJIMA ("Moiré Patterns") are respectively professor of polymer chemistry at the Polytechnic Institute of Brooklyn and lecturer in polymer chemistry at Kyoto University in Japan. Oster and Nishijima have worked in close collaboration since 1953, when Nishijima, then a graduate student from Kyoto University, began working in Oster's laboratory. Their interest in the visual phenomena known as moiré patterns first arose in the course of research on the development of a microscopic apparatus for measuring the diffusion rates of minute particles in liquids. This interest was greatly increased by their viewing, through bamboo screens, a moonrise over Higashiyama, a mountain in the vicinity of Kyoto. Both Oster and Nishijima commute frequently between Brooklyn and Kyoto. Oster received a Ph.D. in physical chemistry from Cornell University in 1943. He went to the Polytechnic Institute of Brooklyn in 1951, having done research at institutions here and abroad, including the Rockefeller Institute and Birkbeck College of the University of London. Nishijima has a Ph.D. in chemistry from Kyoto University.

CHRISTIAN DE DUVE ("The Lysosome") is professor and head of the department of physiological chemistry at the Catholic University of Louvain in Belgium. He is also professor at the Rockefeller Institute, where he recently founded a new laboratory. De Duve received an M.D. from Louvain in 1941 and an advanced degree in chemistry in 1946. For the next 18 months, in the laboratory of the Nobel laureate Hugo Theorell at the Nobel Institute in Stockholm, de Duve did research on the muscle protein myoglobin. He worked for six months with another Nobel prize winner, Carl F. Cori, at Washington University in St. Louis, on a pancreatic hormone. De Duve was appointed to his present post at Louvain in 1947; his association with the Rockefeller Institute began in January of last year.

BRIAN J. O'BRIEN ("Radiation Belts") is associate professor in the department of physics and astronomy at the State University of Iowa. O'Brien was born in Sydney, Australia, in 1934. At the University of Sydney he did doctoral research on the composition of primary cosmic radiation, acquiring a Ph.D. in physics in 1957. After a period as deputy chief physicist of the Australian National Antarctic Research Expeditions, during which he carried out studies of the phenomenon known as the airglow, O'Brien went to the State University of Iowa in 1959. There he has served as scientist-in-charge of the three Injun satellites, which were chiefly designed to perform radiation measurements of the type discussed in his article. Next month O'Brien will join the faculty of Rice University in Houston, Tex., as Professor of Space Sciences.

EDWARD O. WILSON ("Pheromones") is associate professor of zoology at Harvard University. As a native of Alabama, Wilson fairly early in life became acquainted with the Southern agricultural pest known as the fire ant, which he discussed in an article for SCIENTIFIC AMERICAN ("The Fire Ant," March, 1958). Wilson received B.S. and M.S. degrees from the University of Alabama in 1949 and 1950. He took a Ph.D. in biology at Harvard, where he held a National Science Foundation fellowship and a junior fellowship in the Society of Fellows. He joined the Harvard faculty in 1956.

WILLIAM J. MAYER-OAKES ("Early Man in the Andes") is professor of anthropology and head of the department of anthropology and sociology at the University of Manitoba in Winnipeg, Canada. American by birth and education, Mayer-Oakes attended the University of Chicago, receiving an A.M. in 1949 and a Ph.D. in 1954. (As a Chicago

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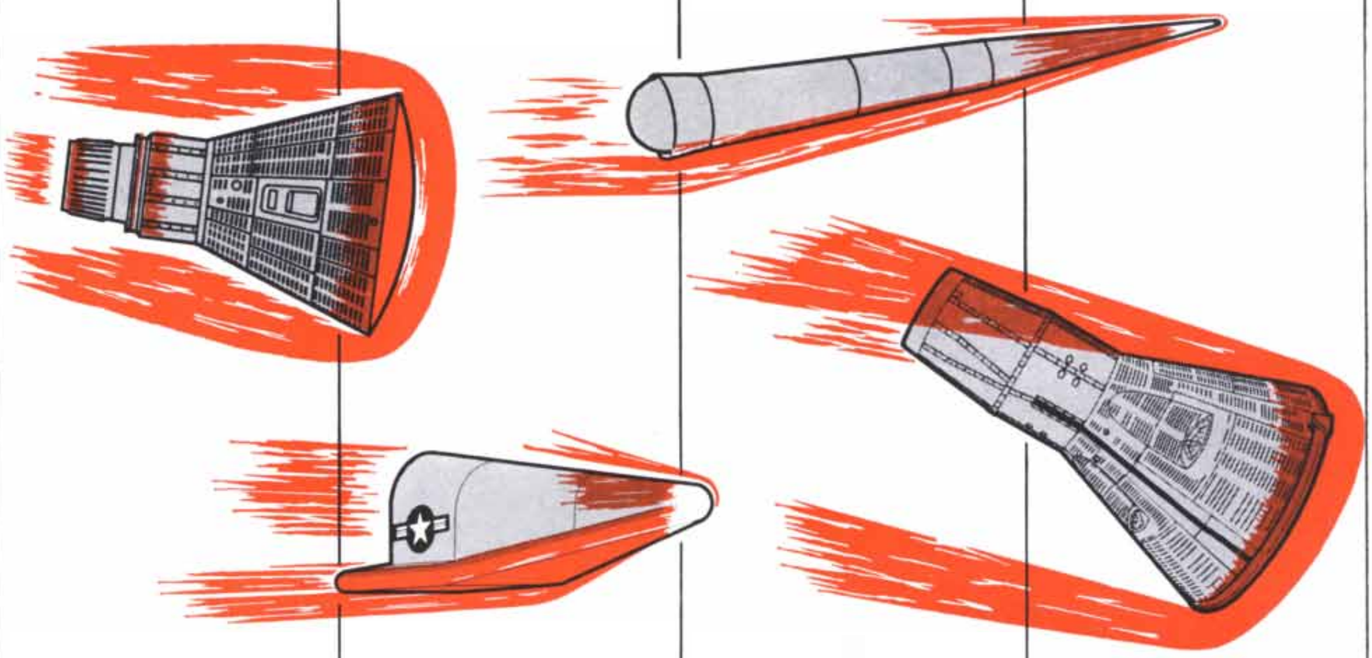

MERCURY, America's first manned orbital spacecraft, utilizes a non-maneuverable ballistic reentry. After retro-rockets slow the spacecraft to bring it out of orbit, reaction jets position it for reentry. Mercury's ballistic shape maintains alignment with the drag vector as it follows a ballistic path through the atmosphere to drogue chute deployment at 21,000 feet. Final descent to an ocean landing is accomplished with a 63-foot ring-sail parachute.

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FIRST FREE MAN IN SPACE TRADEMARK

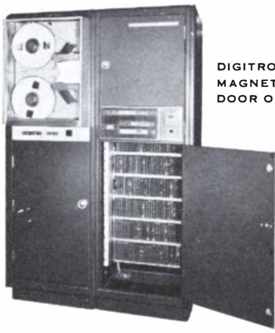
ST. LOUIS

freshman Mayer-Oakes ran the mile in 4:28, winning the Big Ten freshman championship.) From 1950 to 1956 he was chief field archaeologist and director of the Upper Ohio Archeological Survey for the Carnegie Museum in Pittsburgh. While at the Carnegie Museum he also initiated several excavations in central Mexico, and he continued the work as a member of the anthropology department at the University of Toronto from 1956 to 1959. He spent the next three years at the University of Oklahoma, where he was director of the University Museum of Natural History. During this period Mayer-Oakes began the work at El Inga (an archaeological site in Ecuador) that he describes in his article. He went to the University of Manitoba in 1962.

H. J. EYSENCK ("The Measurement of Motivation") is professor of psychology at the Institute of Psychiatry of the University of London, where he directs the Psychological Department of Maudsley Hospital, the main hospital for teaching and training psychiatrists in England. Born in Berlin, Eysenck left Germany in 1934 and studied for a time at the University of Dijon in France and at the University of Exeter in England. He subsequently studied psychology at the University of London, obtaining a B.A. and Ph.D. in 1940 and 1942. Maudsley Hospital had become the Mill Hill Emergency Hospital for the duration of the war, and Eysenck worked there as a research psychologist. Later, when the Institute of Psychiatry was founded as part of the University of London Post Graduate Medical School, he was asked to form a department of psychology.

CHARLES F. HICKLING ("The Cultivation of Tilapia"), now retired, was Fisheries Adviser to the Secretary of State for the Colonies from 1945 to 1961. Before that he had served in the British Ministry of Agriculture and Fisheries since 1927. Hickling, who holds a B.A. and an Sc.D. from the University of Cambridge, was acting director of the Tropical Fish Culture Research Institute in Malacca, Federation of Malaya. Last month Hickling returned to Malacca on a two-year grant from the Nuffield Foundation to do research on fish cultivation.

JOHN PASSMORE, who in this issue reviews *The Career of Philosophy: From the Middle Ages to the Enlightenment*, by John Herman Randall, Jr., is professor of philosophy at the Australian National University in Canberra.



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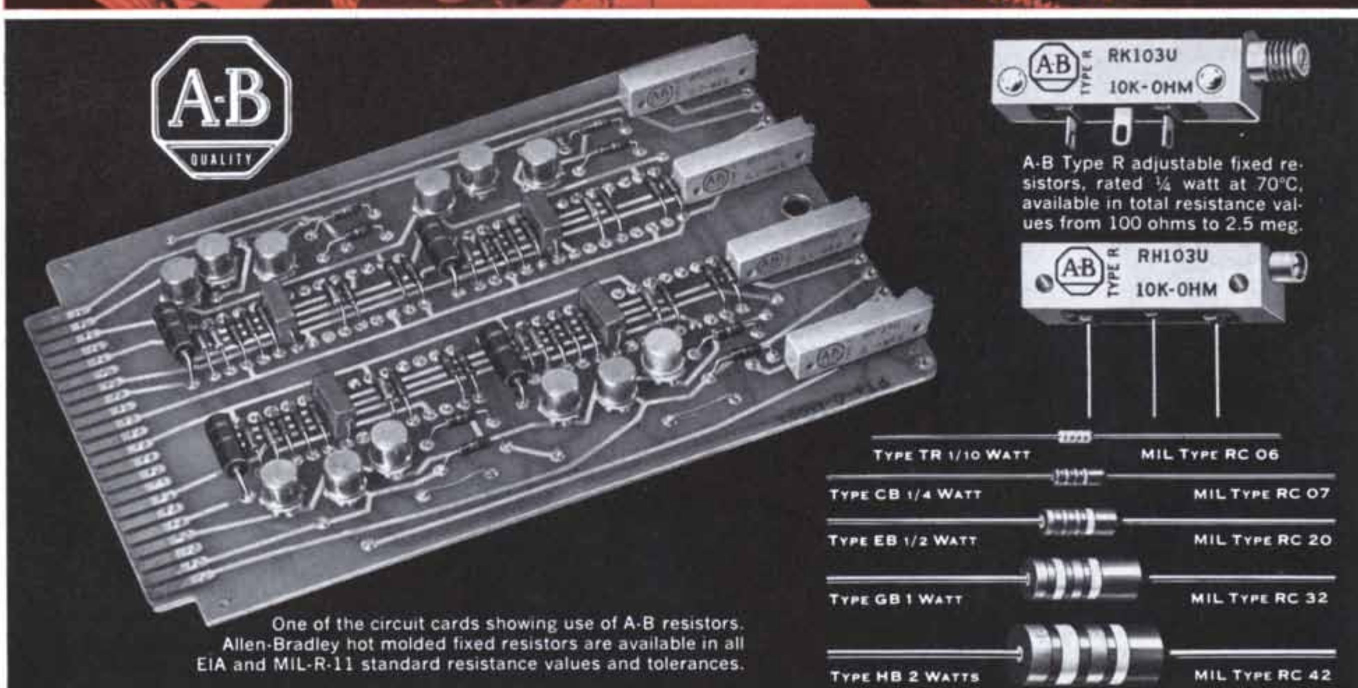

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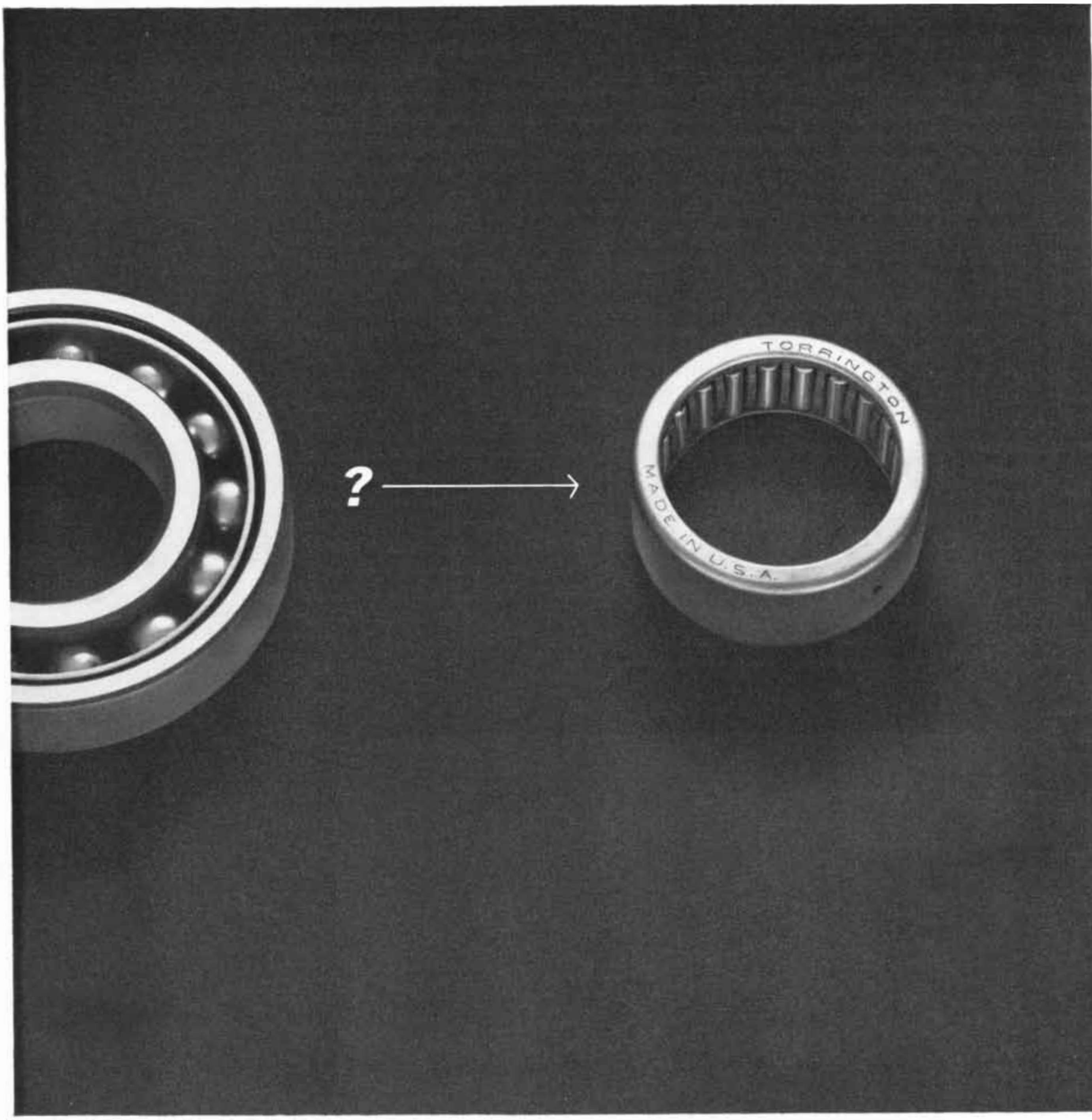

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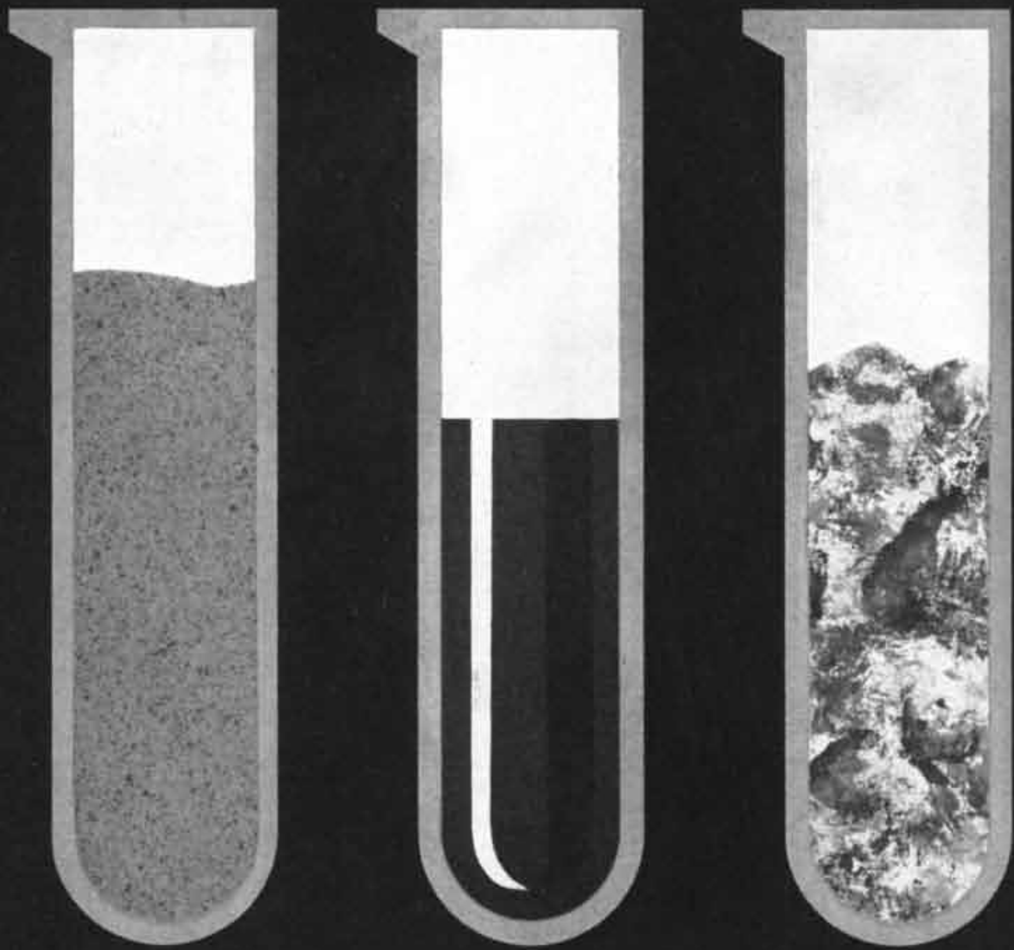

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The Evolution of the Physicist's Picture of Nature

An account of how physical theory has developed in the past and how, in the light of this development, it can perhaps be expected to develop in the future

by P. A. M. Dirac

In this article I should like to discuss the development of general physical theory: how it developed in the past and how one may expect it to develop in the future. One can look on this continual development as a process of evolution, a process that has been going on for several centuries.

The first main step in this process of evolution was brought about by Newton. Before Newton, people looked on the world as being essentially two-dimensional—the two dimensions in which one can walk about—and the up-and-down dimension seemed to be something essentially different. Newton showed how one can look on the up-and-down direction as being symmetrical with the other two directions, by bringing in gravitational forces and showing how they take their place in physical theory. One can say that Newton enabled us to pass from a picture with two-dimensional symmetry to a picture with three-dimensional symmetry.

Einstein made another step in the same direction, showing how one can pass from a picture with three-dimensional symmetry to a picture with four-dimensional symmetry. Einstein brought in time and showed how it plays a role that is in many ways symmetrical with the three space dimensions. However, this symmetry is not quite perfect. With Einstein's picture one is led to think of the world from a four-dimensional point of view, but the four dimensions are not completely symmetrical. There are some directions in the four-dimensional picture that are different from others: directions that are called null directions, along which a ray of light can move; hence the four-dimensional picture is not completely symmetrical. Still, there is a great deal of symmetry among the four dimensions. The only lack of symmetry, so far as concerns the equations of physics, is in the appearance of a minus sign in the equations with respect to the time dimension as compared with the three space dimensions [*see top equation on page 50*].

We have, then, the development from the three-dimensional picture of the world to the four-dimensional picture. The reader will probably not be happy with this situation, because the world still appears three-dimensional to his consciousness. How can one bring this appearance into the four-dimensional picture that Einstein requires the physicist to have?

What appears to our consciousness is really a three-dimensional section of the four-dimensional picture. We must take a three-dimensional section to give us what appears to our consciousness at one time; at a later time we shall have a different three-dimensional section. The task of the physicist consists largely of relating events in one of these sections to events in another section referring to a later time. Thus the picture with four-dimensional symmetry does not give us the whole situation. This becomes particularly important when one takes into account the developments that have been brought about by quantum theory. Quantum theory has taught us that we have to take the process of observation into account, and observations usually require us to bring in the three-dimensional sections of the four-dimensional picture of the universe.

The special theory of relativity, which Einstein introduced, requires us to put all the laws of physics into a form that displays four-dimensional symmetry. But when we use these laws to get results about observations, we have to bring in something additional to the four-dimensional symmetry, namely the three-dimensional sections that describe our consciousness of the universe at a certain time.

Einstein made another most important contribution to the development of our physical picture: he put forward the general theory of relativity, which requires us to suppose that the space of physics is curved. Before this physicists had always worked with a flat space, the three-dimensional flat space of Newton which was then extended to the four-dimensional flat space of special relativity. General relativity made a really important contribution to the evolution of our physical picture by requiring us to go over to curved space. The general requirements of this theory mean that all the laws of physics can be formulated in curved four-dimensional space, and that they show symmetry among the four dimensions. But again, when we want to bring in observations, as we must if we look at things from the point of view of quantum theory, we have to refer to a section of this four-dimensional space. With the four-dimensional space curved, any section that we make in it also has to be curved, because in general we cannot give a meaning to a flat section in a curved space. This leads us to a picture in which we have to take curved three-dimensional sections in the curved four-dimensional space and discuss observations in these sections.

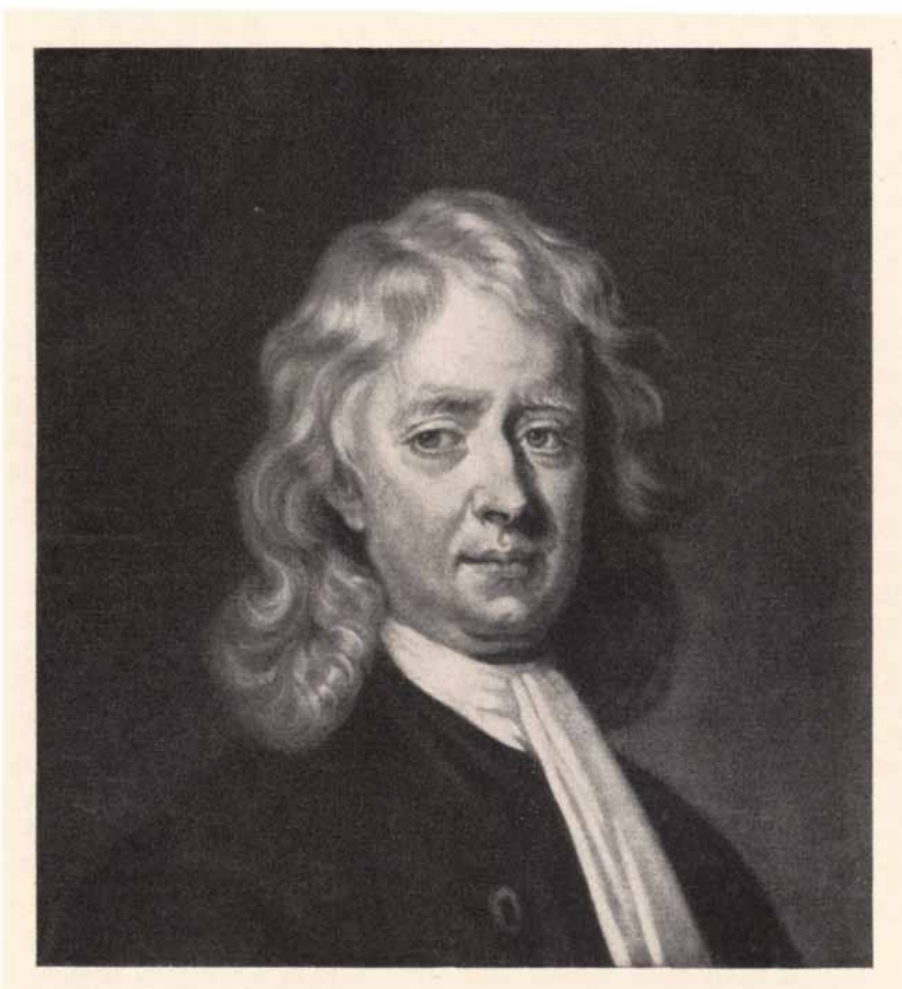
During the past few years people have been trying to apply quantum ideas to gravitation as well as to the other phenomena of physics, and this has led to a rather unexpected development, namely that when one looks at gravitational theory from the point of view of the sections, one finds that there are some degrees of freedom that drop out of the theory. The gravitational field is a tensor field with 10 components. One finds that six of the components are adequate for describing everything of physical importance and the other four can be dropped out of the equations. One cannot, however, pick out the six important components from the complete set of 10 in any way that does not destroy the four-dimensional symmetry. Thus if one insists on preserving four-dimensional symmetry in the equations, one cannot adapt the theory of gravitation to a discussion of measurements in the way quantum theory requires without being forced to a more complicated description than is needed by the physical situation. This result has led me to doubt how fundamental the four-dimensional requirement in physics is. A few decades ago it seemed quite certain that one had to express the whole of physics in four-dimensional form. But now it seems that four-dimensional symmetry is not of such overriding importance, since the description of nature sometimes gets simplified when one departs from it.

Now I should like to proceed to the developments that have been brought about by quantum theory. Quantum theory is the discussion of very small things, and it has formed the main subject of physics for the past 60 years. During this period physicists have been amassing quite a lot of experimental information and developing a theory to correspond to it, and this combination of theory and experiment has led to important developments in the physicist's picture of the world.

The quantum first made its appearance when Planck discovered the need to suppose that the energy of electromagnetic waves can exist only in multiples of a certain unit, depending on the frequency of the waves, in order to explain the law of black-body radiation. Then Einstein discovered the same unit of energy occurring in the photoelectric effect. In this early work on quantum theory one simply had to accept the unit of energy without being able to incorporate it into a physical picture.

The first new picture that appeared was Bohr's picture of the atom. It was a picture in which we had electrons moving about in certain well-defined orbits and occasionally making a jump from one orbit to another. We could not picture how the jump took place. We just had to accept it as a kind of discontinuity. Bohr's picture of the atom worked only for special examples, essentially when there was only one electron that was of importance for the problem under consideration. Thus the picture was an incomplete and primitive one.

The big advance in the quantum theory came in 1925, with the discovery of quantum mechanics. This advance was brought about independently by two men, Heisenberg first and Schrödinger soon afterward, working from different points of view. Heisenberg worked keeping close to the experimental evidence about spectra that was being amassed at that time, and he found out how the experimental information could be fitted into a scheme that is now known as matrix mechanics. All the experimental data of spectroscopy fitted beautifully into the scheme of matrix mechanics, and this led to quite a different picture of the atomic world. Schrödinger worked from a more mathematical point of view, trying to find a beautiful theory for describ-



ISAAC NEWTON (1642–1727), with his law of gravitation, changed the physicist's picture of nature from one with two-dimensional symmetry to one with three-dimensional symmetry. This drawing of him was made in 1760 by James Macardel from a painting by Enoch Seeman.

ing atomic events, and was helped by De Broglie's ideas of waves associated with particles. He was able to extend De Broglie's ideas and to get a very beautiful equation, known as Schrödinger's wave equation, for describing atomic processes. Schrödinger got this equation by pure thought, looking for some beautiful generalization of De Broglie's ideas, and not by keeping close to the experimental development of the subject in the way Heisenberg did.

I might tell you the story I heard from Schrödinger of how, when he first got the idea for this equation, he immediately applied it to the behavior of the electron in the hydrogen atom, and then he got results that did not agree with experiment. The disagreement arose because at that time it was not known that the electron has a spin. That, of course, was a great disappointment to Schrödinger, and it caused him to abandon the work for some months. Then he noticed that if he applied the theory in a more approximate way, not taking into account the refinements required by relativity, to this rough approximation his work was in agreement with observation. He published his first paper with only this rough approximation, and in that way Schrödinger's wave equation was presented to the world. Afterward, of course, when people found out how to take into account correctly the spin of the electron, the discrepancy between the results of applying Schrödinger's relativistic equation and the experiments was completely cleared up.

I think there is a moral to this story, namely that it is more important to have beauty in one's equations than to have them fit experiment. If Schrödinger had been more confident of his work, he could have published it some months earlier, and he could have published a more accurate equation. That equation is now known as the Klein-Gordon equation, although it was really discovered by Schrödinger, and in fact was discovered by Schrödinger before he discovered his nonrelativistic treatment of the hydrogen atom. It seems that if one is working from the point of view of getting beauty in one's equations, and if one has really a sound insight, one is on a sure line of progress. If there is not complete agreement between the results of one's work and experiment, one should not allow oneself to be too discouraged, because the discrepancy may well be due to minor features that are not properly taken into account and that will get cleared up with further developments of the theory.

ALBERT EINSTEIN (1879–1955), **with his special theory of relativity, changed the physicist's picture from one with three-dimensional symmetry to one with four-dimensional symmetry. This photograph of him and his wife and their daughter Margot was made in 1929.**

That is how quantum mechanics was discovered. It led to a drastic change in the physicist's picture of the world, perhaps the biggest that has yet taken place. This change comes from our having to give up the deterministic picture we had always taken for granted. We are led to a theory that does not predict with certainty what is going to happen in the future but gives us information only about the probability of occurrence of various events. This giving up of determinacy has been a very controversial subject, and some people do not like it at all. Einstein in particular never liked it. Although Einstein was one of the great contributors to the development of quantum mechanics, he still was always rather hostile to the form that quantum mechanics evolved into during his lifetime and that it still retains.

The hostility some people have to the giving up of the deterministic picture can be centered on a much discussed paper by Einstein, Podolsky and Rosen dealing with the difficulty one has in forming a consistent picture that still gives results according to the rules of quantum mechanics. The rules of quantum mechanics are quite definite. People

NIELS BOHR (1885–1962) **introduced the idea that the electron moved about the nucleus in well-defined orbits. This photograph was made in 1922, nine years after the publication of his paper.**

MAX PLANCK (1858–1947) **introduced the idea that electromagnetic radiation consists of quanta, or particles. This photograph was made in 1913, 13 years after his original paper was published.**

know how to calculate results and how to compare the results of their calculations with experiment. Everyone is agreed on the formalism. It works so well that nobody can afford to disagree with it. But still the picture that we are to set up behind this formalism is a subject of controversy.

I should like to suggest that one not worry too much about this controversy. I feel very strongly that the stage physics has reached at the present day is not the final stage. It is just one stage in the evolution of our picture of nature, and we should expect this process of evolution to continue in the future, as biological evolution continues into the future. The present stage of physical theory is merely a steppingstone toward the better stages we shall have in the future. One can be quite sure that there will be better stages simply because of the difficulties that occur in the physics of today.

I should now like to dwell a bit on the difficulties in the physics of the present day. The reader who is not an expert in the subject might get the idea that because of all these difficulties physical theory is in pretty poor shape and that the quantum theory is not much good. I should like to correct this impression by saying that quantum theory is an extremely good theory. It gives wonderful agreement with observation over a wide range of phenomena. There is no doubt that it is a good theory, and the only reason physicists talk so much about the difficulties in it is that it is precisely the difficulties that are interesting. The successes of the theory are all taken for granted. One does not get anywhere simply by going over the successes again and again, whereas by talking over the difficulties people can hope to make some progress.

The difficulties in quantum theory are of two kinds. I might call them Class One difficulties and Class Two difficulties. Class One difficulties are the difficulties I have already mentioned: How can one form a consistent picture behind the rules for the present quantum theory? These Class One difficulties do not really worry the physicist. If the physicist knows how to calculate results and compare them with experiment, he is quite happy if the results agree with his experiments, and that is all he needs. It is only the philosopher, wanting to have a satisfying description of nature, who is bothered by Class One difficulties.

There are, in addition to the Class One difficulties, the Class Two difficulties, which stem from the fact that the present laws of quantum theory are not always adequate to give any results. If one pushes the laws to extreme conditions—to phenomena involving very high energies or very small distances—one sometimes gets results that are ambiguous or not really sensible at all. Then it is clear that one has reached the limits of application of the theory and that some further development is needed. The Class Two difficulties are important even for the physicist, because they put a limitation on how far he can use the rules of quantum theory to get results comparable with experiment.

I should like to say a little more about the Class One difficulties. I feel that one should not be bothered with them too much, because they are difficulties that refer to the present stage in the development of our physical picture and are almost certain to change with future development. There is one strong reason, I think, why one can be quite confident that these difficulties will change. There are some fundamental constants in nature: the charge on the electron (designated e), Planck's constant divided by 2π (designated $\hbar$) and the velocity of light (c). From these fundamental constants one can construct a number that has no dimensions: the number $\hbar c/e^2$. That number is found by experiment to have the value 137, or something very close to 137. Now, there is no known reason why it should have this value rather than some other number. Various people have put forward ideas about it, but there is no accepted theory. Still, one can be fairly sure that someday physicists will solve the problem and explain why the number has this value. There will be a physics in the future that works when $\hbar c/e^2$ has the value 137 and that will not work when it has any other value.

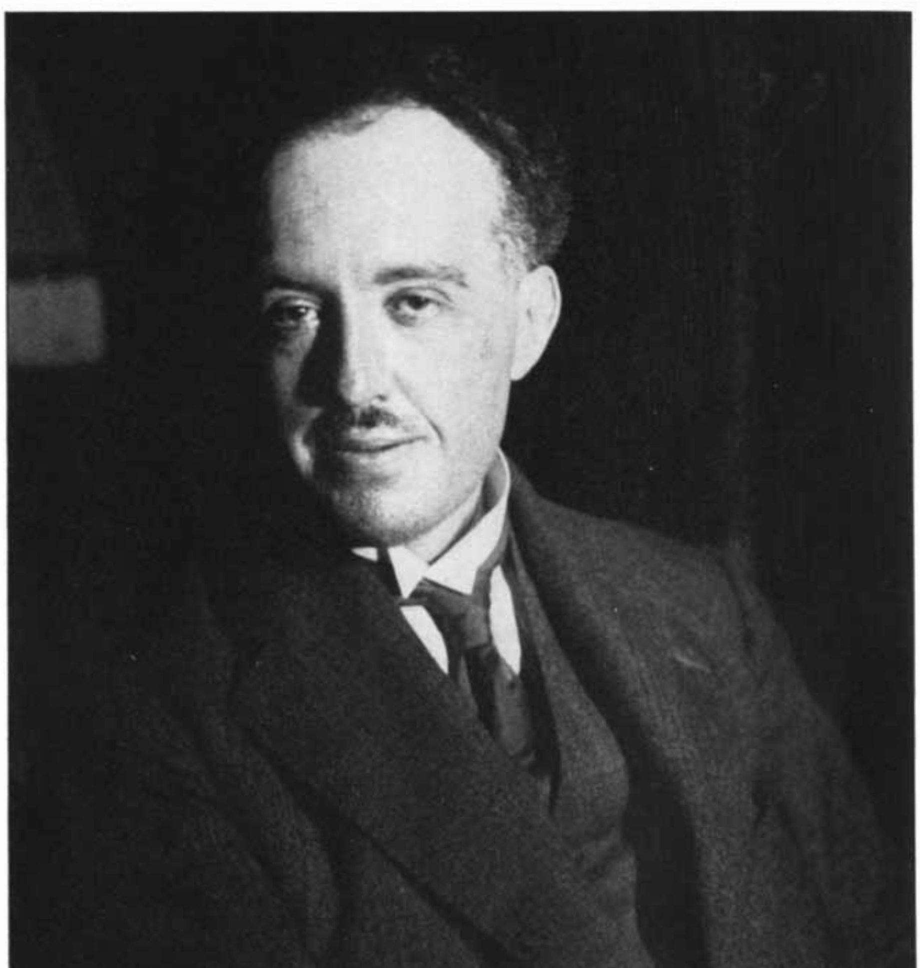
The physics of the future, of course, cannot have the three quantities $\hbar$, e and c all as fundamental quantities. Only two of them can be fundamental, and the third must be derived from those two. It is almost certain that c will be one of the two fundamental ones. The velocity of light, c, is so important in the four-dimensional picture, and it plays such a fundamental role in the special theory of relativity, correlating our units of space and time, that it has to be fundamental. Then we are faced with the fact that of the two quantities $\hbar$ and e, one will be fundamental and one will be derived. If $\hbar$ is fundamental, e will have to be explained in some way in terms of the square root of $\hbar$, and it seems most unlikely that any fundamental theory can give e in terms of a square root, since square roots do not occur in basic equations. It is much more likely that e will be the fundamental quantity and that $\hbar$ will be explained in terms of e^2. Then there will be no square root in the basic equations. I think one is on safe ground if one makes the guess that in the physical picture we shall have at some future stage e and c will be fundamental quantities and $\hbar$ will be derived.

If $\hbar$ is a derived quantity instead of a fundamental one, our whole set of ideas about uncertainty will be altered: $\hbar$ is the fundamental quantity that occurs in the Heisenberg uncertainty relation connecting the amount of uncertainty in a position and in a momentum. This uncertainty relation cannot play a fundamental role in a theory in which $\hbar$ itself is not a fundamental quantity. I think one can make a safe guess that uncertainty relations in their present form will not survive in the physics of the future.

Of course there will not be a return to the determinism of classical physical theory. Evolution does not go backward. It will have to go forward. There will have to be some new development that is quite unexpected, that we cannot make a guess about, which will take us still further from classical ideas but which will alter completely the discussion of uncertainty relations. And when this new development occurs, people will find it all rather futile to have had so much of a discussion on the role of observation in the theory, because they will have then a much better point of view from which to look at things. So I shall say that if we can find a way to describe the uncertainty relations and the indeterminacy of present quantum mechanics that is satisfying to our philosophical ideas, we can count ourselves lucky. But if we cannot find such a way, it is nothing to be really disturbed about. We simply have to take into account that we are at a transitional stage and that perhaps it is quite impossible to get a satisfactory picture for this stage.

I have disposed of the Class One difficulties by saying that they are really not so important, that if one can make progress with them one can count oneself lucky, and that if one cannot it is nothing to be genuinely disturbed about. The Class Two difficulties are the really serious ones. They arise primarily from the fact that when we apply our quantum theory to fields in the way we have to if we are to make it agree with special relativity, interpreting it in terms of the three-dimensional sections I have mentioned, we have equations that at first look all right. But when one tries to solve them, one finds that they do not have any solutions. At this point we ought to say that we do not have a theory. But physicists are very ingenious about it, and they have found a way to make progress in spite of this obstacle. They find that when they try to solve the equations, the trouble is that certain quantities that ought to be finite are actually infinite. One gets integrals that diverge instead of converging to something definite. Physicists have found that there is a way to handle these infinities according to certain rules, which makes it possible to get definite results. This method is known as the renormalization method.

I shall merely explain the idea in words. We start out with a theory involving equations. In these equations there occur certain parameters: the charge of the electron, e, the mass of the electron, m, and things of a similar nature. One then finds that these quantities, which appear in the original equations, are not equal to the measured values of the charge and the mass of the electron. The measured values differ from these by certain correcting terms—Δe, Δm and so on—so that the total charge is $e + \Delta e$ and the total mass $m + \Delta m$. These changes in charge and mass are brought about through the interaction of our elementary particle with other things. Then one says that $e + \Delta e$ and $m + \Delta m$, being the observed things, are the important things. The original e and m are just mathematical parameters; they are unobservable and therefore just tools one can discard when one has got far enough to bring in the things that one can com-



LOUIS DE BROGLIE (1892–) put forward the idea that particles are associated with waves. This photograph was made in 1929, five years after the appearance of his paper.

pare with observation. This would be a quite correct way to proceed if Δe and Δm were small (or even if they were not so small but finite) corrections. According to the actual theory, however, Δe and Δm are infinitely great. In spite of that fact one can still use the formalism and get results in terms of $e + \Delta e$ and $m + \Delta m$, which one can interpret by saying that the original e and m have to be minus infinity of a suitable amount to compensate for the Δe and Δm that are infinitely great. One can use the theory to get results that can be compared with experiment, in particular for electrodynamics. The surprising thing is that in the case of electrodynamics one gets results that are in extremely good agreement with experiment. The agreement applies to many significant figures—the kind of accuracy that previously one had only in astronomy. It is because of this good agreement that physicists do attach some value to the renormalization theory, in spite of its illogical character.

It seems to be quite impossible to put this theory on a mathematically sound basis. At one time physical theory was all built on mathematics that was inherently sound. I do not say that physicists always use sound mathematics; they often use unsound steps in their calculations. But previously when they did so it was simply because of, one might say, laziness. They wanted to get results as quickly as possible without doing unnecessary work. It was always possible for the pure mathematician to come along and make the theory sound by bringing in further steps, and perhaps by introducing quite a lot of cumbersome notation and other things that are desirable from a mathematical point of view in order to get everything expressed rigorously but do not contribute to the physical ideas. The earlier mathematics could always be made sound in that way, but in the renormalization theory we have a theory that has defied all the attempts of the mathematician to make it sound. I am inclined to suspect that the renormalization theory is something that will not survive in the future, and that the remarkable agreement between its results and experiment should be looked on as a fluke.

This is perhaps not altogether surprising, because there have been similar flukes in the past. In fact, Bohr's electron-orbit theory was found to give very good agreement with observation as long as one confined oneself to one-electron problems. I think people will now say that this agreement was a fluke, because the basic ideas of Bohr's orbit theory have been superseded by something radically different. I believe the successes of the renormalization theory will be on the same footing as the successes of the Bohr orbit theory applied to one-electron problems.

The renormalization theory has removed some of these Class Two difficulties, if one can accept the illogical character of discarding infinities, but it does not remove all of them. There are a good many problems left over concerning particles other than those that come into electrodynamics: the new particles—mesons of various kinds and neutrinos. There the theory is still in a primitive stage. It is fairly certain that there will have to be drastic changes in our fundamental ideas before these problems can be solved.

One of the problems is the one I have already mentioned about accounting for the number 137. Other problems are how to introduce the fundamental length to physics in some natural way, how to explain the ratios of the masses of the elementary particles and how to explain their other properties. I believe separate ideas will be needed to solve these distinct problems and that they will be solved one at a time through successive stages in the future evolution of physics. At this point I find myself in disagreement with most physicists. They are inclined to think one master idea will be discovered that will solve all these problems together. I think it is asking too much to hope that anyone will be able to solve all these problems together. One should separate them one from another as much as possible and try to tackle them separately. And I believe the future development of physics will consist of solving them one at a time, and that after any one of them has been solved there will still be a great mystery about how to attack further ones.

I might perhaps discuss some ideas I have had about how one can possibly attack some of these problems. None of these ideas has been worked out very far, and I do not have much hope for any one of them. But I think they are worth mentioning briefly.

One of these ideas is to introduce something corresponding to the luminiferous ether, which was so popular among the physicists of the 19th century. I said earlier that physics does not evolve back-

$$ds^2 = c^2dt^2 - dx^2 - dy^2 - dz^2$$

FOUR-DIMENSIONAL SYMMETRY introduced by the special theory of relativity is not quite perfect. This equation is the expression for the invariant distance in four-dimensional space-time. The symbol *s* is the invariant distance; *c*, the speed of light; *t*, time; *x*, *y* and *z*, the three spatial dimensions. The *d*'s are differentials. The lack of complete symmetry lies in the fact that the contribution from the time direction (c^2dt^2) does not have the same sign as the contributions from the three spatial directions ($-dx^2$, $-dy^2$ and $-dz^2$).

$$\left(\frac{ih}{2\pi c}\frac{\partial}{\partial t} + \frac{e^2}{cr}\right)^2 \psi = \left[m^2c^2 - \frac{h^2}{4\pi^2}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)\right]\psi$$

SCHRÖDINGER'S FIRST WAVE EQUATION did not fit experimental results because it did not take into account the spin of the electron, which was not known at the time. The equation is a generalization of De Broglie's equation for the motion of a free electron. The symbol *e* represents the charge on the electron; *i*, the square root of minus one; *h*, Planck's constant; *r*, the distance from the nucleus; ψ, Schrödinger's wave function; *m*, the mass of the electron. The symbols resembling sixes turned backward are partial derivatives.

$$\left(E + \frac{e^2}{r}\right)\psi = -\frac{h^2}{8\pi^2 m}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)\psi$$

SCHRÖDINGER'S SECOND WAVE EQUATION is an approximation to the original equation, which does not take into account the refinements that are required by relativity.

ward. When I talk about reintroducing the ether, I do not mean to go back to the picture of the ether that one had in the 19th century, but I do mean to introduce a new picture of the ether that will conform to our present ideas of quantum theory. The objection to the old idea of the ether was that if you suppose it to be a fluid filling up the whole of space, in any place it has a definite velocity, which destroys the four-dimensional symmetry required by Einstein's special principle of relativity. Einstein's special relativity killed this idea of the ether.

But with our present quantum theory we no longer have to attach a definite velocity to any given physical thing, because the velocity is subject to uncertainty relations. The smaller the mass of the thing we are interested in, the more important are the uncertainty relations. Now, the ether will certainly have very little mass, so that uncertainty relations for it will be extremely important. The velocity of the ether at some particular place should therefore not be pictured as definite, because it will be subject to uncertainty relations and so may be anything over a wide range of values. In that way one can get over the difficulties of reconciling the existence of an ether with the special theory of relativity.

There is one important change this will make in our picture of a vacuum. We would like to think of a vacuum as a region in which we have complete symmetry between the four dimensions of space-time as required by special relativity. If there is an ether subject to uncertainty relations, it will not be possible to have this symmetry accurately. We can suppose that the velocity of the ether is equally likely to be anything within a wide range of values that would give the symmetry only approximately. We cannot in any precise way proceed to the limit of allowing all values for the velocity between plus and minus the velocity of light, which we would have to do in order to make the symmetry accurate. Thus the vacuum becomes a state that is unattainable. I do not think that this is a physical objection to the theory. It would mean that the vacuum is a state we can approach very closely. There is no limit as to how closely we can approach it, but we can never attain it. I believe that would be quite satisfactory to the experimental physicist. It would, however, mean a departure from the notion of the vacuum that we have in the quantum theory, where we start off with the vacuum state having exactly the symmetry required by special relativity.

ERWIN SCHRÖDINGER (1887–1961) devised his wave equation by extending De Broglie's idea that waves are associated with particles to the electrons moving around the nucleus. This photograph was made in 1929, four years after he had published his second equation.

That is one idea for the development of physics in the future that would change our picture of the vacuum, but change it in a way that is not unacceptable to the experimental physicist. It has proved difficult to continue with the theory, because one would need to set up mathematically the uncertainty relations for the ether and so far some satisfactory theory along these lines has not been discovered. If it could be developed satisfactorily, it would give rise to a new kind of field in physical theory, which might help in explaining some of the elementary particles.

Another possible picture I should like to mention concerns the question of why all the electric charges that are observed in nature should be multiples of one elementary unit, *e*. Why does one not have a continuous distribution of charge occurring in nature? The picture I propose goes back to the idea of Faraday lines of force and involves a development of this idea. The Faraday lines of force are a way of picturing electric fields. If we have an electric field in any region of space, then according to Faraday we can draw a set of lines that have the direction of the electric field. The closeness of the lines to one another gives a measure of the strength of the field—they are close where the field is strong and less close where the field is weak. The Faraday lines of force give us a good picture of the electric field in classical theory.

When we go over to quantum theory, we bring a kind of discreteness into our basic picture. We can suppose that the continuous distribution of Faraday lines of force that we have in the classical picture is replaced by just a few discrete lines of force with no lines of force between them.

Now, the lines of force in the Faraday picture end where there are charges. Therefore with these quantized Faraday lines of force it would be reasonable to suppose the charge associated with each line, which has to lie at the end if the line of force has an end, is always the same (apart from its sign), and is always just the electronic charge, $-e$ or $+e$. This leads us to a picture of discrete Faraday lines of force, each associated with a charge, $-e$ or $+e$. There is a direction attached to each line, so that the ends of a line that has two ends are not the same, and there is a charge $+e$ at one end and a charge $-e$ at the other. We may have lines of force extending to infinity, of course, and then there is no charge.

If we suppose that these discrete Faraday lines of force are something basic in physics and lie at the bottom of our picture of the electromagnetic field, we shall have an explanation of why charges always occur in multiples of e. This happens because if we have any particle with some lines of force ending on it, the number of these lines must be a whole number. In that way we get a picture that is qualitatively quite reasonable.

We suppose these lines of force can move about. Some of them, forming closed loops or simply extending from minus infinity to infinity, will correspond to electromagnetic waves. Others will have ends, and the ends of these lines will be the charges. We may have a line of force sometimes breaking. When that happens, we have two ends appearing, and there must be charges at the two ends. This process—the breaking of a line of force—would be the picture for the creation of an electron (e^-) and a positron (e^+). It would be quite a reasonable picture, and if one could develop it, it would provide a theory in which e appears as a basic quantity. I have not yet found any reasonable system of equations of motion for these lines of force, and so I just put forward the idea as a possible physical picture we might have in the future.

There is one very attractive feature in this picture. It will quite alter the discussion of renormalization. The renormalization we have in our present quantum electrodynamics comes from starting off with what people call a bare electron—an electron without a charge on it. At a certain stage in the theory one brings in the charge and puts it on the electron, thereby making the electron interact with the electromagnetic field. This brings a perturbation into the equations and causes a change in the mass of the electron, the Δm, which is to be added to the previous mass of the electron. The procedure is rather roundabout because it starts off with the unphysical concept of the bare electron. Probably in the improved physical picture we shall have in the future the bare electron will not exist at all.

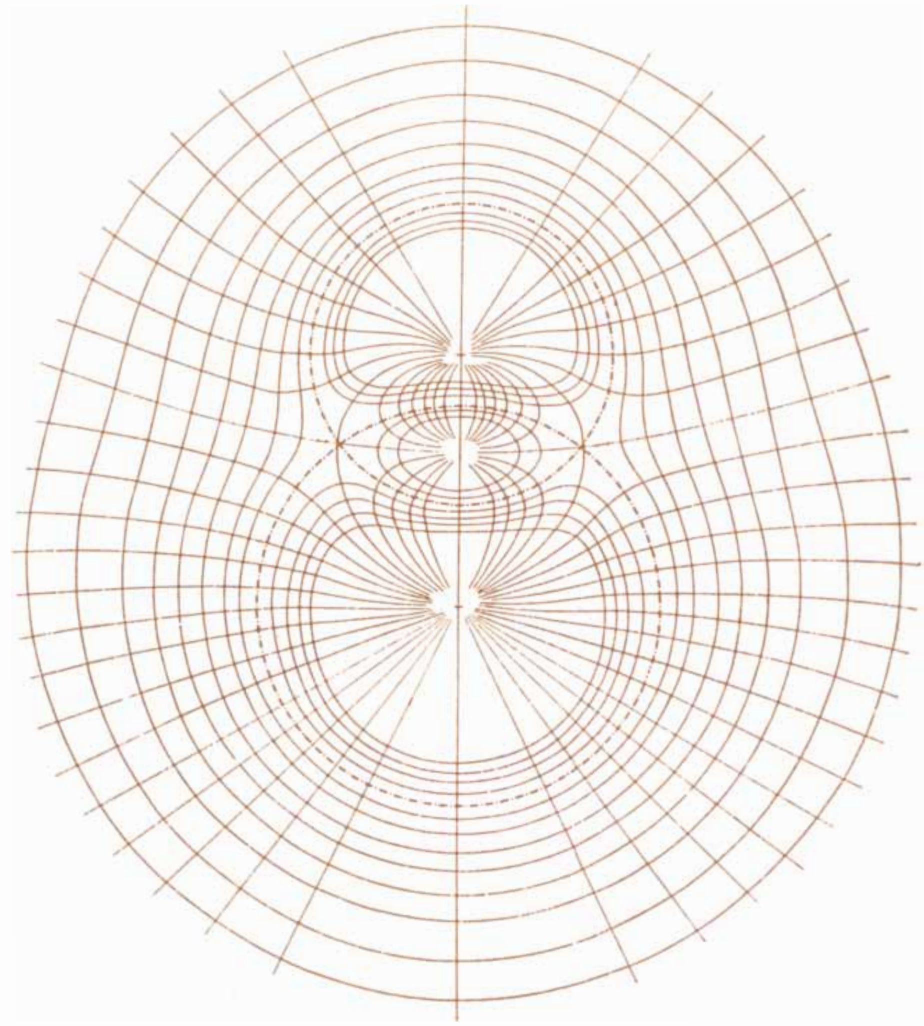
Now, that state of affairs is just what we have with the discrete lines of force. We can picture the lines of force as strings, and then the electron in the picture is the end of a string. The string itself is the Coulomb force around the electron. A bare electron means an electron without the Coulomb force around it. That is inconceivable with this picture, just as it is inconceivable to think of the end of a piece of string without thinking of the string itself. This, I think, is the kind of way in which we should try to develop our physical picture—to bring in ideas that make inconceivable the things we do not want to have. Again we have a picture that looks reasonable, but I have not found the proper equations for developing it.

I might mention a third picture with which I have been dealing lately. It involves departing from the picture of the electron as a point and thinking of it as a kind of sphere with a finite size. Of course, it is really quite an old idea to picture the electron as a sphere, but previously one had the difficulty of discussing a sphere that is subject to acceleration and to irregular motion. It will get distorted, and how is one to deal with the distortions? I propose that one should allow the electron to have, in general, an arbitrary shape and size. There will be some shapes and sizes in which it has less energy than in others, and it will tend to assume a spherical shape with a certain size in which the electron has the least energy.

This picture of the extended electron has been stimulated by the discovery of the mu meson, or muon, one of the new particles of physics. The muon has the surprising property of being almost identical with the electron except in one particular, namely, its mass is some 200 times greater than the mass of the electron. Apart from this disparity in mass the muon is remarkably similar to the electron, having, to an extremely high degree of accuracy, the same spin and the same magnetic moment in proportion to its mass as the electron does. This

WERNER HEISENBERG (1901–) introduced matrix mechanics, which, like the Schrödinger theory, accounted for the motions of the electron. This photograph was made in 1929.

leads to the suggestion that the muon should be looked on as an excited electron. If the electron is a point, picturing how it can be excited becomes quite awkward. But if the electron is the most stable state for an object of finite size, the muon might just be the next most stable state in which the object undergoes a kind of oscillation. That is an idea I have been working on recently. There are difficulties in the development of this idea, in particular the difficulty of bringing in the correct spin.



LINES OF FORCE in an electromagnetic field, if they are assumed to be discrete in the quantum theory, suggest why electric charges always occur in multiples of the charge of the electron. In Dirac's view, when a line of force has two ends, there is a particle with charge $-e$, perhaps an electron, at one end and a particle with charge $+e$, perhaps a positron, at the other end. When a closed line of force is broken, an electron-positron pair materializes.

I have mentioned three possible ways in which one might think of developing our physical picture. No doubt there will be others that other people will think of. One hopes that sooner or later someone will find an idea that really fits and leads to a big development. I am rather pessimistic about it and am inclined to think none of them will be good enough. The future evolution of basic physics—that is to say, a development that will really solve one of the fundamental problems, such as bringing in the fundamental length or calculating the ratio of the masses—may require some much more drastic change in our physical picture. This would mean that in our present attempts to think of a new physical picture we are setting our imaginations to work in terms of inadequate physical concepts. If that is really the case, how can we hope to make progress in the future?

There is one other line along which one can still proceed by theoretical means. It seems to be one of the fundamental features of nature that fundamental physical laws are described in terms of a mathematical theory of great beauty and power, needing quite a high standard of mathematics for one to understand it. You may wonder: Why is nature constructed along these lines? One can only answer that our present knowledge seems to show that nature is so constructed. We simply have to accept it. One could perhaps describe the situation by saying that God is a mathematician of a very high order, and He used very advanced mathematics in constructing the universe. Our feeble attempts at mathematics enable us to understand a bit of the universe, and as we proceed to develop higher and higher mathematics we can hope to understand the universe better.

This view provides us with another way in which we can hope to make advances in our theories. Just by studying mathematics we can hope to make a guess at the kind of mathematics that will come into the physics of the future. A good many people are working on the mathematical basis of quantum theory, trying to understand the theory better and to make it more powerful and more beautiful. If someone can hit on the right lines along which to make this development, it may lead to a future advance in which people will first discover the equations and then, after examining them, gradually learn how to apply them. To some extent that corresponds with the line of development that occurred with Schrödinger's discovery of his wave equation. Schrödinger discovered the equation simply by looking for an equation with mathematical beauty. When the equation was first discovered, people saw that it fitted in certain ways, but the general principles according to which one should apply it were worked out only some two or three years later. It may well be that the next advance in physics will come about along these lines: people first discovering the equations and then needing a few years of development in order to find the physical ideas behind the equations. My own belief is that this is a more likely line of progress than trying to guess at physical pictures.

Of course, it may be that even this line of progress will fail, and then the only line left is the experimental one. Experimental physicists are continuing their work quite independently of theory, collecting a vast storehouse of information. Sooner or later there will be a new Heisenberg who will be able to pick out the important features of this information and see how to use them in a way similar to that in which Heisenberg used the experimental knowledge of spectra to build his matrix mechanics. It is inevitable that physics will develop ultimately along these lines, but we may have to wait quite a long time if people do not get bright ideas for developing the theoretical side.

MOIRÉ PATTERNS

They are produced when figures with periodic rulings are made to overlap. A study of their basic properties reveals that they can illuminate many problems of scientific interest

by Gerald Oster and Yasunori Nishijima

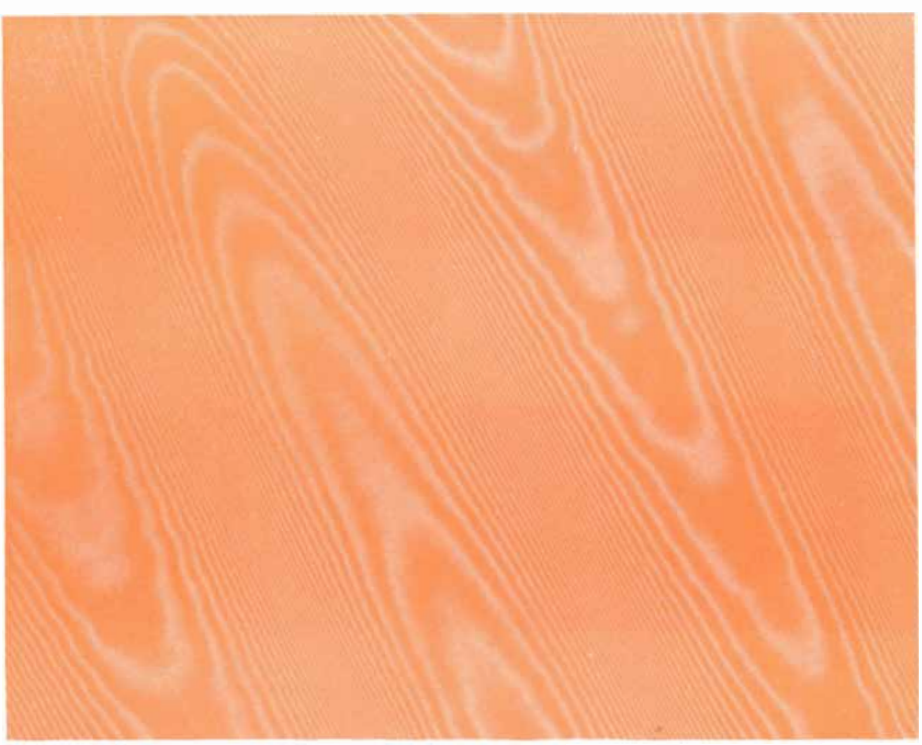
When one looks through a window screen that happens to be in front of another window screen, one sees a curious pattern that results from a combination of the lines in the two screens. Such patterns are called moirés, and they are produced whenever two periodic structures are overlapped. *Moiré* is the French word for "watered"; in English it is most frequently heard in the term "moiré silk," a fabric that has a shimmering appearance resembling the reflections on the surface of a pool of water. Authentic moiré silk (*moiré antique*) is produced from a glossy fabric with a pronounced weave of parallel cords. The fabric is folded so that the cords are nearly aligned and the two layers are pressed so as to engrave the parallel weave of one onto that of the other. When the material is unfolded, it displays a moiré pattern due to the superposition of slightly misaligned parallel lines.

Moiré patterns are nowhere more familiar in daily life than they are in Japan. They appear not only in moiré silks (which were made in the Orient long before they were known in France) but also in two-ply summer kimonos, the pattern of which shimmers with the movements of the wearer, in woven baskets and in the overlapping layers of half-raised bamboo blinds. Such patterns have long fascinated the authors of this article, and we recently undertook to investigate their fundamental properties. As we looked into the matter we soon realized that moiré patterns could be exploited for a number of practical purposes in the laboratory and elsewhere. It is our impression that a systematic exploration of the moiré phenomenon and its potential uses would be highly rewarding.

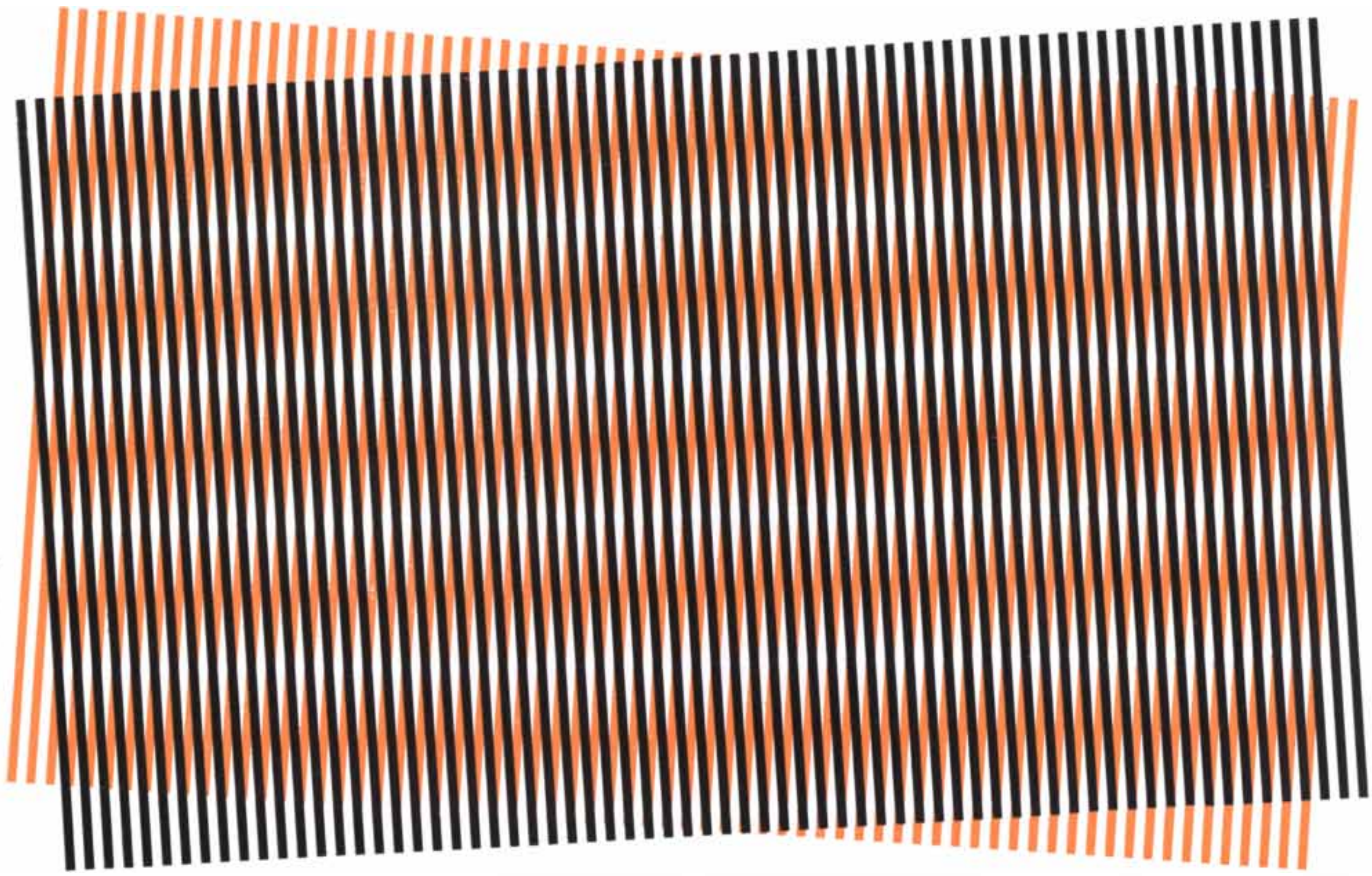
Most moiré patterns are generated by figures that consist of lines, but lines are not strictly necessary. The only general requirement for a moiré pattern is that the interacting figures have some sort of solid and open regions. The solid regions can be lines (straight, curved or wiggly), dots or any other geometric form. Most of this discussion, however, will be limited to moiré patterns resulting from lines, either straight or curved.

In the typical moiré pattern the moiré effect materializes when two sets of straight lines are superposed so that they intersect at a small angle [*see top illustration on opposite page*]. If the superposed lines are nearly parallel, a tiny displacement of one of the figures will give rise to a large displacement in the elements of the moiré pattern. In other words, the displacement is magnified. This phenomenon has far-reaching implications in many disciplines of science. For example, we have developed a system of lensless optics in which the bending of light by the object under examination causes a large change in the resulting moiré pattern.

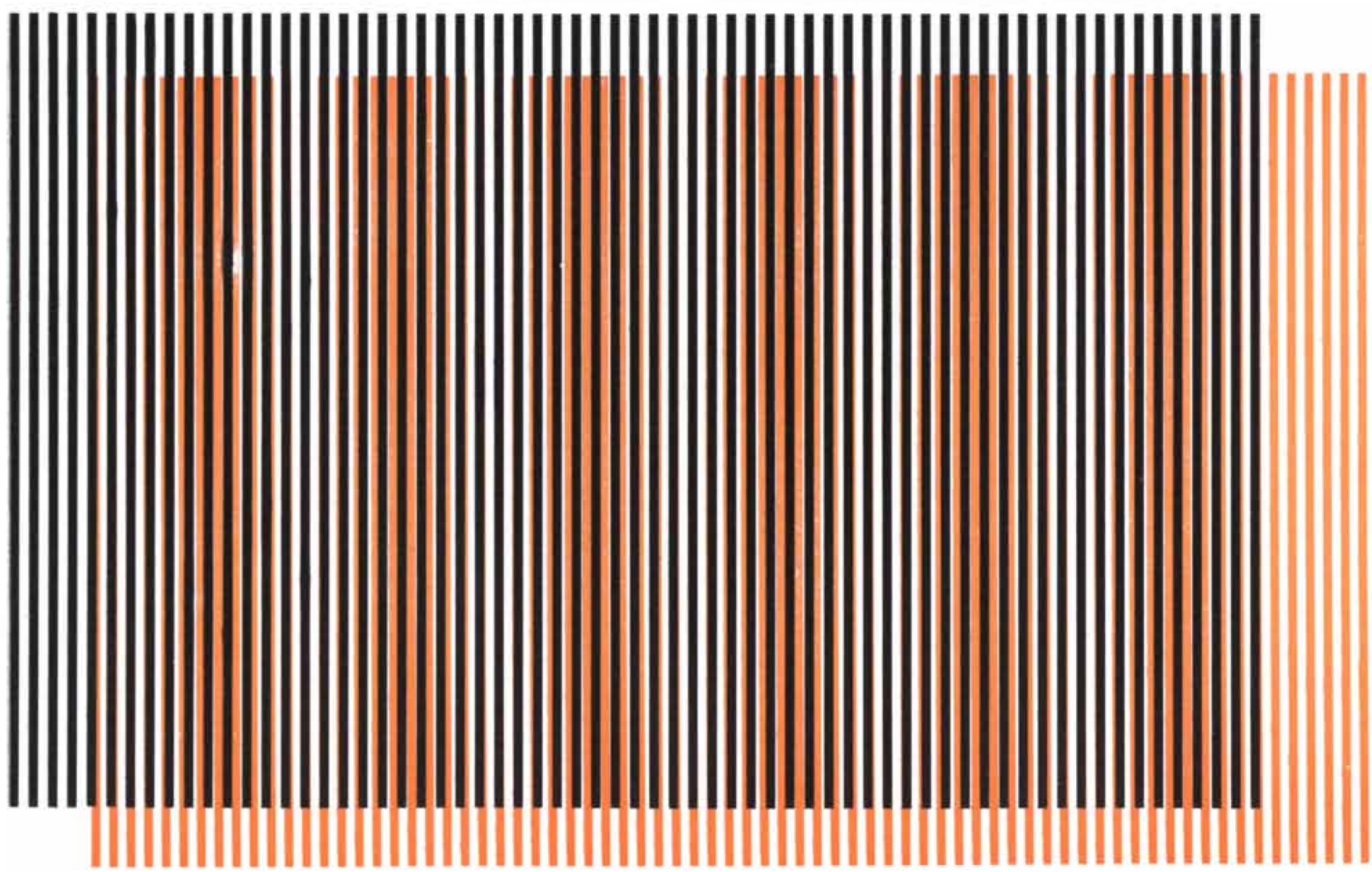
A moiré pattern can be regarded as the mathematical solution to the interference of two periodic functions; hence the moiré technique can be used as an analogue computer. When line figures representing periodic functions are moved about in a continuous manner,



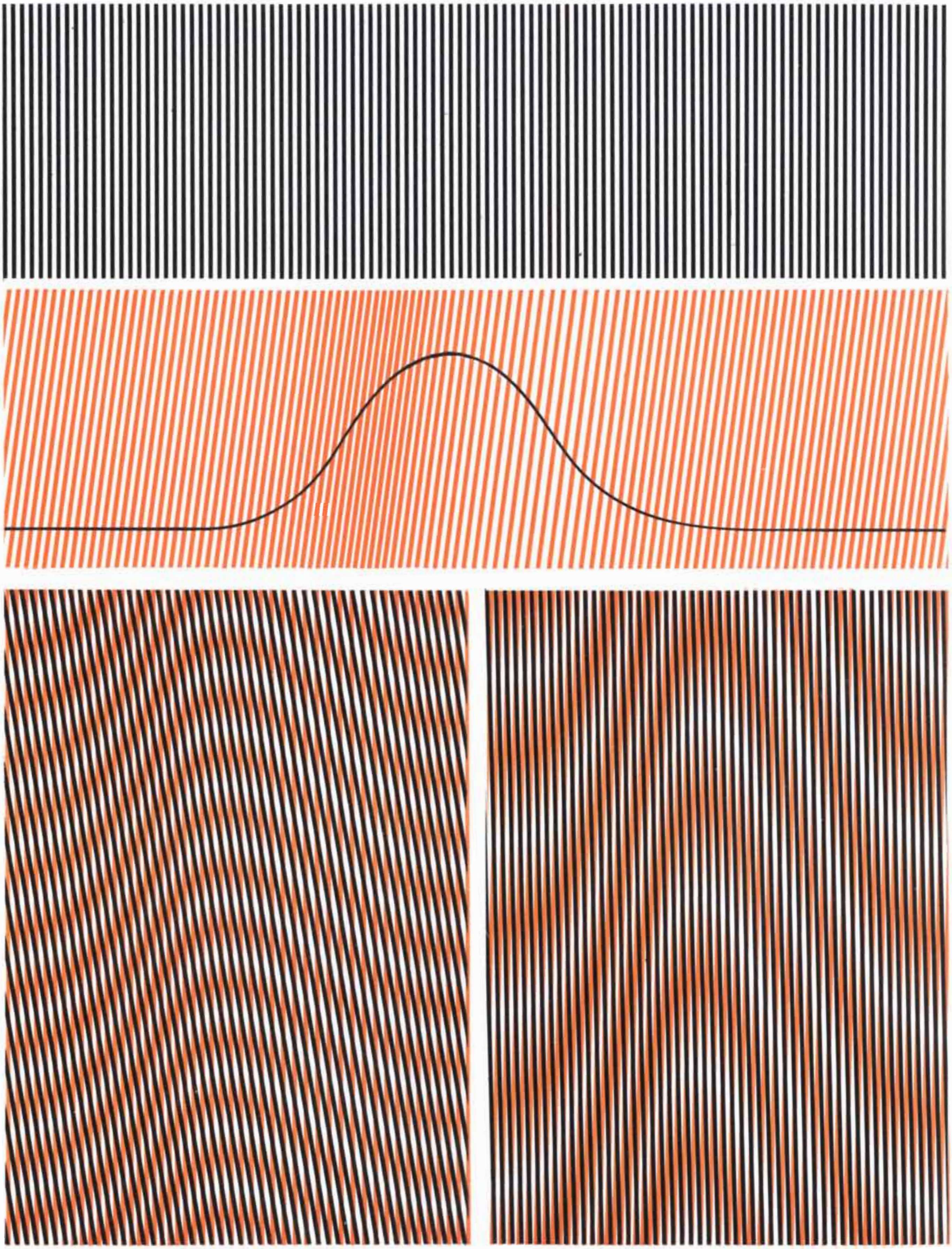
MOIRÉ ANTIQUE is the authentic form of moiré, or "watered," silk in which the pattern is formed by doubling over a glossy corded fabric and pressing the facing surfaces together. When the fabric is unfolded, the superpositioning of two ribbed patterns creates the moiré.



SIMPLE MOIRÉ PATTERN appears when one set of equally spaced straight lines is made to intersect at a small angle with an identical set. Small changes in the angle of intersection of the two figures produce large changes in the spacing of the moiré fringes.



MOIRÉ COMPOSED OF BEATS is produced from nonintersecting parallel lines when the spacing of one set differs from that of another. Because moiré beats magnify small displacements they quickly reveal whether or not two sets of rulings are identical.



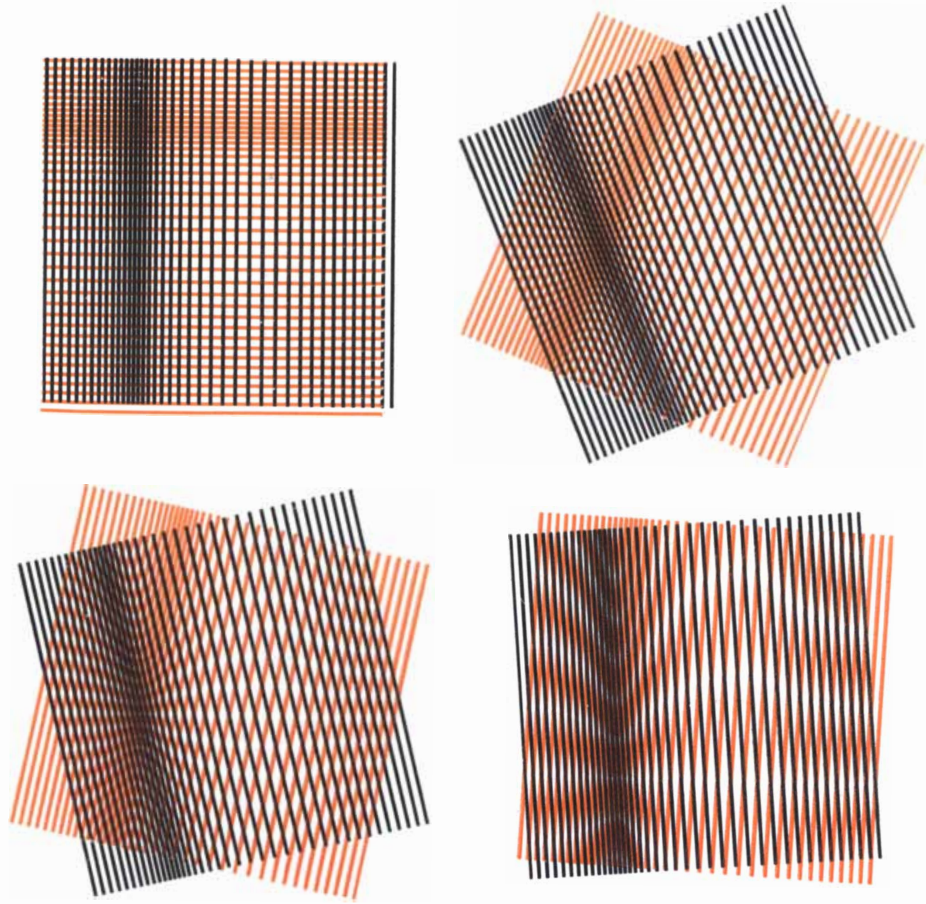
GAUSSIAN CURVES can be created by overlapping one set of lines of equal spacing (*top*) with a second set of lines whose spacings are derived from a Gaussian curve (*second from top*). The second figure is made by drawing a set of equally spaced vertical lines (*not shown*) through a Gaussian curve and then drawing slanting parallel lines through the points where the vertical lines intersect the curve. When the resulting set of rulings is placed over the regular rulings, a series of Gaussian curves is reproduced in a moiré pattern (*lower left*). Reducing the angle of intersection between the two figures steepens the curvature (*lower right*).

the resulting moiré patterns provide a continuous series of curves corresponding to the solutions of mathematical problems [*see illustrations on cover and on opposite page*]. If more than two figures are used, one can obtain with no effort a moiré pattern containing the solution to a multifunctional problem. The use of moiré techniques in this way would be applicable to complex problems involving electromagnetic radiation, acoustical waves or water waves.

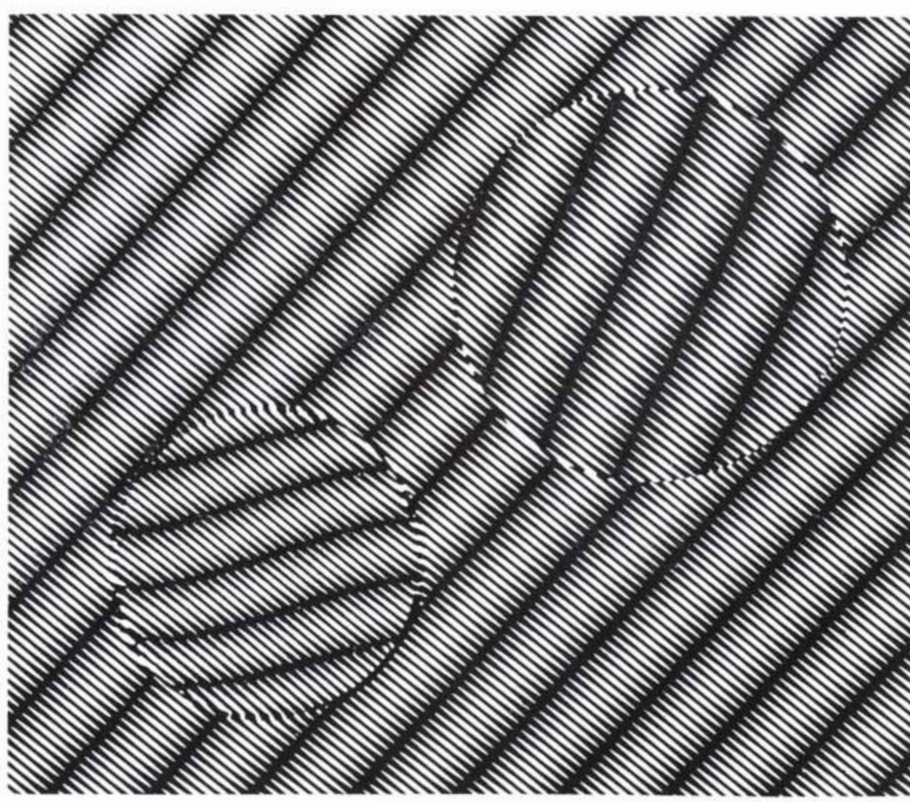
The simplest form of moiré pattern arises from the parallel superposition of two sets of equidistant parallel lines. This kind of pattern is represented by the moving bands one may see when one drives over a bridge at the side of which are two parallel railings consisting of vertical bars. To the observer the spaces between the bars of the nearer railing appear to be somewhat larger than those between the bars of the farther one. Whenever one bar in the nearer railing catches up with and fills a space in the other railing, a beat is observed. This is demonstrated in the bottom illustration on page 55, in which a beat occurs when a line of one figure falls exactly between two lines of the other figure. When the lines are not wide enough to fill a space completely, a beat is produced by an apparent broadening of the lines as the two figures move out of phase. It is obvious that the more closely the two sets of rulings match each other, the farther apart the beats are. Thus if the rulings are a millimeter apart but one set is in error in every spacing by one micron (.001 millimeter), the beat will occur every meter. Hence the moiré pattern represents an enormous magnification (in this case a million times) of the difference in length of the spacings. This system provides an extremely sensitive means of visually detecting minute differences in almost identical repeating figures.

As long ago as 1874 the British physicist Lord Rayleigh suggested that moiré patterns could be used to test the perfection of ruled diffraction gratings. In recent years the technique has been extensively employed, notably at the National Physical Laboratory in England, to test the fidelity of the replica technique for making inexpensive diffraction gratings for optical monochromators. By placing the plastic replica over the original grating one can immediately see any periodic errors made by the ruling engine or any distortions resulting from the production of the replica.

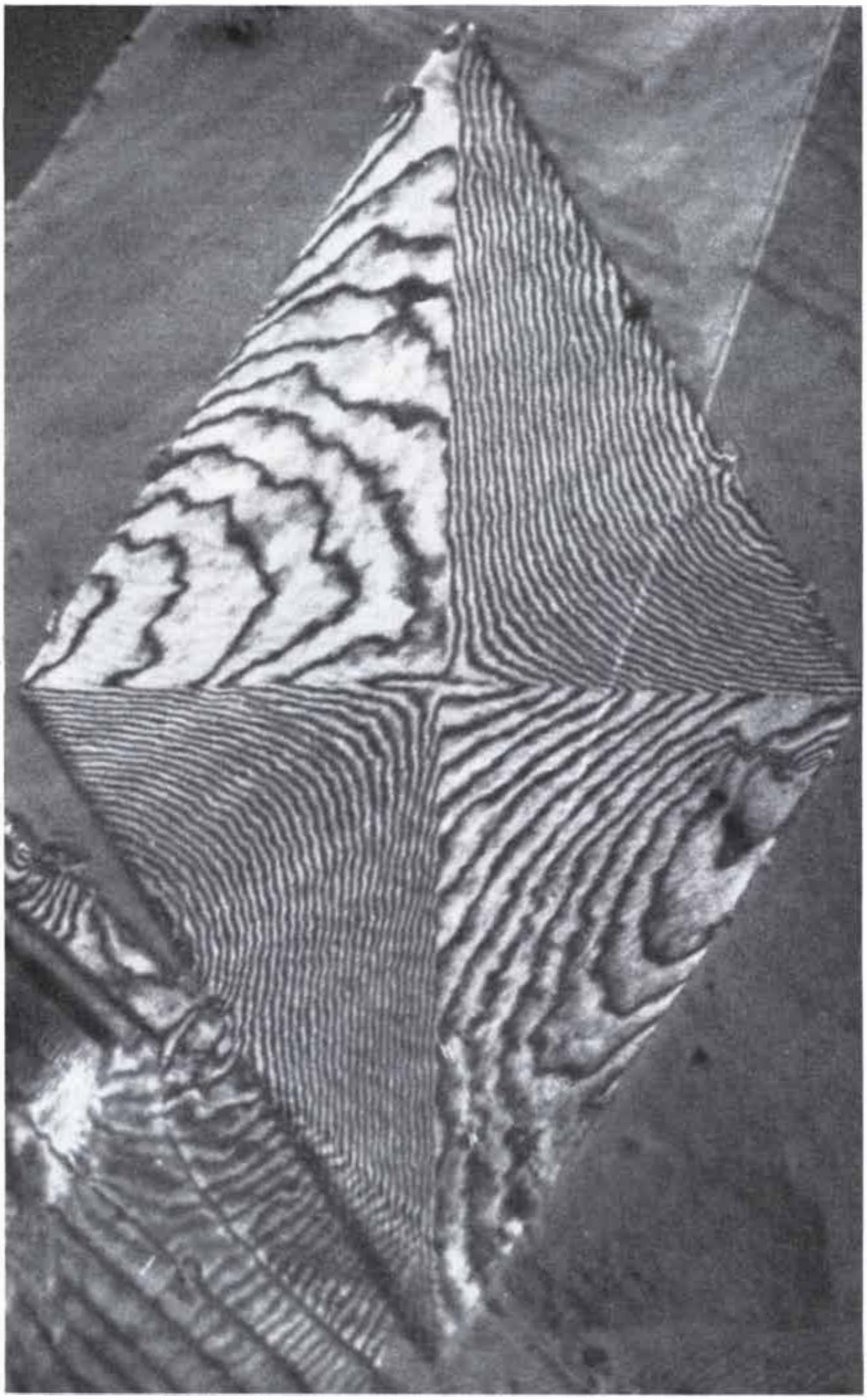
An interesting effect can be produced by taking two rulings that differ slight-



MOIRÉ ON COVER was made by overlapping two identical sets of ruled figures derived from a Gaussian curve, similar to the figure second from the top on the opposite page. This sequence shows how the complex pattern on the cover emerges when the two figures are rotated from a position 90 degrees out of phase (*top left*) until they are almost aligned.



MOIRÉ ROTATION results when optical lenses are placed on a ruled plate and observed through a similar plate. The larger lens, being positive (convergent), contracts the bottom ruling; the smaller lens, being negative (divergent), expands it. Consequently the moirés are rotated in opposite directions. A wavy moiré indicates that the lens contains aberrations.



MOIRÉ CREATED BY TWO CRYSTALS appears in this remarkable electron micrograph made by V. F. Holland of the Chemstrand Research Center, Inc., in Durham, N.C. The picture shows a crystal of polyethylene grown on a layer crystal of the same polymer. The moiré appears because the atomic lattices of the two crystals happen to be in almost direct alignment; the closer the alignment, the wider the spacing between the moiré fringes.

ly in line spacing and moving them with respect to each other. What one sees is a moiré beat that moves much faster than the rulings themselves. The beat is analogous to the beat produced by two waves of slightly different wavelength moving in the same direction. It is evident that the beat can move faster than the individual waves. For example, the beat produced by a collection of light waves forms a wave packet whose "group velocity" exceeds that of light itself. In quantum mechanics such wave packets play an important role in the theory of atomic structure.

Recently moiré patterns produced by stationary beats have been observed in electron micrographs of crystals. To obtain these patterns one must place a thin crystal atop another of the same material; if the crystals are of substantial thickness, the beam energy of the instrument must be several times higher than the voltage of conventional electron microscopes. The extra voltage is needed to penetrate the crystals, and the moiré patterns appear only when the lattices of the two crystals happen to be nearly superposed. The patterns represent the interference occurring when the electrons pass through two almost perfectly matched lattices formed by the atoms in the two crystals. These patterns supply far more detail than can be seen in ordinary electron micrographs [*see illustration at left*].

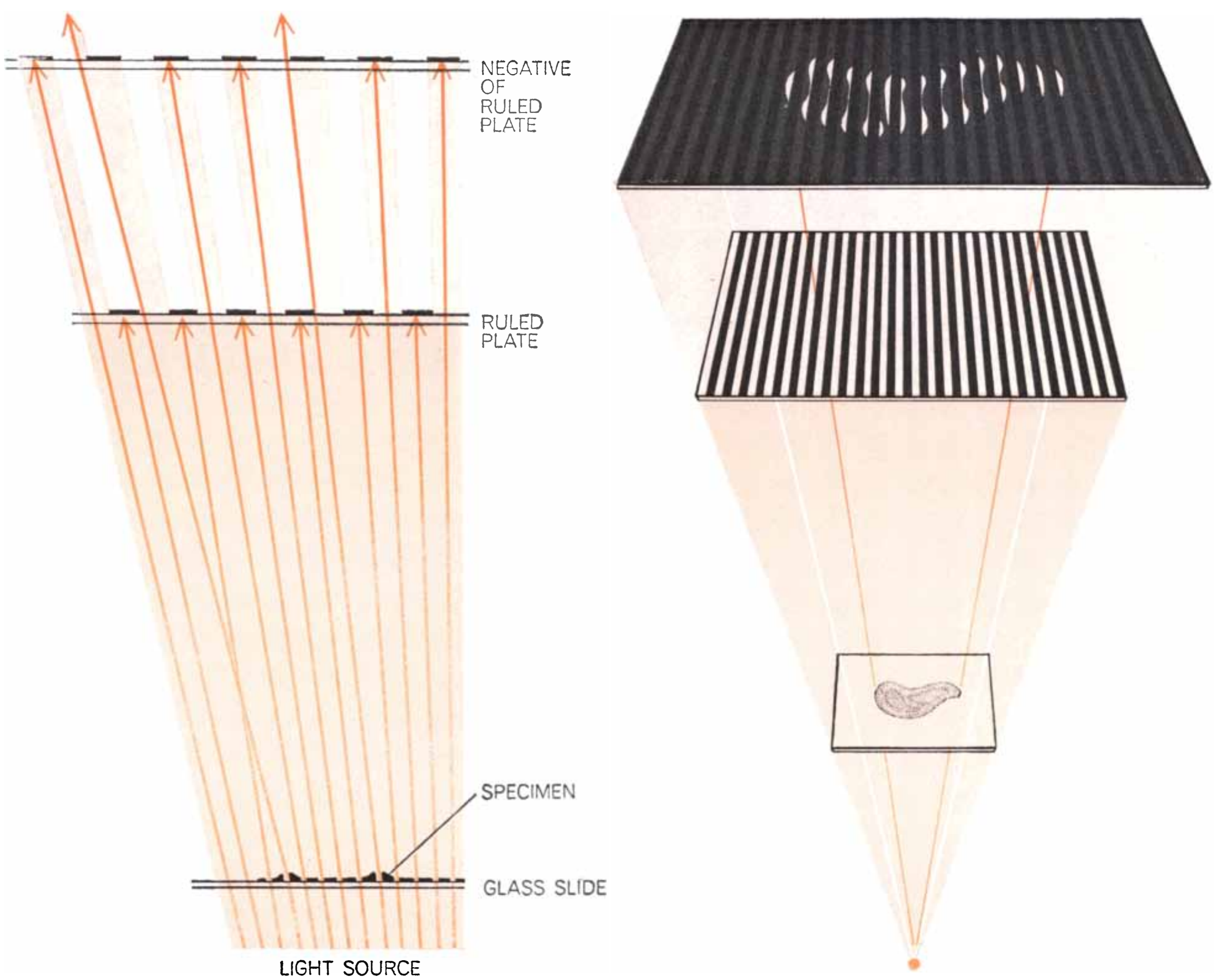
Since the moiré pattern arises from the repeating structure of the crystal, any dislocation that disturbs this regularity will be manifested in the pattern. The magnification implicit in the moiré pattern makes it possible to see dislocations that amount to less than the diameter of an individual atom, or less than one angstrom unit (.01 millionth of a centimeter). This is a factor of 100 or 1,000 better than the resolving power of the electron microscope itself.

Another aid to crystallography may result from using moiré patterns to solve complex equations. In X-ray diffraction studies X rays are deflected by planes of atoms in a crystal, and the deflected wavelets are recorded photographically. Where wavelets reinforce one another the plate is blackened, and where they cancel one another the plate remains clear. The crystallographer's problem is to deduce from such black and white patterns the location of atoms in the crystal. For any given image there are many possible solutions because the phase relations of the waves forming the image are unknown. This simply means that one does not know, in the case of a given wave, whether the plate is recording the crest of the wave or the trough. It is easy to show mathematically that trying out different phase relations, in seeking a solution to the crystal structure, is equivalent to shifting the relation of two periodic figures to form a moiré pattern. In this case the patterns are those formed when the rulings cross at a small angle. The great value of using moiré patterns for this purpose is that one can continuously vary the specifications of the moiré system, thereby obtaining a near infinity of solutions. The correct solution to a crystal-structure problem is one that satisfies all the known restrictions on the way atoms may be fitted together.

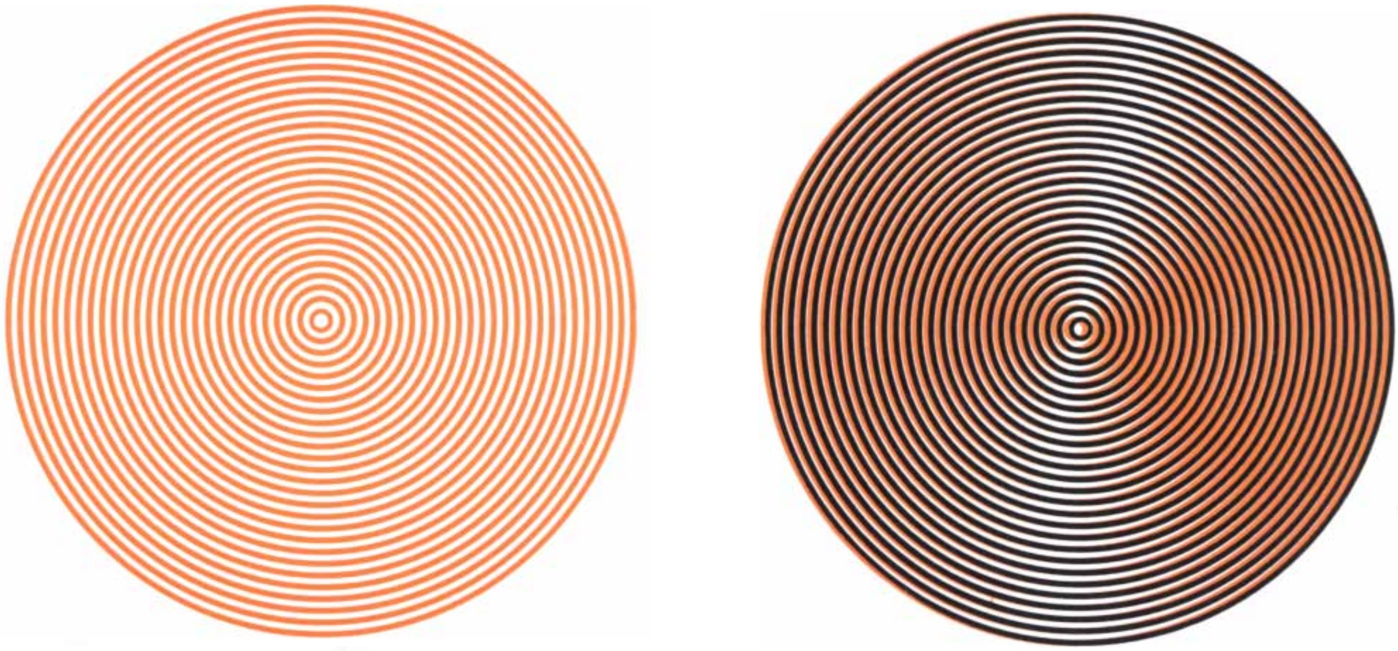
Moiré patterns can be used to demonstrate and measure an interesting property of crystals. All crystals except cubic ones exhibit more than one refractive index. For example, a rhomb of calcite has two refractive indexes, one corresponding to the "ordinary" ray (which passes straight through the crystal) and the other to the "extraordinary" ray (which is bent in passage). Each ray bends different wavelengths of light by different amounts. If a rhomb of calcite is placed between two sets of parallel rulings and illuminated with white light, the extraordinary ray will generally produce a colored moiré pattern. (Although the color is easily seen, it is difficult to show photographically.) The color will not appear, however, when the lines of the ruling nearest the observer lie along the line connecting the points of emergence of the two rays.

If the rhomb of calcite is placed on a single plate that is inscribed with concentric circles instead of straight lines, the overlapping figures produced by the two rays give rise to moiré patterns consisting of hyperbolas. The hyperbolas result from the intersection of overlapping circles and therefore depend on the center-to-center distances of the figures. Thus by counting the number of hyperbolas one can determine the relative displacements caused by the ordinary and extraordinary rays and hence the difference in refractive index of the two rays. This difference is called the birefringence of the crystal.

In another class of applications moiré patterns provide immediate visible evidence of transient changes in a medium placed between two sets of rulings. The technique is much simpler than those customarily employed, which require complex optical systems of either the interference or the schlieren type. Suppose, for example, that one would like to follow the rate at which some compound, say sugar, dissolves in a liquid medium. A flat-sided vessel of the liquid is placed between two sets of rulings, which are adjusted to produce a moiré pattern. A piece of sugar is then suspended in the liquid. As it dissolves it changes the refractive index of the liquid in its immediate vicinity and the changed index causes a proportional bending of the light rays passing through the vessel. The bending in turn distorts the moiré pattern [*see illustration on page 63*]. The distortion in the pattern is related in a direct and simple way to the change in refractive index. The moiré technique could readily be applied to many laboratory procedures,



LENSLESS MOIRÉ MICROSCOPE has been devised by the authors. It employs two precisely aligned ruled plates, one the negative of the other, that totally block light from a point source. If a transparent specimen is placed in the light beam, it bends the rays according to local variations in its refractive index, thereby making some of the light spill around the ruling of the top plate (*left*). Viewing the top plate, one sees a bright moiré on a dark background (*right*). The moiré is a refractive-index map of the specimen.

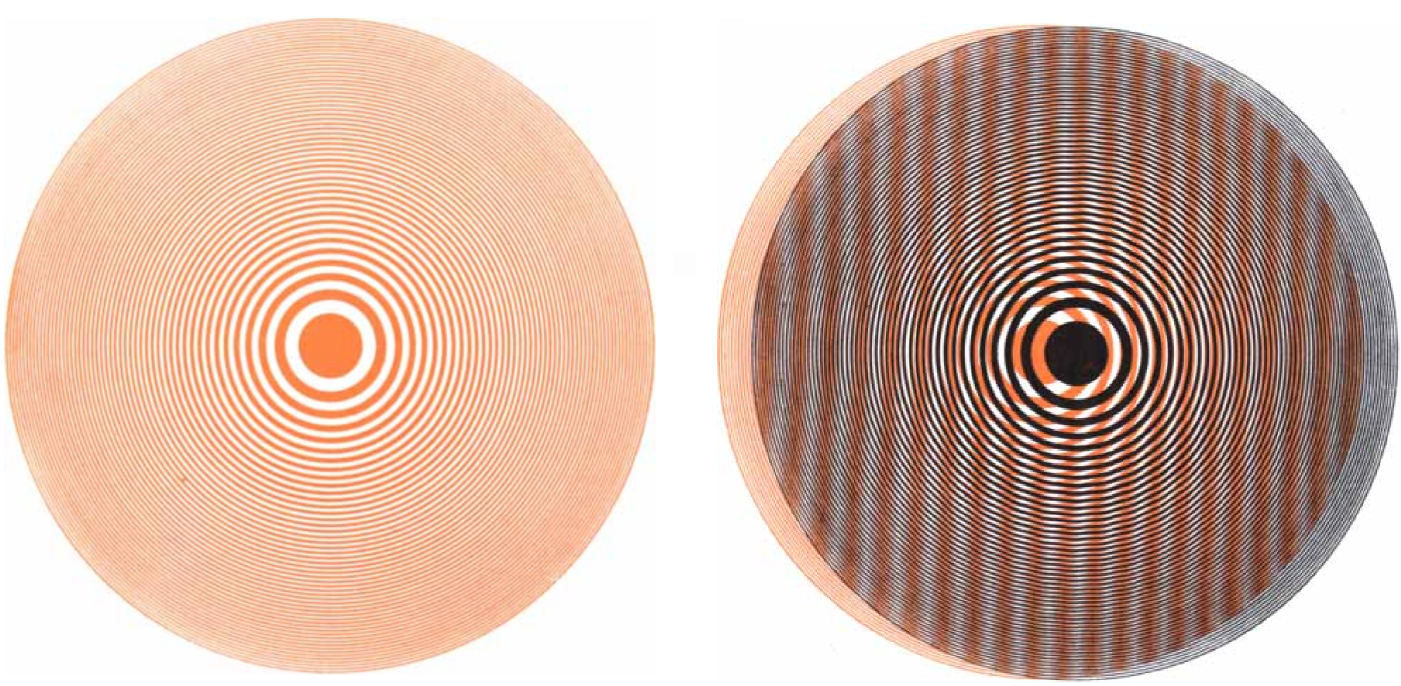


MOIRÉS BASED ON CIRCLES can provide models of many physical phenomena, such as the figures created when two waves are generated in phase from different centers. The set of circles at the left provides the basis for the three patterns shown in subsequent

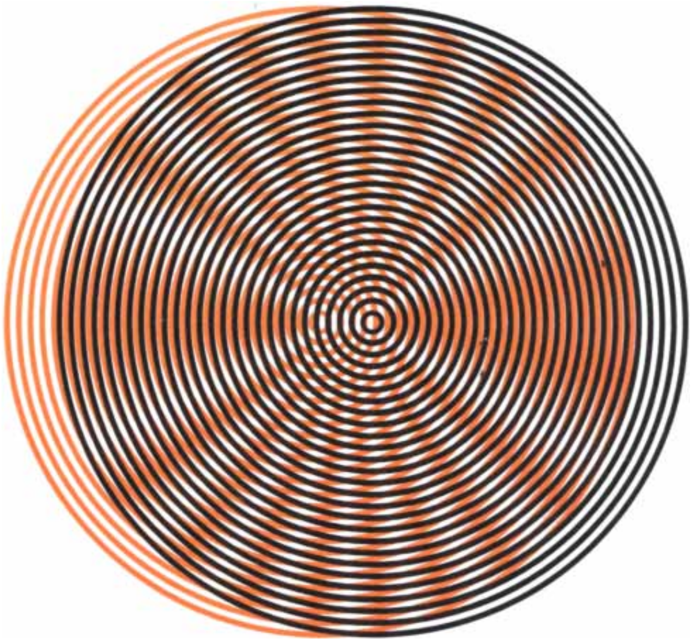
such as ultracentrifugation, diffusion and electrophoresis, that require a continuous monitoring of changes in refractive-index gradients. The size and shape of proteins, nucleic acids and other giant molecules are commonly calculated by combining diffusion and sedimentation rates, which are derived by plotting such gradients.

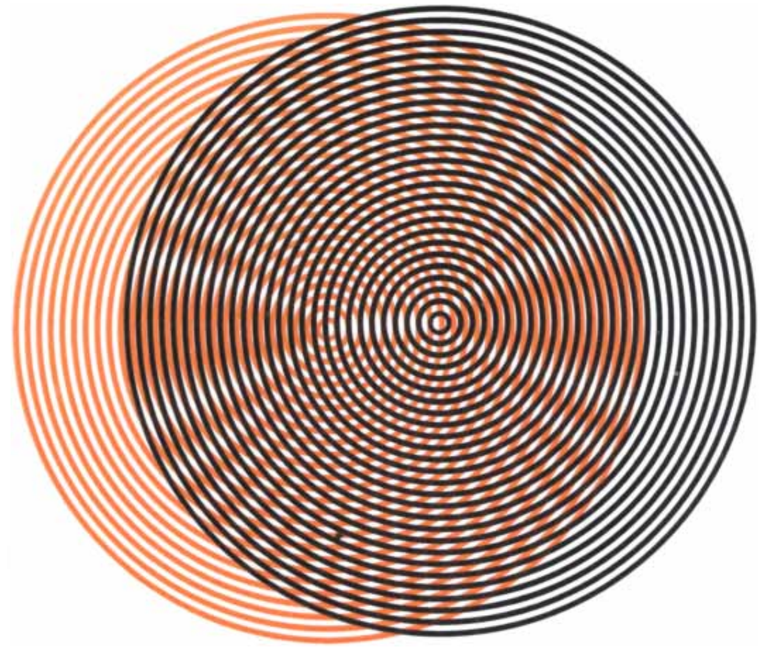
A related use of moiré patterns would be in the examination of biological specimens that have refractive indexes close to that of water. By the use of a suitable apparatus the refractive-index gradient of the specimen can be made to show up as a bright moiré pattern on a black background. An apparatus in which the specimen is illuminated by a divergent beam of light from a point source would constitute a lensless microscope [*see illustration on preceding page*].

A further use of the same principle provides a quick means for testing lenses. The lens to be examined is placed between two sets of rulings. A positive (convergent) lens magnifies the moiré pattern; a negative (divergent) lens reduces it. Positive and negative lenses rotate the moiré in opposite directions, and the angle over which the pattern is turned is proportional to the focal length of the lens. If the lens contains distortions, it will bend the lines of the moiré pattern. If it contains chromatic aberrations, the moiré pattern will exhibit color fringes. With little more difficulty one



FRESNEL-RING MOIRÉS are based on the "Fresnel zone plate" (*far left*), in which the area of every ring, whether open or filled, equals the area of the center spot. When two zone plates are overlapped, the moiré consists of a series of straight lines (*second*



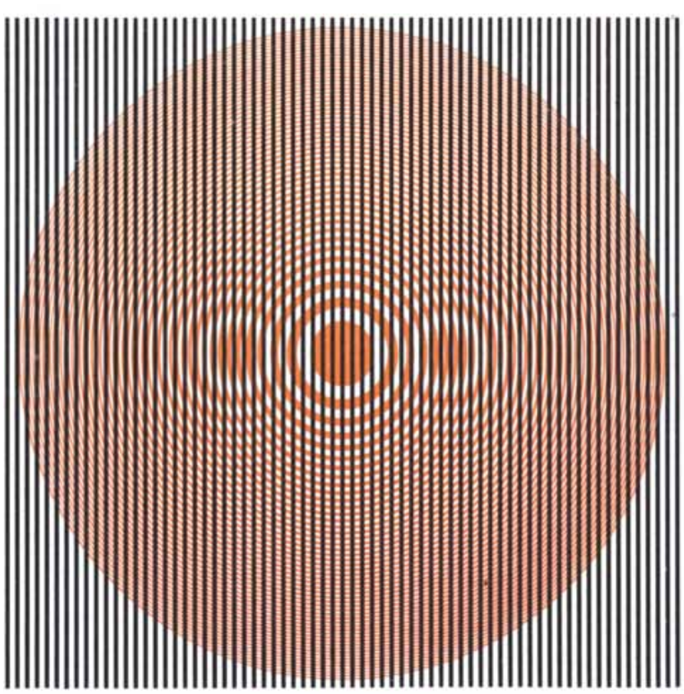


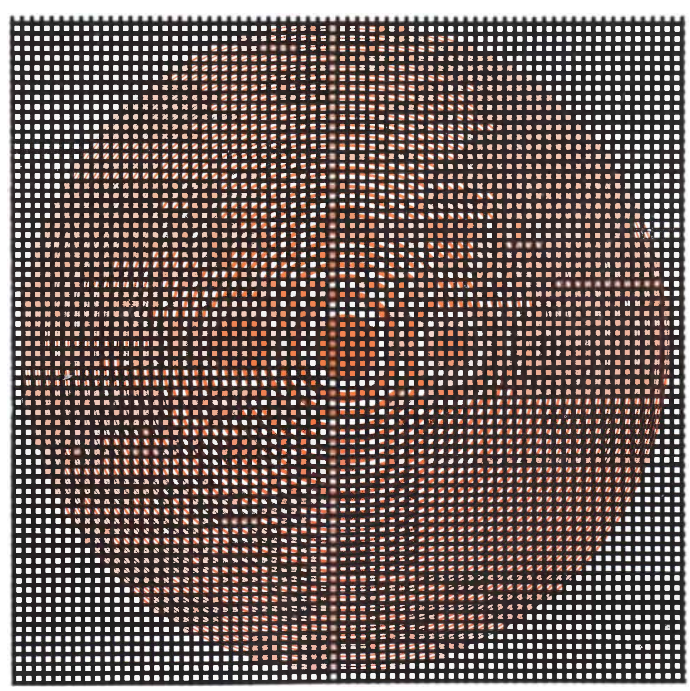
panels. As the two sets of overlapping circles are moved apart, the number of radiating moiré bars (actually hyperbolas) increases. **These moirés duplicate the interference patterns produced when light waves from a common source pass through two pinholes.**

can evaluate combinations of two or more lenses. An extension of the method could be used to design lenses without the need for complicated mathematical computations.

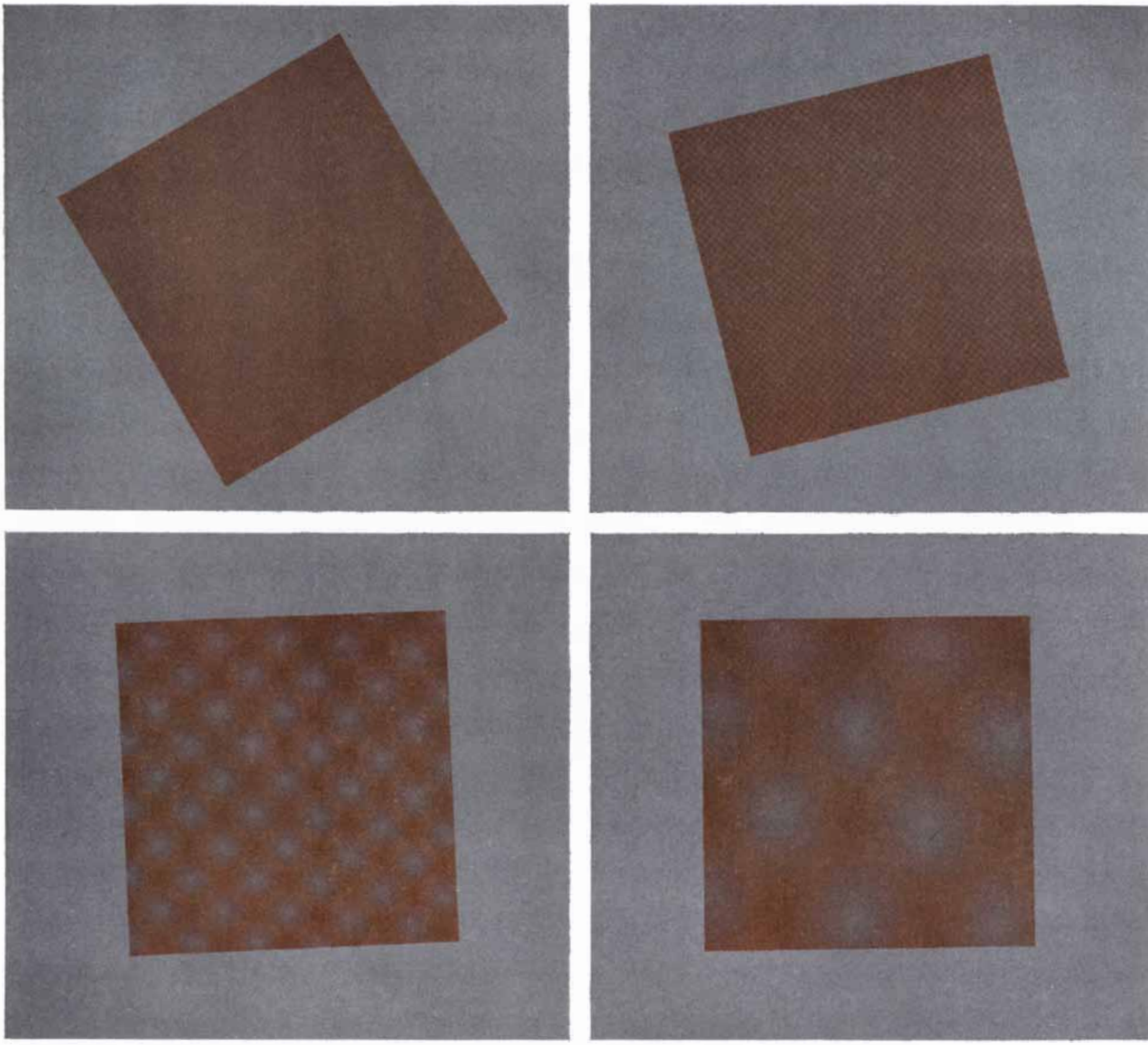
Many novel moiré patterns can be produced by figures containing circular patterns. When two sets of concentric circles are placed together slightly off center, remarkable moiré patterns appear that change rapidly as the circles are moved. In fact, a single figure consisting of concentric circles will produce moiré afterimages in the eye and appear to revolve if the figure is moved slightly while being observed. Interacting circular patterns provide a model for many physical phenomena, such as the electrostatic fields formed by two electrically charged poles or the interference patterns produced when light from a point source passes through two adjacent pinholes in a screen. In fact, moiré patterns can be used to obtain an exact mathematical solution of the interference of light waves. They have already helped to solve problems of architectural acoustics and even to design breakwaters for harbors.

If concentric-ring patterns are drawn in a special way, the resulting moiré pattern will be a series of straight lines. To get this rather unexpected result one must use ring figures called Fresnel zone plates. The plates are made by spacing

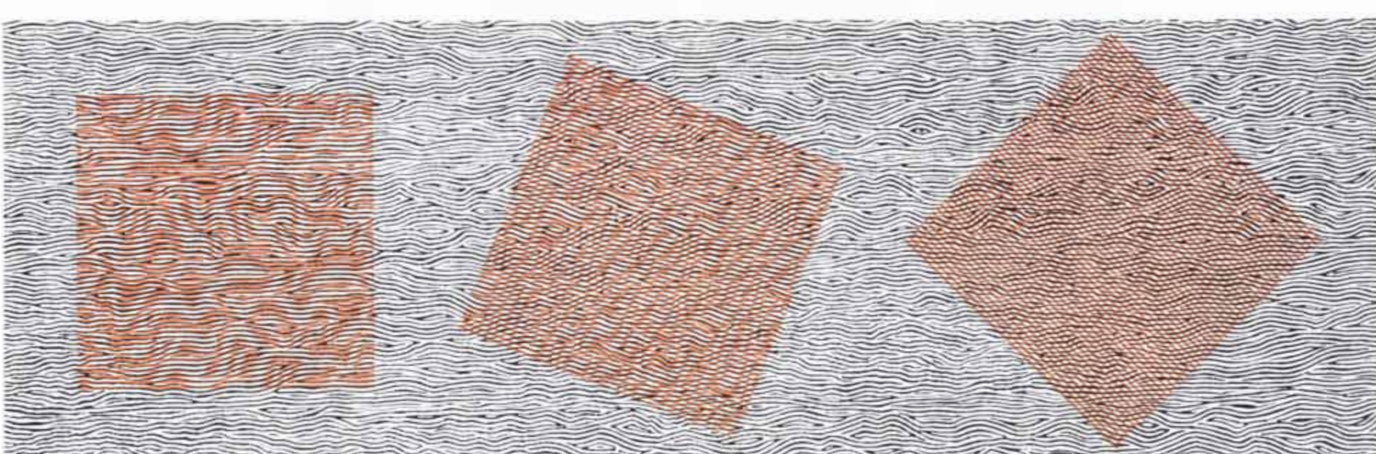




***from left*). When a grid of straight lines is placed over a zone plate, the moiré pattern replicates the zone plate (*third from left*). And** **when a second series of straight lines is placed at right angles to the first, the Fresnel zone plate is replicated again (*fourth*).**



MOIRÉ MAGNIFICATION can be simply demonstrated with the aid of "halftone" screens used by engravers. The photographs in this magazine are reproduced with a screen containing 110 dots to the inch. If two such screens are to be printed one atop the other without producing a moiré, they must intersect at a fairly large angle (*top left*). If the angle is reduced, a moiré of small dots appears (*top right*). As the angle is reduced further, the dot pattern moiré is increasingly magnified, as shown in the two bottom figures.



ANALYSIS OF DISORDERLY PATTERNS can be carried out with the aid of the moiré technique. If the pattern is not wholly random, such as that in the background above, a certain amount of order will appear when the pattern is made to interact with a set of parallel lines rotated at various angles. The background pattern suggests the arrangement of long-chain molecules in a plastic.

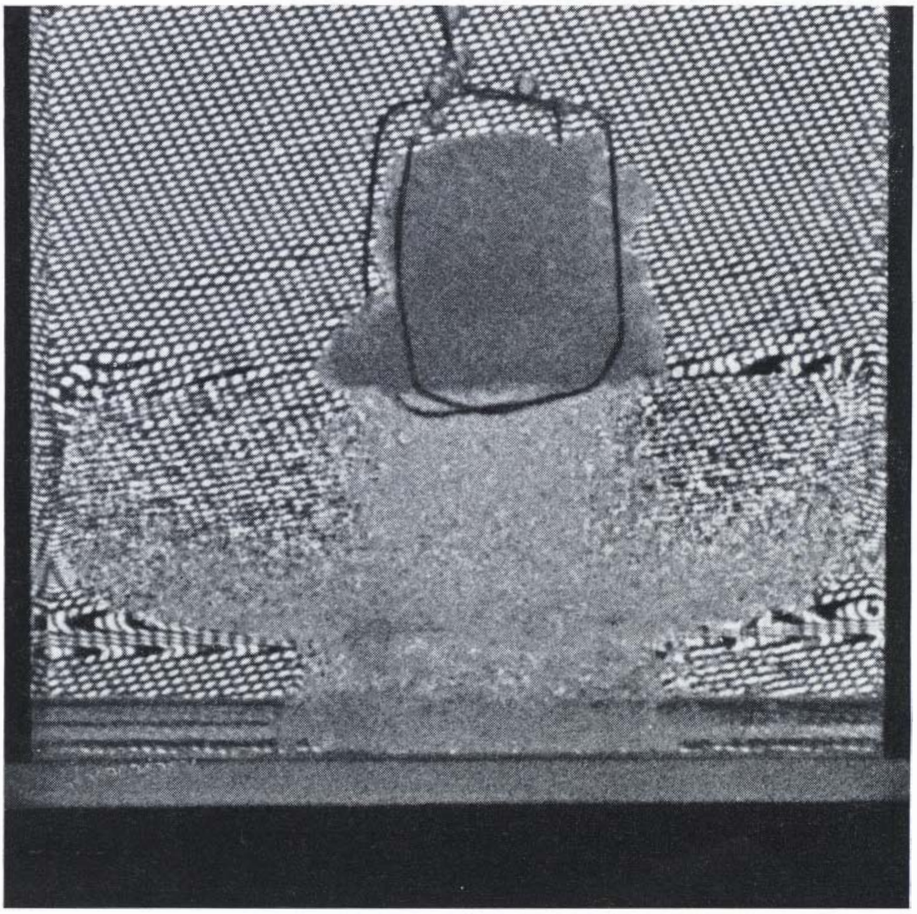
concentric circles so that the areas between them are constant; alternate areas are then blacked out. When two such plates are superposed, the moiré pattern of straight lines materializes [*see right-hand illustration at bottom of page 60*]. If a plate consisting of straight lines is placed over one Fresnel zone plate, the result is a moiré pattern composed of a series of zone plates.

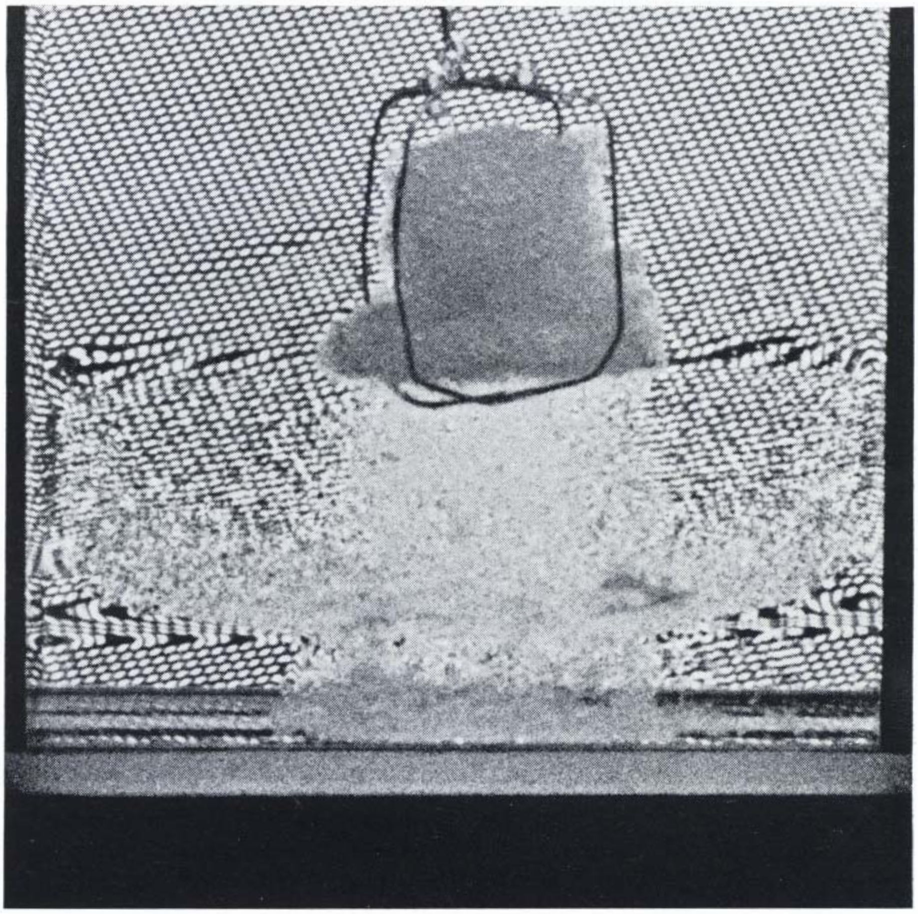
Moiré patterns can be readily created with two screens consisting of a regular pattern of fine dots. Such screens, having anywhere from 50 to 150 dots per inch, are used by photoengravers to make "halftone" reproductions and are called halftone screens. It is not surprising that moiré patterns sometimes plague the printer whenever he is obliged to print two or more halftone impressions one atop the other, which he must do in making multicolored reproductions. To avoid moiré patterns the engraver's plates must be carefully positioned so that the dot patterns intersect at about 30 degrees. One can vividly demonstrate the ability of the moiré technique to magnify an underlying pattern by reducing the angle of intersection between two halftone screens, as shown in the illustrations at the top of the opposite page.

If the underlying screen is distorted slightly, the distortion will be greatly magnified. One can use this effect to advantage as a way to study the strain induced in some object placed under stress. The halftone screen could be printed directly on the object; when viewed through a second screen, any distortion would be instantly apparent.

Another simple use of the moiré technique is for direct observation of a surface containing a periodic pattern. For example, if a parallel ruled grating is placed over a woven fabric, the character of the weave can easily be discerned. If the pattern is a complex one with little evident periodicity, the moiré technique will readily sort out the areas of regularity [*see bottom illustration on opposite page*]. In this sense the moiré method is a means of establishing correlations among statistical data.

We hope this article has given the reader some feeling for the fascinating patterns that can be created by the juxtaposition of inherently simple figures. However, the patterns themselves—the moirés—can represent the solutions of extremely complicated mathematical problems. It is because moirés provide simple analogues of complex phenomena that they have such a wide range of potential usefulness.





DIFFUSION RATES can be plotted by observing changes in moiré patterns caused by changes in the refractive index of a solution. These pictures show successive changes in moiré as a lump of sugar dissolves in a liquid contained between a pair of ruled plates.

THE LYSOSOME

This small particle acts as the digestive tract of the living cell. Its enzymes dissolve the substances ingested by the cell and under certain circumstances can dissolve the cell itself

by Christian de Duve

The study of the living cell has in recent years established an increasingly complete catalogue of its working parts and identified these with their functions. The new understanding has come from a collaborative effort of, on the one hand, the cell anatomist, whose electron micrographs portray the internal structures of the cell in almost molecular detail, and, on the other, the biochemist, who disrupts and fractionates the cell so that he can observe the activity of the cellular organelles and their molecular components in isolation from one another. This concurrent study of structure and function has shown, for example, that the organelles called mitochondria conduct the primary energy transformations of the cell and that the smaller organelles called ribosomes are the centers of enzyme manufacture. The latest addition to the list of organelles is the lysosomes. They serve a function more comprehensible in terms of the grosser life processes of multicelled organisms. The lysosomes are tiny bags filled with a droplet of a powerful digestive juice capable of breaking down most of the constituents of living matter, much as these constituents are fragmented in the gastrointestinal tract of higher animals. In point of fact, the lysosomes function in many ways as the digestive system of the cell.

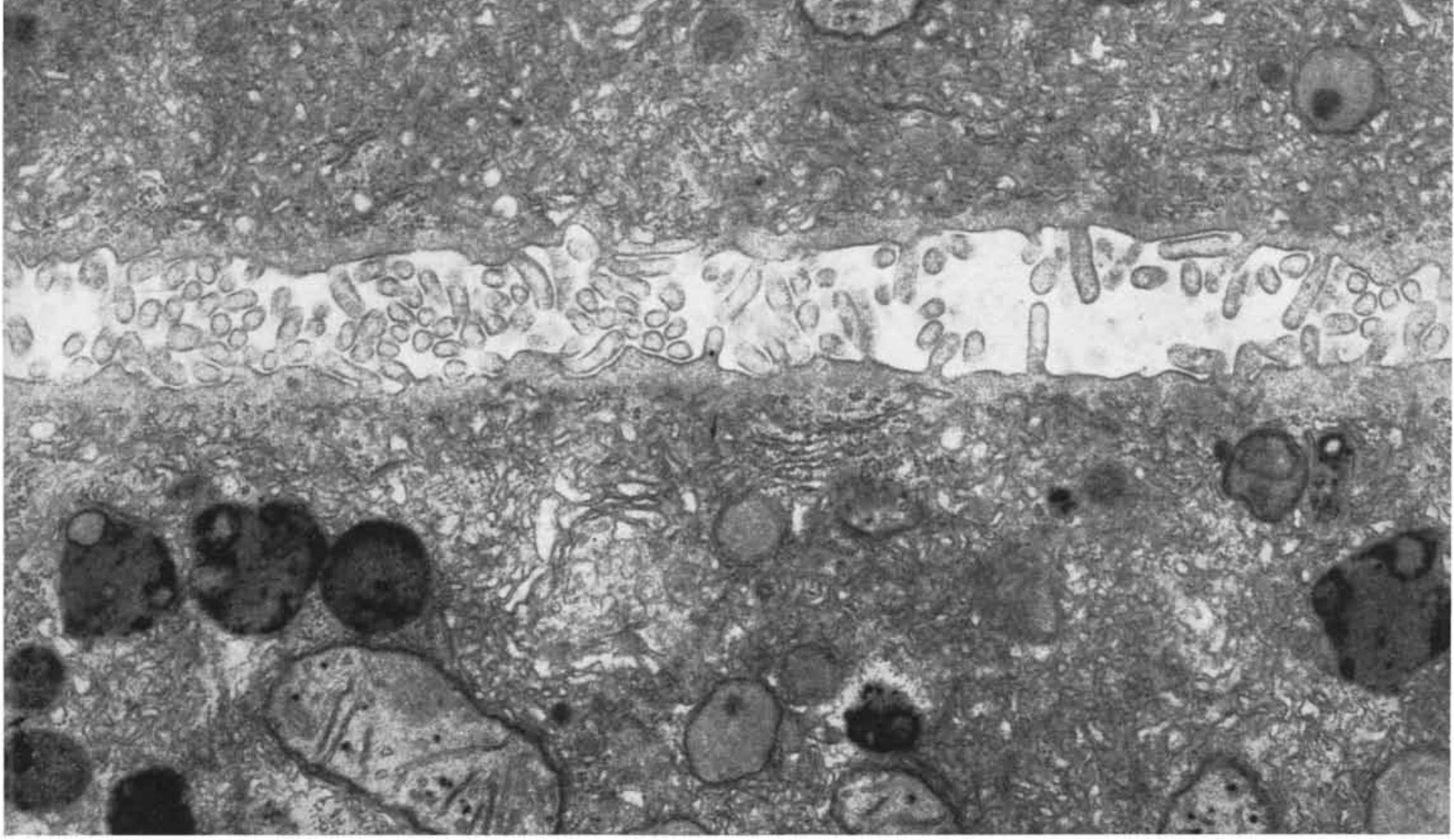
First identified in rat liver cells in 1955, lysosomes are now known to occur in many—possibly in all—animal cells. (It remains to be shown if they are present in plant cells.) It is significant that they are particularly large and abundant in cells, such as the macrophages and the white blood cells, that are called on to perform especially important digestive tasks. Lysosome function and malfunction appear to be involved in such vital processes as the fertilization of the egg and the aging of cells and tissues and in certain diseases. Challenging questions are presented by the properties of the membrane of the lysosome, which enable the organelle to contain enzymes that, on liberation, are capable of digesting the entire cell. Indeed, the death and dissolution of the cell following rupture of the membrane may play a part in the developmental processes of some animals and in a number of degenerative phenomena. This suggests the possibility that cell "autolysis" might be deliberately promoted or retarded for therapeutic purposes by the use of substances affecting the stability of the lysosome membrane.

Although lysosomes are frequently above the lower limit of visibility in the light microscope and are well within the range of the electron microscope, they were not discovered by optical methods. They were undoubtedly seen many times, but their nature and function were not recognized until they had been characterized chemically. The first clue was provided by a chance observation in our laboratory at the Catholic University of Louvain in 1949.

We had just begun to use the then newly developed technique of centrifugal fractionation, in which cells are disrupted in a homogenizer and then spun in a centrifuge at successively higher speeds to yield a number of fractions containing organelles of different types. When isolated in this manner, the organelles still maintain many of their functional properties, which can then be explored by means of biochemical methods. Our object was to localize in such fractions certain enzymes involved in the metabolism of carbohydrates in the liver of the rat and thereby to determine with which cellular structures these enzymes are associated. The standard procedure in this work is first to assay the homogenate of the disrupted cells for the presence of a given enzyme and then to look for the activity of the enzyme in the fractions. Among the enzymes included in our routines was the enzyme called acid phosphatase. This enzyme, which splits off inorganic phosphate from a variety of phosphate esters, is not directly connected with carbohydrate metabolism. We included it largely for control purposes.

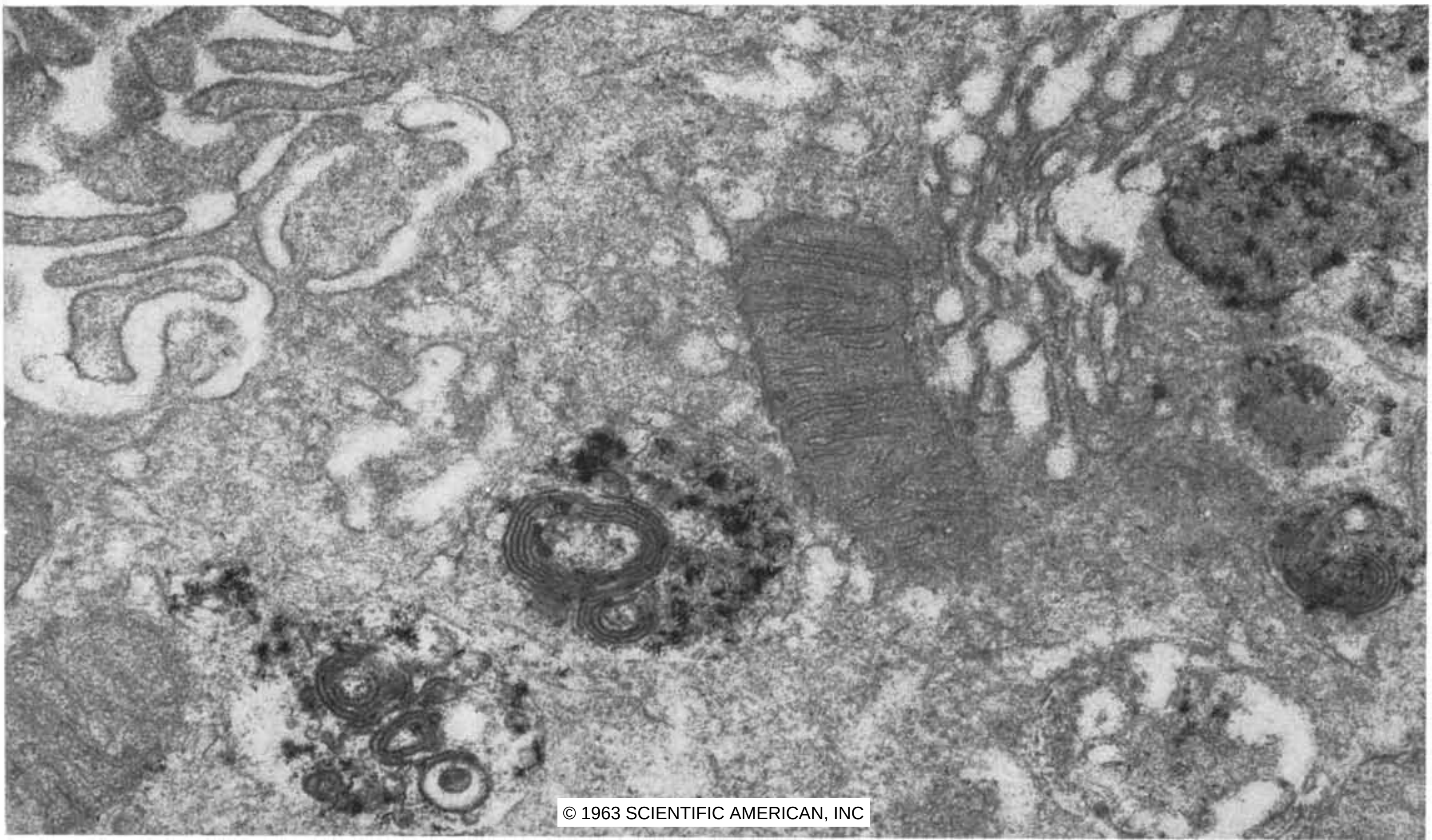
To our surprise the acid-phosphatase activity in the homogenate was only about a tenth of what we had come to expect from previous assays of preparations that had been subjected to the more drastic homogenizing action of a Waring Blendor. The total of the activities found in the fractions, about twice that observed in the homogenate, was still only a fifth of the expected value. When the assays were repeated five days later on the same fractions (they had been kept in the icebox), the enzyme activity was much greater in all the particulate fractions, especially in the fraction containing mitochondria. The total activity was now within the expected range.

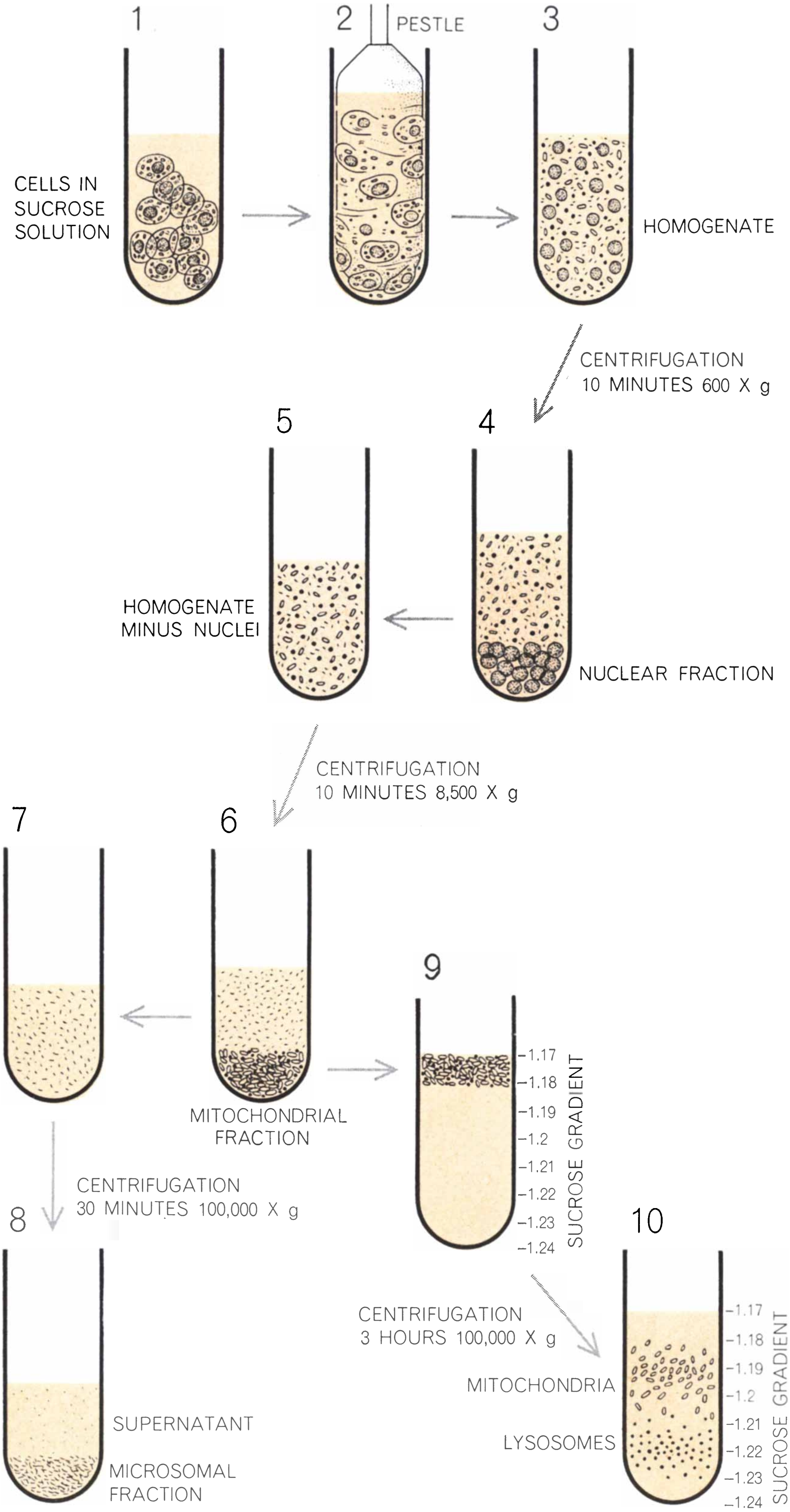
Fortunately we resisted the temptation to discard the first series of results as being due to some technical error, and a few additional experiments quickly gave us the clue to the mystery. In living cells the enzyme is largely or entirely confined within little baglike particles; the surface membrane of these particles is able not only to retain the enzyme inside the particle but also to resist the penetration of the small molecules of phosphate esters used in the assay. What we measured in our assays was only the amount of enzyme that



LYSOSOMES appear as relatively large dark objects in the electron micrograph above, which shows parts of two rat liver cells separated by a bile canaliculus. The canaliculus is the light strip running horizontally through the micrograph; the protuberances in the canaliculus are microvilli. The oblong body near the six lysosomes at bottom left is a mitochondrion. The micrograph was made at the Rockefeller Institute by Henri Beaufay of the Catholic University of Louvain. The magnification is 26,000 diameters.

TWO TYPES OF LYSOSOMES in a nephrotic rat kidney cell are magnified 60,000 diameters in the electron micrograph below: the kidney-shaped "digestive vacuole" at upper right and the two round "residual bodies" near the center and at lower left. Layered structures in the latter are "myelin figures," probably consisting of undigested fats. Minute black areas in the lysosomes are lead phosphate precipitated in staining. The micrograph was made by Alex B. Novikoff of the Albert Einstein School of Medicine.



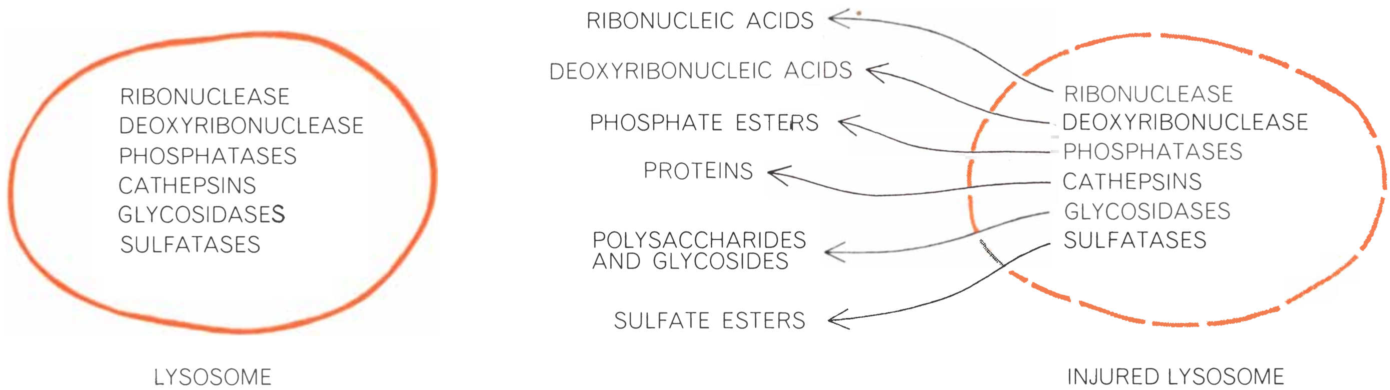


CENTRIFUGAL FRACTIONATION separates cells into fractions containing various cell components. Rapid mechanical rotation of the pestle ruptures the cells, setting the intracellular particles free in the medium. Successive centrifugations of the resulting homogenate produce fractions in which certain cell particles predominate. Steps *1* through *8* represent a method developed by W. C. Schneider of the National Institutes of Health. Steps *9* and *10* show a modification developed by the author and his co-workers; the mitochondrial fraction (*Step 6*) is sedimented by centrifugation for 10 minutes at 25,000 times gravity. Numbers associated with the sucrose gradient give density in grams per cubic centimeter.

either was free in the cell or had escaped from particles injured by our manipulations. Whereas the Waring Blendor disrupts essentially all the particles, the gentler homogenizing procedure we had been using in our fractionation work ruptured only about 10 per cent of the particles, thus accounting for the low result obtained in the original homogenate. Further fractionation released an additional 10 per cent of the total activity from the fractions; the remainder came out as a result of the aging of the particles for five days in the refrigerator.

When these observations were transposed to the living cell, they suggested an interesting means of control of the enzyme activity. Living cells contain numerous phosphate esters of great importance to cellular function. Most of these phosphate compounds can be broken down by acid phosphatase, and investigators had often wondered why this breakdown does not occur in cells where the enzyme is present in large amounts. It now appeared from our results that the protective agent preventing the enzyme from acting indiscriminately on all the compounds might be simply the particle membrane that segregated the enzyme from the rest of the cell. This possibility, opened up by chance, was so interesting that we decided to make it the primary objective of our work.

At first it was believed that the particles containing acid phosphatase were the mitochondria, but later experiments indicated that they formed a distinct group, different from both the mitochondria and the microsomes on which most biochemists had been working. It took several years to establish the identity of the new particles as a separate group. In the meantime the list of enzymes contained within them began to grow. The number now stands at more than a dozen. In common with acid phosphatase, each new enzyme has demonstrated its ability to split important biological compounds in a slightly acid medium. Ultimately all the major classes of biologically active compounds, including proteins, nucleic acids and polysaccharides, were shown to be susceptible to action by the enzymes contained in these particles. As the spectrum of activity broadened, we became the more impressed with the significance of the new particles and of their surrounding membrane. Considered as a group, the enzymes present in the particles could have but one function: a lytic, or digestive, one. Hence the name "lysosome" (meaning lytic body) that

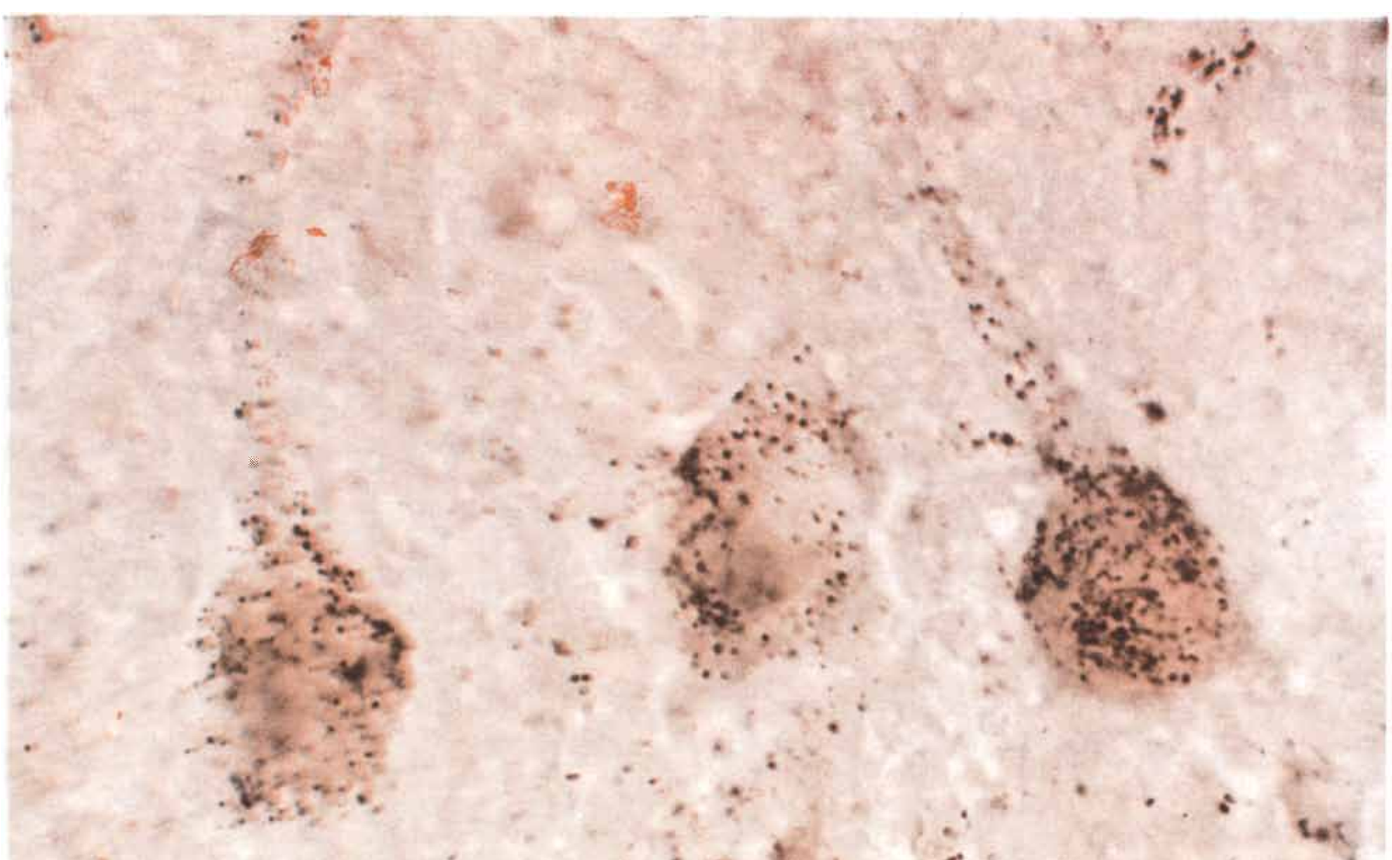


LYSOSOME CONCEPT developed by the author is that of a minute "bag" filled with powerful digestive enzymes. So long as the lysosome membrane remains intact, digestion of the substrates on which these enzymes act is confined within the lysosome. But when the membrane is ruptured, the enzymes leak out and digestion takes place externally, often resulting in digestion of the cell.

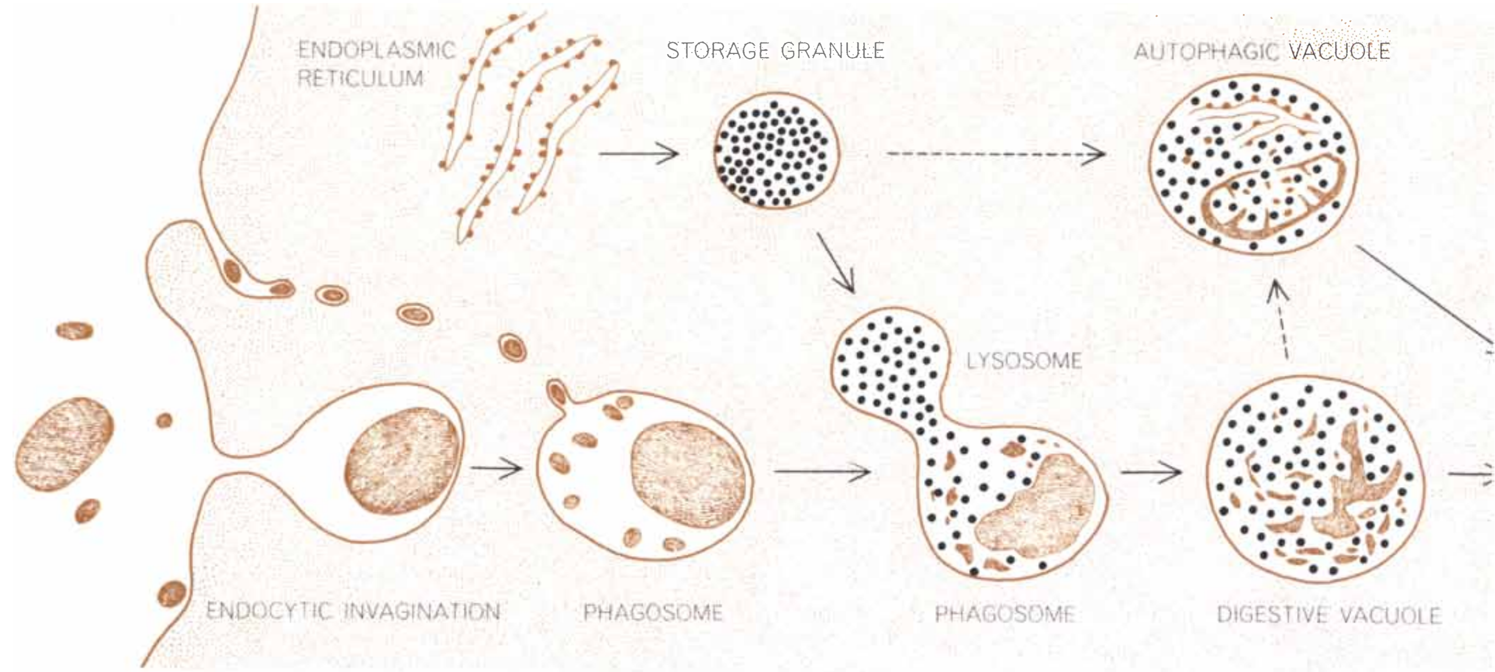
we gave to the particles. As for the membrane, it must act as a shield between this powerful digestive juice and the rest of the cell. The digestive processes, we deduced, must be confined within the limits of the membrane, and the substances to be digested must somehow be taken up in the particles. Conversely, we were alerted to look for those pathological or normal conditions that might lead to the release of the enzymes inside the cell and the dissolution of the cell.

It was not until 1955 that the electron microscope made its contribution to the identification of the lysosomes. Working in collaboration with Alex B. Novikoff of the Albert Einstein College of Medicine in New York, we obtained our first electron micrographs of cell fractions containing partially purified lysosomes. In addition to known particles, mostly mitochondria, the pictures showed large numbers of characteristic bodies that had occasionally been observed in intact liver cells and that had been named "pericanalicular dense bodies." Their function was quite unknown; their name signified only their preferential location in cells along the bile canaliculi—the smaller bile ducts—and their high electron density, or opacity to the beam of the electron microscope. The identification of the lysosome activity with the dense bodies, made provisionally at that time, has since been confirmed by a variety of techniques.

We hoped that the identification of the liver lysosomes would lead quickly to the recognition of the lysosomes in other cells—much as the characteristic structure of the mitochondrion makes it



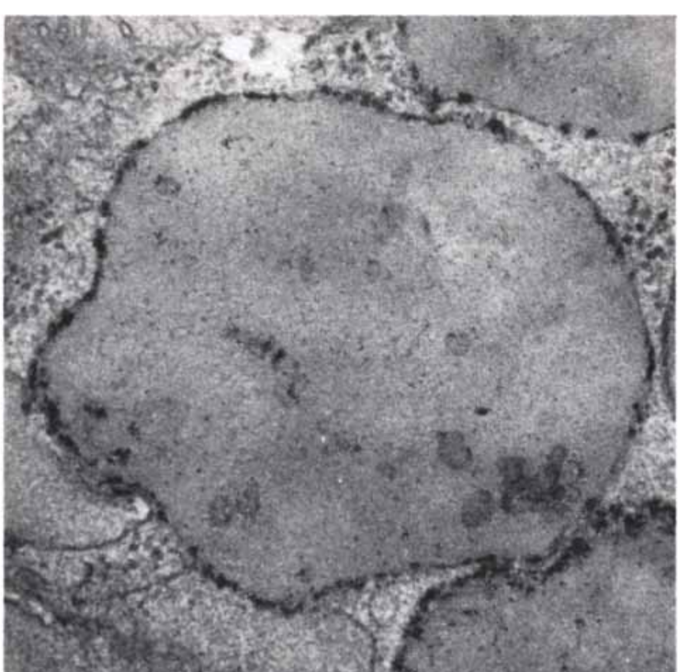
PURKINJE CELLS in the cerebellum of the pigeon contain lysosomes, which appear as tiny dark brown dots. Most of the lysosomes are located in the body of the three cells seen here. Single dendritic processes extending upward from the neurons at left and right also contain a few lysosomes. The magnification of this micrograph, which was made by Novikoff, is 1,600 diameters.



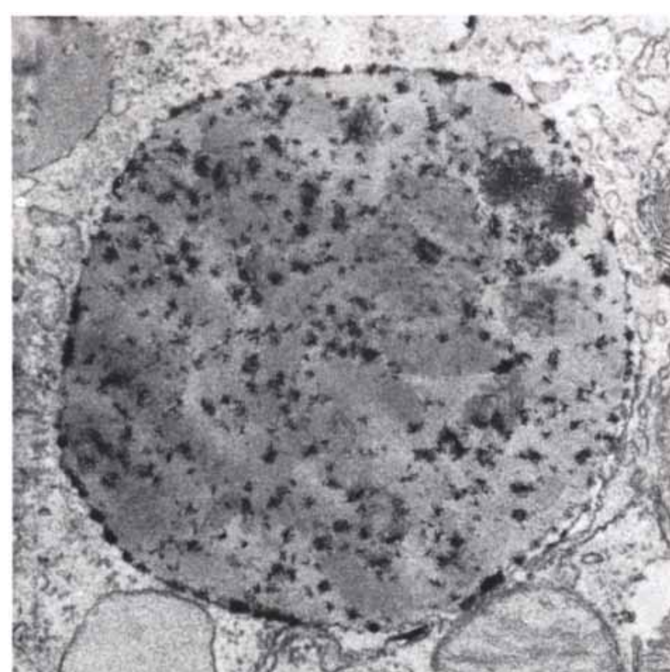
INTRACELLULAR DIGESTION involves lysosomes in various ways. It is necessary to distinguish four kinds of lysosomes: "storage granules," digestive vacuoles, residual bodies and "autophagic vacuoles." The first three are directly involved in the main digestive process. The storage granule is the original form of the lysosome; enzymes in the granule presumably are produced by the ribosomes (*small colored dots*) associated with the endoplasmic reticulum, but the origin of the lysosome membrane is unknown. When the cell ingests substances by endocytic invagination, a phagosome, or food vacuole, is formed. Several phagosomes may fuse together, forming a single vacuole. A storage granule or other lysosome fuses with the phagosome to form a digestive vacuole. Digestion products diffuse through the membrane into the cell. The digestive vacuole can continue its digestive activity, gradually

readily distinguishable in any type of cell. In this we were disappointed. The lysosomes come in a bewildering assortment of shapes and sizes, even in a single type of cell; they cannot be identified solely on the basis of their appearance. In the continuing study of lysosomes, therefore, the cell physiologist or biochemist has had to continue to provide the leads for the cell anatomist and the electron microscopist.

This polymorphism of the lysosomes is now perfectly understandable: their digestive activity causes them to be filled with a variety of substances and objects in an advanced state of disintegration, and it is their contents that determine their shape, size, density and so on. Nonetheless, the lack of any reliable visual criteria has tended to slow the progress of work in this field. The



LYSOSOME is magnified 63,000 diameters. Gomori staining precipitated lead phosphate along lysosome membrane. The micrographs on these two pages, all of mouse kidney cells, were made at the Rockefeller Institute by Fritz Miller of the University of Munich.



DIGESTIVE VACUOLE from kidney cell of mouse injected four hours earlier with hemoglobin is magnified 41,000 diameters. Lead phosphate appears along the membrane and in the interior. Dark gray patches are hemoglobin in the process of being digested.

accumulating indigestible material until it becomes a residual body, which may then be eliminated by fusion with the cell membrane. The distinguishing feature of the autophagic vacuole is the material digested: parts of the cell itself, such as mitochondria and portions of the endoplasmic reticulum.

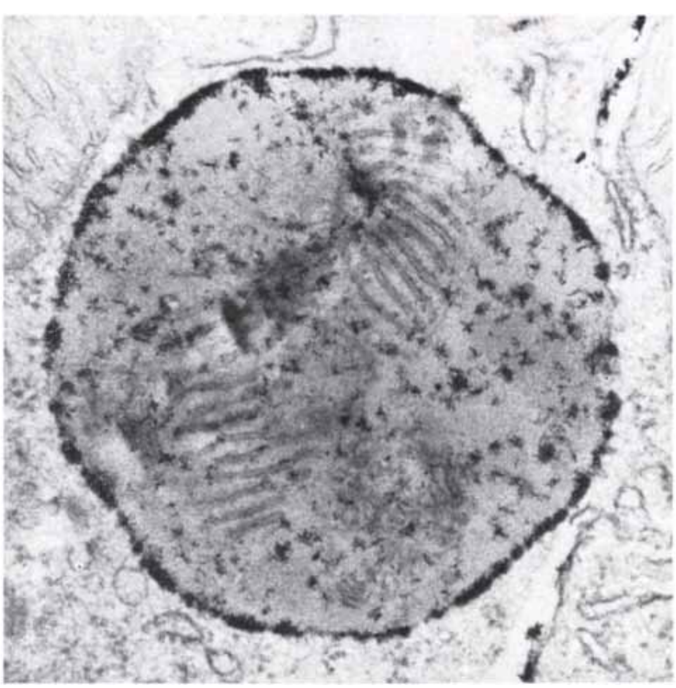
approach used on liver cells has been followed successfully in several other tissues, but it is a laborious one, usually requiring a great deal of repetitive work before one obtains fractions sufficiently pure for electron-microscope studies.

Fortunately one of the lysosomal enzymes—the same acid phosphatase that led to the discovery of the lysosomes—lends itself to visual identification. It can be stained by a method first developed by the late George Gomori of the University of Chicago. A slice of tissue is incubated with a compound susceptible to the action of the enzyme and with lead ions present in solution; at the sites where inorganic phosphate is set free by the action of the phosphatase, the phosphate precipitates in the form of an insoluble lead compound. Because lead has a high electron density the compound plainly shows up in electron micrographs; for visualization in the light microscope the compound is converted to black lead sulfide. Thus the enzyme can be localized inside the cell by means of a precipitated product of its activity. This technique, particularly in the hands of Novikoff, has greatly facilitated the study of lysosomes and their function in numerous tissues in both normal and pathological states.

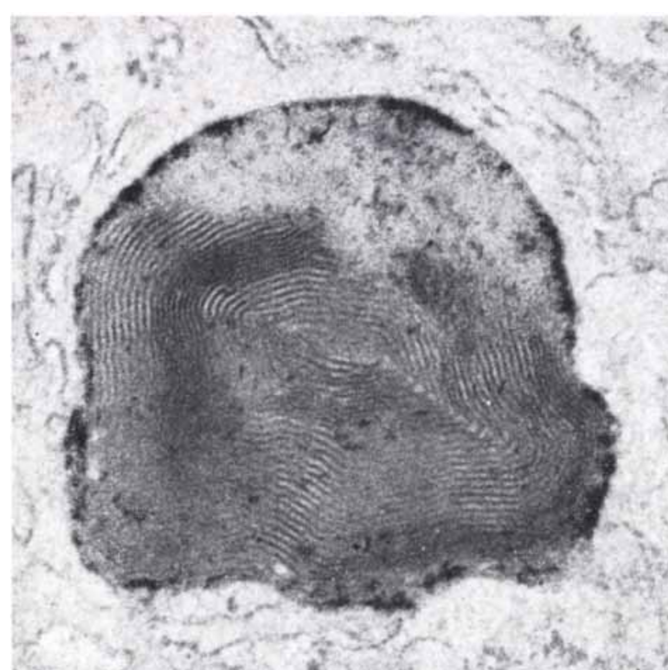
Not all the substances that nurture a cell require digestion by lysosomes. In higher animals tissue cells receive most of their nutrients from the bloodstream in the form of small molecules absorbed through the cell membrane and requiring no digestion in the cell. Some materials, however, are too bulky for direct absorption and too complex chemically for immediate utilization. Objects of this kind must first be "eaten" and digested. Cells are able to engulf large molecules and even bodies as big as bacteria or other cells by a process now generally referred to as "endocytosis." A portion of the cell membrane first attaches itself to the "prey" and then appears to be sucked inward to form a small internal pocket containing the prey. The pocket pinches free from the cell membrane and drifts off into the cell interior, now forming a phagosome, as such bodies have been called by Werner Straus of the University of North Carolina.

The details of the next step vary from one type of cell to another, but they appear in all cases to involve the same fundamental mechanism. The phagosome containing the material to be digested and a lysosome containing the digestive enzymes approach each other; upon contact their membranes fuse to form a single larger vacuole. Digestion then proceeds within the membrane and the products of digestion diffuse into the cytoplasm, leaving behind only such remnants as have proved refractory to attack by the enzymes. Now that the outlines of the process are understood, lysosomes can be recognized in various cells at various stages in the performance of their function, from storage granules for newly synthesized enzymes to digestive vacuoles formed by fusion with a phagosome and finally to bodies containing the residue of previous digestive events.

In some cells, such as the amoeba and other protozoa, the residual bodies are



AUTOPHAGIC VACUOLE contains remnants of mitochondria from its host cell. The remnants appear as pairs of lines. "Needles" of lead phosphate were precipitated by the action of acid phosphatase, a lysosomal enzyme. The magnification is 55,000 diameters.



RESIDUAL BODY containing a layered collection of undigested material is enlarged 76,000 diameters. Lead phosphate is deposited mainly at membrane. The first, third and fourth micrographs on these two pages are published by permission of Academic Press.

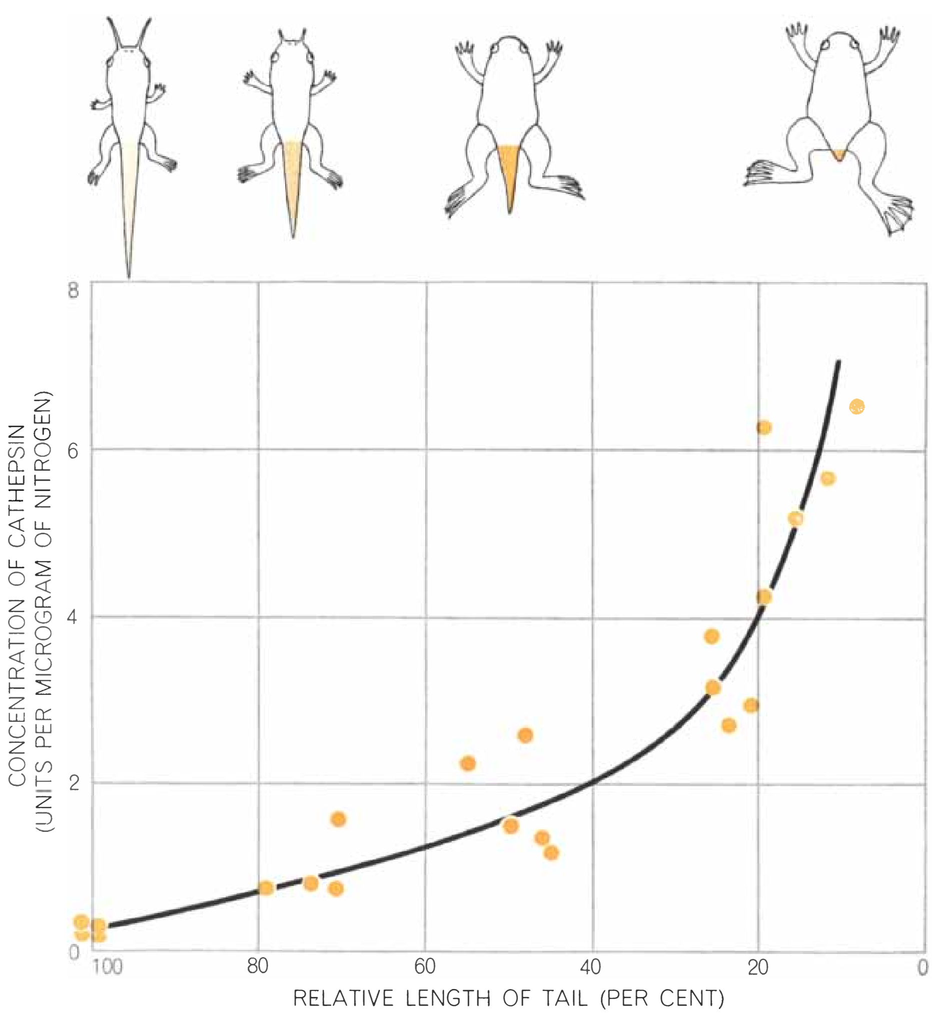
In some cells, such as the amoeba and other protozoa, the residual bodies are eliminated by a kind of endocytosis in reverse, called defecation. In other cells, such as liver cells, defecation is slower or absent; the same digestive vacuoles are engaged repeatedly or continuously in digestive activity. After a time they seem to become charged with increasing amounts of residues, and this accumulation is believed to play a part in the aging of such cells.

As James G. Hirsch and Zanvil A. Cohn of the Rockefeller Institute have brought out, the cellular eating and digestive processes assume their most dramatic form in the white blood cells. These cells seem to spend most of their short life preparing for a single big burst of this activity. It has long been known that at the time the white blood cell enters the bloodstream it is filled with large granules; Hirsch and Cohn have shown that the granules are packages of digestive enzymes fitting the specifications of lysosomes. When the white cell engulfs a particle such as a bacterium, the granules can be seen to disappear one after the other, discharging their contents into the vacuole containing the ingested particle. Eventually the cells lose all their granules and are filled instead with one or more digestive pockets within which foreign particles are in process of dissolution. The cells seem not to recover from this process and eventually die.

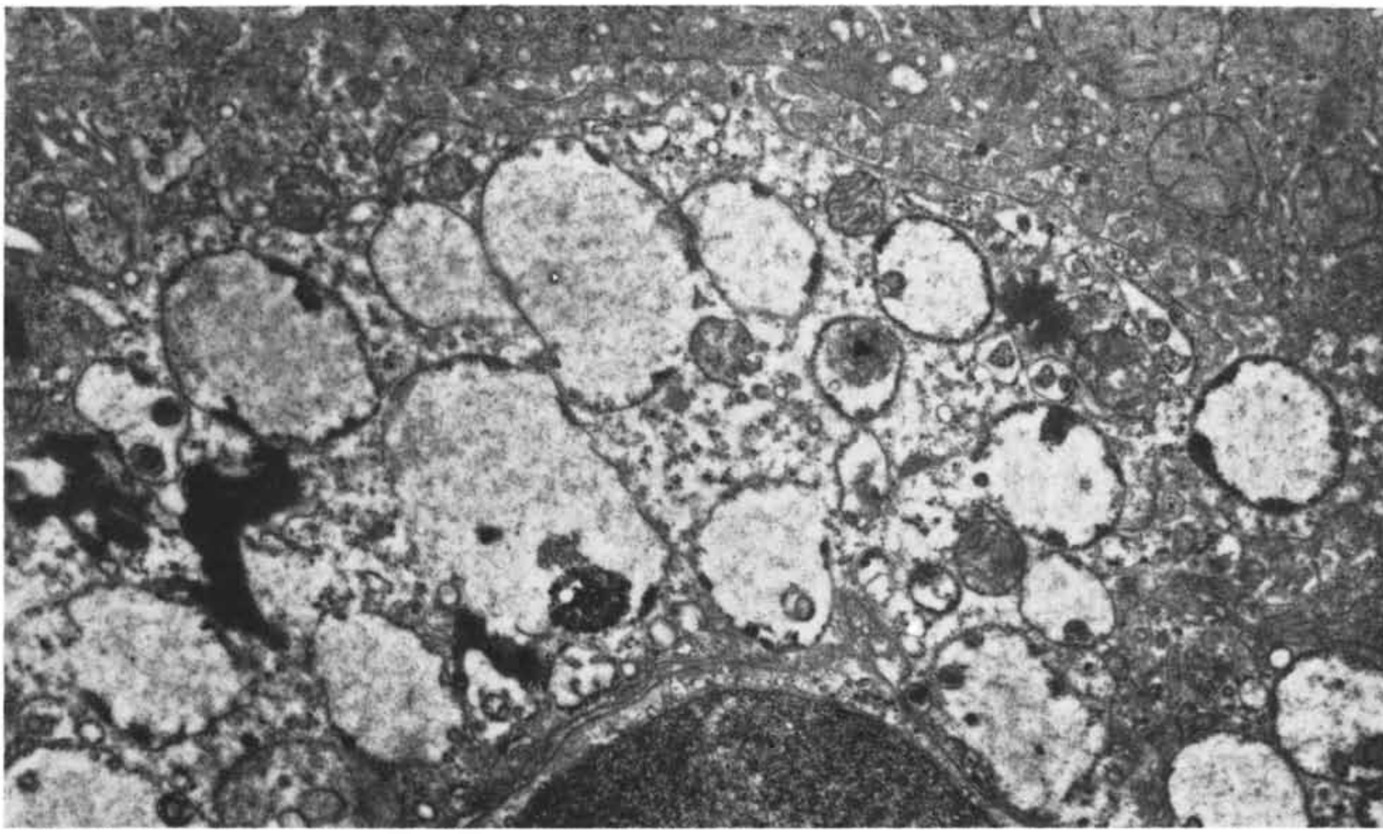
This cycle of events in the cell matches at each point—ingestion, digestion and defecation—the process by which higher animals gain their nutrition. Digestion in both cases takes place behind a resistant envelope that protects the rest of the organism from attack by the digestive juices. In higher animals the resistant envelope forms a canal open at both ends; in most cells it surrounds a number of individual pockets. These are able to mix their contents and also to exchange matter with their environment by processes of coalescence reminiscent of the fusion of soap bubbles. Smaller pockets are also seen to pinch off from bigger ones, but the envelope always remains impermeably sealed around each pocket. One can easily imagine how a more permanent and continuous tract might, under some circumstances, evolve from such a flexible and relatively haphazard system. A primitive alimentary canal is indeed found in some single-celled organisms.

There is evidence that some cells may discharge lysosomal enzymes externally and use them to destroy surrounding structures or to open access for themselves. It is possible that the osteoclasts—bone-destroying cells that, along with bone-building osteoblasts, are responsible for the continuous remodeling of bone tissue—gnaw their way into the bone by a mechanism of this sort. They then complete their destructive action by engulfing bone fragments and digesting them in their lysosomes. It has also been suggested that in the process of fertilization spermatozoa may depend on the release of lysosomal enzymes to dissolve some of the structures that surround the egg cell. Subsequent changes in the egg seem in turn to involve the release of enzymes from the cortical granules that cover the outer surface of the cell. As a result the outer layers of the cell are broken down; a new membrane resistant to such attack is built up underneath, and the metabolism of the egg is geared toward division and development. According to Jean Brachet of the Free University of Brussels the cortical granules may belong to the lysosome family. They can also be ruptured by injury such as the prick of a needle; hence the digestive action of these bodies may have something to do with parthenogenesis: fertilization in which no sperm enters the egg.

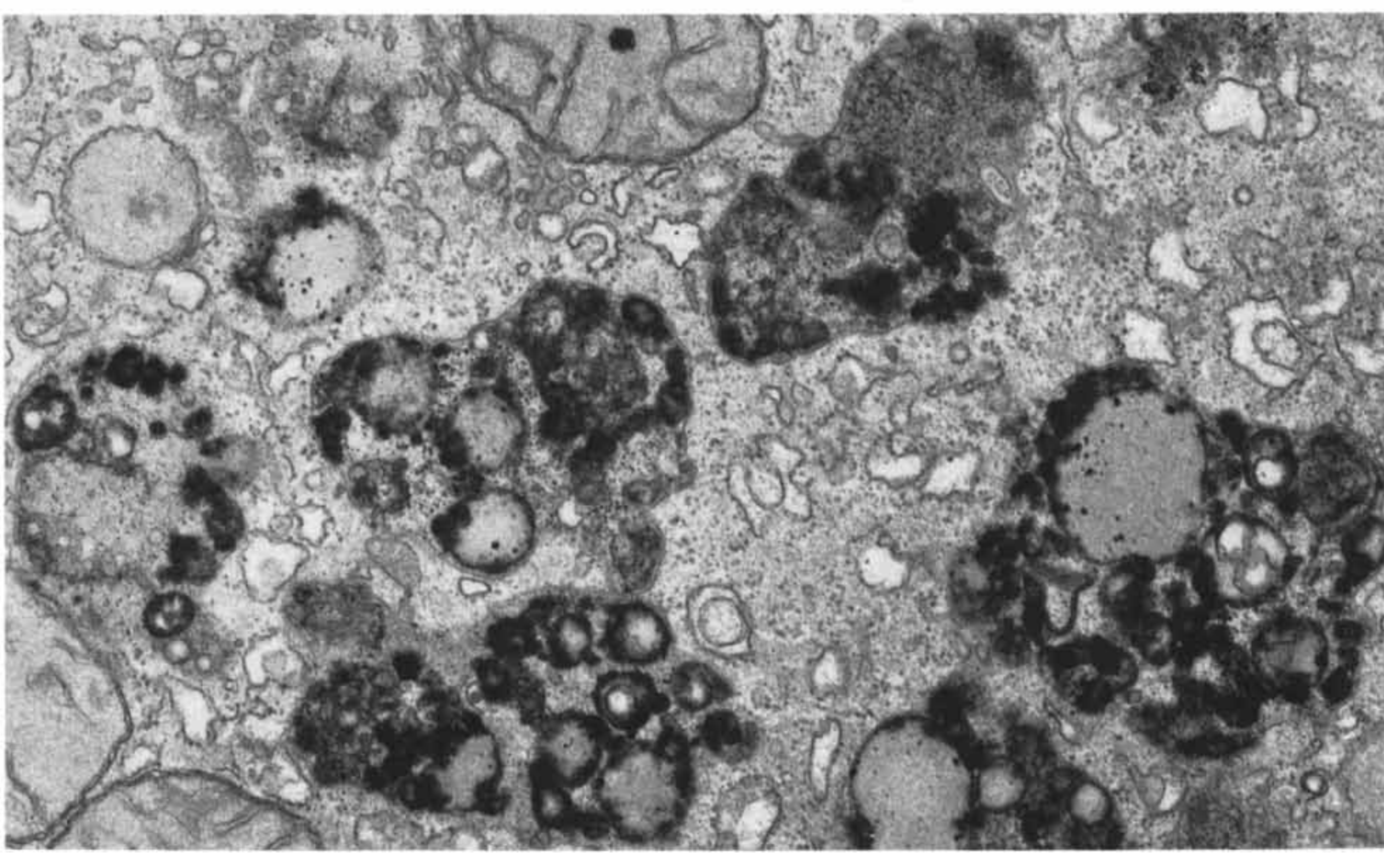
The death of cells, even when it occurs on a large scale, is not necessarily a disastrous event in the life of a complex organism. Many of the component cells of the animal body are short-lived; they die and are replaced by newly formed cells. This is particularly true of the blood cells and of those cells that form the outer layers of the skin and of the mucous-membrane surfaces of the body. Cell death even plays a role in the early molding of the embryo and in the developmental cycle of some animals. As first shown by Rudolph Weber of the University of Berne and recently confirmed and elaborated by Yves Eeckhout in our laboratory at Louvain, when



REGRESSION OF TADPOLE TAIL, in metamorphosis of the South African frog *Xenopus laevis* into an adult, is accomplished by lysosomal digestion of cells. As metamorphosis proceeds the enzyme concentration increases (the absolute amount of enzyme remaining constant). Eventually the stub contains almost nothing but lysosomal enzymes, and it falls off. Data shown here were obtained by Rudolph Weber of the University of Berne.



FORCED FEEDING of Kupffer cells from rat liver was achieved by injecting rats with Triton WR-1339, a detergent. The lysosomes become engorged with the detergent because they cannot digest it. Triton WR-1339 is transparent to electrons; hence the lysosomes, magnified 19,600 diameters, appear as light gray amorphous areas bounded by single membranes. The dark gray area at bottom center is a cell nucleus. The micrograph was made by Pierre Baudhuin and Robert Wattiaux of the Catholic University of Louvain.



STARVATION caused a number of lysosomes in this cell from a rat liver to become autophagic vacuoles. That is, parts of the host cell (e.g., mitochondria) have found their way into the lysosomes. The mechanism that thus enables the cell to feed on its own substance without damaging itself irreparably is not known. The lysosomes are not stained; they appear as amorphous collections of objects of varying sizes, shapes and shades. The magnification of this micrograph, which was made by Beaufay, is about 38,000 diameters.

a tadpole tail has been reduced to an almost invisible stub, it still contains practically all its original complement of lysosomal enzymes and little else.

Lysosomal enzymes play their role in these processes in three different modes. In the first, white cells and other scavenger cells invariably invade the areas where cell destruction occurs: the lysosomes are there engaged through their normal digestive function inside the cell. A second mode, which has been discovered only recently, can be called cellular "autophagy": portions of a cell somehow find their way inside the cell's own lysosomes and are broken down. How the self-engulfment of the cell fragments takes place is not known. During starvation this process apparently enables the cell to use part of its own substance for fuel and for the renewal of essential constituents without doing itself irreparable damage. As in normal endocytosis, autophagy is kept localized by the limiting membrane.

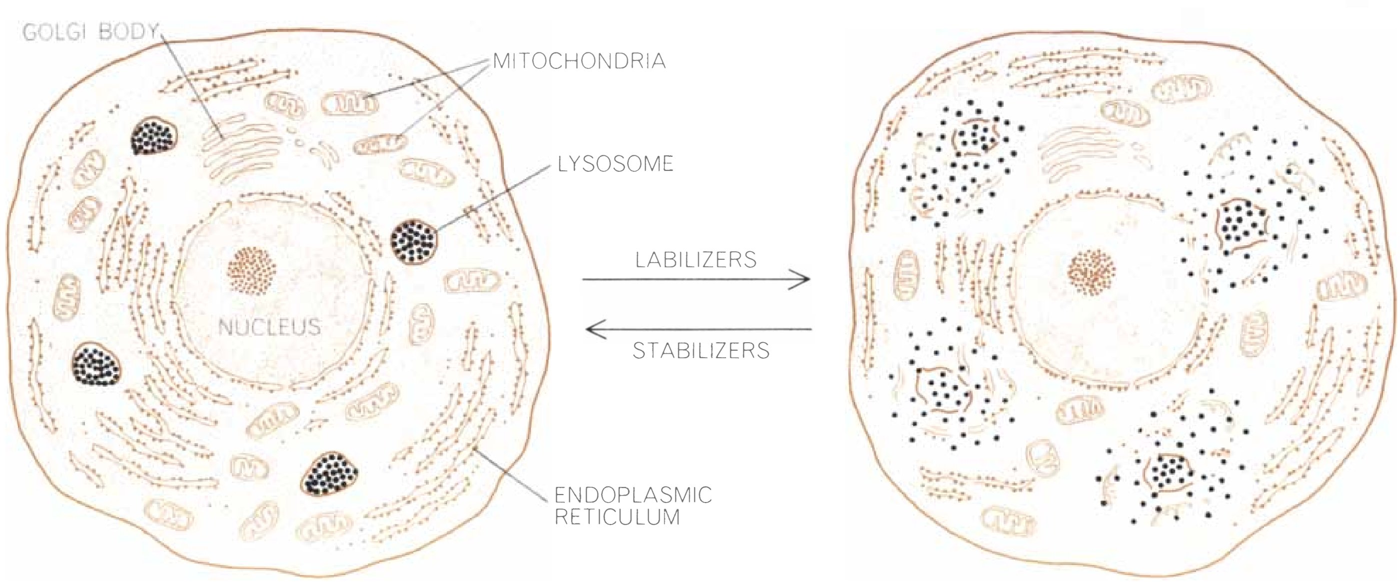
The third mode of action involves the actual rupture of the lysosome membrane inside the cell and the digestion of the latter as a whole by the released enzymes. It can be described as a perforation of the cellular digestive tract. Such ruptures take place fairly quickly in dead cells, in a manner that recalls the rapid post-mortem putrefaction of the digestive mucosae in higher animals. It is obvious that once repair mechanisms are interrupted the areas most sensitive to dissolution will be those immediately adjacent to destructive enzymes. In the normal life processes of multicellular organisms lysosome rupture following death of a cell may have some value as a built-in mechanism for the self-removal of dead cells.

Of considerably greater interest is the possibility that the autodissolution of cells may occur as a pathological process. Present evidence indicates that the lysosome membranes may rupture in cells suddenly deprived of oxygen or exposed to cell poisons of certain kinds. As the enzymes are released they attack the cell itself, and they may also diffuse into the surrounding medium, damaging extracellular structures. Honor B. Fell and her co-workers at the University of Cambridge have shown that this is what happens in the cartilage and bones of animals receiving excess vitamin A. Damage by lysosomal enzymes released from the cells apparently explains the spontaneous fractures and other lesions that attend vitamin A intoxication.

Lysosomes can be involved in cell pathology in still other ways. Cells that are forced to engulf large amounts of foreign substances for the digestion of which they are not equipped will tend to accumulate such material in their lysosomes, possibly to the detriment of their general health. Plasma substitutes, such as dextran or polyvinyl pyrrolidone, have been known to cause this condition. It could also be involved in silicosis, the disease that results from the inhalation of silica dust; the particles of silica may accumulate in the lysosomes. Normal substances might accumulate in the same way if a key digestive enzyme is lacking in the lysosomes as a result, let us say, of a genetic abnormality. H. G. Hers of our department at Louvain recently discovered such a deficiency in the tissues of children who had died of a particularly severe form of glycogen-storage disease; he found that a lysosomal enzyme that attacks glycogen was missing.

If lysosomes can indeed act as "suicide bags"—and we now have good reason to believe that they can and sometimes do act in that way—the question arises as to whether or not their rupture can be influenced by means of drugs. Two possibilities come to mind. Agents acting as stabilizers of the lysosome membrane could be used to protect cells in a critical condition. Or substances that weaken the membrane could be employed to get rid of undesirable cells (for example cancer cells) if their action were sufficiently selective and specific.

So far no conscious attempt has been made to influence lysosomes in either way. But substances of both kinds are already known and some were used therapeutically before their effects on lysosomes were discovered. Vitamin A, in excess, has already been mentioned; although it is not highly specific, it appears to act preferentially on connective-tissue structures. According to recent studies performed by Lewis Thomas and Gerald Weissmann of the New York University School of Medicine, working in collaboration with the Fell group at Cambridge, cortisone and hydrocortisone appear to have a stabilizing influence on the lysosome membrane. This property may account, at least partly, for the well-known anti-inflammatory effects of these drugs. It would seem that in the individual cell, as in the multicellular organism, the digestive system occupies a pivotal position both in physiology and in pathology.



"SUICIDE BAG" is the term coined by the author to describe a lysosome that releases its complement of enzymes within a normal cell. The result is autolysis, or cell death by dissolution. It has been found that some substances affect the stability of the lysosome membrane adversely, thereby increasing the occurrence of autolysis. Other substances are known to have a stabilizing effect.

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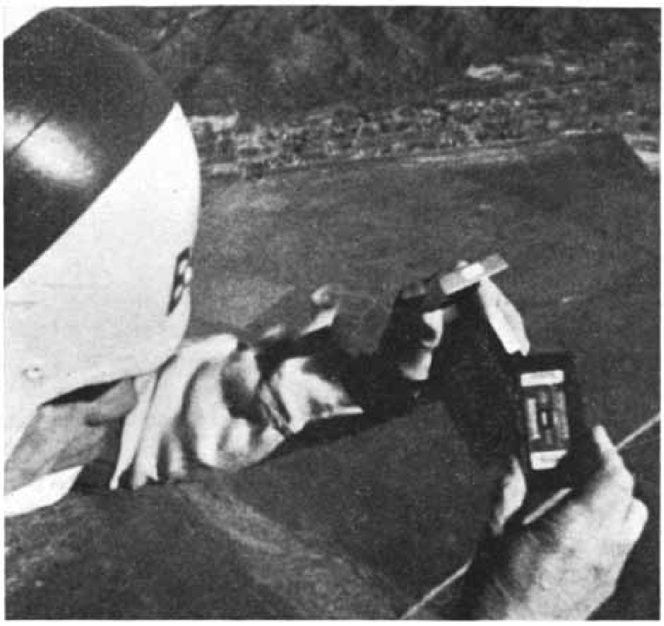

After Mr. Sinclair is sure the camera is all set for picture-taking, he snaps Miss Donna Abrescia, another former passenger in the aircraft, on the film so loaded, with the accompanying result (but in color). Then ripcords are pulled.

Honest!

While it remains possible and even permissible to purchase film in rolls, to retire with it to a place of subdued light, and there to thread the mechanism, such behavior becomes lovably quaint with the advent of the new KODAK INSTAMATIC *Camera demonstrated by Mr. Sinclair. In "electric-eye" models, the mere act of dropping in a film cartridge even automatically sets the exposure control for the speed of film contained within. Only in the processing laboratory does the film finally emerge from its cartridge.* INSTAMATIC *Camera prices range from less than $16 upward. See nearby dealer.*

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One factor that limits the growth rate of the business (and hence of the list) is the groping that so many prospective customers have to do in finding what they want among all the names we might possibly be calling it. We see no early prospects of licking this problem. It's even worse for scientific workers who are not organic chemists and not schooled in *Chemical Abstracts* nomenclature, with which for better or worse we have cast our lot.

With pity for courageous wanderers through the 221 alphabetical pages of our catalog ("EASTMAN Organic Chemicals, List No. 43"), we have lit a feeble candle. For those who know nothing whatever of organic chemistry it will shed little light, but such have no business buying EASTMAN Organic Chemicals anyway. This second edition of "EASTMAN Organic Chemicals Classified by Functional Groups" (it replaces an earlier candle of the same name, now sputtered out) is being mailed to all who automatically receive each new alphabetical catalog and to anybody else who requests it from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company). Those who do not already have List No. 43 should say so.

For the customers' customers' customers

A little party was held in Kingsport, Tenn. recently to celebrate our dedication of 254,000 square feet of laboratory space. The sober mind can find such affairs dull until, beneath the mood of innocent self-congratulation appropriate to the occasion, it sees the situation realistically.

The day-to-day material life of the nation is to be considerably affected from these 254,000 square feet, not surreptitiously but anonymously for the most part. Eastman Chemical Products, Inc. (Subsidiary of Eastman Kodak Company located there) prefers to see all the credit radiate out to its customers, and its customers' customers, and its customers' customers' customers. Some of the chains extend out quite long. Each link draws some reasonable quota of technological support from the next one inward. An outfit like us, working the center position, is expected to generate answers on its own but steal no thunder from manufacturers of swimsuits, Mars probes, or fudge when they put a product of ours into theirs.

The newly dedicated acres comprise three laboratories charged with making this aspect of present-day industrial society work properly. We don't call them research laboratories, because *those* are entirely separate and concern themselves more with next decade's business than this one's. These service laboratories belong right in the midst of the production hurly-burly, right where our people who manufacture the stuff will get themselves wound up in the customer's problems. That's where they have been put.

"The stuff" includes polyester fibers, acetate fibers, modacrylic fibers, butyrate plastics, propionate plastics, acetate plastics, polyethylene plastics, polypropylene plastics, polyallomer plastics, a remarkable adhesive, plasticizers, textile dyes and finishes, lacquer ingredients, aircraft functional fluids, food-grade antioxidants, rubber antiozonants, gasoline additives, paper-coating compounds, and tank-car industrial alcohols, aldehydes, acids and anhydrides, inter alia. *Anybody in a position to order any of this marvelous array of materials in industrial quantities has the right to see what happens when fair questions are asked about their use. Phone 615-246-2111.*

Incidentally, the new setup includes a tailor shop, which makes sense, but you wouldn't want it in a research laboratory.

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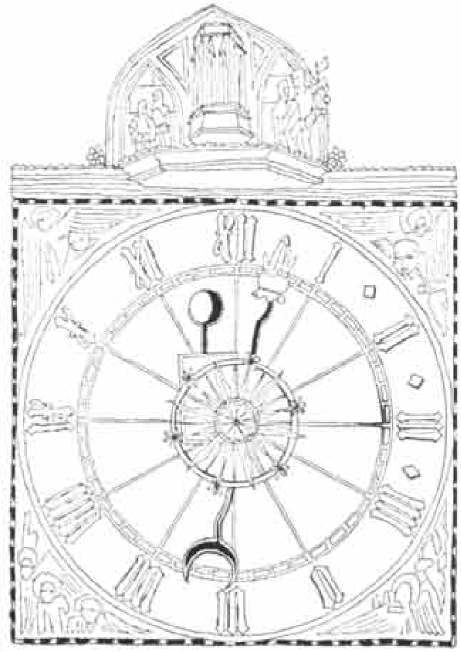
This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

SCIENCE AND



Appointments

Leland J. Haworth, 58, a nuclear physicist and member of the Atomic Energy Commission for the past two years, has become the new director of the National Science Foundation. President Kennedy named him to succeed Alan T. Waterman, who retired in March after directing the foundation throughout the 12 years of its existence. Before joining the AEC Haworth served for 13 years as the director of the Brookhaven National Laboratory.

The President appointed Gerald F. Tape, 47, to replace Haworth on the AEC. Tape was deputy director of Brookhaven for 10 years before he became president last year of Associated Universities, which operates Brookhaven and the National Radio Astronomy Observatory. His appointment means that the AEC will continue to consist of three scientists and two attorneys.

Vaccines for Measles

After some nine years of development and testing, two measles vaccines—one a live-virus preparation and the other an inactivated one—are now licensed for use in the U.S. Simultaneously with the licensing, a U.S. Public Health Service advisory committee has recommended immunization with one or the other vaccine for all children over nine months old without a history of measles. Of the two vaccines, the live-virus preparation is expected to have the wider use, because in more than 95 per cent of measles-susceptible children a single injection of it evokes an antibody response equal to that of natural measles in both level and permanence. The live vaccine, however, produces a variety of side effects, including a fever of 103 degrees or more in 30 to 40 per cent of children receiving the vaccine; the side effects are moderated but not entirely eliminated by concurrent administration of gamma globulin. Good protection is also provided by three injections of inactivated vaccine, but the duration of protection is in doubt.

Both vaccines make use of a strain of virus isolated in 1954 by John F. Enders and Thomas C. Peebles of the Harvard Medical School and subsequently attenuated in Enders' laboratory. Public health workers have eagerly watched the development of the vaccines; measles is more hazardous to the health of children than most people are aware. In the U.S., where two million to four million cases of measles occur a year, the disease exacts an average annual toll of 450 lives and leaves several times that number of individuals handicapped by hearing defects and brain damage. About one case of measles in 1,000 results in encephalitis; in a third of these individuals the brain damage is permanent. Measles is an even more serious problem among children in the less developed areas of the world, where the fatality rate of the disease runs as high as 25 per cent.

Science for the Citizen

Scientists concerned about the citizen's growing need for sound technical information on which to base major public policy decisions have formed a Scientists' Institute for Public Information. The institute, which will serve the common needs of a number of independent information committees established during the past five years, was established by representatives of 19 such groups, who held a two-day conference in New York in February. The new organization will undertake to handle technical and publication services for the individual committees, act as a clearinghouse for ideas, stimulate the formation of new committees and hold conferences.

The institute's founders noted that the accelerating progress of science calls for political decisions that cannot be made unless citizens understand a growing body of relevant scientific information. "Therefore," they said, "it becomes the special responsibility of scientists to serve their fellow citizens by providing the necessary information in understandable form." This information, they held, should be unencumbered by political or moral judgments that are properly the concern of all citizens, should cover divergent studies and interpretations and should be freely available to everyone. Although the committees have concentrated on questions arising from the industrial, medical and military applications of nuclear energy and radiation, they may in the future function in other areas in which scientific data bear on decisions, such as automation, air and water pollution, insecticides and problems of urban life.

Among the 21 members of the institute's board of directors are Theodosius Dobzhansky, Rene J. Dubos and Edward L. Tatum of the Rockefeller Institute, Margaret Mead of the American Museum of Natural History, Warren Weaver of the Alfred P. Sloan Foundation, Barry Commoner of Washington University in St. Louis, Russell H. Morgan of the Johns Hopkins Hospital, Hardin B. Jones of the University of California, Jason J. Nassau of the Case Institute of Technology and James P. Dixon, Jr., president of Antioch College. Jules Hirsch of the Rockefeller Institute is chairman of a temporary committee that will organize the institute and plan its first year's activities.

Metamorphism in the Act

A mile-deep well near southern California's low-lying Salton Sea is providing geologists with what may be their first look at the transformation of sedimentary rock into another major type of rock: metamorphic. The transformation, one of the major processes in the evolution of the earth's crust, requires great heat and pressure and is believed ordinarily to take place at depths of 25,000 feet or more. In a hot-spring area southeast of the Salton Sea, however, drill cores have revealed what appear to be new metamorphic rocks within 5,000 feet of the earth's surface.

The well, 5,232 feet in over-all depth, was drilled in 1961 and 1962 to tap volcanic heat for power. During the drilling a superheated brine of remarkably high salinity and specific gravity was encountered. Analysis showed it to be freighted with more than 33 per cent of dissolved solids, including unusual concentrations of potassium, lithium, iron, lead, silver and other metals. Writing in *Science*, Donald E. White of the U.S. Geological Survey and two associates—E. T. Anderson of O'Neill Geothermal, Inc., drillers of the well, and Donald K. Grubbs, a University of Virginia student—describe the brine as a sample, probably man's first, of an ore-forming "magmatic" water from the earth's interior. Geologists believe that such waters have been responsible for the formation of many ore bodies.

Examination of drill cores also produced a surprise. Cores from between 4,477 and 4,923 feet showed gradually increasing density and a progressive change from soft shales or siltstones to harder minerals characteristic of an early stage of metamorphism. Moreover, the minerals were bedded horizontally in the cores, as might be expected of new metamorphic rock formed *in situ*, not old rock uplifted from the depths of the earth. It has so far proved impossible to measure the temperature at the bottom of the hole. White and his associates believe that it may be as high as 1,290 degrees Fahrenheit, perhaps more than enough under suitable conditions of pressure to initiate the metamorphic process and to produce the first samples of metamorphic rock yet found that are less than 10 million years old.

Brightest Galaxies

Two peculiar celestial objects, previously thought to be rather bright stars within our own galaxy, have turned out to be distant galaxies 10 to 30 times brighter than any hitherto observed. This would make them about 100 times brighter than our galaxy; they are relatively faint only because they are among the most distant objects known. Conceivably they are being observed in the early stages of a titanic explosion.

The two brilliant galaxies belong to a group of five radio-emitting objects that are listed in the third Cambridge Catalogue of Radio Sources as 3C-48, 3C-147, 3C-196, 3C-273 and 3C-286. Radio astronomers at Jodrell Bank in England determined that all five are point sources. This is in contrast to the diffusiveness of most radio sources found to be associated with optically visible galaxies. With the aid of the California Institute of Technology's twin 90-foot dish antennas, U.S. observers assigned precise positions to four of the five objects. Australian radio observers established the location of the fifth. Thomas A. Matthews of Cal Tech superimposed the positions of the five objects on star photographs made with Palomar telescopes and found that each coincided with the position of what seemed to be a fairly bright star. This in itself was surprising because ordinary stars emit so little radio energy that the sun is the only star close enough to be "seen" with radio telescopes.

The next step was to look at the optical spectra of the five objects to see what could be learned of their chemical and physical nature. The spectra made no sense; they failed to show any of the familiar lines of hydrogen or other elements. Jesse L. Greenstein and Maarten Schmidt of the Mount Wilson and Palomar Observatories began to doubt that they were stars at all. If they were galaxies instead, Greenstein and Schmidt speculated, they should be receding—as most galaxies are—and this would show up as a red shift in their spectra. This assumption solved the mystery. In the spectrum of 3C-273 spectral lines indicating the presence of hydrogen, normally seen in the green and violet regions, are shifted so far that they are barely recognizable in the yellow and red regions. Decisive confirmation of the spectral shift was made by John B. Oke of Mount Wilson and Palomar. The shift indicates that 3C-273 is receding at a sixth the speed of light. The red-shift-distance relation for galaxies indicates that 3C-273 is nearly two billion light-years away. Unlike other galaxies at that distance, which can barely be recorded with the largest telescopes, 3C-273 has an apparent visual magnitude of 12.6, which puts it easily within range of amateur telescopes.

The second object, 3C-48, was found by Greenstein to have a red shift corresponding to a recession velocity of more than a third the speed of light, or a distance of 3.6 billion light-years. This distance is exceeded by only one other known galaxy, which is five billion to six billion light-years away. The spectra of the remaining three unusual objects —3C-147, 3C-196 and 3C-286—are still being studied. It is possible that they may establish new records for distance.

Einstein Upheld

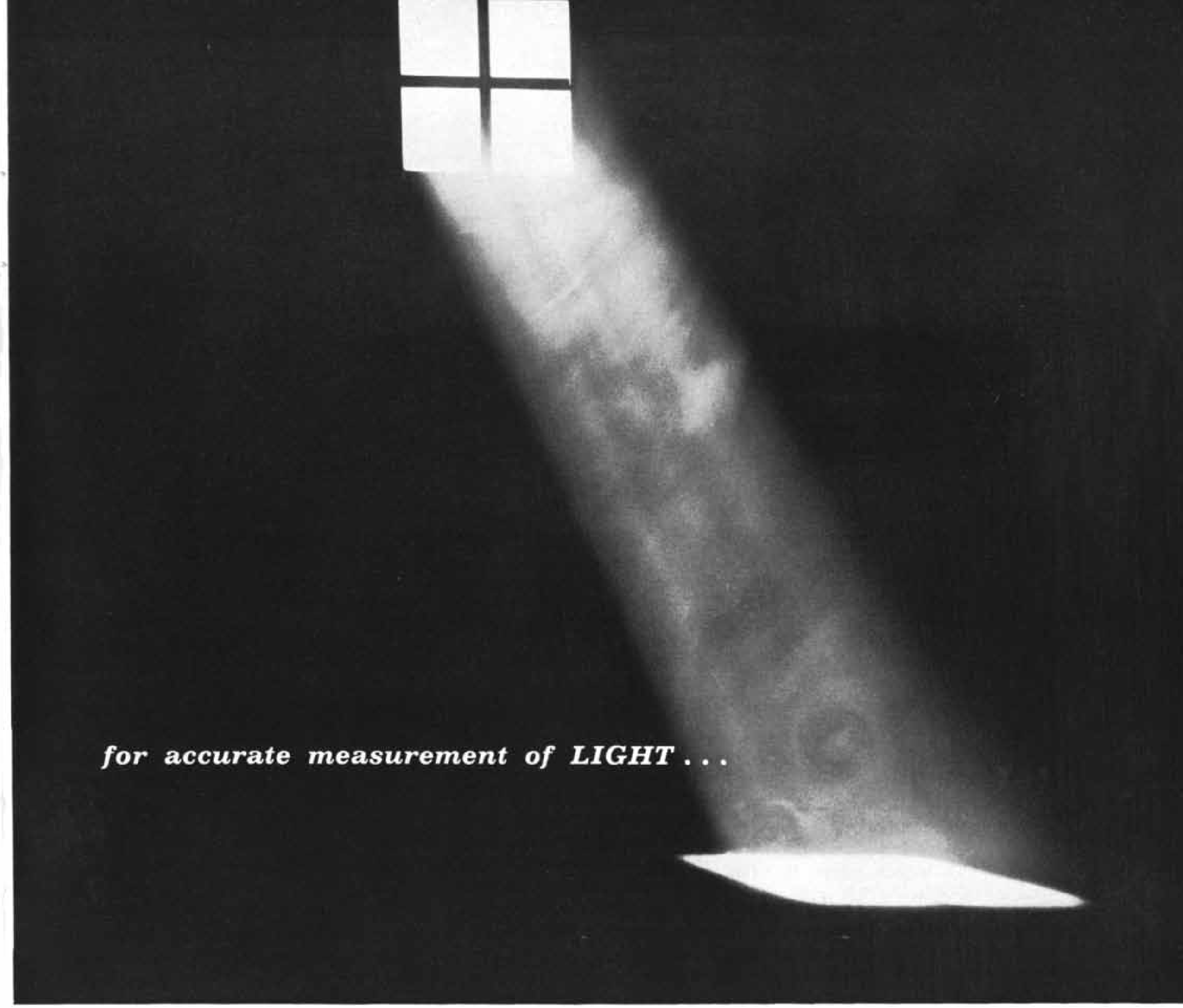
The constancy of the velocity of light, the second postulate of Einstein's special theory of relativity, was called into question by certain experiments performed last year. They purported to show that light traveling through a piece of glass in motion had a velocity different from light moving through the glass at rest. Because the glass was moving at a speed far less than that of light, the test was not decisive. A new test of the second postulate, reported in *Physical Review Letters,* upholds Einstein and appears to be decisive. The new test was conducted by D. Sadeh of the Israel Atomic Energy Commission.

Sadeh based his measurements on the velocity of gamma rays emitted when a positron and an electron annihilate each other. If the annihilation takes place when the particles are at rest, the two gamma rays go off in opposite directions at the same velocity—the velocity of light. For this case there is no disagreement between classical theory and relativity. If, however, the annihilation takes place when the positron is in flight, classical theory predicts that a gamma ray emitted in the direction of flight should have its velocity augmented by the velocity of the positron. A gamma ray fired to the rear should go slower by an equal amount. Because positrons typically travel at about half the speed of light, the effect of the classical prediction should be easy to observe.

To test the two divergent predictions Sadeh contrived a simple apparatus. At one end of a short tunnel he placed a sample of the radioactive isotope copper 64, which emits positrons. The positrons emerge from the tunnel and strike a target made of clear acrylic plastic. Sixty centimeters from the target, in roughly opposite directions, are two crystals that scintillate when struck by gamma rays. One crystal records rays emitted in the general line of flight of the positron; the other records rays fired generally to the rear. Photomultiplier tubes record the flashes at the two crystals, and a fast-acting electronic circuit detects whether or not the two gamma rays from a single annihilation arrive at the same time. Sadeh found that the counts coincided, confirming the Einstein postulate.

Coral Clock

The study of fossils provides a relative chronology for geological deposits and events but not an absolute time scale. Now John W. Wells of Cornell University has proposed a method by which it may eventually become possible to examine some kinds of fossils and estimate their absolute age. Wells's technique would combine paleontology with the findings of astronomy to get results



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that can now be obtained only by measuring the decay of radioactive isotopes.

Astronomers have determined that the speed of the earth's rotation on its axis is slowly decreasing; the current estimate of the rate of decrease is two seconds per 100,000 years. At the beginning of the Cambrian period (isotope-dated at 600 million years ago) a day was less than 21 hours long and there were 424 days in a year. On this basis one can establish a theoretical days-per-year scale for geologic time that shows, for example, 396 days in the Devonian year and 390 in the Pennsylvanian.

Writing in *Nature,* Wells connects these figures with fossils by noting that the annual growth rate has been established for a number of species of corals; in some cases this is particularly easy because there are clear annual growth rings. The epitheca, or outer covering, of some of the corals also bears ridges that clearly reflect some regular variation in calcium carbonate secretion. Is it perhaps a daily variation?

Wells counted the fine lines on some recent corals and found that there were roughly 360 within the space of a year's growth, suggesting that the lines do reflect daily, or approximately daily, variations. It was much harder to find fossil corals with annual growth rings and fine growth lines distinct enough to count. But he did determine that some Devonian corals had between 385 and 410 lines per year, with a mean near 400. And two different corals from the Pennsylvanian period respectively gave counts of 390 and 385 lines per year. All these values fit the theoretical days-per-year scale within reason, implying that the geophysical estimates (from isotope dating) and the astronomical estimates (from rotation-time variation) of the earth's age agree. Wells does not claim that the growth-line verification proves that either of the two standard estimating methods is surely correct. But he suggests that fossils other than corals may also bear diurnal records of some kind. If these can be identified, he writes, paleontology may be able to supply "a third stabilizing, and much cheaper, clue to the problem of geochronometry."

Contrapuntal Bird Songs

Recordings of a unique courtship duet sung by an African shrike have yielded new evidence on the remarkably fast auditory reaction time of birds. Ornithologists have observed that in some tropical and subtropical birds mutual

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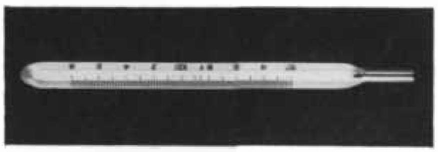
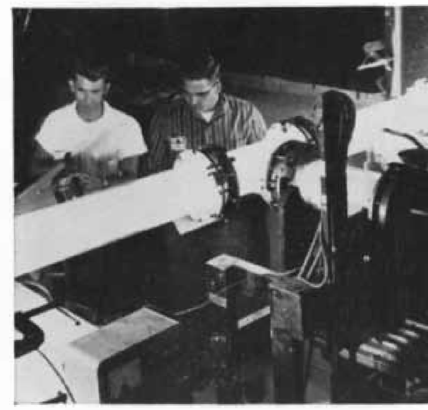


Capillary tubing. Know how we make some of this? We take a thick bubble of glass and s-t-r-e-t-c-h it—whoosh—all the way up a 185-foot tower. One whoosh and you've got enough capillary tube to make 350 thermometers. Maybe you'd like minuscule-I.D. tubing for some other purpose.

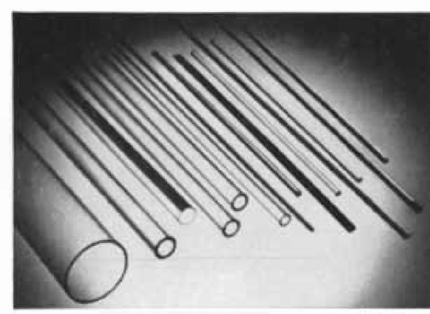
Heater tubing. Here's VYCOR® brand tubing that can really take it. Superb heat-shock resistance, as you can see. Put a wire element inside one of these tubes and you've got the most efficient *far* infrared heater we know of. You can stop right here, if you're interested in heaters *per se*.

BIG cylinders. Like this one for blueprints. It's in here just as a reminder that we can seal the ends of tubing in almost any size if you need something on this order.

High-temperature tubing. The man is about to measure the temperature of molten steel. The thermocouple wires are protected by a tiny VYCOR brand tube. It can withstand 3000°F. long enough to yield an accurate reading and come back for more two times out of three. Tough stuff.



Pipe. Make tubing big enough and strong enough and you can call it pipe. We do. Gas waves traveling at Mach 80 pass through this pipe and collide in the middle where scientists photograph the impact. Our pipe also carries chemicals, mustard, cherries, and milk, among other things. Testimony to its chemical inertness, which means it won't corrode or contaminate in *your* application.



Moral: we make glass tubing in several different glass compositions and in many different sizes, and to tolerances that abolish further finishing operations in most cases. Precision is a good word for it. Economical fits, too.

More information? If we've piqued your interest to the point where you want *specifics* on what we can do for you in tubing, write us about your application. Details, please, so that our reply will be most meaningful.

Meanwhile, can we interest you in a new brochure? "Engineering with Glass" explores many design applications for the family of materials we know best.

Write Industrial Components Dept., Corning Glass Works, 4905 Crystal St. Corning, N. Y.

CORNING

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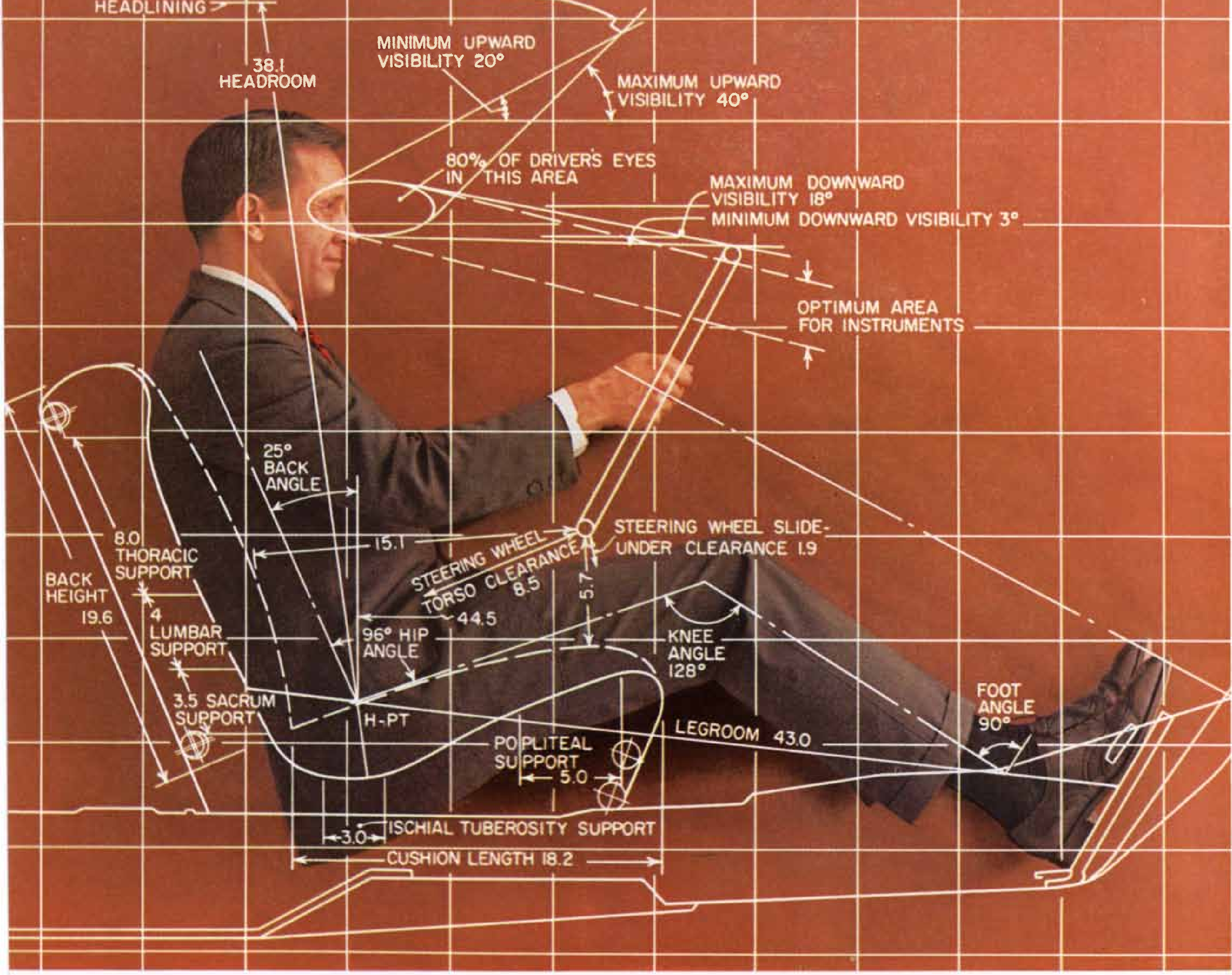

Chrysler Corporation engineers use "Anthropometrical" figures like this in designing cars to "fit" man's needs for comfort and safety.

Man is a challenge—the biggest one we face

Man is all shapes and sizes. So is his family.

Man is the motorist who can sense steering-wheel vibrations as minute as forty millionths of an inch.

Man is the astronaut in outer space.

Man is the engineer on whose skill and imagination great dreams depend.

Man is the car dealer who must back up his promises.

All these aspects of man add up to the biggest challenge any company must meet.

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By selecting the best engineers for intensive training and advanced degrees at Chrysler Institute of Engineering.

By maintaining the high quality of Chrysler-built cars and trucks.

By analyzing sound and vibrations so scientifically as to cause the entire literature of sound to be rewritten.

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auditory display supplements or replaces visual display, particularly in areas where dense foliage makes visual recognition difficult. The male and female of a species utter different sounds and alternate their calls in antiphonal duets of great precision. W. H. Thorpe of the University of Cambridge has recorded and analyzed antiphonal duets sung by birds of Uganda in East Africa. He reports in *Nature* that in some species of the genus *Laniarius* individual pairs of birds develop duet patterns by which they can distinguish each other from other birds in the locality.

Thorpe was struck by the accuracy with which two birds of a pair time their singing, the phrases from each alternating so perfectly that "in no case would one suppose that two birds were involved unless one sees them or until one happens actually to come between them." In the case of the black-headed gonolek (*Laniarius erythrogaster*) the notes are particularly simple: a "yoick" from the first bird is followed by a hissing sound from the mate. Since there was no variation in melody pattern, Thorpe decided that the birds in each pair must recognize each other by a characteristic time interval between the notes uttered by each member of the pair. The second bird (presumably the female) appeared to time its answer from the beginning of the first bird's note and to maintain the same interval in spite of variations in the rhythm of the first bird's calls. Thorpe recorded a series of eight duets in which the time between "yoicks" ranged between 2.5 and 5.6 seconds. He found that the answering hiss nevertheless followed the onset of the "yoick" after a mean interval of 144 milliseconds, with a standard deviation of only 12.6 milliseconds. In a more leisurely duet sung by a different pair the mean interval, or reaction time, was 425 milliseconds and the standard deviation was only 4.9 milliseconds.

Thorpe points out that the shortest reaction time recorded for gonoleks is about three times faster than a human subject's under somewhat similar conditions. The accuracy with which the time interval is maintained is even more striking. Both the speed and the accuracy confirm earlier circumstantial evidence that the auditory reaction time of birds is extremely fast, and they indicate that the avian ear has superior powers of time discrimination. Thorpe suggests that the physiological basis of this ability might be investigated by raising birds in captivity under conditions so good that they learn to sing their duets as they do in the jungle.

Radiation Belts

It has been five years since these rings of trapped particles were discovered. Presenting a review of present knowledge of the belts, with special reference to particles injected by nuclear explosions

by Brian J. O'Brien

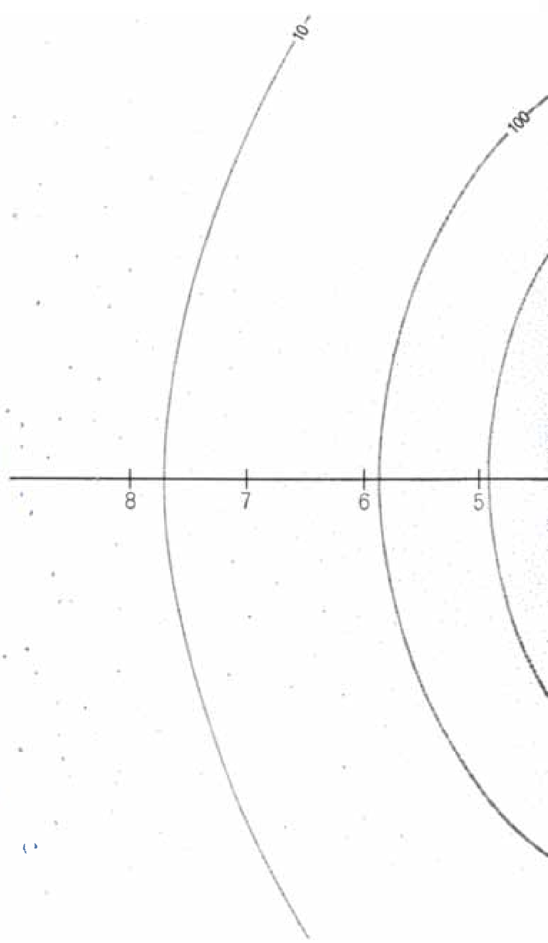
A decade ago man thought he was shielded from the hazards and the vacuum of interplanetary space by only a thin layer of atmospheric gases, perhaps 100 miles thick. He visualized the magnetic field of the earth as spreading symmetrical lines of force out to hundreds of thousands of miles, becoming weaker with distance and finally fading completely away in the still vacuum of interplanetary space. These views changed dramatically with the advent of the man-made satellites of the earth.

Today it is known that the atmosphere extends outward for thousands of miles, a thin, electrified gas of electrons and protons that gyrate along the lines of force of the earth's magnetic field and form a vast toroidal region of radiation around the earth. The outer reaches of this "magnetosphere" are engaged in turbulent interaction with hot, ionized gas streaming from the sun. Through mechanisms still unknown, events here at the boundary between the solar and terrestrial atmospheres seem to be involved in generating the displays of the aurora, the faint high-altitude airglow and the magnetic storms that disrupt communications on the ground; they seem also to contribute to the heating of the lower atmosphere. Conditions in the magnetosphere are so diverse and so variable, however, that millions of observations by scores of satellites and rocket probes have only begun to plot the broad outlines of this extension of the earth into space.

The electrically charged particles streaming toward the earth in the "solar wind" blow aside the outermost lines of force of the earth's magnetic field and compress the lines nearer the earth on the sunlit side; on the dark side they stretch the lines of force downwind for many thousands of miles [*see illustration on pages 86 and 87*]. The magnetosphere may thus be visualized as an elongated egg-shaped cavity in the solar wind; it measures some tens of thousands of miles across (at right angles to the solar radius) and more than 100,000 miles long (along the solar radius). Its boundary with interplanetary space is sharp—only 100 miles deep—on the sunlit side, and moves readily in response to pressure from the solar wind. When the wind is weak, the sunlit boundary of the magnetosphere is 40,000 miles from the earth (the edge on the dark side has not been probed), but a strong wind or gust from the sun can push it back to within 25,000 miles of the earth.

The lines of force that trap the outermost electrons and protons and describe the boundary of the magnetosphere come to earth at 70 to 75 degrees north and south magnetic latitudes. Above the polar regions space is empty of trapped particles; this is the central hole in the toroid that is "plugged" with the sphere of the solid earth. Protons and electrons of relatively low energy permeate the whole trapping region from an altitude of a few hundred miles out to the boundary of the magnetosphere. A belt of high-energy protons is trapped in the portion of the magnetic field that arches some 2,000 miles above the earth at the magnetic equator. Still another belt, containing high-energy electrons, girdles the magnetic equator about 10,000 miles out from the earth. These are the original Van Allen belts, named for James A. Van Allen of the State University of Iowa; it was the instrumentation designed by Van Allen and his colleagues and placed aboard the first U.S. satellites that discovered and mapped the belts [see "Radiation Belts around the Earth," by James A. Van Allen; SCIENTIFIC AMERICAN, March, 1959].

To the perturbations of the magnetosphere induced by the activity of the sun the activity of man has recently added a new kind of disturbance. In 1958 and again in 1962 the U.S. and the U.S.S.R. detonated nuclear bombs at high altitudes, injecting clouds of high-energy particles into the magnetosphere. Although these experiments produced useful information, they have made it difficult, for many years to come, to study certain vital aspects of the natural radiation and its sources.



EARLY MAP of radiation belts around the earth is still accurate but is now known to be incomplete. Contours show counting

Ever since the discovery of the Van Allen radiation almost every satellite and rocket probe has carried instruments, often as the major payload, to measure and report back on the magnetosphere. Yet the total mass of all the trapped particles is about equal to that of one man—the particles are so few and far between that the density of the magnetosphere would be considered an excellent vacuum in a laboratory on the earth. The total weight of all the electrons in the man-made radiation belts, in spite of their profound short- and long-term effects, is less than .01 ounce! Millions of dollars and uncounted man hours are being expended in the study of this small amount of matter because it holds so many clues to the relations of earth and sun and because the radiation poses a hazard to astronauts and to the functioning of satellites.

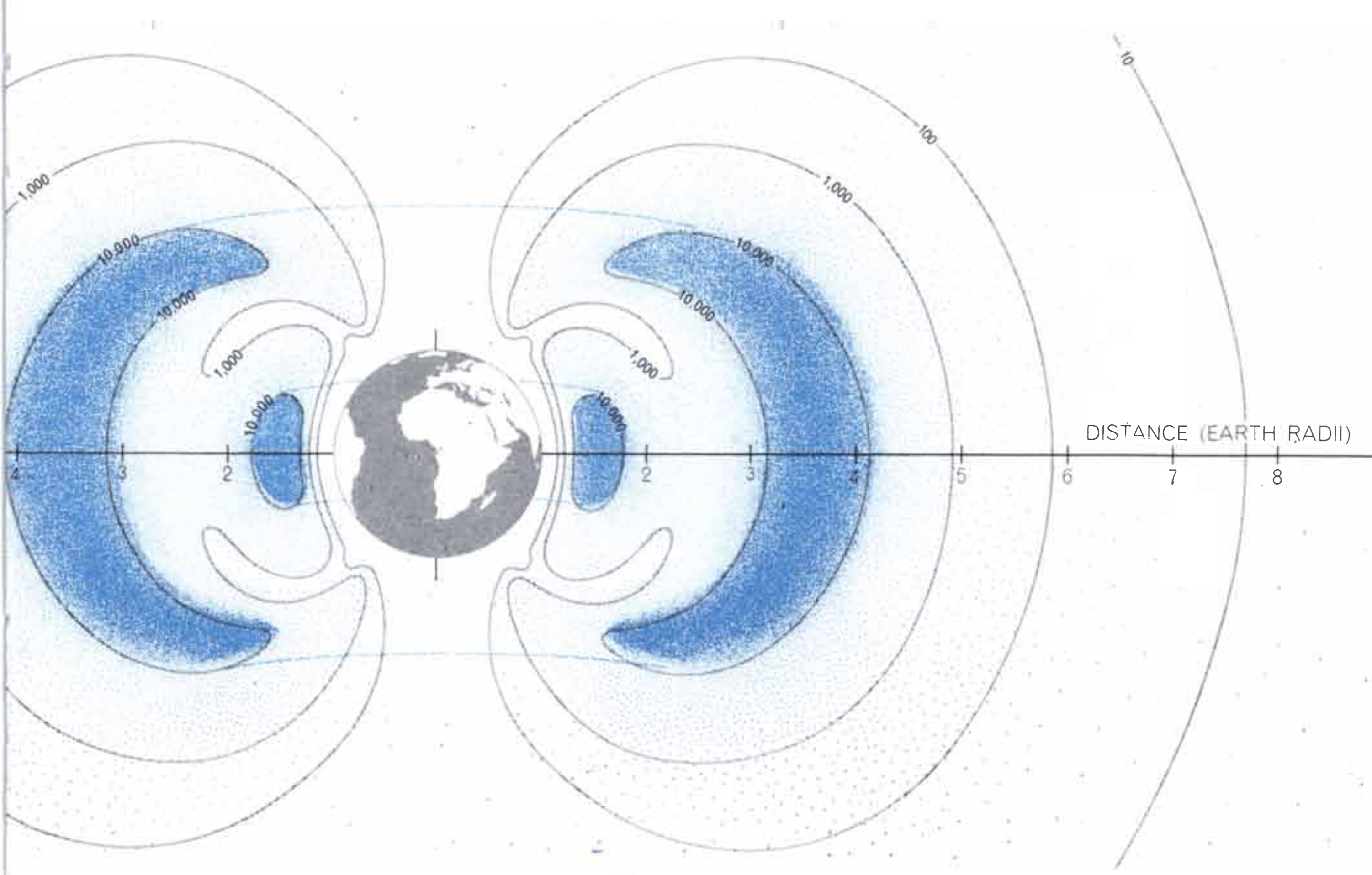
The Discovery of the Radiation

The first earth satellite launched from the territory of the U.S., *Explorer I,* went into orbit on January 31, 1958, carrying a simple Geiger tube to count cosmic rays, those mysterious particles that fall on the earth from sources unknown. A Geiger tube records only the flux of radiation, that is, the number of particles crossing unit area in unit time; it does not distinguish particles by species and, in fact, does not of itself distinguish between particles and radiant energy. Because the atmosphere near the earth absorbs most cosmic rays everyone expected that the flux would increase at higher altitudes. In accordance with this expectation the Geiger tube was fitted with a shield to exclude particles of low energy. To the surprise of all concerned, the counting rate decreased with altitude and sometimes dropped to zero as the satellite crossed the equatorial regions. The investigators wondered if the violence of the rocket launching had damaged the Geiger tube.

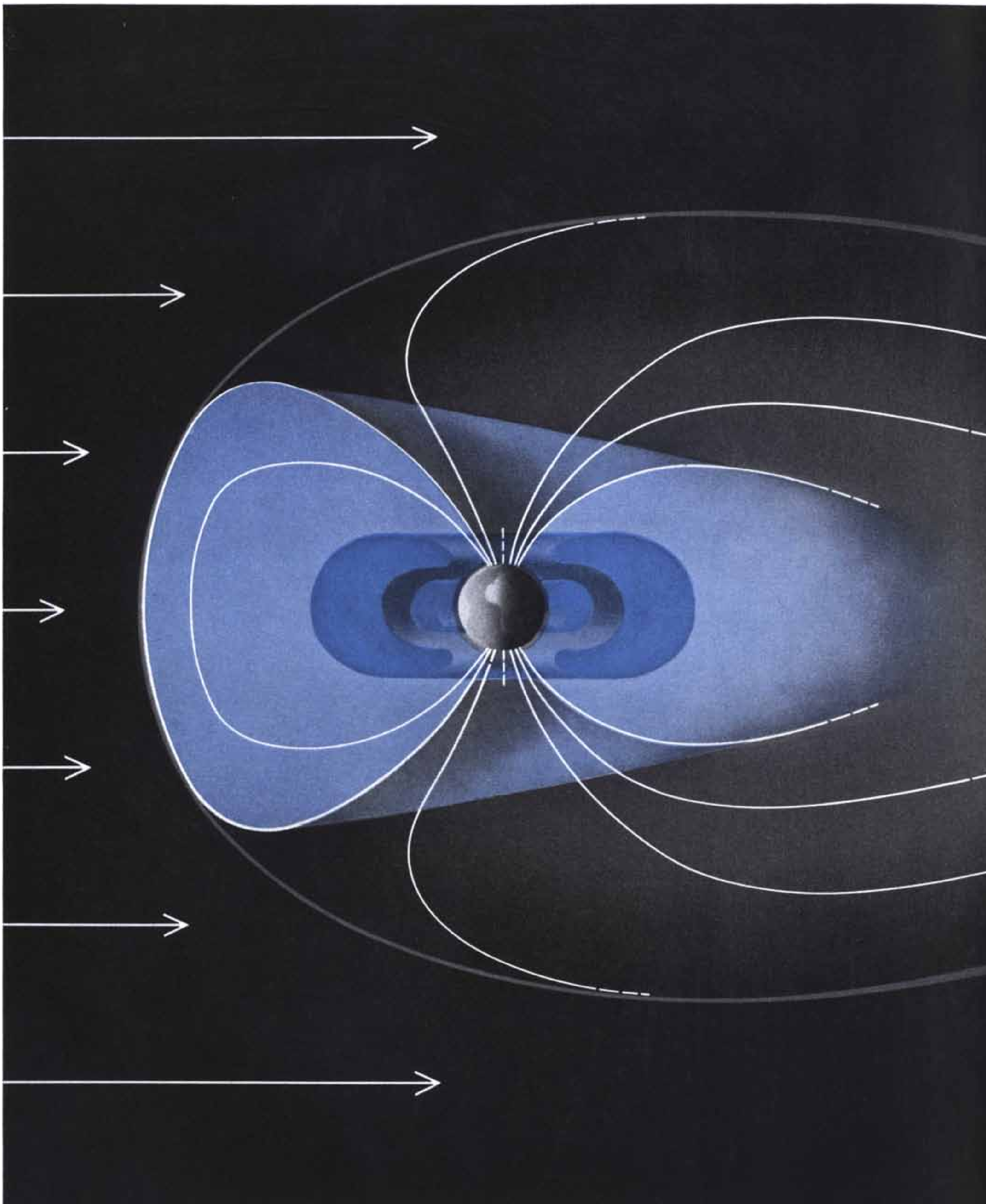
When another tube in *Explorer III* did exactly the same thing, it was recognized that the low apparent counting rate actually meant that an unexpectedly high flux of radiation was saturating and jamming the counters. This was quickly confirmed, and the findings were extended by *Explorer IV,* by the three U.S. moon probes, *Pioneer I, Pioneer III* and *Pioneer IV,* and by the U.S.S.R.'s second and third earth satellites and first moon vehicle.

The measured radiation so far exceeded the levels anticipated from cosmic rays that another explanation had to be sought. Theoreticians came forward with the idea, first proposed in 1907 by the Norwegian geophysicist Carl Störmer, that the earth's magnetic field could act as a trap for charged particles. In obedience to the familiar right-hand rule of electromagnetism—as formulated for this special case by the Dutch physicist H. A. Lorentz—an energetic, or fast-moving, charged particle entering a magnetic field is deflected at right angles to both its original course and the lines of force of the field.

The particle thereupon pursues a spiral path around the line of force. Far out in the earth's magnetic field, where the field strength is low, the spiral is quite open, but near the earth it becomes tighter, until the particle finally moves exactly at a right angle to the line of force. Here it "mirrors" and is reflected in the opposite direction along a similar path [*see illustration on page 91*]. The round trip from the Northern Hemisphere to the Southern Hemisphere and back requires no more than a few seconds. If a particle does not mirror before it comes down to about 400 miles above



rates of shielded Geiger tubes in *Pioneer III* and *Explorer IV*. The high count in inner belt was caused by small number of very energetic, or fast-moving, protons, whereas extremely energetic electrons caused high count in outer belt. This map was drawn in 1959 on the assumption that radiation contours follow lines of force of earth's magnetic field, an assumption that has since been proved true.



TRAPPED RADIATION AND MAGNETOSPHERE as visualized today occupy large regions around earth. Low-energy radiation (*light color*) extends outward for thousands of miles between north and south latitudes of 70 to 75 degrees. Original "inner" and "outer" Van Allen belts (*dark color*) are now known to hold high-energy protons and high-energy electrons respectively. "Solar wind" (*arrows*) distorts and blows back lines of force of earth's magnetic field (*white curves*). The field hollows out large space, known

as magnetosphere, in stream of solar particles. Gray line marks its edge. Conditions far out on dark side of earth have not been studied as extensively as those on sunlit side.

the surface of the earth, it will be absorbed by the atmosphere or at least deflected out of the trapping orbit. This sets the lower limit of the magnetosphere. Conversely, since trapping can occur in the first place only along relatively undistorted lines of force, the distortion of the lines at the outer edge of the magnetosphere sets the upper-altitude limit on trapped radiation.

The increase in strength of the magnetic field near the earth not only causes mirroring but also makes the spiral motion tighter on the side closer to the earth. This compression of the spiral causes the particles to drift in longitude, traveling around the world within a few minutes or a few hours. Electrons move eastward, protons westward [*see illustration on page 90*]. The combination of mirroring in latitude and drifting in longitude accounts for the toroidal shape of the magnetosphere.

Early satellites and high-latitude sounding rockets, which go out as far as 4,000 miles and then fall back, made it clear that trapping does not occur above about 75 degrees north and south latitude on the sunlit side and 70 degrees on the dark side of the earth. The fact that auroras generally appear at these or slightly lower latitudes gave rise to the idea that the polar boundaries of the magnetosphere are somehow related to the violent mechanisms that generate the high fluxes of electrons and protons known to be responsible for auroras. It is probable that the lines of force conduct the particles into the atmosphere in the auroral zones.

The Inner Belt

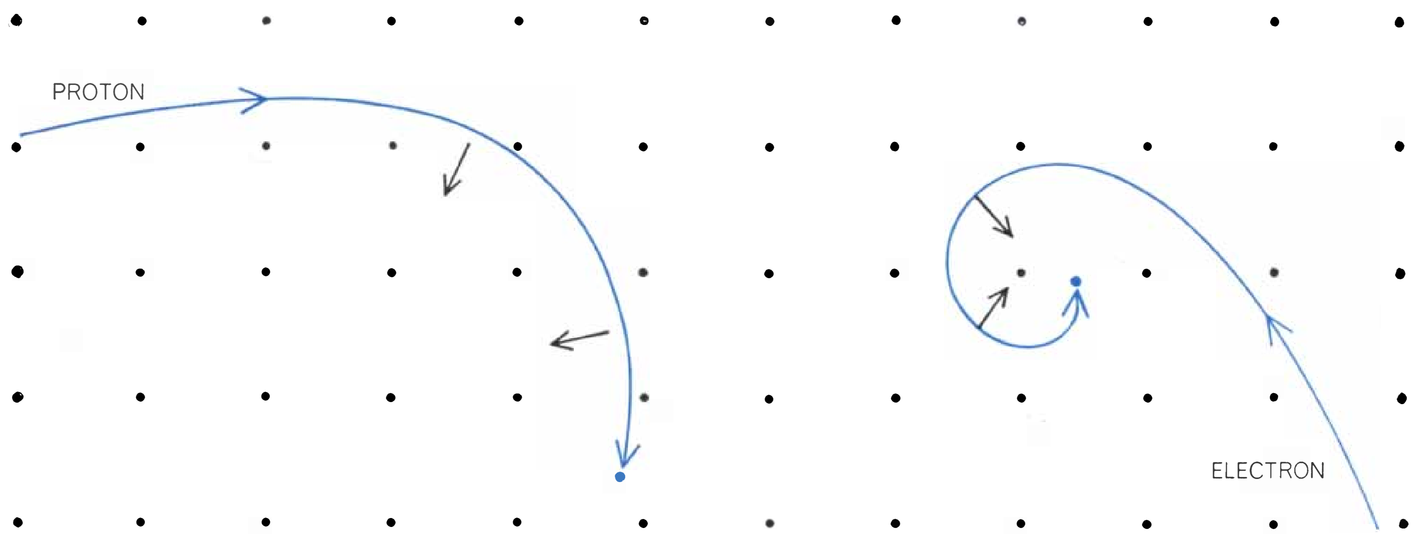
Because mirroring shuttles the particles back and forth across the magnetic equator, the flux is usually highest in the plane of the Equator. In 1958 and 1959 the moon probes *Pioneer III* and *Pioneer IV*, carrying shielded Geiger tubes through the magnetosphere roughly in the equatorial plane, confirmed the original deduction that the magnetic field traps two belts of high-energy particles. The two passes made by *Pioneer III* (the second unintended but nonetheless fruitful) showed that the inner belt is characterized by radiation energetic enough to penetrate a lead shield a quarter of an inch thick. Some months later *Pioneer IV* reported radiation of the same intensity and flux across the 3,000-mile cross section at the inner belt. In the outer belt, however, *Pioneer IV* found conditions radically different from those reported by *Pioneer III*. The radiation had increased greatly in flux and the belt had expanded greatly in cross section.

Later U.S. and Soviet satellites have made it clear that the flux in the outer belt varies in less than a day by a factor of 10 or more, whereas the flux of the inner zone takes about a year to change by a factor of three. As a measurement of the number of particles crossing a unit area per unit time, flux is the product of the density and the velocity of particles. The difference in the behavior of the two belts accordingly suggested that their particles might come from different sources. Many workers have concluded that a relatively weak source of particles can sustain the stable fluxes of the inner belt; the low-flux but steady cosmic radiation seems to fit some of the specifications. For the outer belt, on the other hand, there must be a variable and abundant source. The coincidence of fluctuations in the outer belt with the same solar activity that produces geomagnetic storms strongly points to the solar wind and the sun itself as constituting this source.

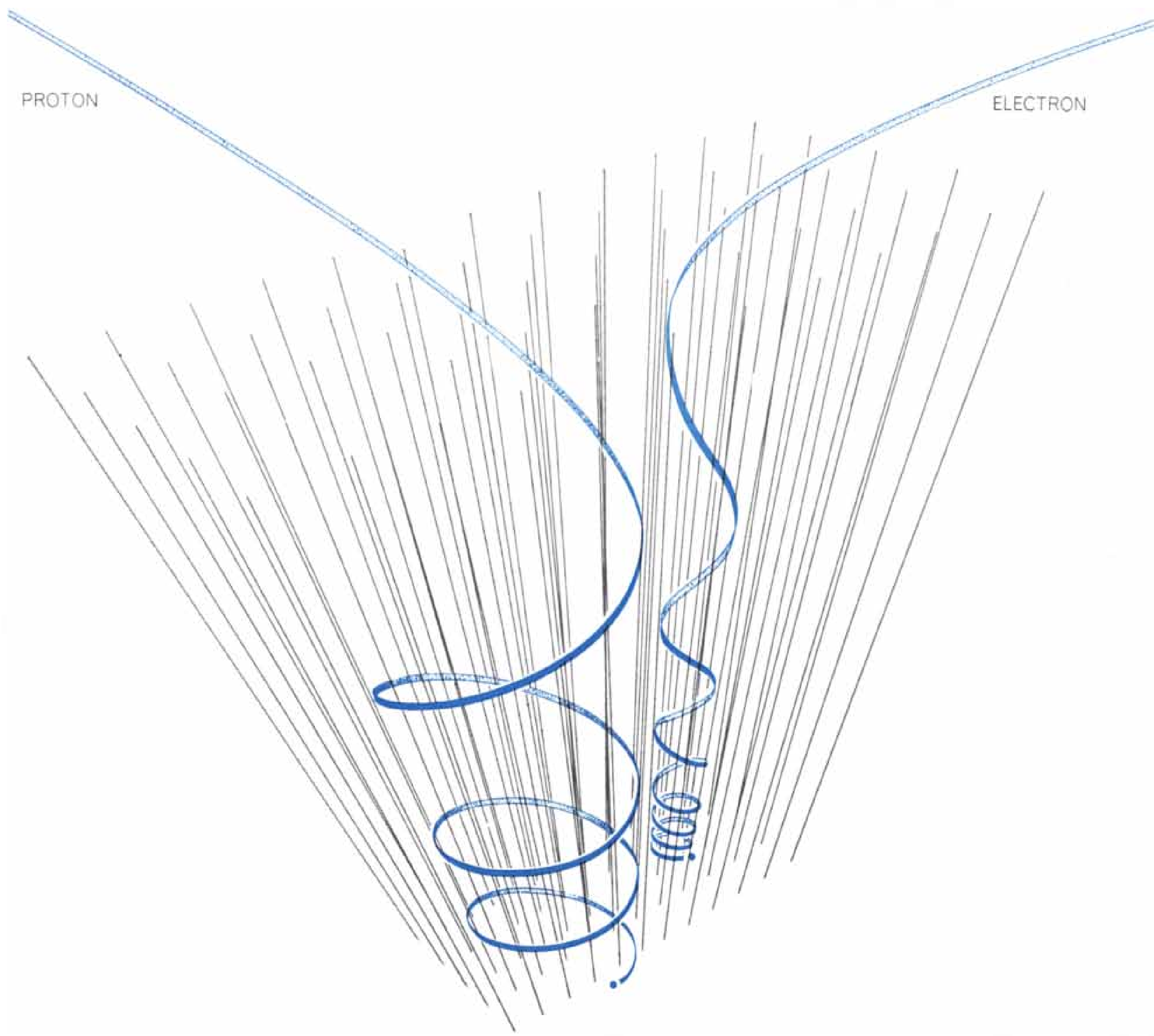
The simple Geiger tubes of the Pioneers, unable to distinguish between protons and very energetic electrons, could tell nothing about the composition of the two belts. Early in 1959 Stanley C. Freden and R. S. White of the Aerospace Corporation flew special nuclear photographic emulsions into the inner belt aboard sounding rockets and recovered them. These revealed that the penetrating particles are protons, some with energies as high as 600 to 700 Mev (million electron volts), the highest energies ever recorded in the Van Allen belts. Most of these, at 20 to 40 Mev, could easily have penetrated the shielding of the Geiger tubes aboard the first Explorers; this accounts in part for the saturation of those tubes. In September, 1960, John E. Naugle and D. A. Kniffen of the National Aeronautics and Space Administration sent up and recovered an apparatus that exposed different portions of a nuclear emulsion along a trajectory that carried it through the edge of the inner Van Allen belt at an altitude of about 1,000 miles. Analysis of the record showed that the average energy of the protons increased as the rocket moved from the northern, or outer, edge of the inner belt into its interior.

The Outer Belt

Determination of the composition of the outer belt, which lies so much far-



LORENTZ FORCE, named for the Dutch physicist H. A. Lorentz, tends to make a charged particle entering a magnetic field travel at right angles to both the direction of its original motion and the lines of force. In this schematic cross section through the earth's field at magnetic equator, viewed from north, a proton (*left*) and an electron (*right*) are beginning to spiral. Dots mark field lines, which lie at right angle to plane of the page. The black arrows denote the direction of the force that causes particles to spiral.



PERSPECTIVE VIEW shows proton and electron as they spiral through magnetic field. Strength of the field is increasing toward bottom of diagram and the spirals are growing tighter. The electron spiral is almost flat and the particle is thus about to "mirror."

ther from the earth, proved to be more difficult. While awaiting definitive measurements, the investigators proposed tentative theories to guide further research and the design of equipment to do it. Because shielding heavier than .1 inch of aluminum strongly absorbed the radiation, Van Allen and others suggested that the particles were likely to be of relatively low energy. This would mean that the Geiger tubes in the Pioneers had counted not particles but X rays produced when electrons of some 40 or 50 Kev (thousand electron volts) bombarded the shielding. Such electrons would not be energetic enough to penetrate the shielding but would generate X rays in it. Geiger tubes are inefficient in detecting X rays produced in this way, emitting only one electrical pulse for every 100,000 to one million electrons striking the shield. The more than 100,000 counts per second recorded by *Pioneer IV* would therefore indicate a flux of 10^{10} to 10^{11} (10 billion to 100 billion) electrons per square centimeter per second. This idea gained fairly wide tentative acceptance because it was consistent with early data from sounding rockets in the auroral zone and with the discovery of a predominance of low-energy particles there.

The data from *Pioneer IV* were susceptible, however, to an entirely different interpretation. If it was assumed that the tubes had counted particles of sufficient energy to penetrate the shielding, then a much smaller number of electrons could explain the more than 100,000 counts per second. In fact, since Geiger tubes count particles with high efficiency, a flux of only 10^6 penetrating particles would be sufficient. Among the proponents of this view was A. J. Dessler, now at Rice University, who had reviewed the results obtained by the first and second Soviet moon vehicles. K. I. Gringauz of the U.S.S.R., working from other data from the same vehicles, also argued that the outer-zone flux was 1,000 times less than that tentatively suggested by Van Allen.

Variations in the counting rate recorded during 1959 and 1960 by Geiger tubes aboard *Explorer VI* and *Explorer VII* served to compound the confusion. The theoreticians had a grand time trying to explain these in terms of accompanying solar and geophysical disturbances. Unfortunately, with the energies and numbers of the particles unknown, it was impossible to tell just what caused the changes in the rate.

The issue remained in dispute until we were able in August, 1961, to place new discriminating particle detectors along with a Geiger tube of the Pioneer type aboard the satellite *Explorer XII*. This satellite operated for three months with an apogee of about 50,000 miles and a perigee of about 200 miles, making about one orbit a day. By combining the data from seven detectors Van Allen, L. A. Frank, C. D. Laughlin and I showed that there are, in essence, two components to the electron radiation in the outer zone. These had been summed in the indiscriminate counting of the Geiger tubes. First of all, we found that the high counting rates of the shielded tubes in the heart of the outer zone result primarily from a flux of penetrating, or high-energy, particles. With the data from the second Soviet moon vehicle taken into account along with our own, we decided that these penetrating particles must be electrons with energies above one or two Mev. Their peak flux in the heart of the outer zone ranges over a period of time between 10^3 and 10^6 particles per square centimeter per second. These accounted for the changes in counting rate that the theoreticians had been trying to explain earlier. There are relatively few of these high-energy electrons in the outer zone, but they travel with such great velocity that they can produce a good-sized flux. The cause of the wide variations in flux of high-energy particles remains uncertain, but it may be related to the betatron, or pumping, action of the fluctuating geomagnetic field during magnetic storms, which could accelerate low-energy electrons to high energies or decelerate high-energy electrons.

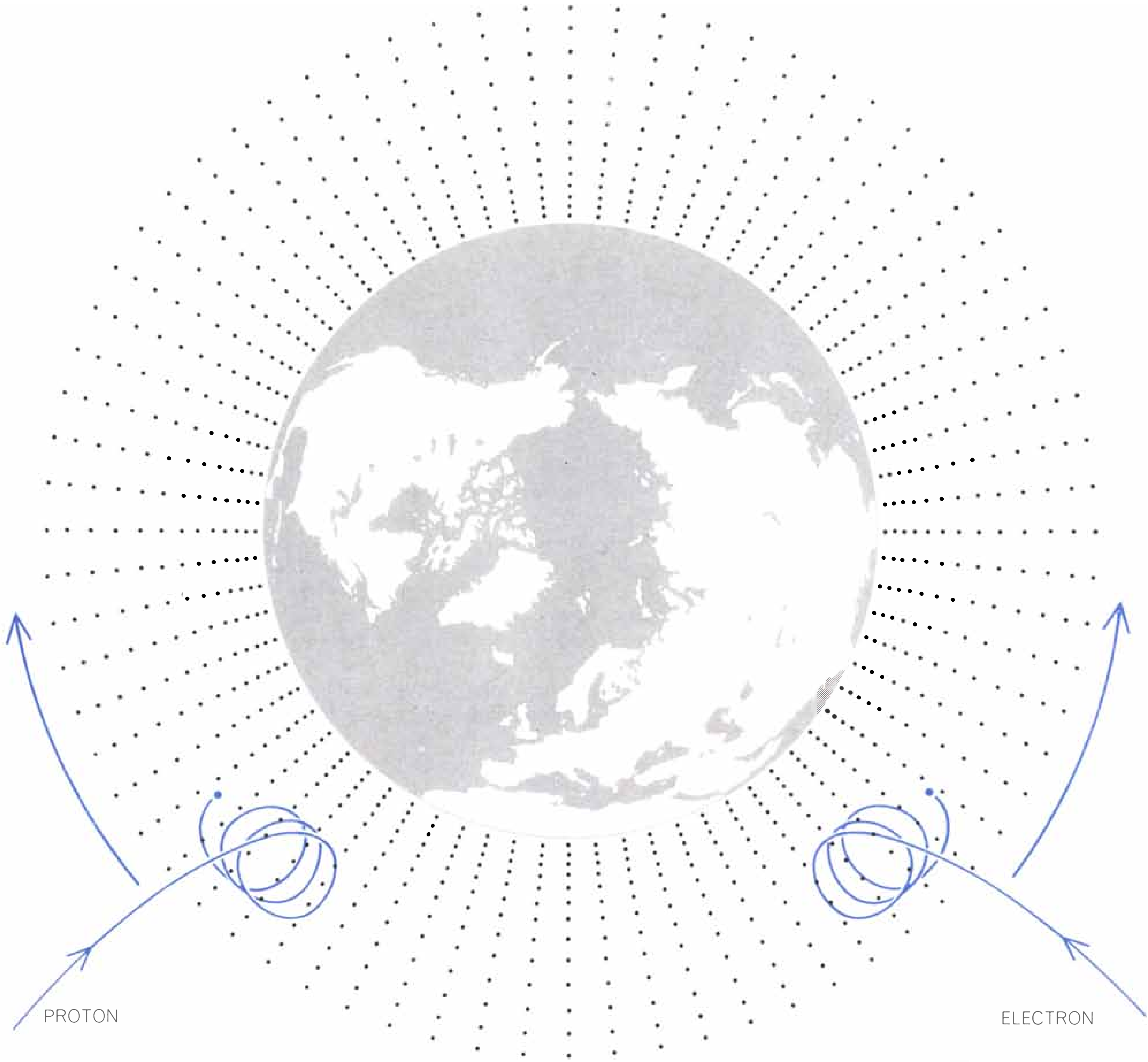
Underlying this high-energy flux, the instruments aboard *Explorer XII* showed, there is a steadier "background" flux of low-energy electrons. With energies measured in tens of thousands of electron volts rather than in millions, these must indeed have registered their presence by generating X rays in the shielded Geiger tubes. After subtracting the flux of the high-energy particles that registered their presence directly, however, the low-energy flux could be set at 10^7 or 10^8, rather than at 10^{10} or 10^{11}, as postulated earlier by Van Allen and others. By direct detection of low-energy electrons, we concluded that their normal flux in the outer zone is of the order of 10^7 particles per square centimeter per second, falling to 10^6 or rising to 10^8 during geomagnetic storms.

The Magnetosphere

Explorer XII completed the broad outlines of our present picture of the magnetosphere when it showed that the flux of low-energy electrons (those able to penetrate .0001 inch of aluminum) remains about the same in the equatorial plane from the inner Van Allen belt of high-energy radiation, through the outer high-energy zone and on out to the edge of the magnetosphere. These findings nicely bracketed the results obtained with *Explorer IV*, which in 1958 had disclosed the presence of low-energy radiation in the inner belt. Sounding rockets bearing Geiger tubes with small magnets mounted in front of their windows supplied conclusive evidence that this radiation came from electrons. The magnets sharply bent the trajectories of the particles; only electrons, which have a very low mass, would have responded in this way. By the end of 1959 various studies had shown that more than 99.9 per cent of the inner-zone radiation able to penetrate .0004 centimeter of aluminum consists of electrons. The high-energy protons that overwhelmed the counters in *Explorer I* and *Explorer III*, and that first revealed the presence of trapped radiation, make up less than .1 per cent of the particles in the inner belt.

That the magnetosphere is also pervaded with low-energy protons traveling on trapping orbits was demonstrated by another experiment carried aboard *Explorer XII*. Leo Davis and J. M. Williamson of the Goddard Space Flight Center designed the instrumentation to detect these particles. It revealed just as large a flux of low-energy protons in the heart of the outer zone as we had found there to be low-energy electrons. Here again *Explorer XII* extended prior findings by rocket probes that the average proton energy decreases as the altitude increases. In the heart of the inner zone most of the protons have enough energy to penetrate the shielding of the Geiger tubes of the early Explorer and Pioneer flights, but in the heart of the outer zone they do not. Part of this decrease in average proton energy occurs because the weaker geomagnetic field at higher altitudes cannot hold high-energy protons in tight enough spirals to trap them. A proton with an energy of 100 Mev in the outer zone, for example, would spiral in a loop about 3,000 miles in diameter, so that it rarely would make more than one mirroring reflection before it plunged into the atmosphere. A proton with an energy of 100 Kev, on the other hand, has a spiral diameter in the outer zone of only about 100 miles, and an electron with an energy of 100 Kev has a spiral diameter of only one mile.

Throughout the magnetosphere—except for regions occupied by the two

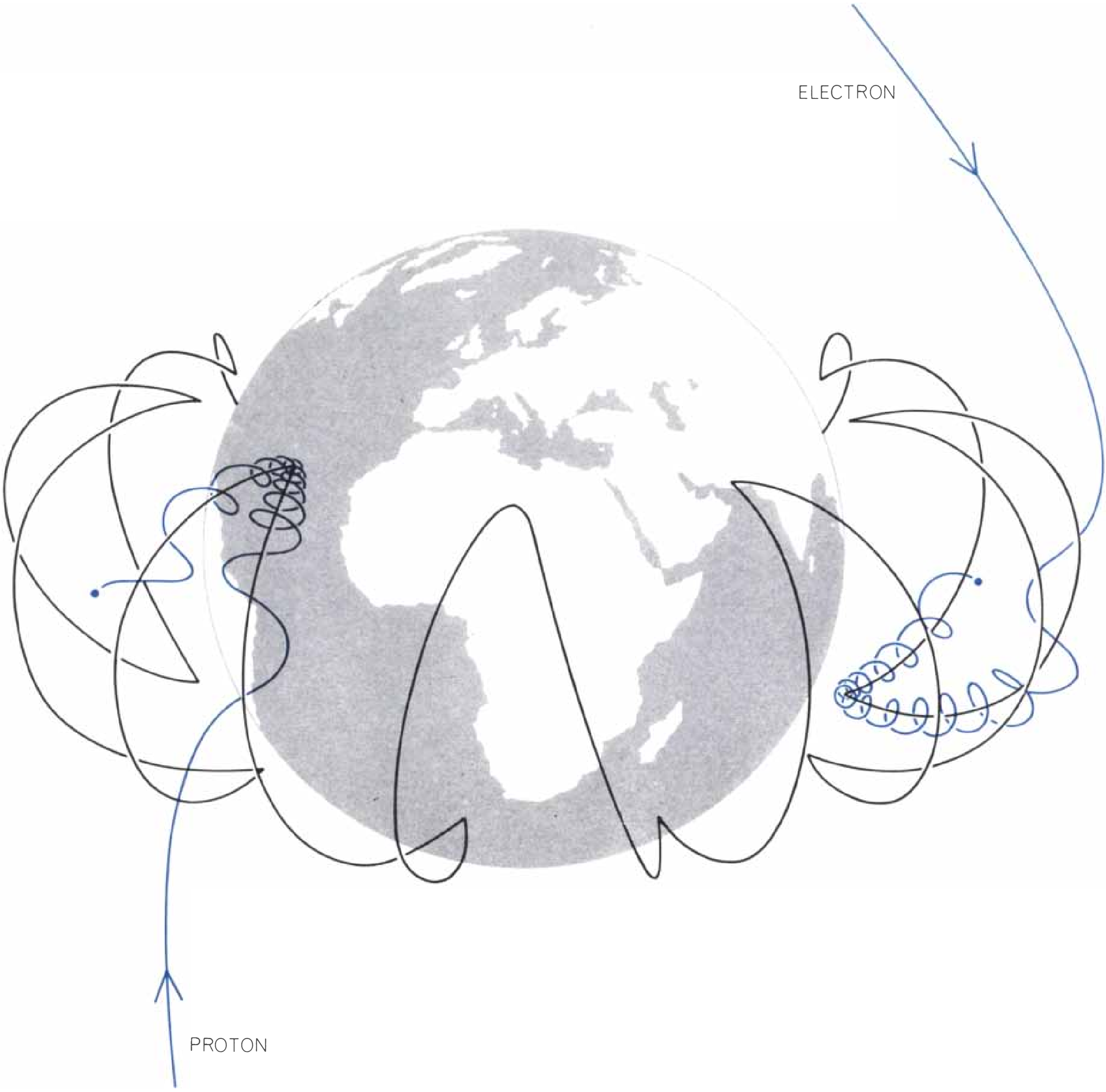


DRIFTING IN LONGITUDE by charged particles occurs because greater strength of magnetic field on side nearer earth makes spiral tighter there. Proton (*left*) drifts westward, electron (*right*) eastward. This view, from North Pole, does not show mirroring.

high-energy Van Allen belts—the flux of protons of a given energy seems on occasion to be roughly equal to the flux of electrons of that energy [*see illustration on page* 95]. This might imply that the radiation energy is shared equally by the protons and electrons that strike the magnetosphere after traveling in an electrically neutral cloud from the sun. It is not, however, immediately apparent why there should be such equipartition of energy between the two species of particles. If, as is thought, they travel together in the same cloud and with the same velocity from the sun, the protons will be much more energetic because they are 1,840 times heavier (kinetic energy being equal to half the mass multiplied by the square of the velocity). The proton energies in the solar wind measured by *Explorer X* and *Mariner II* (the recent Venus probe) are a few thousands of electron volts, so that electrons traveling at the same velocity should have only about one electron volt of energy. Protons of the observed energy could come in far enough to be trapped by the Lorentz force, but the electrons could hardly penetrate the geomagnetic field.

Theory on this question is still unsettled. It appears that the protons will set up a region of excess positive charge near the boundary of the magnetosphere, whereas farther out the electrons make a region of excess negative charge. The electric field created by the separation of charges will pull the low-energy electrons into the region of positive charge, thereby accelerating them up to energies of at least a few thousand electron volts. The possibility that this theory holds for energies of hundreds of Kev as well as for a few Kev remains to be investigated.

The low-energy protons may be responsible for some of the changes in the strength of the magnetic field observed on the ground. Although there are roughly equal numbers of electrons and protons of a given energy crossing a unit area in unit time, the heavy protons travel much slower than the light electrons. For example, a 100-Kev proton moves at about 1.5 per cent of the speed of light, but a 100-Kev electron moves at nearly 55 per cent of the speed of light. Thus in a given time a given number of such electrons will spread through about 40 times more



ROUTE OF PARTICLES (*color*) mirroring in latitude and drifting in longitude is shown in this diagram. The proton and the electron are tracing out their spirals along the route. Any number of other routes are possible for other particles trapped in the field.

space than the same number of protons of the same energy. Davis finds, for instance, about one low-energy proton per 10 cubic centimeters; we find one low-energy electron per 400 cubic centimeters. The protons must therefore carry most of the energy density (the number of electron volts of particle energy per unit volume). As Davis points out, the energy density of the protons is comparable to that of the earth's magnetic field; the very movement of the protons must generate local magnetic fields similar in magnitude to the earth's field in the region. Several observers have speculated that some of the changes in strength of the field observed on the ground during magnetic storms may be caused by the longitudinal drifting of newly trapped protons.

On its travels out to an apogee of 50,000 miles *Explorer XII* found that the boundary of the magnetosphere is remarkably thin, sometimes only 100 miles across. A magnetometer placed on the satellite by Lawrence Cahill of the University of New Hampshire disclosed that beyond the boundary the earth's magnetic field is highly distorted and variable in magnitude and direction. Cahill suggests that this is the intermediate zone of interaction between the earth's field and the true solar atmosphere in the earth's orbit.

The *Explorer XII* data apply only to the sunlit side of the earth; the satellite did not traverse the dark side. *Explorer X*, which went to the dark side but operated for only a short time, has given a tentative picture that shows the magnetosphere extending out past 80,000 miles. Herbert S. Bridge of the Massachusetts Institute of Technology and J. P. Heppner of NASA, who designed much of the instrumentation for this satellite, reported that the earth's magnetic field appears to be carried outward on the dark side by the solar wind. It is not yet known, however, how much of this region beyond the outer high-energy belt is occupied by trapped particles.

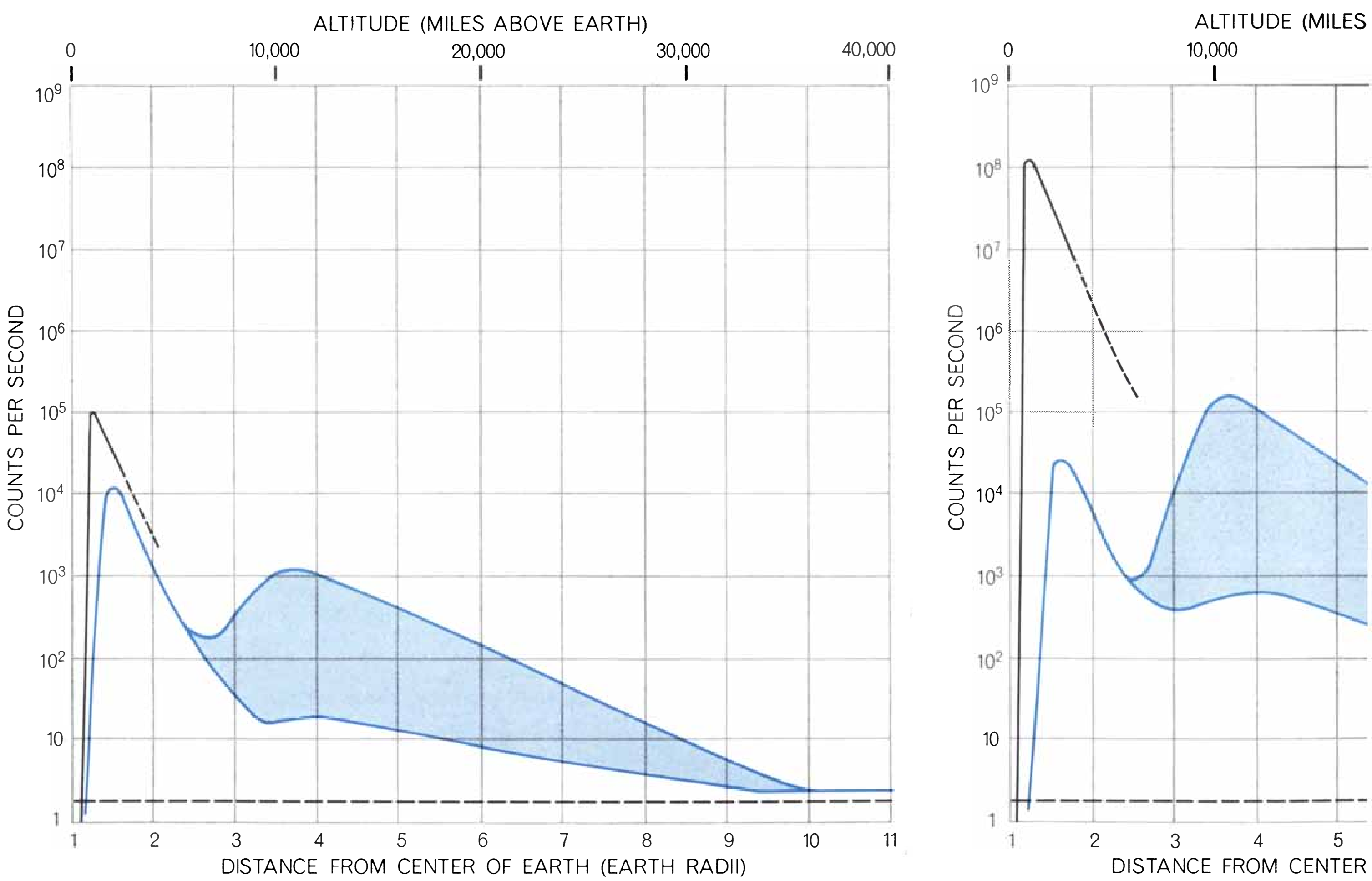
With each advance in knowledge of the magnetosphere, investigators have been designing new systems of instrumentation to answer the questions such new knowledge proposes. One such system was the work of the author, assisted by William Whelpley and his fellow graduate students in our laboratory at the State University of Iowa. They put together the integrated, 40-pound *Injun I*, which in June, 1961, was placed in a nearly circular orbit 600 miles high and inclined at an angle of 67 degrees to the Equator. This was the first satellite to move beyond the auroral zone of North America and so pass through and beyond the ends of the two high-energy Van Allen belts (which approach the earth at about 40 and 55 degrees latitude respectively). By the time it took its first holiday—from Christmas Day, 1962, to January 17, 1963—it had made about 100 million useful measurements.

The findings of *Injun I* contributed in turn to the design of *Injun II*, which was destroyed in a rocket malfunction at launch, and of *Injun III*, which went into orbit late in 1962. *Injun III* weighs 114 pounds and contains 18 different particle detectors as well as photometers to measure spectral lines in the auroras and the airglow. It also carries detectors to study very-low-frequency (VLF) electromagnetic waves. These range from 700 to 7,000 cycles per second and, when they are piped into a loud-speaker, make curious peeps, whistles and twitters. Their origin is not understood, but it has been suggested that some of the VLF waves might accelerate electrons resident in the upper atmosphere to the status of energetic membership in the outer Van Allen high-energy belt.

The Artificial Radiation

The principal obstacle to work in geophysics is that most processes in this realm cannot be reproduced under controlled conditions. The deliberate injection of charged particles into the magnetosphere by the explosion of a nuclear bomb has therefore held out promise of being a useful as well as a spectacular experiment. In principle the creation of an artificial belt of radiation at a known instant and with a known source strength should be of help in determining such little-known variables as the rundown time, or lifetime, of the trapped particles. Measurements of the decay would give an idea of the strength of the source required to keep the natural belts in equilibrium, and this would provide clues to the sources of the natural radiation. It must be emphasized, however, that scientific considerations have little to do with whether or not such explosions take place. The predominant considerations have obviously been political and military, and an evaluation solely on the basis of scientific usefulness is unrealistic.

In the first undertaking motivated by this combination of considerations the U.S. in 1958 exploded five nuclear bombs at high altitude. Of these, two were megaton (equivalent to a million tons of TNT) bombs set off less than 50 miles above Johnston Island in the Pacific Ocean. The effects disappeared after a few days because the axis of the earth's magnetic field passes about 250 miles to one side of the center of the earth away from the South Atlantic Ocean. A trapped particle drifting around the earth always mirrors at the same magnetic-field strength. The particles injected only 50 or 100 miles above the Pacific therefore sought to mirror closer and closer to earth as they drifted eastward in longitude and were absorbed in the atmosphere long before



FLUX OF CHARGED PARTICLES per square centimeter per second as function of altitude in plane of magnetic equator is shown in idealized curves based on studies with many Geiger tubes. Shielding of .25 centimeter of lead gives curves at left, .25 centimeter of aluminum gives curves at center. At right are curves obtained with shielding of .0004 centimeter of aluminum. Black curve in each case was made by belt of artificial fission electrons 10 hours after injection by Starfish high-altitude nuclear blast.

they made their way around to the Atlantic [*see illustration on page 96*]. Later in the same year three one- to two-kiloton bombs were detonated 300 miles above the South Atlantic. These Project Argus shots created artificial radiation belts that were clearly "seen" for several weeks by shielded Geiger tubes in *Explorer IV.*

In the spring of 1962 the U.S. announced plans to explode a submegaton bomb over the Pacific at an altitude of 500 miles and a larger bomb at 200 miles or so. The military task force charged with these two enterprises did not carry through the first but it did succeed in the second, code-named Starfish. The controversy that started with the original announcement of plans has continued to the present. Many investigators were concerned lest the explosions, particularly the one at 500 miles, severely disturb the natural radiation region for a long time, perhaps decades, and seriously hamper its continued study. The emotional overtones excited by the military aspects of the proposed experiments often obscured the scientific issues in the controversy; this obscuration has persisted even after the event, being deepened by other human and institutional failings, such as the undue authority accorded to proclamations issuing from Government agencies and competition among investigators for the public and political spotlight.

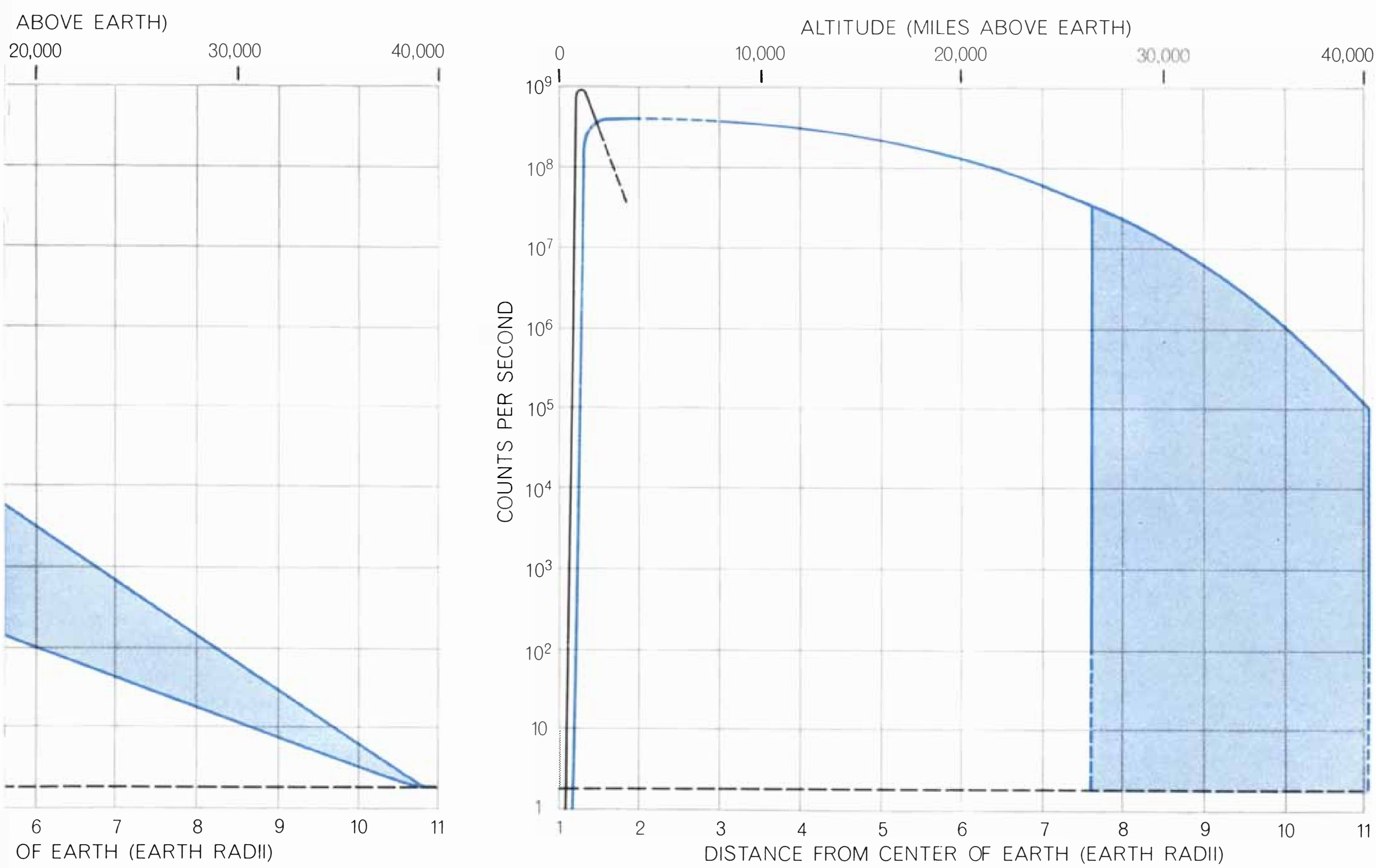
In sum, the scientific objectives of the Starfish experiment were overridden. Even now it is difficult to get agreement on answers to the first questions one wants to ask about Starfish radiation: the composition, flux and extent of this radiation in space, how fast the flux is dropping and if the answers to these questions are the same as the predictions beforehand.

The Starfish bomb exploded with a power of 1.4 megatons 250 miles above Johnston Island on the night of July 9, 1962. The immediate effects of the blast were spectacular. Brilliant auroras appeared even over New Zealand, 3,000 miles away. Radio propagation in the vicinity was completely disrupted. The earth's entire magnetic field shook and continued to oscillate violently as the shock spread around the world.

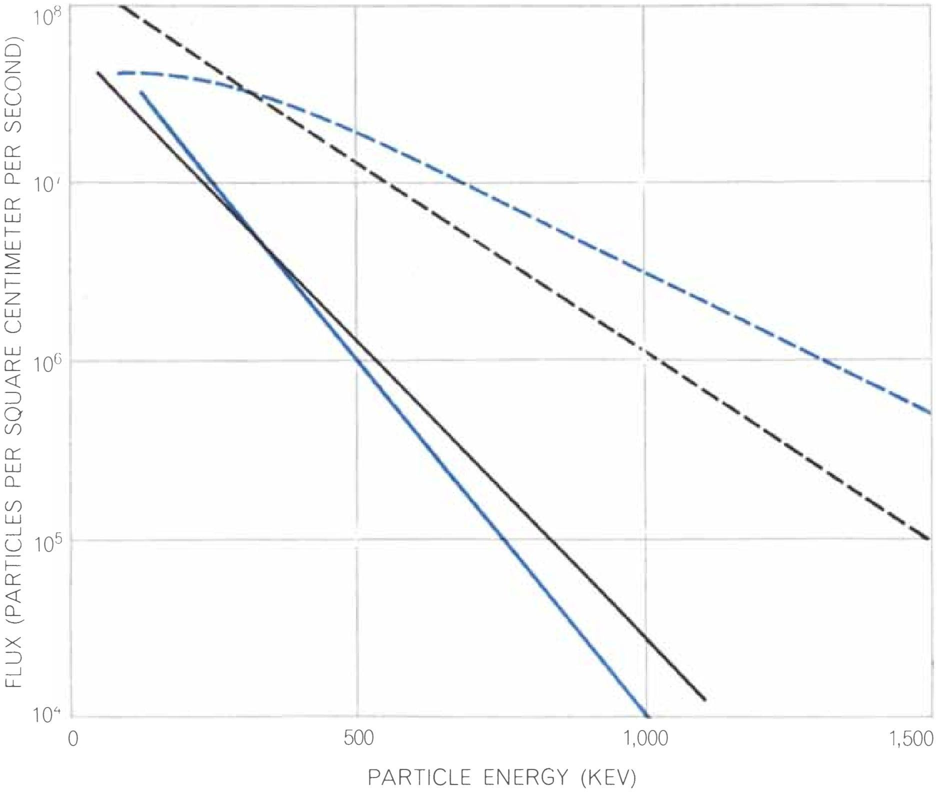
The fission products from the blast decayed fairly rapidly into some 10^{27} high-energy electrons. The explosion also sprayed a comparable number of neutrons in all directions. Because neutrons, having no electric charge, are unaffected by magnetic forces, many went out to great heights, even beyond the magnetosphere, but some decayed in the magnetosphere into protons and low-energy electrons that became trapped.

Most investigators, including the author, had expected the Starfish particles to plunge into the Atlantic in short order. This proved to be in error: the explosion produced the largest and longest-lasting artificial belt to date, a dubious distinction I hope it will retain for many years. Evidently the atmospheric density 250 miles up is so low that the fireball "jetted" upward to great altitude, leaving many of the high-energy fission electrons trapped in the geomagnetic field well above the absorbing atmosphere. They quickly drifted around the earth and soon dominated the underside of the natural inner belt.

Within hours after the blast the satellite *Injun I,* which was already a venerable one year old, detected and began



Black broken horizontal line is interplanetary counting rate for cosmic rays. In left and center graphs colored curves show inner and outer high-energy Van Allen belts and colored area covers variations found in counting rates in outer zone. At right the colored area denotes the disturbed region through which the outer limit of the magnetosphere shifts on sunlit side of earth. Counting rate drops abruptly at the edge of the magnetosphere. The broken sections of the various curves indicate uncertainty as to the flux.



SIMILAR FLUXES of protons (*color*) and electrons (*black*) of a given energy are found in outer Van Allen high-energy zone. Broken curves summarize results at 10,000-mile altitude, solid curves at 15,000 miles. Average energy drops with altitude. Figures may be wrong by a factor of 10 due to outer-zone variations and experimental uncertainties.

mapping the new belt of high-flux fission electrons. Because we had made millions of measurements of the natural radiation with *Injun I*, we had no trouble measuring the artificial radiation. This was fortunate; so few features of the Van Allen radiation are reliably established that these discriminations are clouded with uncertainty when one works from the data produced by other satellites, such as *Telstar*, launched after the bomb was exploded. Differences in orbit and instrumentation, for example, make it extremely difficult to compare the pre-Starfish *Injun I* data with the post-Starfish *Telstar* observations.

By the end of July, 1962, with Laughlin and Van Allen, I was able to write a report of the *Injun I* findings on the flux and extent of the belt. I presented this paper on August 16 at a meeting at the Goddard Space Flight Center. Others at the meeting reported that three satellites, *Transit IVB*, *Traac* and the U.S.-United Kingdom satellite *Ariel*, had ceased operating soon after the Starfish explosion. Using our estimates of particle flux, R. E. Bourdeau of NASA and R. E. Fischell of the Applied Physics Laboratory of Johns Hopkins University calculated that each square centimeter of the surface of these satellites had been irradiated by some 10^{12} or 10^{13} high-energy fission electrons each day, more than enough to ruin the solar cells that supplied the satellites with power.

In the weeks following the meeting, data from *Telstar* and *Traac* began to be studied. Starting on August 19 the results of these studies were issued in a still continuing series of public announcements, some official, with a Government agency as their "author," and some unofficial, representing the individual enterprise of an investigator. These pronouncements often contradicted one another and generated total confusion. Many failed to reckon with the pre-Starfish data on the natural radiation. As a result some wild overestimates of the radiation generated by the bomb have received wide circulation. In what follows I can only give my best judgment of what the belt was like 10 hours after the burst and of how it has changed. Not all investigators will agree with my conclusions.

Erosion by the atmosphere keeps the underside of the natural belt worn down. It is in this "safe space" that all flights by astronauts have been made. Starfish temporarily populated the region with charged particles, but the atmosphere immediately began to erode them away, turning the artificial belt into a thin, crescent-shaped zone extending about 20 degrees north and south of the magnetic equator, with its peak flux at an average altitude of about 800 miles. Half of the 10^8 to 10^9 fission electrons measured 10 hours after the blast had an initial energy of less than one Mev and half of them had more than that, some up to seven Mev.

In the heart of the artificial belt scattering and absorption by the tenuous atmosphere cause the flux to drop, but only by a factor of two every few months. The radiation will therefore continue to be detectable for a number of years. At much higher altitudes—above 2,000 miles—the rapid changes in flux that accompany geophysical disturbances presumably eliminated the fission electrons within a few months. *Explorer XIV* found none early in October, 1962.

The situation as depicted by the *Injun I* data that I have summarized does not agree with the interpretation of *Telstar* data by W. N. Hess of the Goddard Space Flight Center. According to Hess the injected particles were high in flux to an altitude of 12,000 miles, with the peak of their flux at 2,000 miles. He has said that the belt contained perhaps 30 times more fission electrons than we estimated from the *Injun* data. Governmental announcements have given wide publicity to this *Telstar* picture, and they have given it the mantle of authority as well.

Today we are rather certain, on the basis of evidence from later satellites, that *Injun I* had indeed given us a correct idea of the distribution of the most energetic of the fission electrons. It may be that Hess mistakenly identified natural electrons as fission electrons. This was possible because *Telstar* went into orbit after the explosion and had made no measurements of the natural, uncontaminated environment. Furthermore, the *Telstar* count includes electrons of low energies, which are particularly plentiful in the natural radiation, whereas the shielding on the relevant *Injun I* detector excluded the low-energy electrons.

Hess now believes it to be likely, however, that the fluxes he initially attributed to high-energy fission electrons may actually have been a combination of lower-energy electrons resulting from the explosion. These would have been a mixture of neutron-decay electrons and fission-decay electrons (mostly the latter) but with an average energy much less than those in the belt mapped out by *Injun I*. We are trying to learn which view is correct.

Using the *Telstar* picture, official

statements have held that the fission-electron belt was larger in size and flux than had been predicted by those who planned the Starfish project. I do not know whether the predictions were more nearly matched by the data from *Telstar* or that from *Injun I*, because the predictions are not in the open literature. One lesson to be learned from the whole Starfish controversy is that governmental agencies should be wary of accepting and vesting with the semblance of validity scientific opinions and discoveries that have not been fully tested in the conventional warfare of open scientific discussion.

On October 22, October 28 and November 1, 1962, the U.S.S.R. exploded three nuclear bombs at high altitudes. The resulting belts of artificial radiation showed fluxes similar to that in the Starfish belt. W. L. Brown of the Bell Telephone Laboratories has found, in a review of data supplied by *Telstar* and *Explorer XV*, that these belts were established at higher altitudes—in the "slot" between the inner and outer high-energy Van Allen zones. As in the case of the Argus belts, which spread around the world at much the same altitudes, the flux of the Soviet belts decreased by a factor of two or more every few days. The high rate of decay in this region contrasts with the low rate of decay on the underside of the inner Van Allen belt, where the Starfish radiation still persists. There may be two reasons. First, the geomagnetic field in the slot doubtless fluctuates more readily in response to solar disturbances than does the field in the Starfish region, and thus may shake out the injected particles. Second, if the Soviet bombs were exploded at a high latitude (the Starfish explosions were near the Equator), most of the electrons would mirror at these latitudes and hence at low altitudes or deeper in the atmosphere than do the Starfish electrons. They would therefore be more likely to be scattered out of their trapped trajectories.

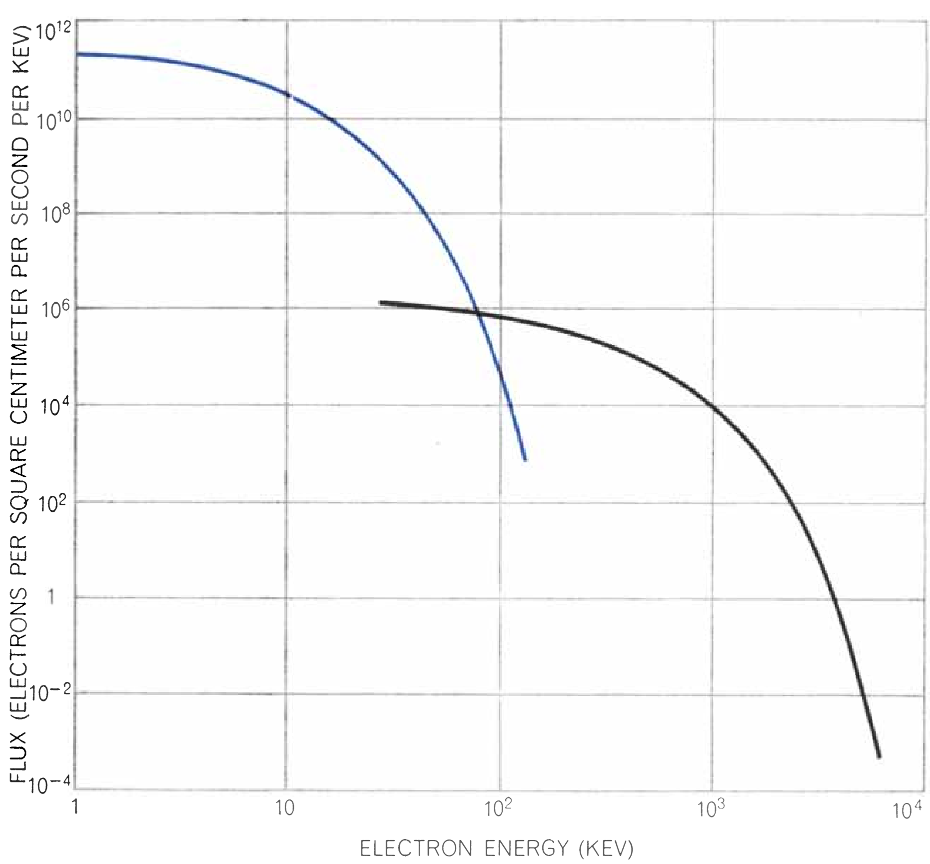
The confusion engendered in nature as well as in the scientific literature by the Starfish radiation can be illustrated in connection with the knotty question posed by the high-energy protons of the inner Van Allen belt. It has been postulated that they have their origin in the decay of neutrons produced in cosmic ray interactions with the particles in the atmosphere; the range of energies of protons found in the zone agrees with this view. One way to test the idea is to see if the inner-zone electrons have the same origin, since the decay of a neutron produces a proton and an electron. Unfortunately the observed energy spectrum of these low-energy electrons does not square with the range of energies predicted by the theory that they come from neutron decay. Yet the theory supporting the cosmic ray origin remains an attractive one because it can be placed in a mathematical framework, and its proponents die hard. A truly decisive experiment would be the determination of whether or not any natural electrons in the inner zone have energies above about 780 Kev—the maximum possible if they come from neutron decay. Before Starfish it had been found that the flux of inner-zone electrons above this energy was less than about 10,000 per square centimeter per second, but it might have been 9,999 or one for all we knew. Most of the fission electrons released by Starfish had energies above 780 Kev. Initially the flux of these injected particles stood at 10^9. The flux will have to decay by a factor of 10^5 before the question can be examined again, and this will not be for many years.

The neutrons liberated by the Soviet experiments as well as by Starfish create problems of this kind all over the magnetosphere. They are serious probably only in the vicinity of the inner zone, where the man-made electrons will remain for a long time.

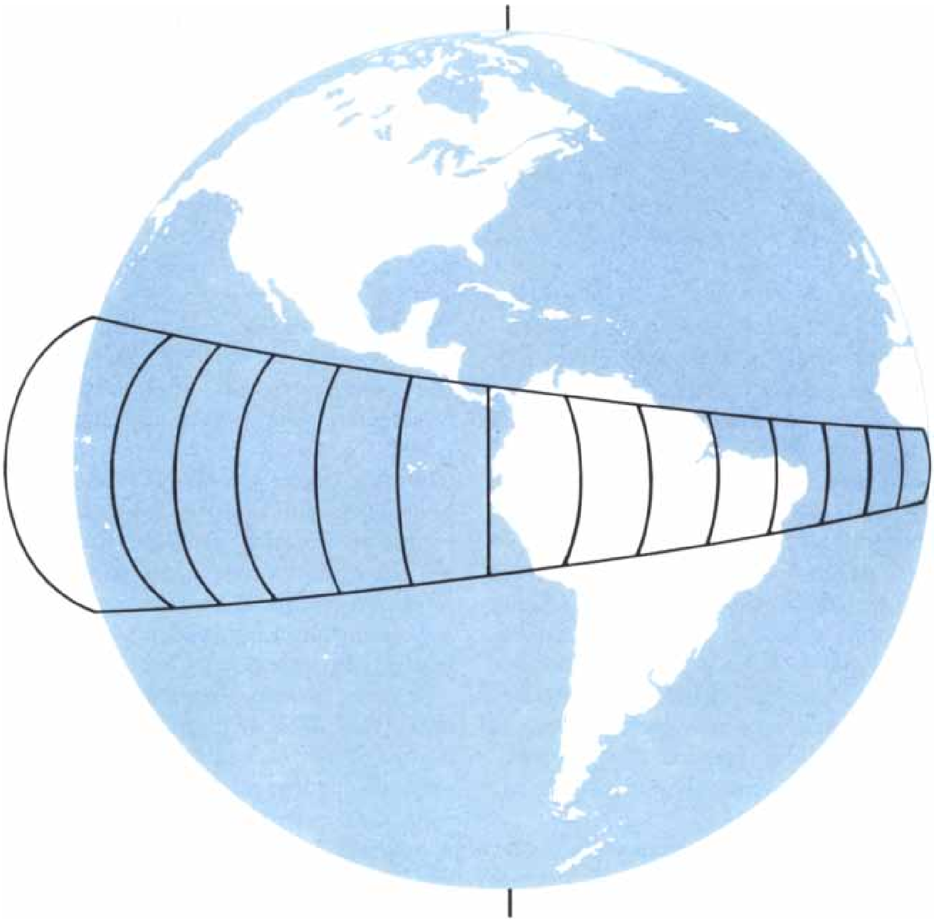
The Auroras

The original discovery that the high-energy charged particles of the outer Van Allen belt are trapped on the magnetic-field lines connecting the northern and southern auroral zones naturally led many investigators to propose that the trapped particles somehow generate the auroras. In his 1959 article in SCIENTIFIC AMERICAN Van Allen proposed the "leaky bucket" explanation. The outer belt was the "bucket" that held particles coming in from the sun; a gust of incoming particles carried by the solar wind would cause the bucket to slop over, mainly in the auroral zone, generating auroras, magnetic storms and related disturbances.

It soon became apparent that the outer Van Allen belt, if it served as a bucket at all, was more than a simple reservoir holding particles until they ran over. Experiments in 1959 and 1960 by Kinsey A. Anderson of the University of California, Winckler and others disclosed that surprisingly high and varying fluxes of electrons with a wide range of energies were being dumped into the



GREAT RANGE OF FLUXES at different particle energies makes study of trapped radiation extremely complex. Most intense natural flux ever measured in space (*colored curve*) was found by *Injun I* at one end of outer high-energy belt on September 25, 1961. Flux could have sustained very bright aurora. Black curve shows typical flux in heart of outer belt.



LINES OF EQUAL MAGNETIC FORCE are much closer to earth over the Atlantic Ocean (*right*) than over Pacific (*left*). Particles injected over Pacific will therefore hit atmosphere as they drift toward the Atlantic. The "displacement" of magnetic-field lines is caused by fact that axis of magnetic field tilts and passes about 250 miles to one side of earth's axis of rotation, toward the Pacific. Starfish particles went so high that this did not affect them.

atmosphere. It seemed unlikely that the particles came in from the sun in such different energy states. Evidently the "bucket" had a stirring mechanism that sometimes accelerated particles.

In April, 1960, an intense solar flare sent a great cloud of charged particles through interplanetary space. *Pioneer V* flew through this cloud about five million miles from the earth. R. L. Arnoldy and R. A. Hoffman of the University of Minnesota and Winckler reported that their Geiger tube on *Pioneer V* showed practically no increase in counting rate. Evidently the particles were of extremely low energy, in the range of a few hundred or so electron volts. Van Allen found, however, that a few days later, after the cloud of solar particles hit the earth, a similar Geiger tube aboard *Explorer VII,* in orbit around the earth at the altitude of the outer Van Allen belt, showed a thousandfold increase in counting rate. If the new solar particles were causing this increase, they had obviously been accelerated locally.

Even the more complex leaky-bucket model, incorporating a stirring mechanism, began to be less attractive when *Explorer XII* showed that the number of electrons trapped in the outer belt was 1,000 times less than had been postulated. There simply were not enough particles in the bucket to cause the occasional bright auroras. This became the more apparent when the instruments on *Injun I* showed that the constant flux of particles spilling out of the magnetosphere into the atmosphere—quite apart from the surges that must attend the auroras—would empty the outer zone of its trapped electrons in a few hours in the absence of a source of constant flow into the bucket.

On the basis of present evidence I would turn the model around and regard the outer high-energy Van Allen belt as a "splash-catcher" rather than a leaky bucket. The splash-catcher model does not propose a source for the trapped particles themselves. It could be supposed that they come from the sun with quite low energies or that they have been resident in the upper atmosphere since the formation of the earth—the remains of an ancient ionosphere. The splash-catcher model simply postulates that some unknown mechanism accelerates electrons in a direction predominantly parallel to the magnetic-field lines so that they plunge into the atmosphere, causing the auroras and also sustaining the average constant "drip" observed by *Injun I.* From time to time solar and geomagnetic disturbances increase or decrease the strength of the accelerating mechanism. This mechanism would also accelerate a few electrons at angles to the magnetic field sufficiently large for these particles to be trapped. Recent data from *Injun III* prove that this effect does occur. As Winckler phrased it: "Instead of picturing the outer zone as a bucket that occasionally slops over to cause an aurora, one might regard it as a bucket held under Niagara Falls. It catches a little of what falls, but most rushes past." This would make the outer zone of energetic electrons purely an incidental and secondary consequence of the mechanisms that cause auroras.

We know just as little about the source of the low-energy protons that permeate the trapping regions of the magnetosphere from below the inner high-energy belt out to the edge. In addition to the protons with a few Kev of energy in the steady solar wind, the sun sometimes shoots out protons with energies of hundreds of Mev. We do not know whether the protons detected by Davis and others are due to such a solar source, or whether they are also accelerated locally.

At this juncture it must be conceded that physical theory has failed to provide an adequate explanation for the source or sources of the particles in the magnetosphere and the mechanisms that give them their various energies. The experimentalist therefore continues to make as many observations and measurements as he can in the hope that analysis of many events will reveal some common denominator. He is groping in a new realm of physics, occasionally overwhelmed by the magnitude of the projects and their cost. He is also being drowned in his own data. *Explorer I* produced some 5,000 measurements, *Explorer VII* about a million and *Injun I* 100 million. A geophysicist could easily spend a lifetime analyzing the results from one satellite. Within a year, however, he can usually devise much better methods of studying the environment of the earth, so he wants to put up a new satellite and start again. Perhaps the next measurements from the next satellite, or from the one after that, will provide the clues that will give coherence to all the observations of the Van Allen radiation, thereby turning a valiant exploration into a disciplined science.

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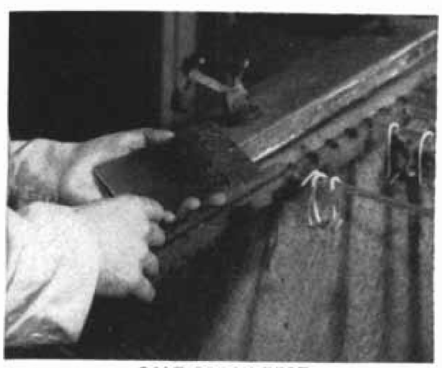

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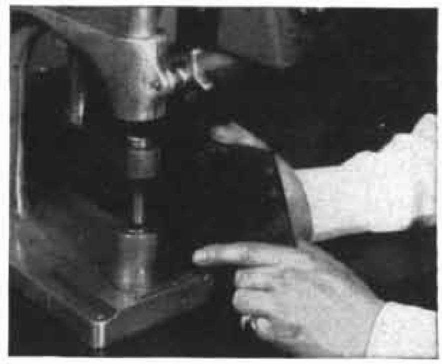

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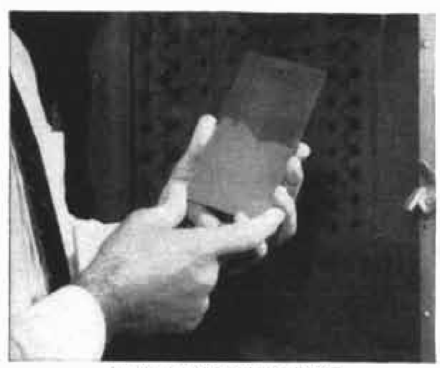

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PHEROMONES

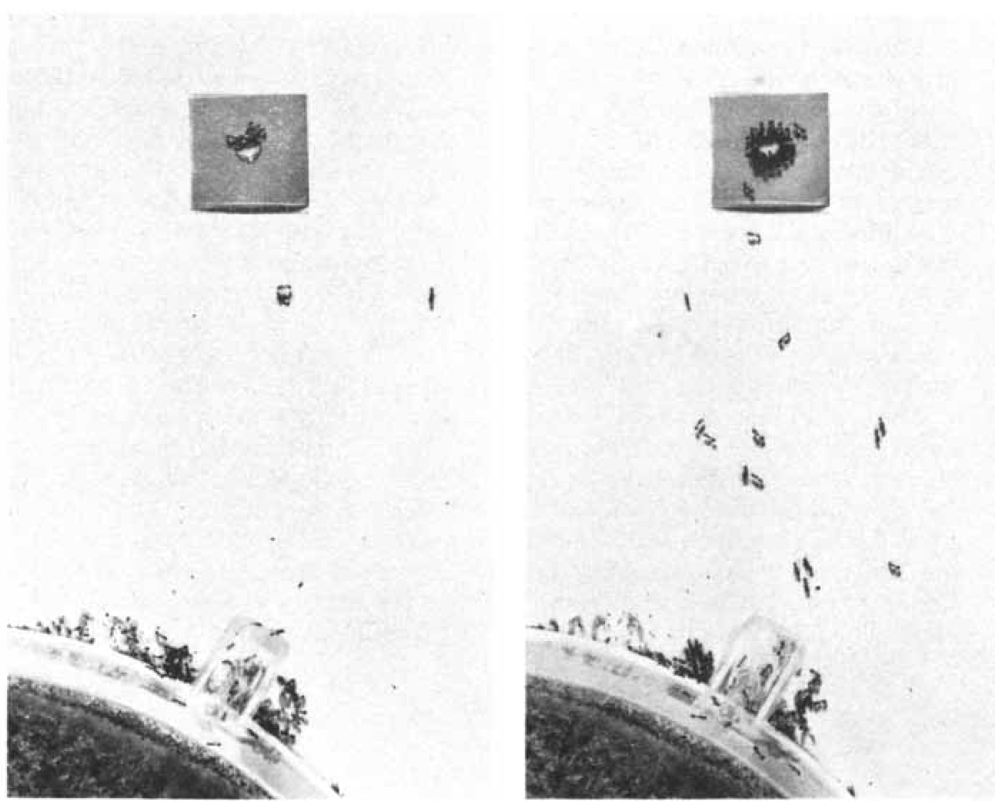
A pheromone is a substance secreted by an animal that influences the behavior of other animals of the same species. Recent studies indicate that such chemical communication is surprisingly common

by Edward O. Wilson

It is conceivable that somewhere on other worlds civilizations exist that communicate entirely by the exchange of chemical substances that are smelled or tasted. Unlikely as this may seem, the theoretical possibility cannot be ruled out. It is not difficult to design, on paper at least, a chemical communication system that can transmit a large amount of information with rather good efficiency. The notion of such a communication system is of course strange because our outlook is shaped so strongly by our own peculiar auditory and visual conventions. This limitation of outlook is found even among students of animal behavior; they have favored species whose communication methods are similar to our own and therefore more accessible to analysis. It is becoming increasingly clear, however, that chemical systems provide the dominant means of communication in many animal species, perhaps even in most. In the past several years animal behaviorists and organic chemists, working together, have made a start at deciphering some of these systems and have discovered a number of surprising new biological phenomena.

In earlier literature on the subject, chemicals used in communication were usually referred to as "ectohormones." Since 1959 the less awkward and etymologically more accurate term "pheromones" has been widely adopted. It is used to describe substances exchanged among members of the same animal species. Unlike true hormones, which are secreted internally to regulate the organism's own physiology, or internal environment, pheromones are secreted externally and help to regulate the organism's external environment by influencing other animals. The mode of influence can take either of two general forms. If the pheromone produces a more or less immediate and reversible change in the behavior of the recipient, it is said to have a "releaser" effect. In this case the chemical substance seems to act directly on the recipient's central nervous system. If the principal function of the pheromone is to trigger a chain of physiological events in the recipient, it has what we have recently labeled a "primer" effect. The physiological changes, in turn, equip the organism with a new behavioral repertory, the components of which are thenceforth evoked by appropriate stimuli. In termites, for example, the reproductive and soldier castes prevent other termites from developing into their own castes by secreting substances that are ingested and act through the *corpus allatum*, an endocrine gland controlling differentiation [see "The Termite and the Cell," by Martin Lüscher; SCIENTIFIC AMERICAN, May, 1953].

These indirect primer pheromones do not always act by physiological inhibition. They can have the opposite effect. Adult males of the migratory locust *Schistocerca gregaria* secrete a volatile substance from their skin surface that accelerates the growth of young locusts. When the nymphs detect this substance with their antennae, their hind legs,



INVISIBLE ODOR TRAILS guide fire ant workers to a source of food: a drop of sugar solution. The trails consist of a pheromone laid down by workers returning to their nest after finding a source of food. Sometimes the chemical message is reinforced by the touching of antennae if a returning worker meets a wandering fellow along the way. This is hap-

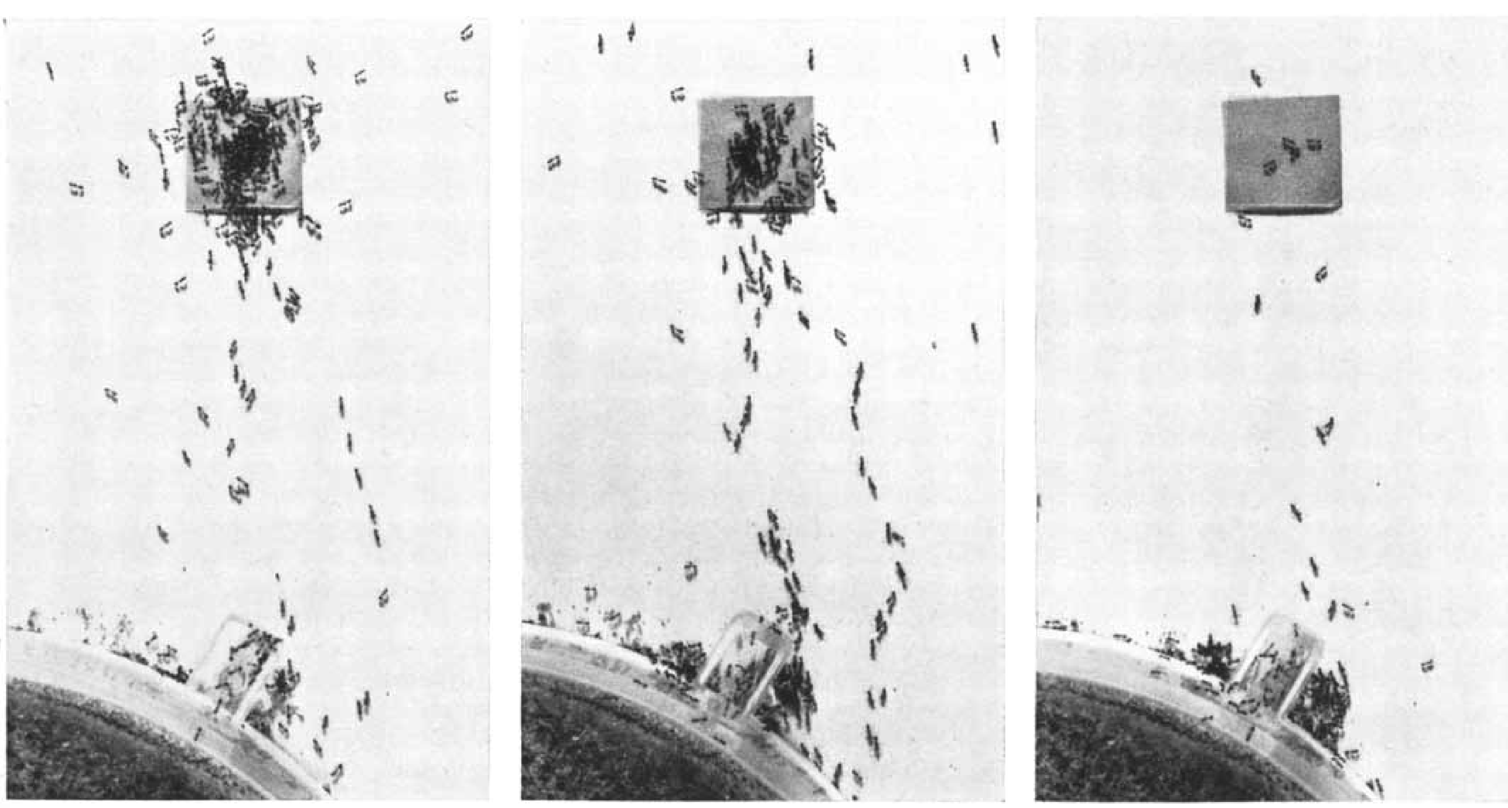
some of their mouth parts and the antennae themselves vibrate. The secretion, in conjunction with tactile and visual signals, plays an important role in the formation of migratory locust swarms.

A striking feature of some primer pheromones is that they cause important physiological change without an immediate accompanying behavioral response, at least none that can be said to be peculiar to the pheromone. Beginning in 1955 with the work of S. van der Lee and L. M. Boot in the Netherlands, mammalian endocrinologists have discovered several unexpected effects on the female mouse that are produced by odors of other members of the same species. These changes are not marked by any immediate distinctive behavioral patterns. In the "Lee-Boot effect" females placed in groups of four show an increase in the percentage of pseudopregnancies. A completely normal reproductive pattern can be restored by removing the olfactory bulbs of the mice or by housing the mice separately. When more and more female mice are forced to live together, their oestrous cycles become highly irregular and in most of the mice the cycle stops completely for long periods. Recently W. K. Whitten of the Australian National University has discovered that the odor of a male mouse can initiate and synchronize the oestrous cycles of female mice. The male odor also reduces the frequency of reproductive abnormalities arising when female mice are forced to live under crowded conditions.

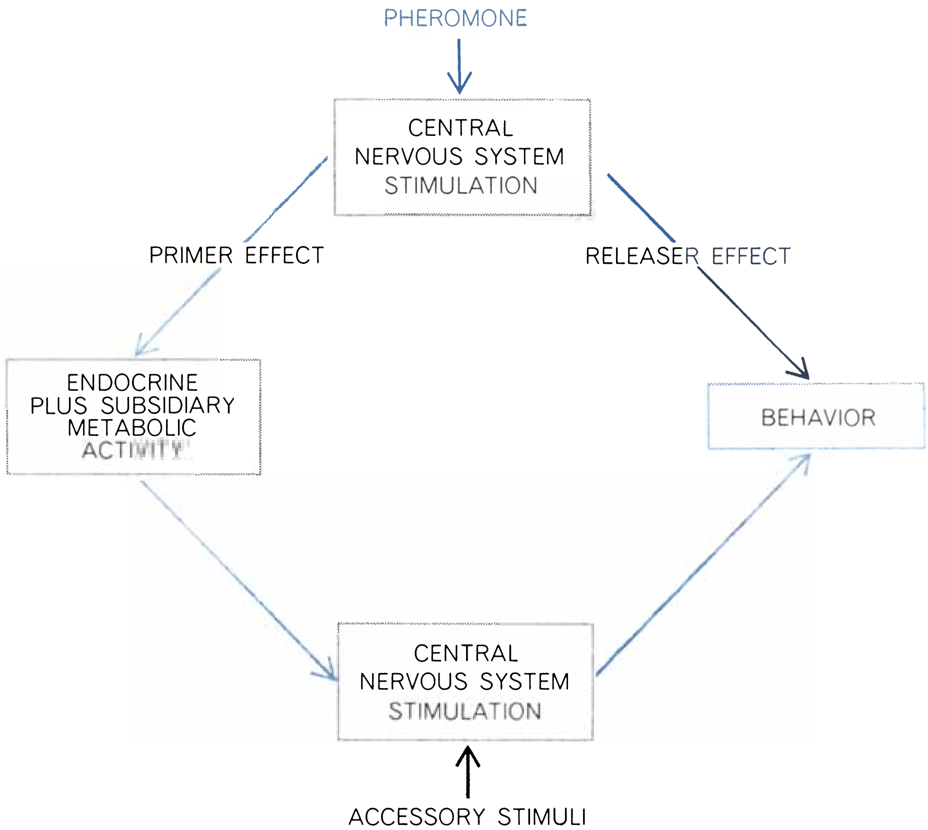
A still more surprising primer effect has been found by Helen Bruce of the National Institute for Medical Research in London. She observed that the odor of a strange male mouse will block the pregnancy of a newly impregnated female mouse. The odor of the original stud male, of course, leaves pregnancy undisturbed. The mouse reproductive pheromones have not yet been identified chemically, and their mode of action is only partly understood. There is evidence that the odor of the strange male suppresses the secretion of the hormone prolactin, with the result that the *corpus luteum* (a ductless ovarian gland) fails to develop and normal oestrus is restored. The pheromones are probably part of the complex set of control mechanisms that regulate the population density of animals [see "Population Density and Social Pathology," by John B. Calhoun; SCIENTIFIC AMERICAN, February, 1962].

Pheromones that produce a simple releaser effect—a single specific response mediated directly by the central nervous system—are widespread in the animal kingdom and serve a great many functions. Sex attractants constitute a large and important category. The chemical structures of six attractants are shown on page 108. Although two of the six—the mammalian scents muskone and civetone—have been known for some 40 years and are generally assumed to serve a sexual function, their exact role has never been rigorously established by experiments with living animals. In fact, mammals seem to employ musklike compounds, alone or in combination with other substances, to serve several functions: to mark home ranges, to assist in territorial defense and to identify the sexes.

The nature and role of the four insect sex attractants are much better understood. The identification of each represents a technical feat of considerable magnitude. To obtain 12 milligrams of esters of bombykol, the sex attractant of the female silkworm moth, Adolf F. J. Butenandt and his associates at the Max Planck Institute of Biochemistry in Munich had to extract material from 250,000 moths. Martin Jacobson, Morton Beroza and William Jones of the U.S. Department of Agriculture processed 500,000 female gypsy moths to get 20 milligrams of the gypsy-moth attractant gyplure. Each moth yielded only about .01 microgram (millionth of a gram) of



pening in the photograph at the far left. A few foraging workers have just found the sugar drop and a returning trail-layer is communicating the news to another ant. In the next two pictures the trail has been completed and workers stream from the nest in increasing numbers. In the fourth picture unrewarded workers return to the nest without laying trails and outward-bound traffic wanes. In the last picture most of the trails have evaporated completely and only a few stragglers remain at the site, eating the last bits of food.



PHEROMONES INFLUENCE BEHAVIOR directly or indirectly, as shown in this schematic diagram. If a pheromone stimulates the recipient's central nervous system into producing an immediate change in behavior, it is said to have a "releaser" effect. If it alters a set of long-term physiological conditions so that the recipient's behavior can subsequently be influenced by specific accessory stimuli, the pheromone is said to have a "primer" effect.

gyplure, or less than a millionth of its body weight. Bombykol and gyplure were obtained by killing the insects and subjecting crude extracts of material to chromatography, the separation technique in which compounds move at different rates through a column packed with a suitable adsorbent substance. Another technique has been more recently developed by Robert T. Yamamoto of the U.S. Department of Agriculture, in collaboration with Jacobson and Beroza, to harvest the equally elusive sex attractant of the American cockroach. Virgin females were housed in metal cans and air was continuously drawn through the cans and passed through chilled containers to condense any vaporized materials. In this manner the equivalent of 10,000 females were "milked" over a nine-month period to yield 12.2 milligrams of what was considered to be the pure attractant.

The power of the insect attractants is almost unbelievable. If some 10,000 molecules of the most active form of bombykol are allowed to diffuse from a source one centimeter from the antennae of a male silkworm moth, a characteristic sexual response is obtained in most cases. If volatility and diffusion rate are taken into account, it can be estimated that the threshold concentration is no more than a few hundred molecules per cubic centimeter, and the actual number required to stimulate the male is probably even smaller. From this one can calculate that .01 microgram of gyplure, the minimum average content of a single female moth, would be theoretically adequate, if distributed with maximum efficiency, to excite more than a billion male moths.

In nature the female uses her powerful pheromone to advertise her presence over a large area with a minimum expenditure of energy. With the aid of published data from field experiments and newly contrived mathematical models of the diffusion process, William H. Bossert, one of my associates in the Biological Laboratories at Harvard University, and I have deduced the shape and size of the ellipsoidal space within which male moths can be attracted under natural conditions [*see bottom illustration on opposite page*]. When a moderate wind is blowing, the active space has a long axis of thousands of meters and a transverse axis parallel to the ground of more than 200 meters at the widest point. The 19th-century French naturalist Jean Henri Fabre, speculating on sex attraction in insects, could not bring himself to believe that the female moth could communicate over such great distances by odor alone, since "one might as well expect to tint a lake with a drop of carmine." We now know that Fabre's conclusion was wrong but that his analogy was exact: to the male moth's powerful chemoreceptors the lake is indeed tinted.

One must now ask how the male moth, smelling the faintly tinted air, knows which way to fly to find the source of the tinting. He cannot simply fly in the direction of increasing scent; it can be shown mathematically that the attractant is distributed almost uniformly after it has drifted more than a few meters from the female. Recent experiments by Ilse Schwinck of the University of Munich have revealed what is probably the alternative procedure used. When male moths are activated by the pheromone, they simply fly upwind and thus inevitably move toward the female. If by accident they pass out of the active zone, they either abandon the search or fly about at random until they pick up the scent again. Eventually, as they approach the female, there is a slight increase in the concentration of the chemical attractant and this can serve as a guide for the remaining distance.

If one is looking for the most highly developed chemical communication systems in nature, it is reasonable to study the behavior of the social insects, particularly the social wasps, bees, termites and ants, all of which communicate mostly in the dark interiors of their nests and are known to have advanced chemoreceptive powers. In recent years experimental techniques have been developed to separate and identify the pheromones of these insects, and rapid progress has been made in deciphering the hitherto intractable codes, particularly those of the ants. The most successful procedure has been to dissect out single glandular reservoirs and see what effect their contents have on the behavior of the worker caste, which is the most numerous and presumably the most in need of continuing guidance. Other pheromones, not present in distinct reservoirs, are identified in chromatographic fractions of crude extracts.

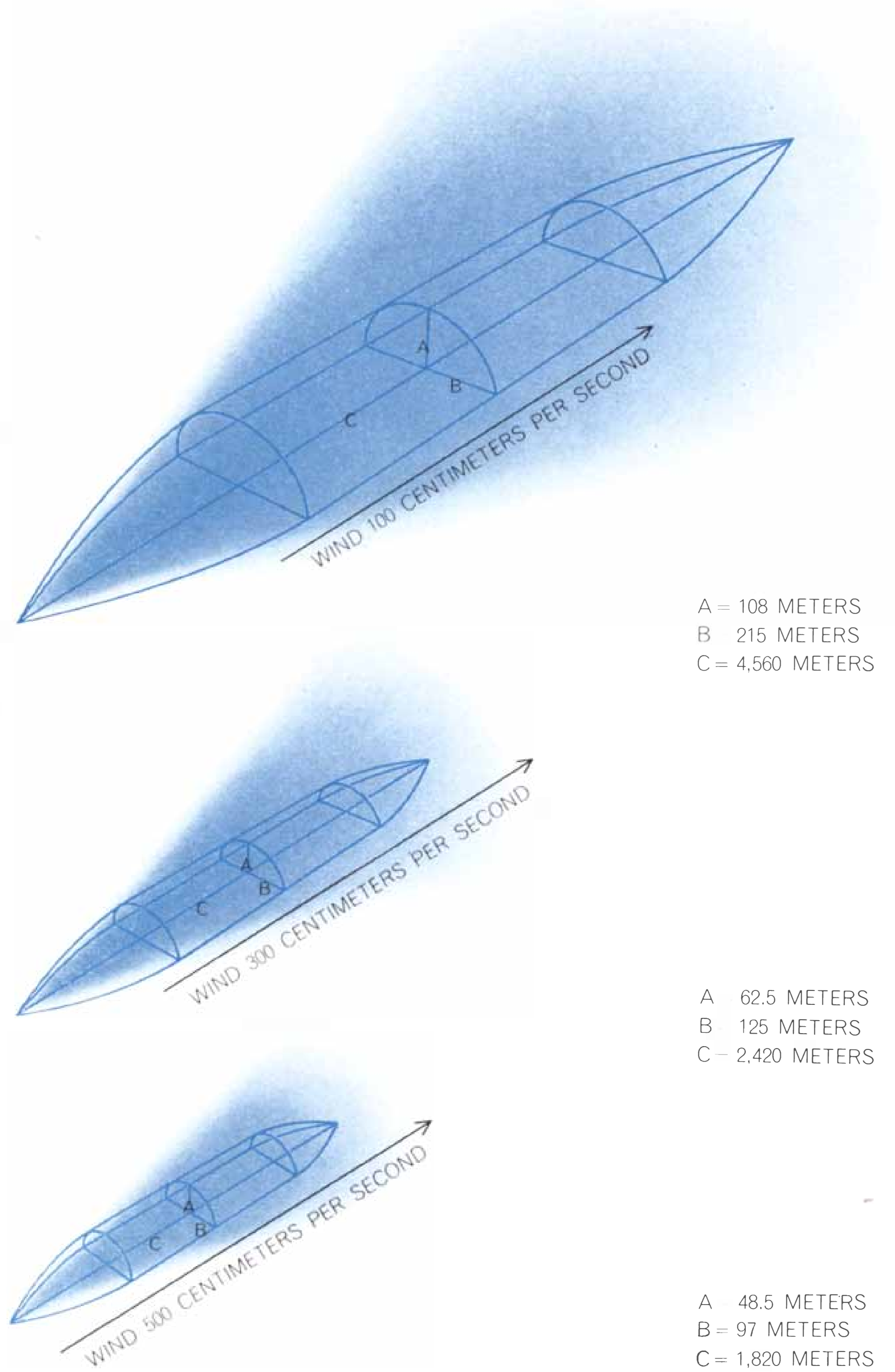
Ants of all castes are constructed with an exceptionally well-developed exocrine glandular system. Many of the most prominent of these glands, whose function has long been a mystery to entomologists, have now been identified as the source of pheromones [*see illustra-*

tion on page 105]. The analysis of the gland-pheromone complex has led to the beginnings of a new and deeper understanding of how ant societies are organized.

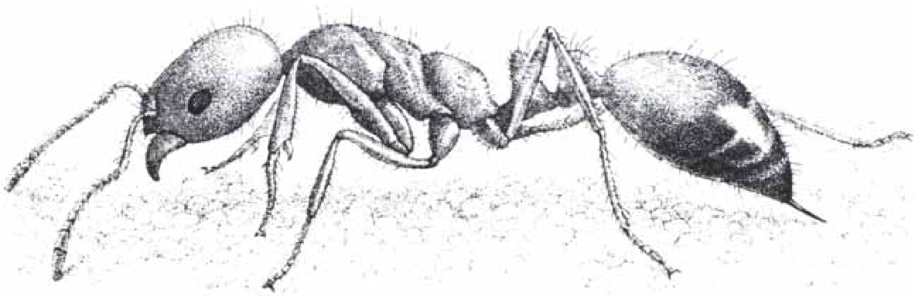
Consider the chemical trail. According to the traditional view, trail secretions served as only a limited guide for worker ants and had to be augmented by other kinds of signals exchanged inside the nest. Now it is known that the trail substance is extraordinarily versatile. In the fire ant (*Solenopsis saevissima*), for instance, it functions both to activate and to guide foraging workers in search of food and new nest sites. It also contributes as one of the alarm signals emitted by workers in distress. The trail of the fire ant consists of a substance secreted in minute amounts by Dufour's gland; the substance leaves the ant's body by way of the extruded sting, which is touched intermittently to the ground much like a moving pen dispensing ink. The trail pheromone, which has not yet been chemically identified, acts primarily to attract the fire ant workers. Upon encountering the attractant the workers move automatically up the gradient to the source of emission. When the substance is drawn out in a line, the workers run along the direction of the line away from the nest. This simple response brings them to the food source or new nest site from which the trail is laid. In our laboratory we have extracted the pheromone from the Dufour's glands of freshly killed workers and have used it to create artificial trails. Groups of workers will follow these trails away from the nest and along arbitrary routes (including circles leading back to the nest) for considerable periods of time. When the pheromone is presented to whole colonies in massive doses, a large portion of the colony, including the queen, can be drawn out in a close simulation of the emigration process.

The trail substance is rather volatile, and a natural trail laid by one worker diffuses to below the threshold concentration within two minutes. Consequently outward-bound workers are able to follow it only for the distance they can travel in this time, which is about 40 centimeters. Although this strictly limits the distance over which the ants can communicate, it provides at least two important compensatory advantages. The more obvious advantage is that old, useless trails do not linger to confuse the hunting workers. In addition, the intensity of the trail laid by many workers provides a sensitive index of the amount of food at a given site and the rate of its depletion. As workers move to and from

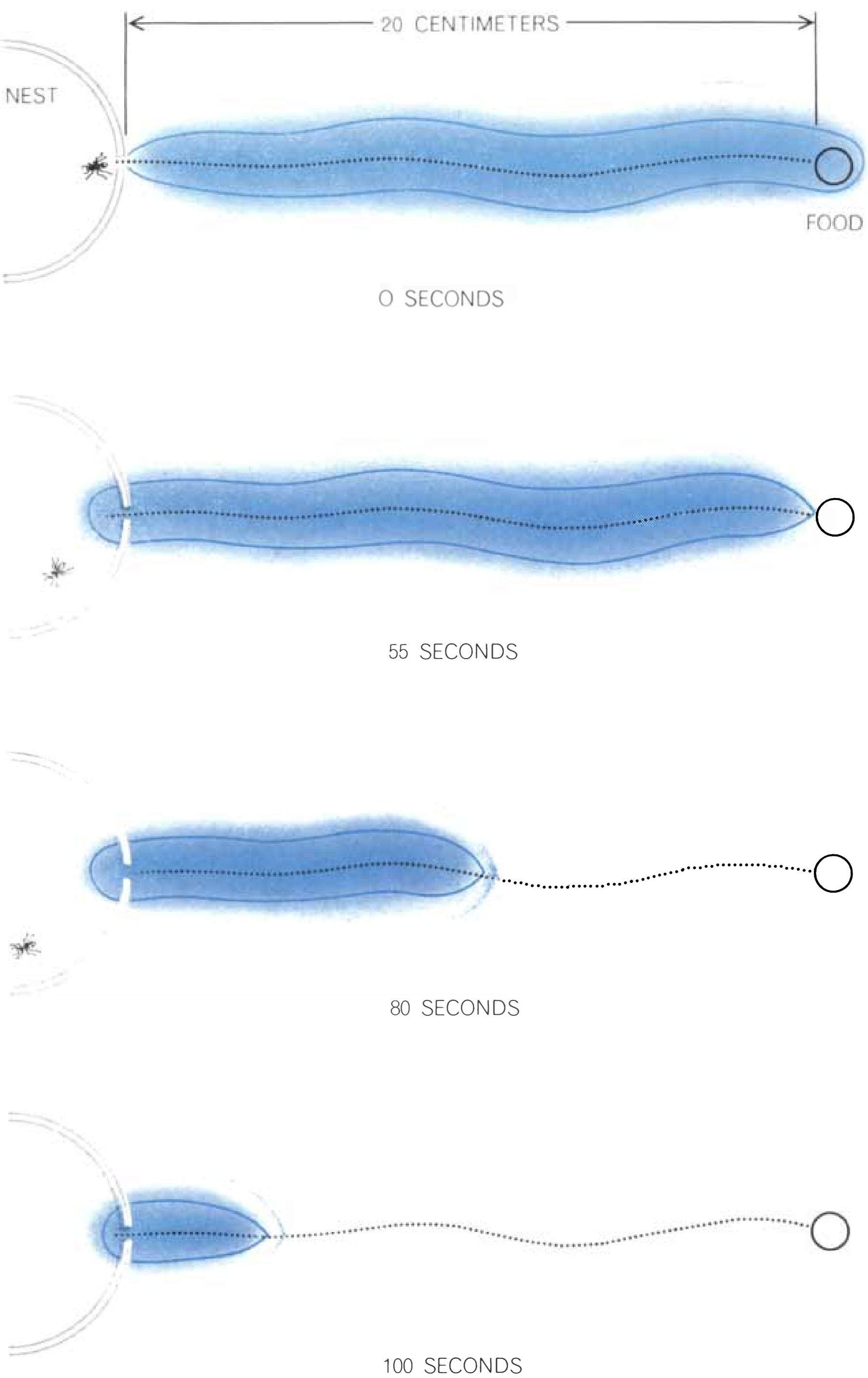
ANTENNAE OF GYPSY MOTHS differ radically in structure according to their function. In the male (*left*) they are broad and finely divided to detect minute quantities of sex attractant released by the female (*right*). The antennae of the female are much less developed.



ACTIVE SPACE of gyplure, the gypsy moth sex attractant, is the space within which this pheromone is sufficiently dense to attract males to a single, continuously emitting female. The actual dimensions, deduced from linear measurements and general gas-diffusion models, are given at right. Height (*A*) and width (*B*) are exaggerated in the drawing. As wind shifts from moderate to strong, increased turbulence contracts the active space.



FIRE ANT WORKER lays an odor trail by exuding a pheromone along its extended sting. The sting is touched to the ground periodically, breaking the trail into a series of streaks.



ACTIVE SPACE OF ANT TRAIL, within which the pheromone is dense enough to be perceived by other workers, is narrow and nearly constant in shape with the maximum gradient situated near its outer surface. The rapidity with which the trail evaporates is indicated.

the food finds (consisting mostly of dead insects and sugar sources) they continuously add their own secretions to the trail produced by the original discoverers of the food. Only if an ant is rewarded by food does it lay a trail on its trip back to the nest; therefore the more food encountered at the end of the trail, the more workers that can be rewarded and the heavier the trail. The heavier the trail, the more workers that are drawn from the nest and arrive at the end of the trail. As the food is consumed, the number of workers laying trail substance drops, and the old trail fades by evaporation and diffusion, gradually constricting the outward flow of workers.

The fire ant odor trail shows other evidences of being efficiently designed. The active space within which the pheromone is dense enough to be perceived by workers remains narrow and nearly constant in shape over most of the length of the trail. It has been further deduced from diffusion models that the maximum gradient must be situated near the outer surface of the active space. Thus workers are informed of the space boundary in a highly efficient way. Together these features ensure that the following workers keep in close formation with a minimum chance of losing the trail.

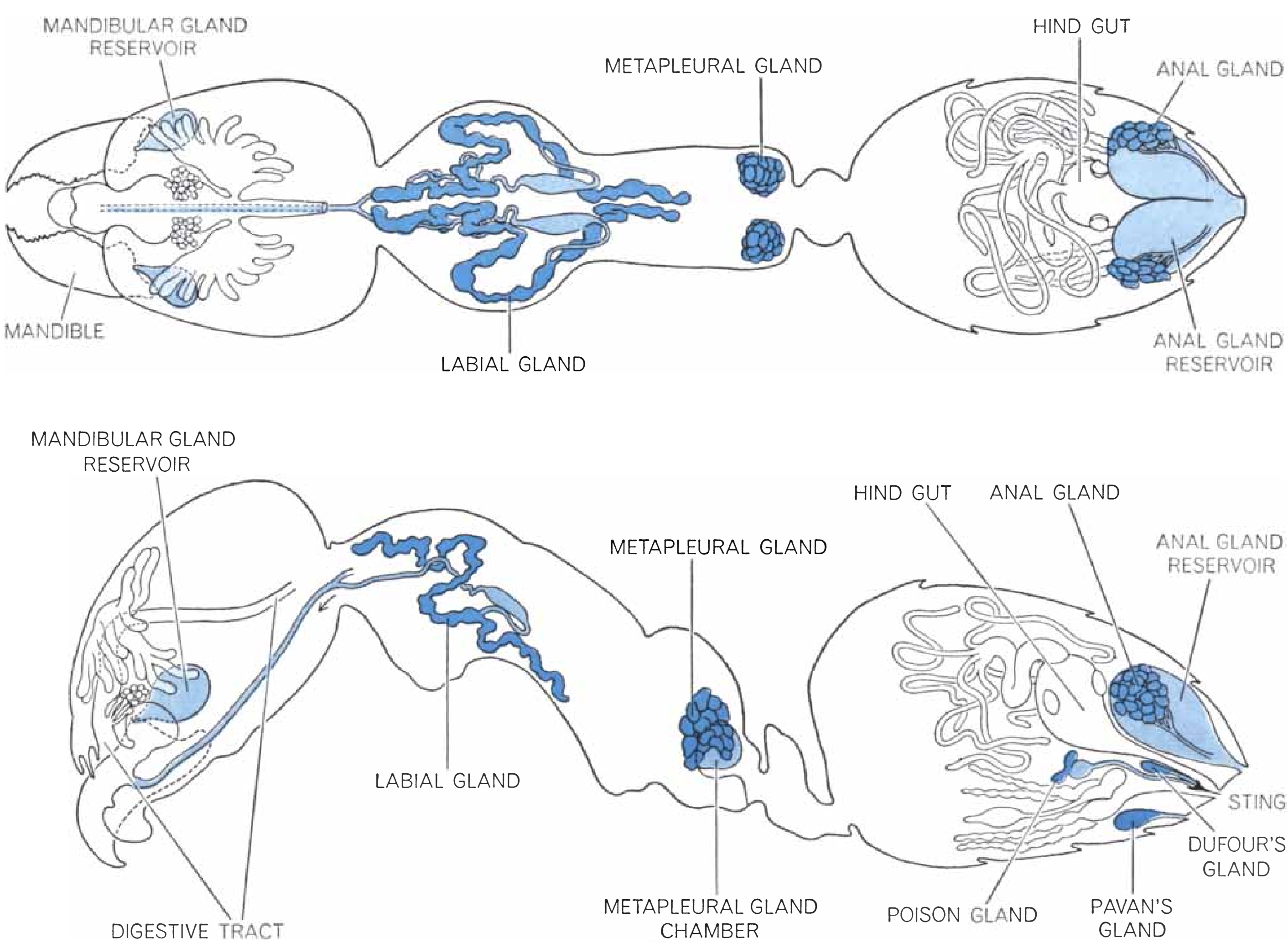
The fire ant trail is one of the few animal communication systems whose information content can be measured with fair precision. Unlike many communicating animals, the ants have a distinct goal in space—the food find or nest site—the direction and distance of which must both be communicated. It is possible by a simple technique to measure how close trail-followers come to the trail end, and, by making use of a standard equation from information theory, one can translate the accuracy of their response into the "bits" of information received. A similar procedure can be applied (as first suggested by the British biologist J. B. S. Haldane) to the "waggle dance" of the honeybee, a radically different form of communication system from the ant trail [see "Dialects in the Language of the Bees," by Karl von Frisch; SCIENTIFIC AMERICAN, August, 1962]. Surprisingly, it turns out that the two systems, although of wholly different evolutionary origin, transmit about the same amount of information with reference to distance (two bits) and direction (four bits in the honeybee, and four or possibly five in the ant). Four bits of information will direct an ant or a bee into one of 16 equally probable sectors of a circle and two bits will identify one of four equally probable distances. It is conceivable that these information values represent the maximum that can be achieved with the insect brain and sensory apparatus.

Not all kinds of ants lay chemical trails. Among those that do, however, the pheromones are highly species-specific in their action. In experiments in which artificial trails extracted from one species were directed to living colonies of other species, the results have almost always been negative, even among related species. It is as if each species had its own private language. As a result there is little or no confusion when the trails of two or more species cross.

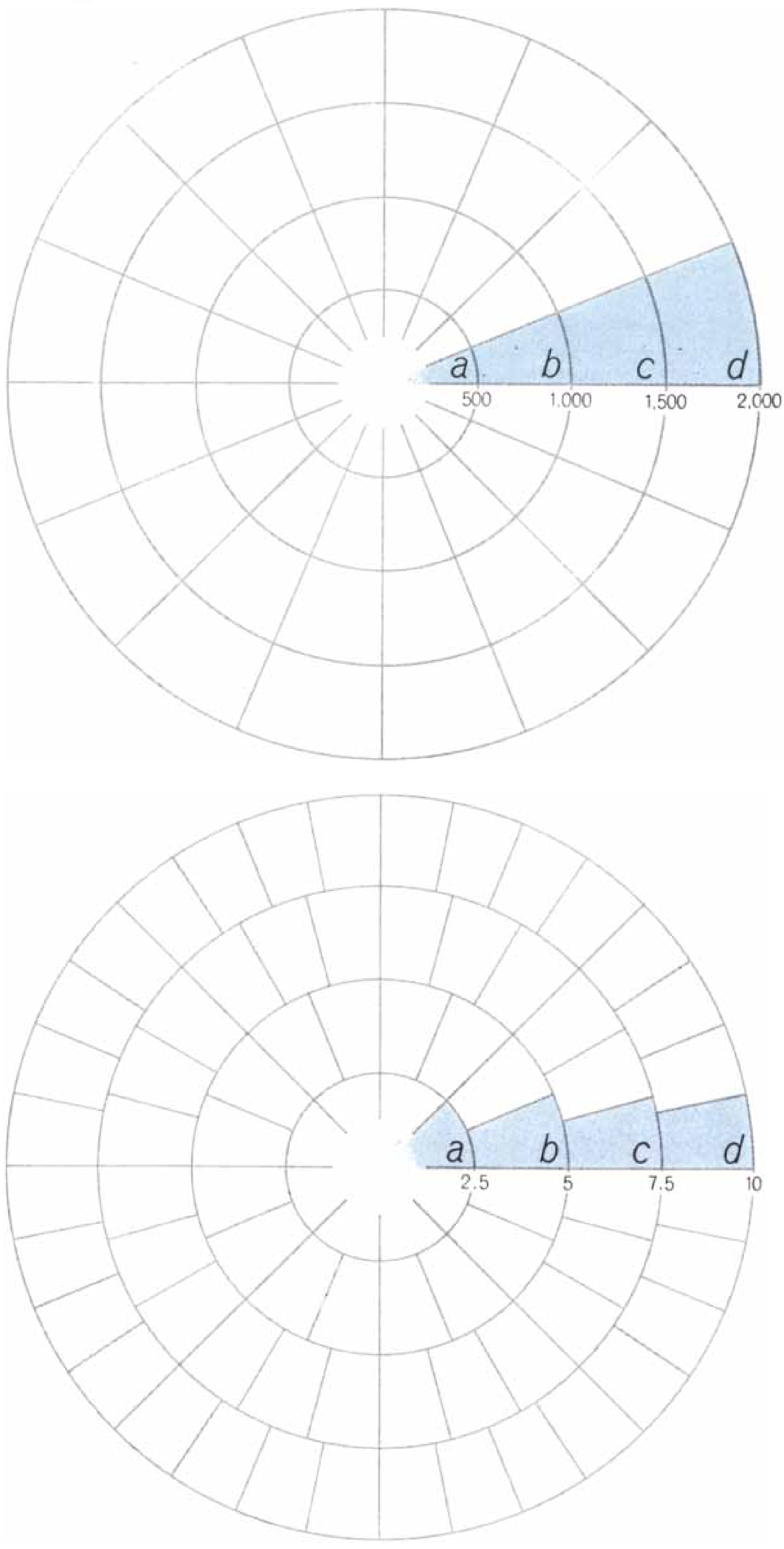
Another important class of ant pheromone is composed of alarm substances. A simple backyard experiment will show that if a worker ant is disturbed by a clean instrument, it will, for a short time, excite other workers with whom it comes in contact. Until recently most students of ant behavior thought that the alarm was spread by touch, that one worker simply jostled another in its excitement or drummed on its neighbor with its antennae in some peculiar way. Now it is known that disturbed workers discharge chemicals, stored in special glandular reservoirs, that can produce all the characteristic alarm responses solely by themselves. The chemical structure of four alarm substances is shown on page 114. Nothing could illustrate more clearly the wide differences between the human perceptual world and that of chemically communicating animals. To the human nose the alarm substances are mild or even pleasant, but to the ant they represent an urgent tocsin that can propel a colony into violent and instant action.

As in the case of the trail substances, the employment of the alarm substances appears to be ideally designed for the purpose it serves. When the contents of the mandibular glands of a worker of the harvesting ant (*Pogonomyrmex badius*) are discharged into still air, the volatile material forms a rapidly expanding sphere, which attains a radius of about six centimeters in 13 seconds. Then it contracts until the signal fades out completely some 35 seconds after the moment of discharge. The outer shell of the active space contains a low concentration of pheromone, which is actually attractive to harvester workers. This serves to draw them toward the point of disturbance. The central region of the active space, however, contains a concentration high enough to evoke the characteristic frenzy of alarm. The "alarm sphere" expands to a radius of about three centimeters in eight seconds and, as might be expected, fades out more quickly than the "attraction sphere."

The advantage to the ants of an alarm signal that is both local and short-lived becomes obvious when a *Pogonomyrmex* colony is observed under natural conditions. The ant nest is subject to almost innumerable minor disturbances. If the



EXOCRINE GLANDULAR SYSTEM of a worker ant (*shown here in top and side cutaway views*) is specially adapted for the production of chemical communication substances. Some pheromones are stored in reservoirs and released in bursts only when needed; others are secreted continuously. Depending on the species, trail substances are produced by Dufour's gland, Pavan's gland or the poison glands; alarm substances are produced by the anal and mandibular glands. The glandular sources of other pheromones are unknown.



FOREAGING INFORMATION conveyed by two different insect communication systems can be represented on two similar "compass" diagrams. The honeybee "waggle dance" (*top*) transmits about four bits of information with respect to direction, enabling a honeybee worker to pinpoint a target within one of 16 equally probable angular sectors. The number of "bits" in this case remains independent of distance, given in meters. The pheromone system used by trail-laying fire ants (*bottom*) is superior in that the amount of directional information increases with distance, given in centimeters. At distances *c* and *d*, the probable sector in which the target lies is smaller for ants than for bees. (For ants, directional information actually increases gradually and not by jumps.) Both insects transmit two bits of distance information, specifying one of four equally probable distance ranges.

alarm spheres generated by individual ant workers were much wider and more durable, the colony would be kept in ceaseless and futile turmoil. As it is, local disturbances such as intrusions by foreign insects are dealt with quickly and efficiently by small groups of workers, and the excitement soon dies away.

The trail and alarm substances are only part of the ants' chemical vocabulary. There is evidence for the existence of other secretions that induce gathering and settling of workers, acts of grooming, food exchange, and other operations fundamental to the care of the queen and immature ants. Even dead ants produce a pheromone of sorts. An ant that has just died will be groomed by other workers as if it were still alive. Its complete immobility and crumpled posture by themselves cause no new response. But in a day or two chemical decomposition products accumulate and stimulate the workers to bear the corpse to the refuse pile outside the nest. Only a few decomposition products trigger this funereal response; they include certain long-chain fatty acids and their esters. When other objects, including living workers, are experimentally daubed with these substances, they are dutifully carried to the refuse pile. After being dumped on the refuse the "living dead" scramble to their feet and promptly return to the nest, only to be carried out again. The hapless creatures are thrown back on the refuse pile time and again until most of the scent of death has been worn off their bodies by the ritual.

Our observation of ant colonies over long periods has led us to believe that as few as 10 pheromones, transmitted singly or in simple combinations, might suffice for the total organization of ant society. The task of separating and characterizing these substances, as well as judging the roles of other kinds of stimuli such as sound, is a job largely for the future.

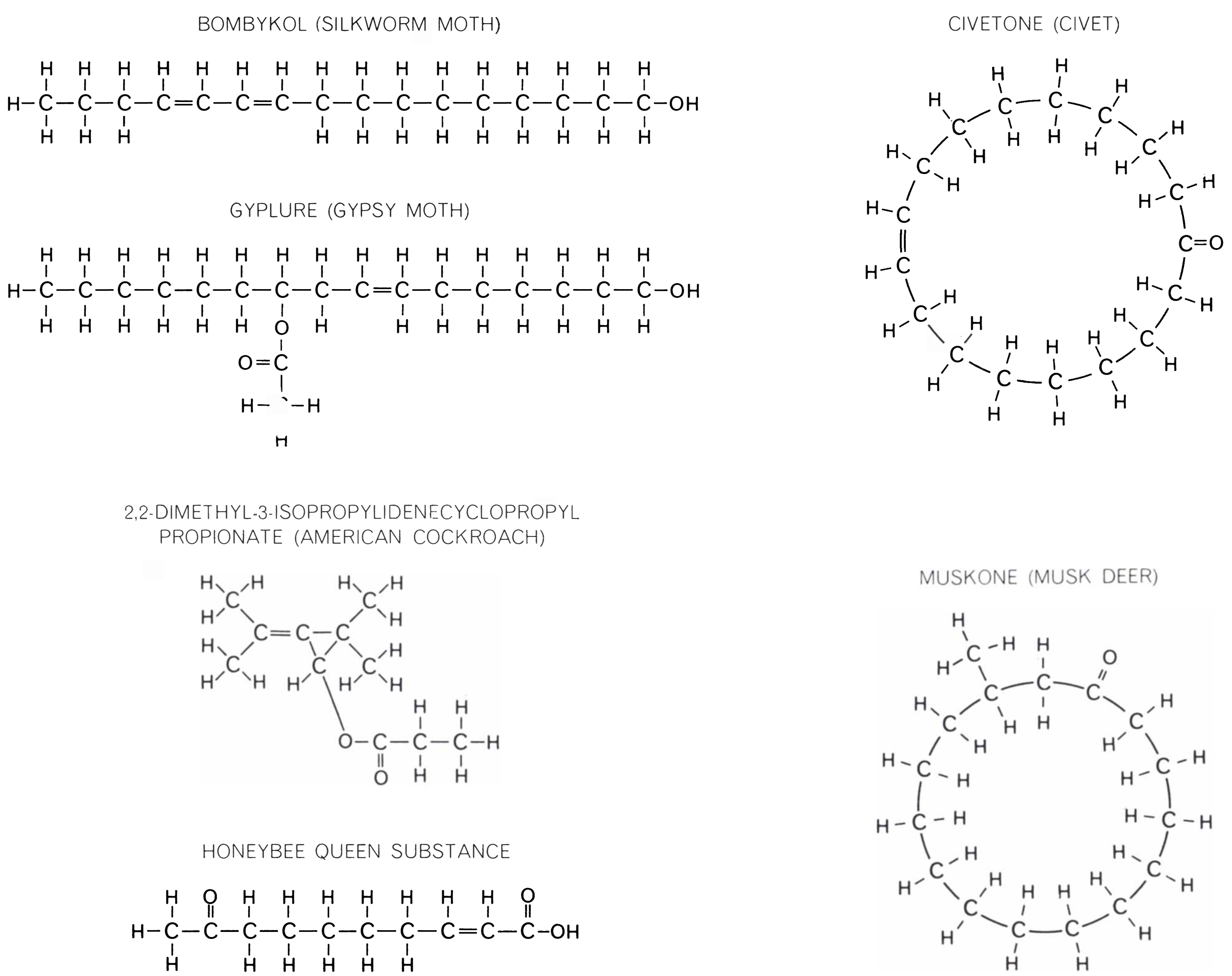
Even in animal species where other kinds of communication devices are prominently developed, deeper investigation usually reveals the existence of pheromonal communication as well. I have mentioned the auxiliary roles of primer pheromones in the lives of mice and migratory locusts. A more striking example is the communication system of the honeybee. The insect is celebrated for its employment of the "round" and "waggle" dances (augmented, perhaps, by auditory signals) to designate the location of food and new nest sites. It is not so widely known that chemical signals

play equally important roles in other aspects of honeybee life. The mother queen regulates the reproductive cycle of the colony by secreting from her mandibular glands a substance recently identified as 9-ketodecanoic acid. When this pheromone is ingested by the worker bees, it inhibits development of their ovaries and also their ability to manufacture the royal cells in which new queens are reared. The same pheromone serves as a sex attractant in the queen's nuptial flights.

Under certain conditions, including the discovery of new food sources, worker bees release geraniol, a pleasant-smelling alcohol, from the abdominal Nassanoff glands. As the geraniol diffuses through the air it attracts other workers and so supplements information contained in the waggle dance. When a worker stings an intruder, it discharges, in addition to the venom, tiny amounts of a secretion from clusters of unicellular glands located next to the basal plates of the sting. This secretion is responsible for the tendency, well known to beekeepers, of angry swarms of workers to sting at the same spot. One component, which acts as a simple attractant, has been identified as isoamyl acetate, a compound that has a banana-like odor. It is possible that the stinging response is evoked by at least one unidentified alarm substance secreted along with the attractant.

Knowledge of pheromones has advanced to the point where one can make some tentative generalizations about their chemistry. In the first place, there appear to be good reasons why sex attractants should be compounds that contain between 10 and 17 carbon atoms and that have molecular weights between about 180 and 300—the range actually observed in attractants so far identified. (For comparison, the weight of a single carbon atom is 12.) Only compounds of roughly this size or greater can meet the two known requirements of a sex attractant: narrow specificity, so that only members of one species will respond to it, and high potency. Compounds that contain fewer than five or so carbon atoms and that have a molecular weight of less than about 100 cannot be assembled in enough different ways to provide a distinctive molecule for all the insects that want to advertise their presence.

It also seems to be a rule, at least with insects, that attraction potency increases with molecular weight. In one series of esters tested on flies, for instance, a doubling of molecular weight resulted in as much as a thousandfold increase in efficiency. On the other hand, the molecule cannot be too large and complex or it will be prohibitively difficult for the insect to synthesize. An equally important limitation on size is



SIX SEX PHEROMONES include the identified sex attractants of four insect species as well as two mammalian musks generally believed to be sex attractants. The high molecular weight of most sex pheromones accounts for their narrow specificity and high potency.

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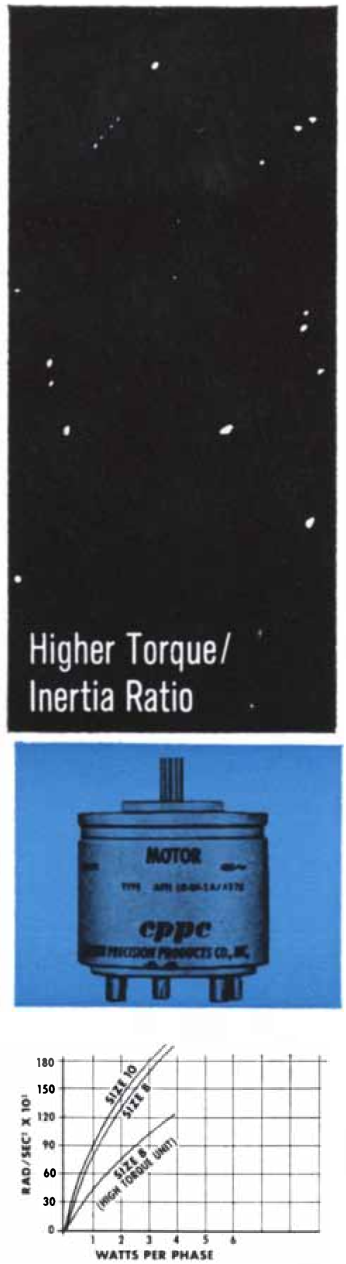

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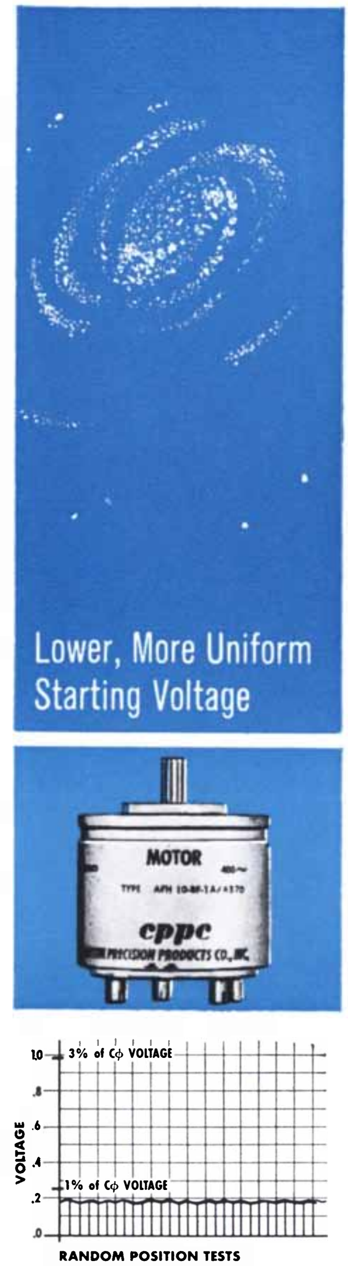

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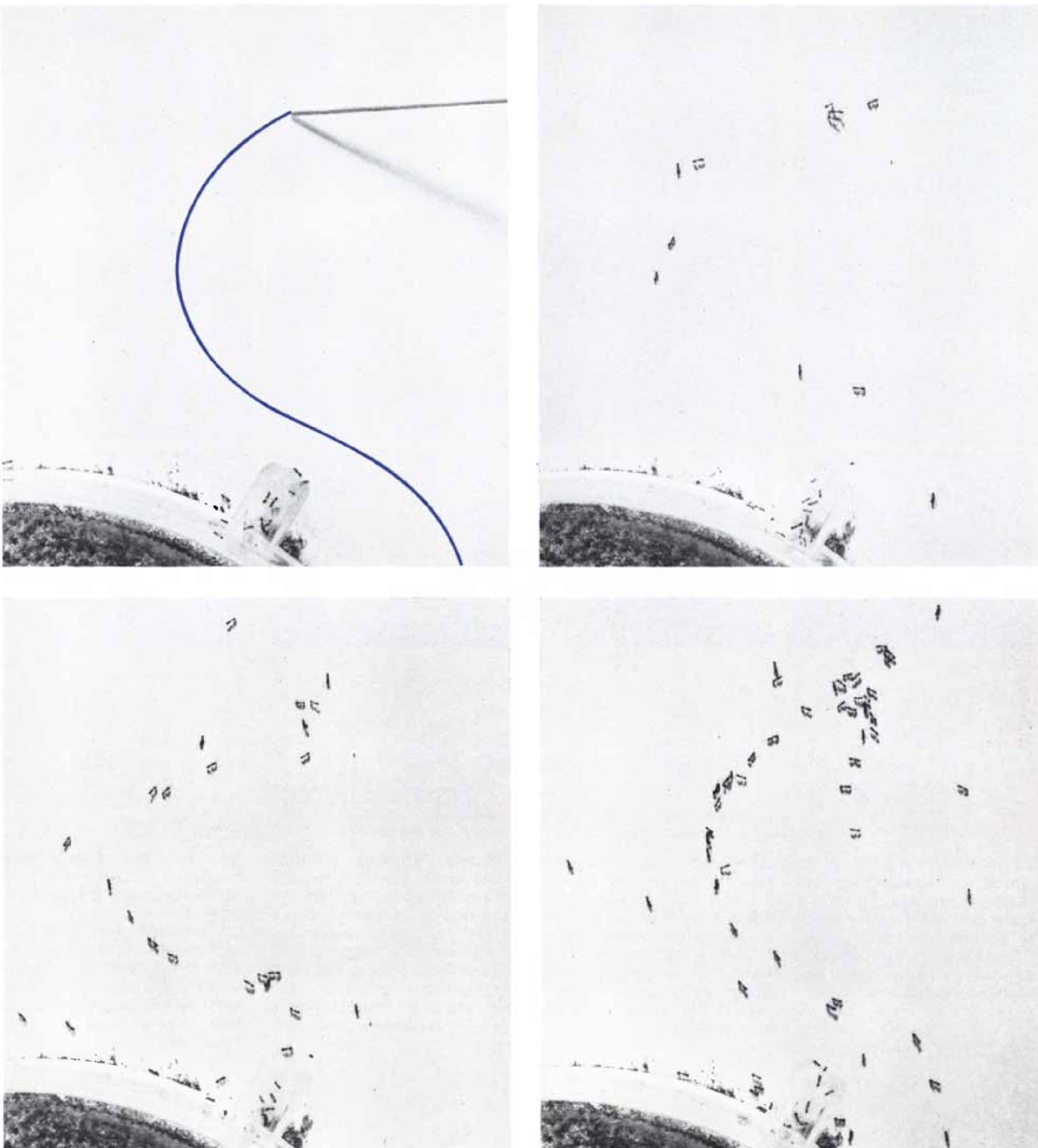
the fact that volatility—and, as a result, diffusibility—declines with increasing molecular weight.

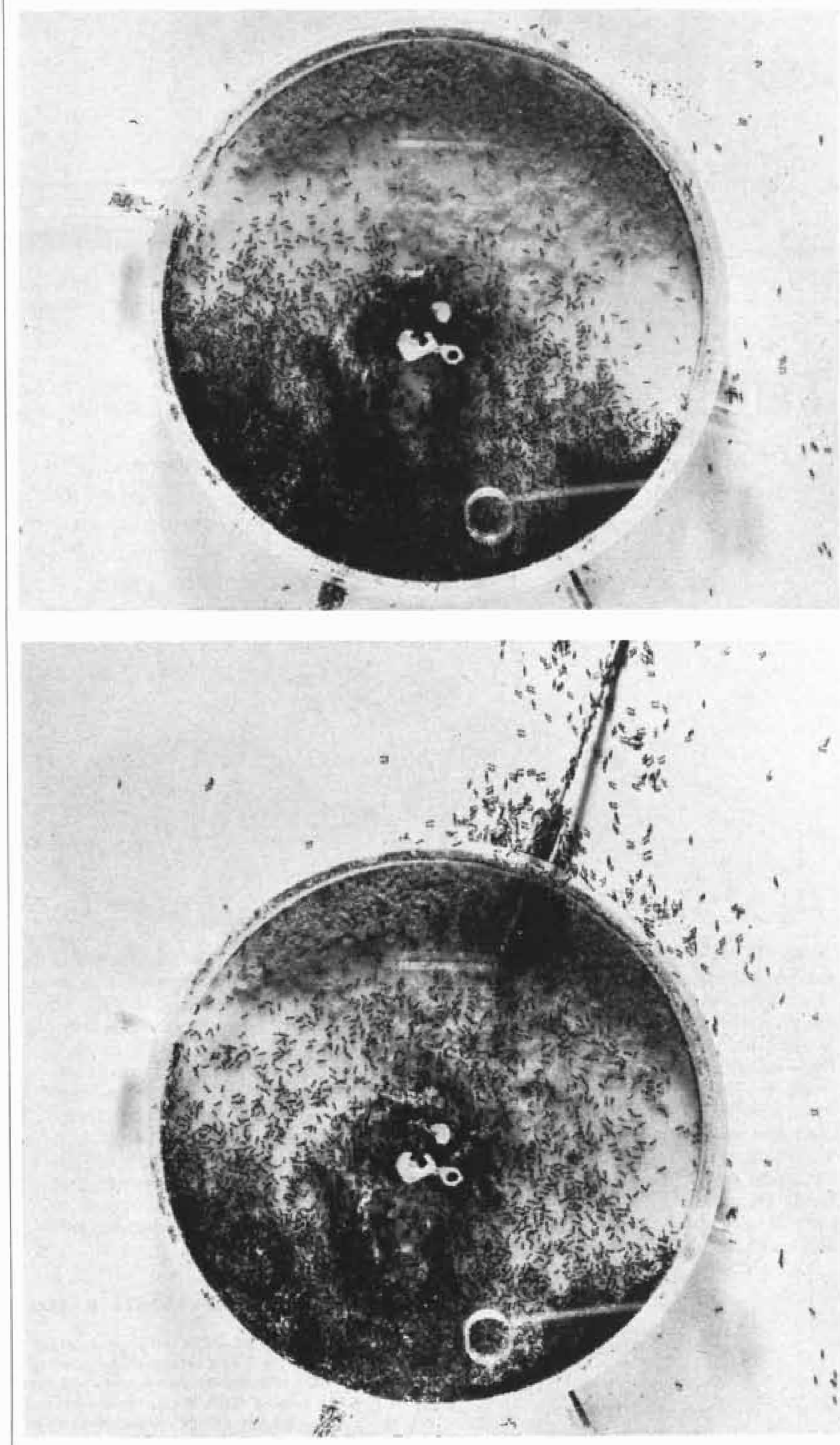
One can also predict from first principles that the molecular weight of alarm substances will tend to be less than those of the sex attractants. Among the ants there is little specificity; each species responds strongly to the alarm substances of other species. Furthermore, an alarm substance, which is used primarily within the confines of the nest, does not need the stimulative potency of a sex attractant, which must carry its message for long distances. For these reasons small molecules will suffice for alarm purposes. Of seven alarm substances known in the social insects, six have 10 or fewer carbon atoms and one (dendrolasin) has 15. It will be interesting to see if future discoveries bear out these early generalizations.

Do human pheromones exist? Primer pheromones might be difficult to detect, since they can affect the endocrine system without producing overt specific behavioral responses. About all that can be said at present is that striking sexual differences have been observed in the ability of humans to smell certain



ARTIFICIAL TRAIL can be laid down by drawing a line (*colored curve in frame at top left*) with a stick that has been treated with the contents of a single Dufour's gland. In the remaining three frames, workers are attracted from the nest, follow the artificial route in close formation and mill about in confusion at its arbitrary terminus. Such a trail is not renewed by the unrewarded workers.

substances. The French biologist J. LeMagnen has reported that the odor of Exaltolide, the synthetic lactone of 14-hydroxytetradecanoic acid, is perceived clearly only by sexually mature females and is perceived most sharply at about the time of ovulation. Males and young girls were found to be relatively insensitive, but a male subject became more sensitive following an injection of estrogen. Exaltolide is used commercially as a perfume fixative. LeMagnen also reported that the ability of his subjects to detect the odor of certain steroids paral-

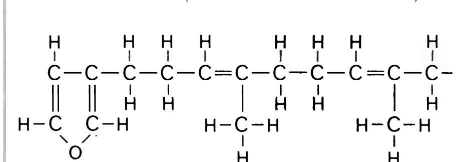


MASSIVE DOSE of trail pheromone causes the migration of a large portion of a fire ant colony from one side of a nest to another. The pheromone is administered on a stick that has been dipped in a solution extracted from the Dufour's glands of freshly killed workers.

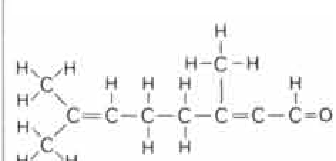
leled that of their ability to smell Exaltolide. These observations hardly represent a case for the existence of human pheromones, but they do suggest that the relation of odors to human physiology can bear further examination.

It is apparent that knowledge of chemical communication is still at an early stage. Students of the subject are in the position of linguists who have learned the meaning of a few words of a nearly indecipherable language. There is almost certainly a large chemical vocabulary still to be discovered. Conceivably some pheromone "languages" will be found to have a syntax. It may be found, in other words, that pheromones can be combined in mixtures to form new meanings for the animals employing them. One would also like to know if some animals can modulate the intensity or pulse frequency of pheromone emission to create new messages. The solution of these and other interesting problems will require new techniques in analytical organic chemistry combined with ever more perceptive studies of animal behavior.

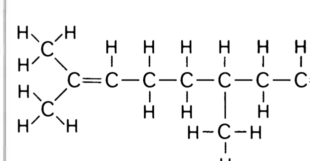
DENDROLASIN (*LASIUS FULIGINOSUS*)



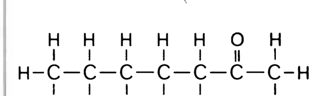
CITRAL (*ATTA SEXDENS*)



CITRONELLAL (*ACANTHOMYOPS CLAVIGER*)

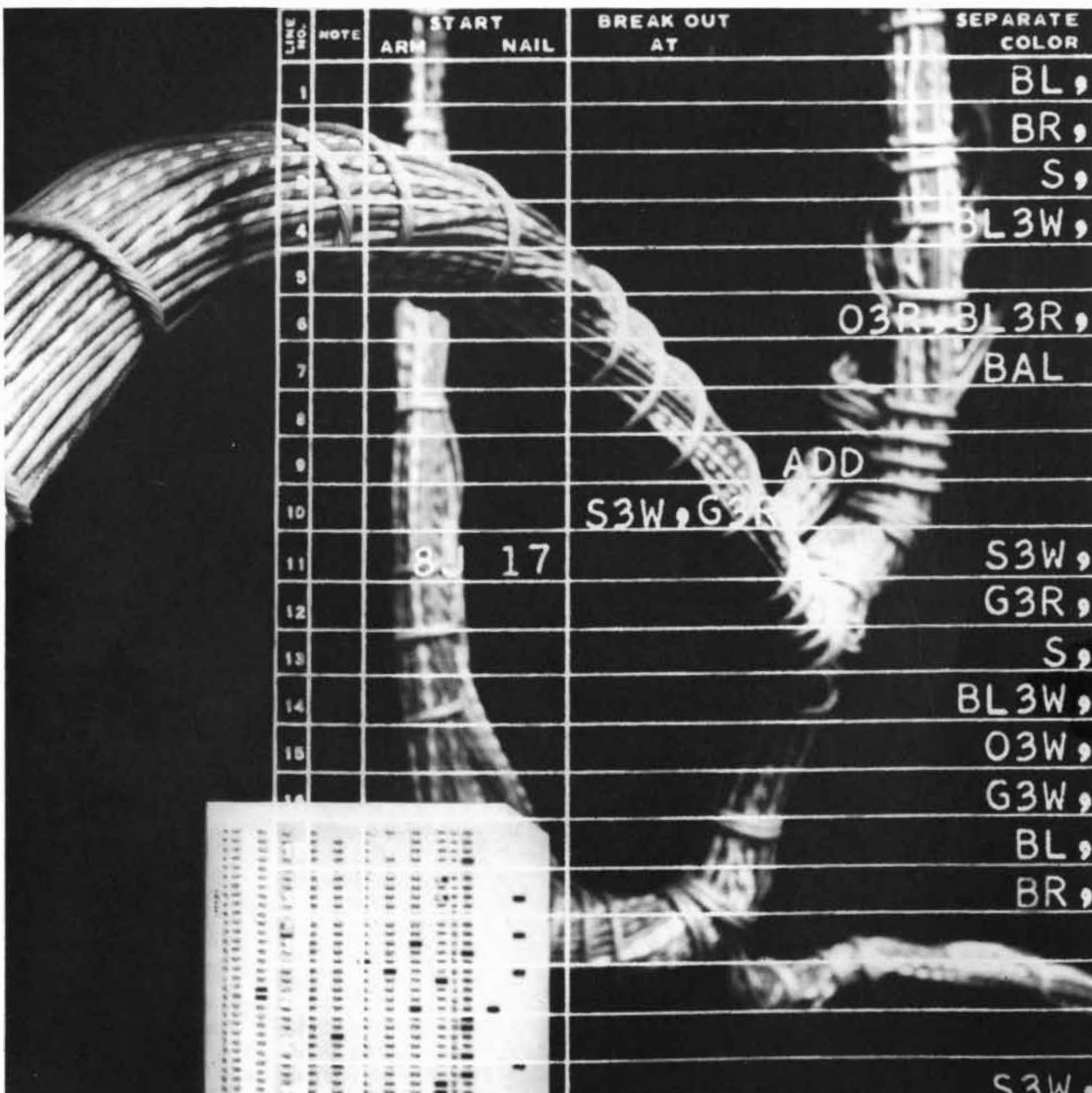


2-HEPTANONE (*IRIDOMYRMEX PRUINOSUS*)



FOUR ALARM PHEROMONES, given off by the workers of the ant species indicated, have so far been identified. Disturbing stimuli trigger the release of these substances from various glandular reservoirs.

PROCESSES. To keep improving the communications products it makes for the nationwide Bell telephone network, and hold costs down, Western Electric constantly seeks new and better manufacturing processes. A recent example is the mechanization and optimization of instruction lists for the forming of wires which electrically interconnect the maze of circuit components in Bell telephone switching offices. A unique digital computer program was written to provide running lists that are detailed "roadmaps" for the cable formers, allowing them to handle a maximum number of wires with a minimum of wire changes. The result is standardization of the way each type of network is laid out (some units require over 10,000 separate wires), reduced efforts of both equipment engineers and cable formers, and considerable savings to the Bell System. Last year alone, over $250,000 was saved through fewer rejects and more wire networks produced. Another reason why America has the finest, most reasonably priced communications services in the world. **WESTERN ELECTRIC**



OBSIDIAN BLADES were among the significant finds at El Inga. Blades, found here for the first time in South America, were long flakes struck from obsidian cones to serve as knives and as generalized blanks from which a wide variety of tools was fashioned.

VARIOUS TOOLS made from blades are shown in this photograph made, like the others on this page, by Robert E. Bell of the University of Oklahoma. The two objects at the left are chisels. In the middle is a pair of gravers, pointed tools for cutting designs on stone or bone surfaces. At the right are two "strangulated," or notched, blades that served as spokeshaves for shaping round shafts.

PROJECTILE POINTS and fragments at El Inga included these stemmed styles similar to points found at Level I of Fell's Cave at the tip of South America. Many of these points had "fluted" bases, as in the case of the two in the middle of the top row and the second, fourth and fifth from the left in the bottom row. All the tools shown on this page are reproduced at about their actual size.

Early Man in the Andes

A rich assemblage of obsidian tools has been discovered at El Inga, high in the mountains of Ecuador. It may provide a long-sought link between the prehistoric men of the U.S. and those of South America

by William J. Mayer-Oakes

In 1926 a distinctive kind of stone projectile point was found near Folsom, N.M., in unmistakable association with the bones of a long extinct species of bison. The discovery stimulated the search for further traces of the Paleo-Indians who had made the points and for evidence of the migrations of the men who first populated the New World. It is now fairly clear that the first Americans were nomadic hunters who crossed the Bering Strait from Asia on a land bridge that existed at the end of the last glacial period. As early as 10,000 years ago they had diffused across what is now Canada and the U.S. and down the spine of the Americas all the way to the Strait of Magellan. Filling in the details of this broad outline has proved to be difficult: the archaeological trail is faint. Investigators have found very few skeletal remains of the earliest men and hardly any artifacts made of perishable organic material that can be dated by the radioactive-carbon method. They have had to rely almost entirely on one kind of evidence: bits of worked flint and obsidian, the fragmentary weapons and tools of the ancient hunters, unearthed at sites from Alaska to the tip of South America.

By comparing the kinds of tools at various sites, their shapes and the precise chipping techniques by which they were fashioned, investigators are establishing relations among sites in the circumpolar region and reconstructing early man's movements across the U.S. in some detail. In recent years they have been able to find traces of North American tool industries as far south as Mexico and Central America. Below the Isthmus of Panama, however, the trail of these cultures seemed to end abruptly. Most sites in South America yielded quite different artifacts; their cultures seemed to be only obscurely related to one another and were not linked to the north. There was good evidence that men had camped in caves near the Strait of Magellan some 10,000 years ago but nothing to explain how quickly and by what route they had arrived there. What was needed was the discovery of a tool assemblage of sufficient size and richness to show relations among the various sites in South America and perhaps also a link to North American origins.

For the past three years Robert E. Bell of the University of Oklahoma and I have been investigating just such a site high in the Andes near Quito in Ecuador. El Inga, as we have named the place, appears to have been a workshop and campsite for some of the first South Americans. Its location confirms a current belief that the early migrants were a highland people who followed a mountain route, thus maintaining a fairly constant climatic and ecological environment as they moved through the equatorial regions to the sub-Antarctic.

El Inga was discovered by an American geologist, A. Allen Graffham, who worked in Ecuador from 1956 to 1959. Graffham is also an amateur archaeologist, and he often went on weekend outings with his family in search of sites and specimens. On one such excursion he came on a group of heavily eroded hummocks some 15 miles from Quito, near the gorge of the Rio Inga at an altitude of 9,100 feet. Scattered over the surface he noticed pieces of obsidian, a volcanic glass, that he quickly decided had been shaped by man and might represent a significant archaeological find. Graffham gathered some specimens; when he returned to the U.S. he took the collection to Bell, who agreed that his find was significant. The obsidian objects were projectile points and other tools that had been carefully worked by distinctive techniques, some of them reminiscent of the stoneworking methods of the Paleo-Indians in the North American Plains region.

Bell was particularly impressed by some of the fragments. They appeared to be the bases of lanceolate, or lance-shaped, spear or dart points and they were "fluted"; that is, "channel flakes" had been chipped from the bases parallel to the long axis of the points. Both shape and fluting resembled those of the Folsom points and the closely related Clovis points found in the western and southwestern U.S.

When Bell invited me to examine the find, I was struck by another aspect of the collection. For me the most distinctive items were several "fishtail"-stemmed points identical in shape with points unearthed nearly 30 years ago at the Strait of Magellan sites by Junius B. Bird of the American Museum of Natural History. Bird had found these points, sometimes associated with the bones of extinct sloth and horse species, in excavations at Palli Aike and Fell's Cave in a level he called Fell's Cave I.

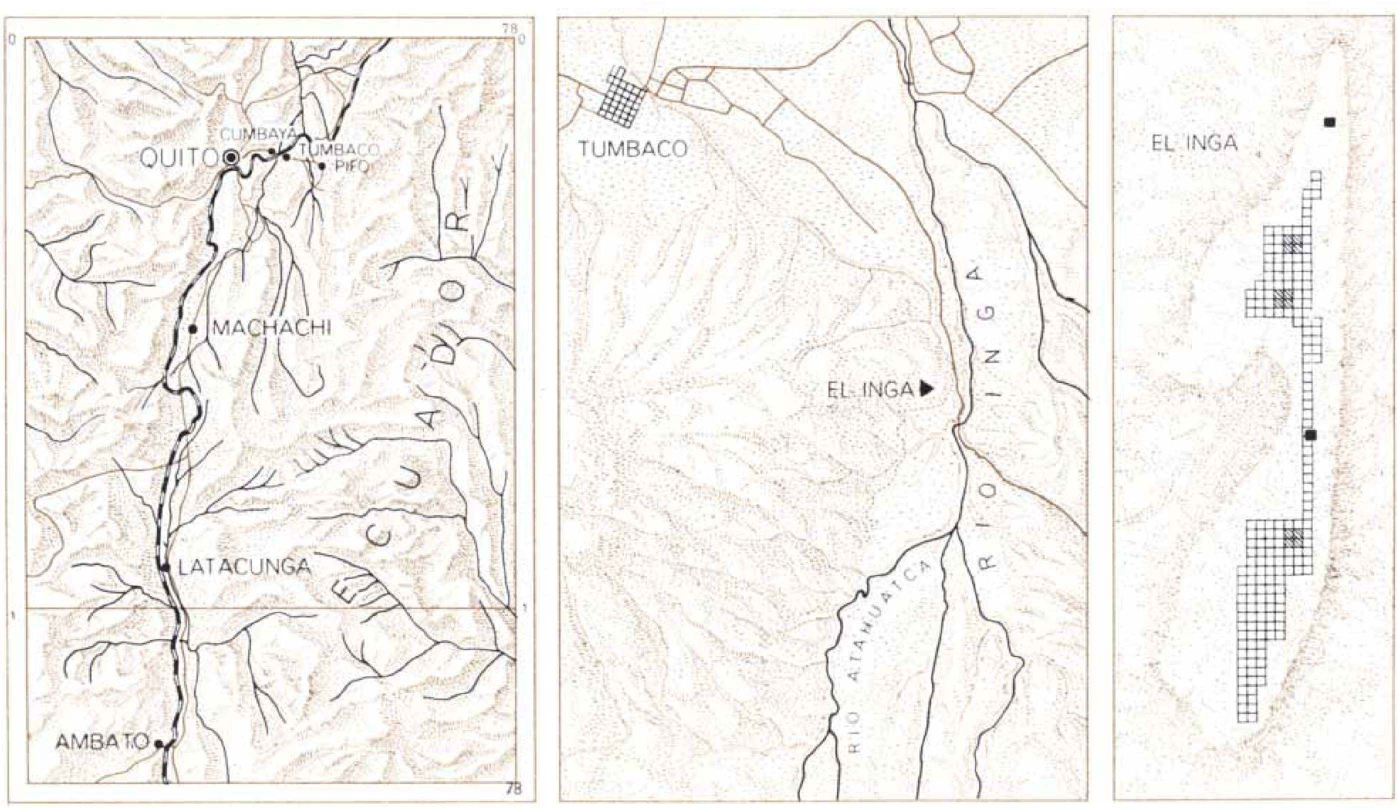
It was apparent to us that excavations at El Inga might provide the link that had been lacking between the Paleo-Indians of the Plains region and the men of Fell's Cave and so tell much about the nature of the north-south migrations. The El Inga collection might also show us how the style characteristics of projectile points could serve in South America, as they had in North America, as significant markers for dating occupation levels and interrelating a number of sites.

In the fall of 1959 I joined Bell at the University of Oklahoma, and the next January we flew to Quito. Graffham had suggested that we go out to El Inga as he had—by taxi. This seemed a rather

MAJOR EXCAVATIONS got under way at El Inga in June, 1961, on the largest uneroded hummock from which rain had been washing the obsidian artifacts. The mountain ridge in the background, to the southeast, is the last one before the Amazon drainage basin.

mundane way of penetrating the high Andes to a newly discovered prehistoric site, but we found the driver he recommended and set out, armed with a sketch map of the site and the route to it from Quito. Beyond the little town of Tumbaco the dirt road forked and there were the landmarks indicated on the map: trail, bridge, mountain and, right next to the road, the eroded hummocks. But something else made us certain we had relocated El Inga. It was obsidian. The surface was littered with pieces of the shiny black glass.

Erosion had done the preliminary excavating here: rain water had cut into the hummocks, washing the artifacts of early man out of the topsoil onto exposed patches of the underlying hardpan, and they lay there in plain view. We spent the day scouting the area and picking up loose obsidian. For the next two weeks we commuted to the site daily, collecting artifacts from the surface and digging

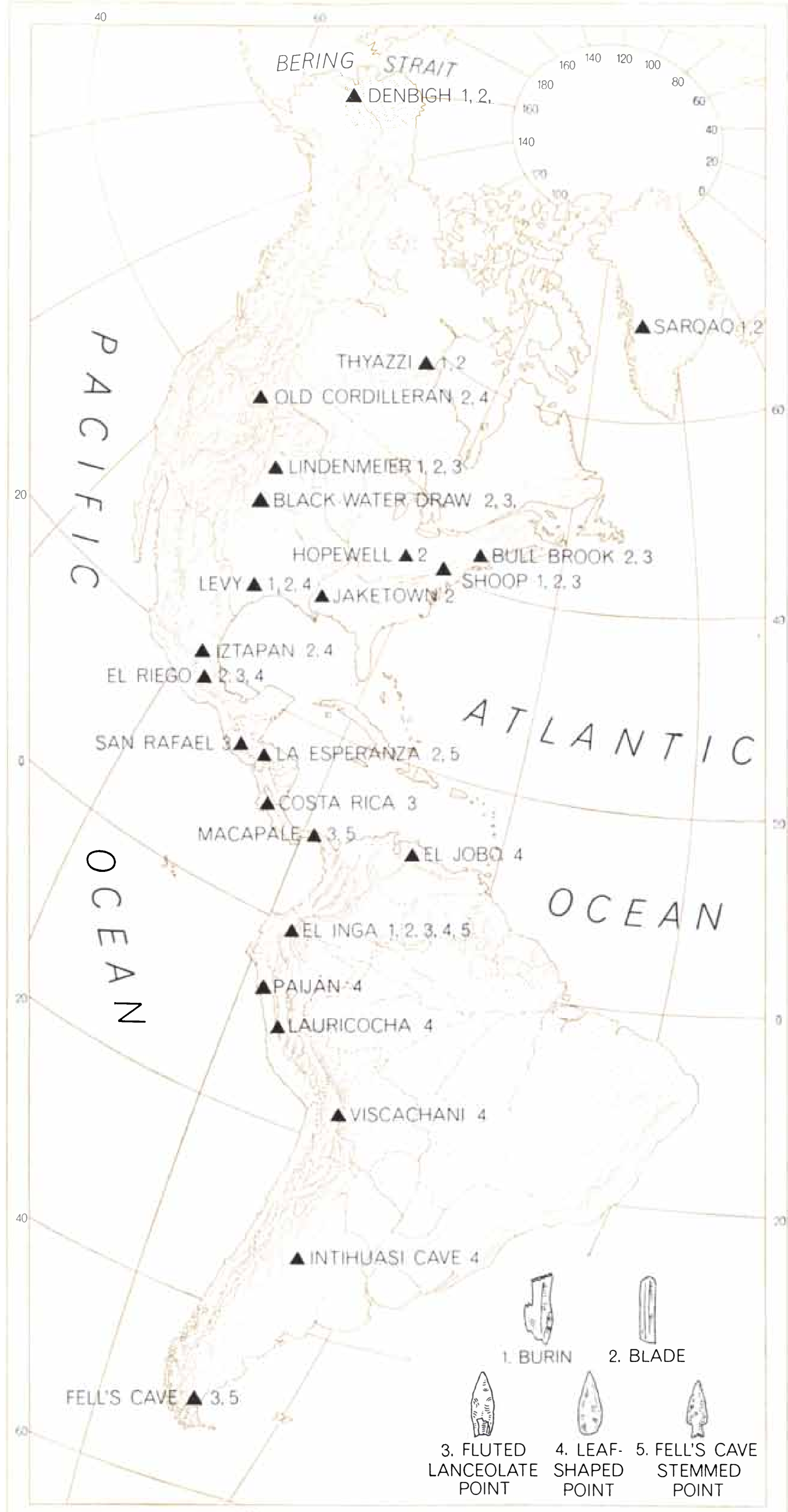


EL INGA is in northern Ecuador, east of Quito, between Tumbaco and Pifo on the map at the left. The center map shows the location of the site, on a trail that branches from the road along the Rio Inga gorge. The major excavation, laid out in five-foot squares, is shown at the right. The 10-foot squares (*hatched*) are the three "stratigraphic blocks" (*see text*); test pits are shown in black.

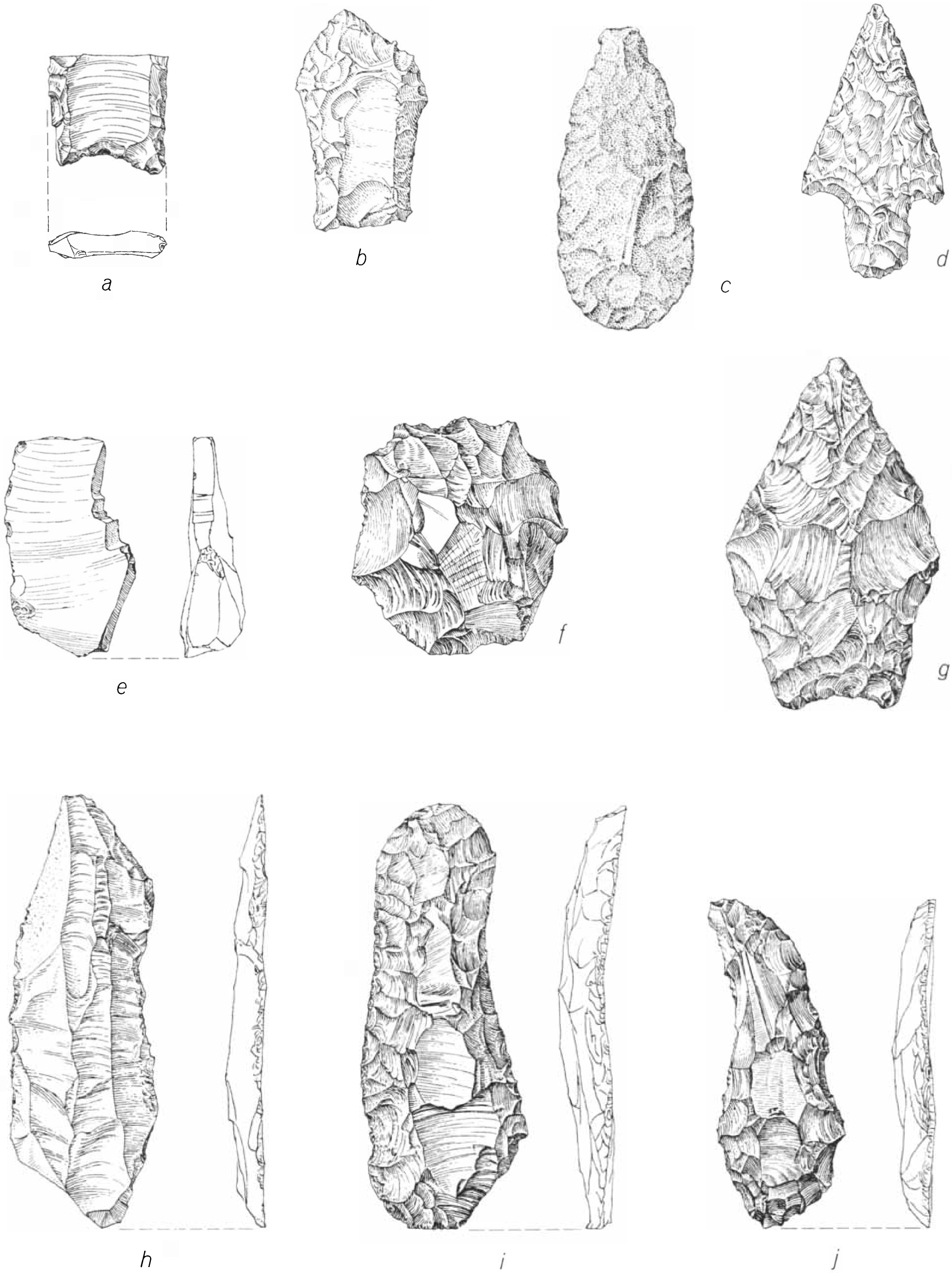
two five-foot-square test pits in an uneroded area. We found that there was a top level of soil, from eight to 10 inches deep, that had been periodically disturbed by plowing. Then came a darker band of unplowed soil, the "midden," in which most of the obsidian lay. This level extended to 18 or 20 inches below the surface and was underlain by a yellow hardpan, a consolidated volcanic tuff that contained no obsidian.

In two weeks we collected almost 600 pounds of obsidian, which we shipped back to Oklahoma. When we set to work sorting through the material and classifying it, the haul proved to be richer than we had expected. There was, first of all, a large sample of all the kinds of objects Graffham had brought back: points, scrapers, gravers and other tools. But we also found something new: a number of nicely fashioned parallel-sided flakes, smooth on one face and faceted with a few long surfaces on the other. These were "blades": flakes struck from specially prepared conical obsidian "cores" and subsequently used as knives or blanks from which many different specialized tools could be made. Flint or obsidian cores and blades are the hallmark of a number of rather advanced tool industries and are characteristic in particular of several Upper Paleolithic cultures in Europe and Asia. We knew that blades had been found at a few sites in North America and that they were typical of the pre-Columbian Mexican obsidian industries. But so far as we knew they had not yet been seen in South America.

In this preliminary search through the material we found one other significant detail. Among the numerous randomly shaped pieces, many of which were waste material from the toolmaking process, we noticed a number of peculiar flat-sided flakes of a distinctive shape. We suspected that they might have something to do with a burin industry, something so far unknown south of the U.S. Burins are special tools made by a special technique. They are chisel-pointed groovers or engraving tools fashioned by striking the end of a blade or a piece of a blade in such a way that slivers are split away to leave a cutting edge [*see illustration on page 128*]. The peculiar flakes we saw appeared to be burin spalls, or slivers. Like most New World archaeologists, we were not closely acquainted with burin technology. But the indicated presence of burins at El Inga, combined with the presence of blades, suggested a strong connection



NEW-WORLD DISTRIBUTION of El Inga traits is shown on this map. Five significant El Inga artifacts are shown at the lower right and their occurrence at various sites is indicated by the numbers on the map. The importance of El Inga lies largely in the variety of its artifacts, suggesting relations to sites widely scattered in North and South America. The pattern of the sites on the map suggests how early men diffused through the Americas.

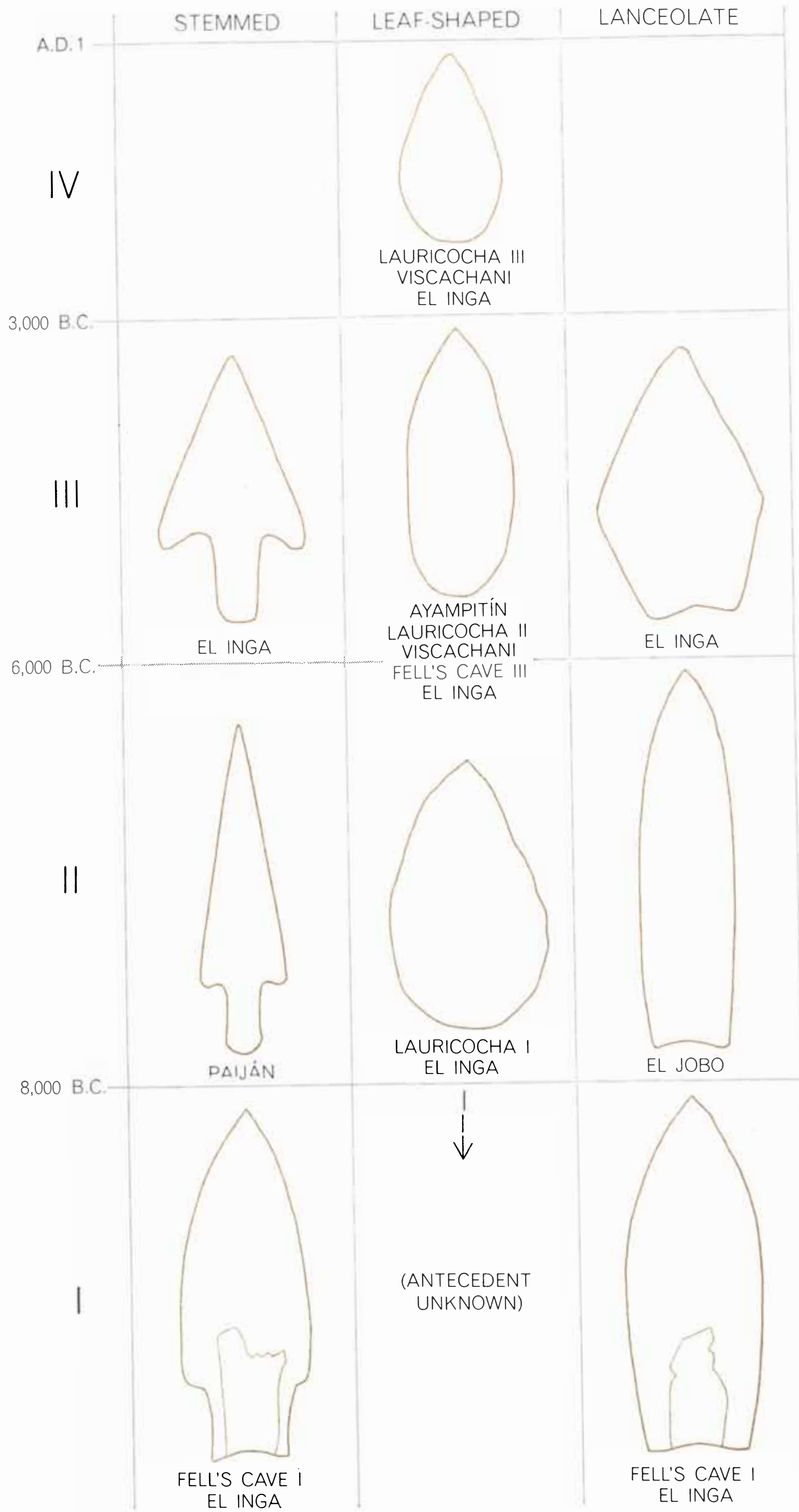


STYLES AND TECHNIQUES represented at El Inga are illustrated. Four different point styles are shown in the top row: the broken base of a Clovis-style point, fluted on both faces (*a*), a small Fell's Cave stemmed point (*b*), a leaf-shaped Ayampitín point (*c*) and a long-stemmed point peculiar to El Inga (*d*). The smooth, intricately chipped object (*e*) is an angle burin, a specialized grooving tool. The small hemispheric core (*f*) is seen from above. The large point (*g*) is in a modified lanceolate style. In the bottom row there are three unifacial tools, chipped only on one face: a blade (*h*), an end-and-side scraper (*i*) and a strangulated blade, or spokeshave (*j*). All tools are drawn at their actual sizes. The Ayampitín point (*c*) is basalt; all the other tools are obsidian.

with the northern cultures. El Inga deserved further investigation.

In the summer of 1961 Bell spent three months excavating the new Andean site. A large crew of local farmers and villagers cut a trench 200 feet long and five feet wide along the axis of the largest uneroded hummock. Then they expanded it where possible until some 5,000 square feet had been excavated in five-foot squares to an average depth of two feet—deep enough to penetrate the hardpan. We had noted from our 1960 test pits that there did not seem to be any correlation between the differences in the styles of the points and tools and the levels from which they had been recovered. But in such situations careful statistical classification of an excavated collection sometimes reveals changes in style and technology over a period of time. This kind of study requires that a large number of items be recovered and that they be kept separated according to the depth at which they were found. Bell had the workers dig carefully, slicing off the hard, dry soil in four-inch layers, screening each shovelful for pieces of obsidian and collecting the pieces from each four-inch level of each five-foot square separately. In a further effort to preserve whatever time sequence existed, Bell prepared three "stratigraphic blocks": 10-foot squares that were first isolated from the surrounding earth and then excavated only two inches at a time. By the end of the season he had a sample about as large as our first collection, but it came from throughout the mantle of soil as well as from the surface, and we knew precisely where each item had been found.

Unfortunately this major excavation failed to uncover any other explicit signs of occupation: no human burials or animal bones, no storage or garbage pits, no fireplaces. As a result we have no charcoal that can be subjected to radioactive-carbon dating. The fact that the undisturbed cultural deposit is between eight and 12 inches thick indicates that more than one occupation level may be represented. The variety of point styles and tool types also suggests that different cultures may be represented, perhaps covering as many as 4,000 or 5,000 years of intermittent occupation. The presence of different kinds of tools and quantities of waste material would seem to mean that El Inga was not merely a hunters' kill site but a combination workshop and campsite. Perhaps it was convenient to a good hunting area as well as to the extinct volcano Antisana, 21 miles to the southeast, where the



TIME SEQUENCE of three major early projectile-point styles in prehistoric South America is suggested here on the basis of the available evidence. Two of the El Inga points are judged to be very early because of their similarity to Fell's Cave Level I styles; others either look like or appear to be related to points from later levels at other sites. This tentative arrangement can be revised as firm dates are obtained for more of the early-man sites.

hunters may have obtained their obsidian. All this is speculation. More definite conclusions must be based on detailed examination of the tools.

With Bell's return to Oklahoma in the fall of 1961 the detailed studies began in earnest. From the more than 15,000 pieces collected from the surface we selected for study 6,500 specimens that obviously were fashioned, functional tools. I have been analyzing this collection at the University of Manitoba while Bell works at Oklahoma with the 1961 excavation finds. The El Inga assemblage as a whole is characterized primarily by a wide variety of "unifacial" tools —tools made by chipping away at the upper, or faceted, surface of a blade. In the surface collection I have counted some 200 small hemispheric cores from which the blades were struck. The size of the cores suggests that they must have been worked down to become tools (of unknown function) in themselves after having yielded as many blades as possible. There are more than 500 blades and many hundreds of scrapers, gravers, chisels and other tools made on blades. So far I have found about 50 burins and several hundred burin spalls. Another group consists of bifacial tools—tools chipped on both faces. These include crude choppers, cleavers and food grinders made of basalt as well as knives and scrapers made of obsidian, and of course the points. The 23 complete projectile points and 204 fragments are in a number of different styles: they are stemmed in the Fell's Cave style; lanceolate, leaf-shaped and long-stemmed. Many of the Fell's Cave and lanceolate points are fluted. (It is possible that some of these merely appear to have been fluted. Having been fashioned from blades, they may still retain the original chipping pattern of the blade surface, which might account for their fluted appearance.)

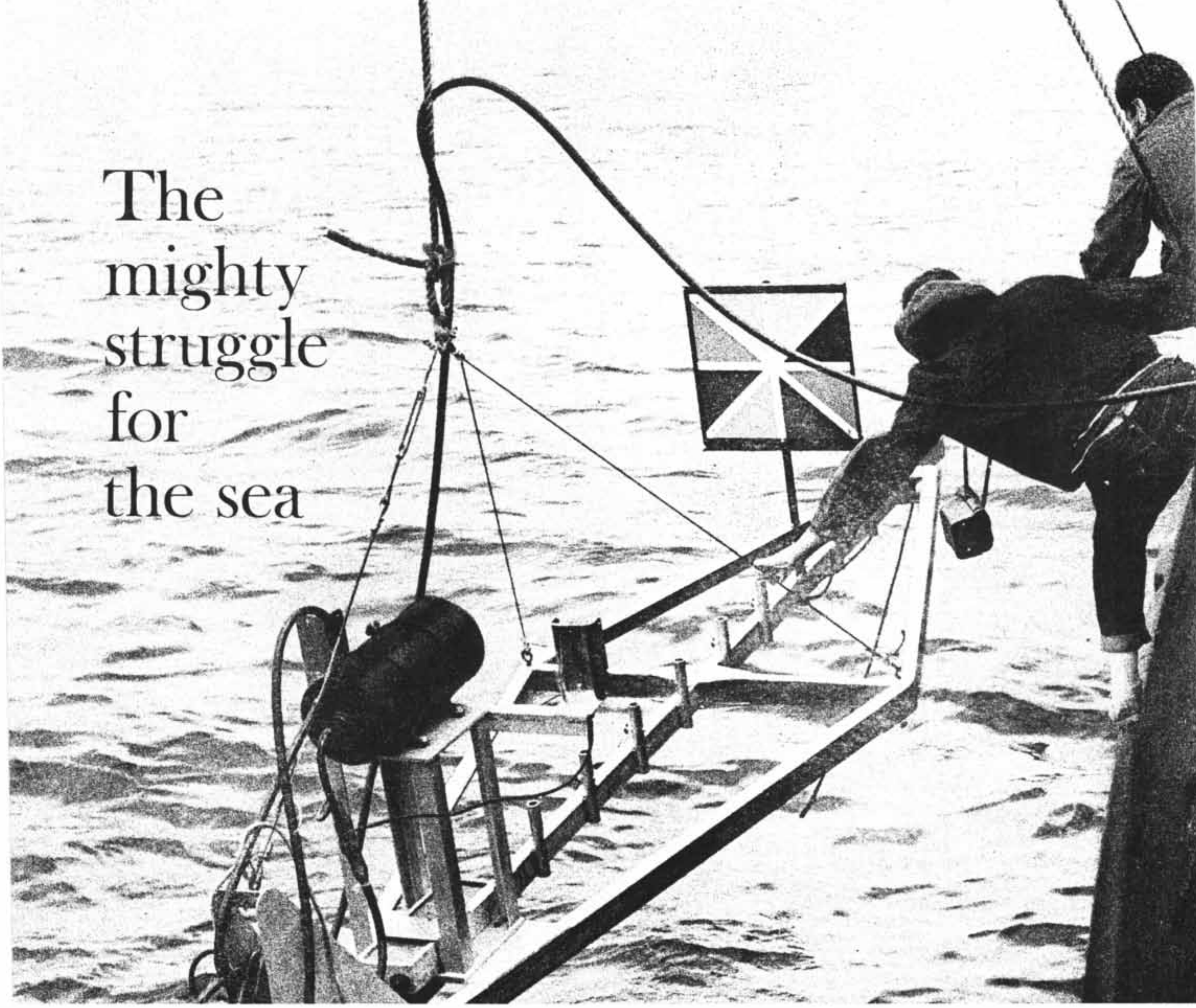
The discovery of this diverse stone-tool technology, the like of which had not been seen before in the New World, comes at a time when a number of workers are turning their attention to the early hunting cultures of South America. Excavations in Venezuela, Peru, Bolivia and Argentina have yielded a variety of projectile points and other tools, and investigators are just beginning to see the outlines of an early highland culture pattern. South American archaeology, in other words, is about at the stage of North American early-man investigations in the late 1920's and early 1930's, when the Folsom points were being sought as the distinctive feature of the Paleo-Indian culture. The first discoveries have been made and are leading to others, and the task of synthesis is under way.

Ten years ago fluted points were found for the first time south of the U.S. border in Costa Rica. By now these points have also been identified in Mexico, Guatemala and Panama. Interestingly enough, the points from Costa

INITIAL TRENCH was laid out along the major axis of the hummock. It was 200 feet long and five feet wide. The crew excavated slowly, digging down four inches in a five-foot square, screening the earth for obsidian and then repeating the process.

STRATIGRAPHIC BLOCKS, prepared so that obsidian objects could not fall to a spurious level from the walls of the trench, were excavated two inches at a time to assure precise vertical control. Here the top level of a block is being cut away.

The mighty struggle for the sea



One phase of Hughes pioneering work in underwater visibility—where the effects of various conditions on closed circuit TV are gathered first hand.

How far can TV "see" underwater? How does sound behave in the sea? Are there unexploited new techniques which could be useful in this hostile environment? These are questions which are being answered by Hughes engineers and scientists aboard oceanographic ships and at land facilities.

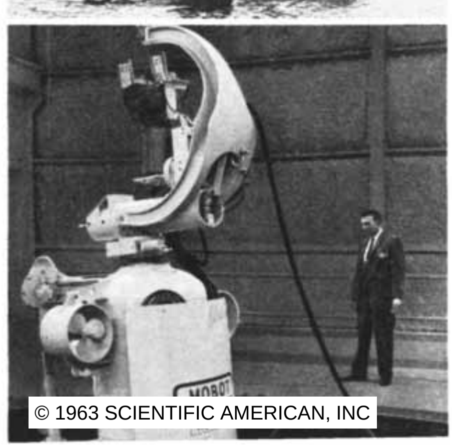
Each answer is a vital link in a massive struggle — to know the sea is to control it. And while we know a great deal about the atmosphere and space beyond — we know less about the sea even though it holds much greater potential usefulness.

One of Hughes most important activities is in Sonar — Sound Navigation and Ranging — presently man's most effective tool in undersea defense and exploration.

For example, as submarines have become more capable — diving deeper, running farther and faster — we are obliged to develop more effective means of detection, classification and localization. Working with the U. S. Navy, Hughes scientists and engineers are engaged in all aspects of research, development, production and installation of sonar systems. They are being developed for surface vessels, submarines, aircraft and for the ocean's floor.

Some specific programs include submarine-radiation measurements, analytical and acoustical testing, classification and methodology studies, and the development of

The 100-foot Tilman J oceanographic vessel is one of two research ships docked near Hughes plants — just minutes from deep water. Fully instrumented for military and commercial work, it has a 5,000-mile range.



MOBOT* is lowered into one of the two test tanks maintained by Hughes for underwater research. This 105,000-gallon tank is one of the largest facilities for acoustic transducer tests and noise field measurement studies.

*Trademark Hughes Aircraft Company

CREATING A NEW WORLD WITH ELECTRONICS

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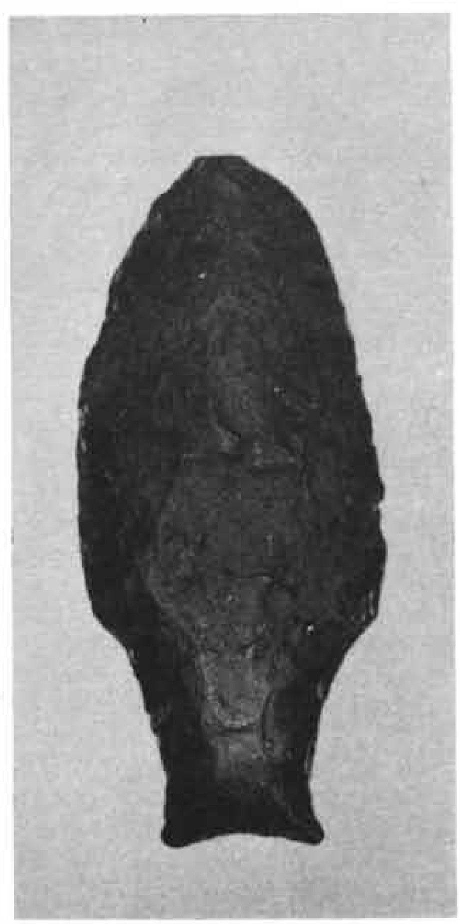
Rica and Panama are much like the El Inga fluted lanceolate points: they were struck from blades and are somewhat modified versions of the typical northern points. A different kind of evidence comes from Venezuela. The El Jobo assemblage there is quite unlike the Central American industries but is markedly similar to the Angostura industries that followed the fluted-point era in North America. All this evidence of relations between the Americas is tentative and suggestive; it may well be reinforced by the presence of lanceolate points at El Inga.

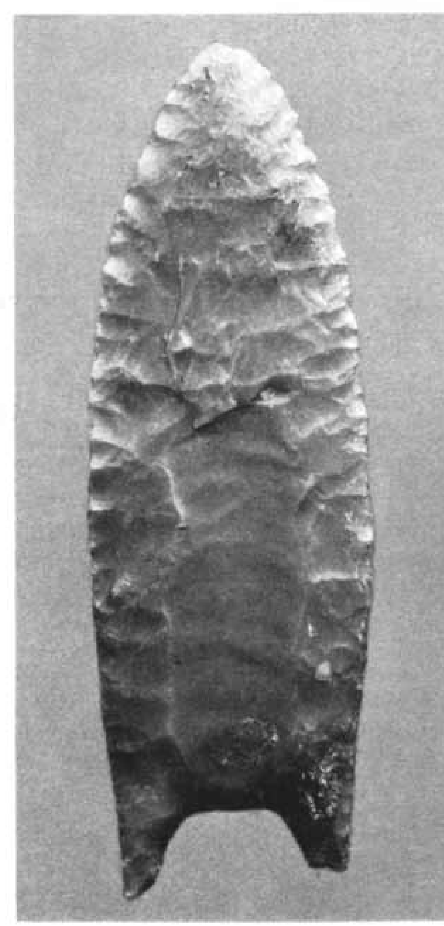
The implications of El Inga's leaf-shaped and stemmed points are less clear. Various versions of the leaf-shaped point have been found at sites in South America. One style takes its name from the Ayampitín level at Intihuasi Cave in Argentina, where it was found in a context carbon-dated at 6000 B.C. El Inga has yielded points in this style and others, some apparently earlier and some later than Ayampitín. As for the stemmed point, its typical style, from the very old Fell's Cave level, has now been entered in the record from El Inga. A long-stemmed variety that may have developed from it is also represented at the Ecuadorian site and, in slightly different form, at Paiján in Peru. And just recently Ripley P. Bullen of the Florida State Museum and William Plowden, Jr., reported finding fluted, stemmed points far to the north, at La Esperanza in the highlands of Honduras.

What is not yet determined is just how characteristic these various point styles are of specific peoples and times. If more firm dates are established for certain styles, and if it can be shown that they are good "horizon," or time, markers, tracing their occurrence across the continent should eventually reconstruct the pattern of early man's nomadic wanderings. The lack of dates at El Inga and many other sites is a handicap in this effort. But the fact that the leaf-shaped and stemmed varieties both occur at El Inga may yet lead to an insight that will make the whole jigsaw puzzle complete. La Esperanza may be a valuable additional source of information; Bullen and Plowden found blades—a sign of northern influence—in association with stemmed points there just as we have at El Inga.

Point styles and point technology



STEMMED POINT from Fell's Cave Level I is in the collection of the American Museum of Natural History in New York City. Made of basalt, it is 2.17 inches long.



CLOVIS POINT from Black-Water Draw in New Mexico is made of chalcedony and is 3.07 inches long. It is in the University Museum of the University of Pennsylvania.

TERRAIN AT EL INGA is examined by Robert E. Bell of the University of Oklahoma, with whom the author has collaborated in the investigations reported in this article. Bell is pointing to the contact between the obsidian-bearing "midden" and the light-colored subsoil exposed by erosion. This photograph was made during a preliminary field trip in 1960.

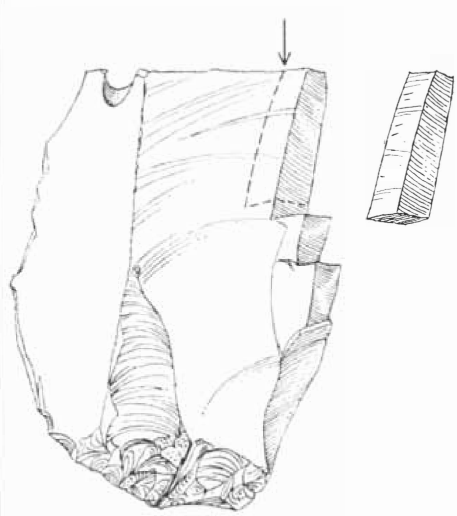
aside, El Inga has a fascination that makes it unique among South American sites, and perhaps among all New World sites. This special quality stems from the sheer size and variety of the complex and the fact that it is a core-blade industry that includes burins. We were so intrigued by the burins that we asked Jeremiah F. Epstein of the University of Texas, who had studied burin technology in detail, to examine a portion of our collection. He too was surprised at the number and variety of burins and burin spalls. Having just spent the summer excavating an Upper Paleolithic site in southern France, he was struck by the similarities between this Ecuadorian tool industry and the French material. We borrowed a French Upper Paleolithic collection from the University of Minnesota and saw that both the French flint and the Ecuadorian obsidian industries were based on blades struck from cores and included burins and bifacial tools. Many of the tools in the two collections were almost identical; the only real differences seemed to be that the obsidian items were smaller than the flints and had finer and more complex chipping patterns. We are not proposing that there was a direct connection of any sort between the Old World culture and El Inga. No such link need be postulated. Most New World archaeologists would probably say that the first men who crossed the Bering Strait from Asia were an Upper Paleolithic people. "Upper Paleolithic" covers a long time span—perhaps 35,000 to 40,000 years—and Stone Age cultures persisted almost unchanged for many thousands of years. It is quite reasonable to expect that related Upper Paleolithic cultures and peoples existed in Europe and Asia, and that somewhere in China or Asiatic Russia someone will one day find tools that suggest the direct source of the earliest New World cultures. Recent work in Siberia and Japan has yielded tantalizing hints of such Asiatic sources but no unequivocal evidence.

In a way the correspondence between the Ecuadorian and the French tools is unfortunate. It is easy to make sweeping comparisons between New World and Old World cultures and to apply the terminology of the Old World Paleolithic without much reason or precision in South America. What really counts is not broad comparisons but specific relations among sites within reasonable distances of one another. As the analysis of the El Inga finds proceeds and as other finds of core-blade industries in the New World and in Asia are reported, it should be possible to establish relations between El Inga and more geographically appropriate sites than one in southern France.

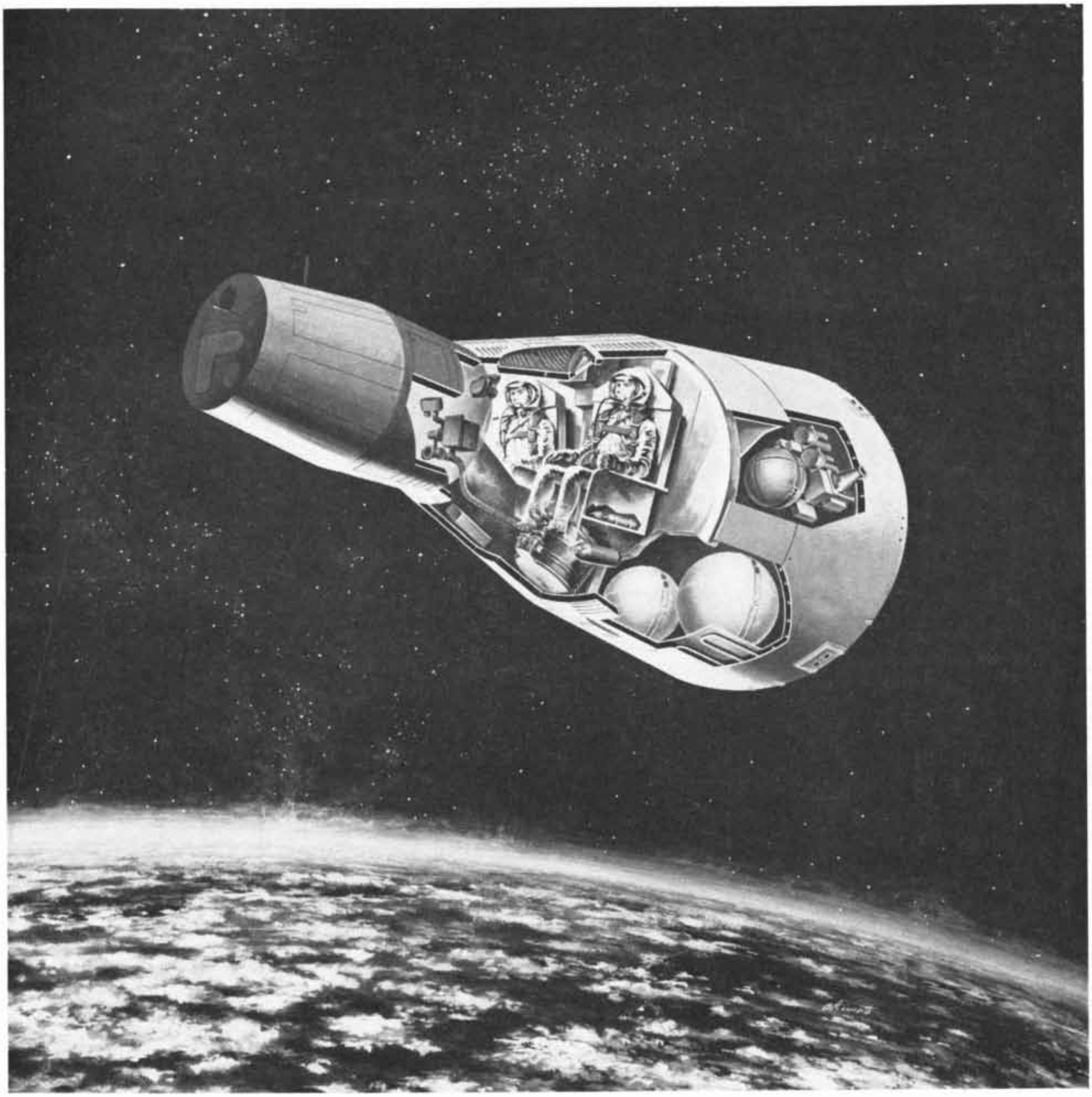
In this effort we shall not be making comparisons based on gross categories such as "hand axes," a practice that has often led to glib conclusions in the past. We shall be comparing very specific tool types: a "strangulated" blade (a blade notched to form a concave edge with

which to shape arrow or spear shafts) or an "angle burin on a break" (a burin made on the broken end of a blade). We shall be looking at details of style and technique. This microanalytic approach gives promise of dredging up far more information from a site or indeed a single piece of stone than has previously been possible. Perhaps there are, in tool collections long considered safely described, typed and filed away, bits of evidence that can be reassessed in the light of the El Inga discoveries. Already Epstein has found burins at west Texas sites and in other New World complexes where they had been overlooked simply because they are hard to identify.

In addition to pressing ahead with our analytical study of the El Inga material and comparing it with other tool complexes, we are anxious to make an intensive survey of the Ecuadorian highlands. There are many indications that El Inga does not stand alone. With luck we may find at other sites in the area additional evidence that is lacking at El Inga, including even some skeletal remains of the early men. At least we should obtain some good organic samples for radioactive-carbon dating, and animal bones that will tell us what these early hunters hunted and provide information on their environment. New field work is also needed elsewhere in South America, and this too should be stimulated by El Inga. In the long run we expect that the Ecuadorian workshop and campsite will be significant not only for its rich collection of points and tools but also as a fertile source of research leads for investigators of early man in the New World.



BURIN was fashioned by striking successive spalls, or slivers (*right*), from a blade. The next burin blow (*at the arrow*) would split away a spall outlined by the broken line. Striking successive spalls may have been the means of sharpening a dull burin.



THE MEASUREMENT OF MOTIVATION

A basic human attribute that has long resisted investigation can now be measured with the help of a simple device. The key to the measurement is what happens when the subject is given a short rest

by H. J. Eysenck

Without motivation the work of the world would never get done and the history of man would be a blank tablet. Yet no aspect of human behavior has proved more resistant to analysis and measurement. The effort of psychologists to grapple with drive and motivation has evoked a remarkable variety of unsatisfactory solutions, ranging from purely semantic exercises to pseudomathematical treatment of nonexistent data. As a result there is still no generally accepted method of measuring the degree of motivation under which a person is working at any particular time. In this article I shall describe some recent advances in theory and experiment that look promising and that suggest that valid measuring techniques may at last be in sight.

Let us start with a common-sense sort of idea. We would normally expect a highly motivated person to do a given job better, quicker and with fewer errors than a person who is poorly motivated. If so, why not use performance as an index of drive or motivation? The answer, of course, is that performance depends not only on drive but also on innate ability, hand-eye co-ordination and a host of other things, as well as on a person's experience in performing the task, which one can call habit. If an experiment is well designed and is performed with enough subjects, however, one can minimize most of the variables, such as innate ability, and one is left chiefly with drive and habit strength. Given equal habit strength, one would expect subjects with higher drive to achieve better performance. Unfortunately there is evidence that the relation between drive and performance is not simple; as drive increases, performance indeed tends to improve—up to a point. Once this optimum has been reached further increase in drive leads to a worsening of performance.

This optimum is not to be found in the same place for each experimental subject, nor for each task. It turns out that for complex tasks optimum performance is achieved when the drive is relatively low; only for simple tasks is the optimum achieved with relatively high drive. This is the Yerkes-Dodson law, originally proposed by Robert M. Yerkes and John D. Dodson of Harvard University before World War I, and it has received much confirmation since [*see illustration on opposite page*]. The validity of this law is widely recognized in everyday life, for example by the coach who tells an athlete that he is trying too hard.

The explanation of this apparent paradox is that in complex tasks the predominant habits are likely to be poorly adapted to the performance of the task, so that the drive potentiates wrong habits rather than right ones. Learning is thereby made more difficult because the wrong habits, powered by strong drives, are more difficult to eradicate. The resulting rigidity of behavior has often been linked observationally—and more recently experimentally—with neuroticism, a condition in which strong emotion provides the drive that pushes motivation beyond the optimum level.

In our effort to measure motivation at the University of London we have obtained promising results with a simple device called the pursuit rotor [*see illustration on page 132*]. It consists of a hard-plastic turntable into which is set a small metal disk that constitutes the target. While the turntable is revolving at 60 revolutions per minute the subject tries to hold a metal stylus in continuous contact with the target. Contact activates an electric clock that integrates time-on-target over successive 10-second periods. At the beginning few people achieve more than about 5 per cent of time-on-target, but with a few hours' practice many can reach values of more than 90 per cent. Women tend to be worse than men, and intelligence is not much help. One version of the target consists of concentric rings rather than a single bull's-eye; scores can then be weighted according to distance from the target center.

The illustration on page 133 shows the typical result we get from experiments with this instrument when we average scores for groups of subjects. Plotted are the performances of two groups of subjects, one working under conditions of "massed," or continuous, practice (the lower set of curves) and the other working under conditions of "distributed" practice (the upper set). For the former group the task consisted of three sets of 30 consecutive 10-second performances separated by 10-minute rest periods. The latter group was given a 30-second rest period between each 10-second performance and in addition was given 10-minute rest periods on two occasions. It is obvious from the illustration that the 30-second rest periods were extremely effective in increasing performance; after a total of 15 minutes' practice the distributed-practice group was on target about 60 per cent of the time, whereas the massed-practice group was on target only about 25 per cent of the time. How do we account for this difference? The theory to be presented here is due largely to Clark L. Hull of Yale University and was specifically applied to drive measurement by Gregory A. Kimble of Duke University. The precise form given here, however, differs in many ways from the early presentations.

There is considerable evidence in the

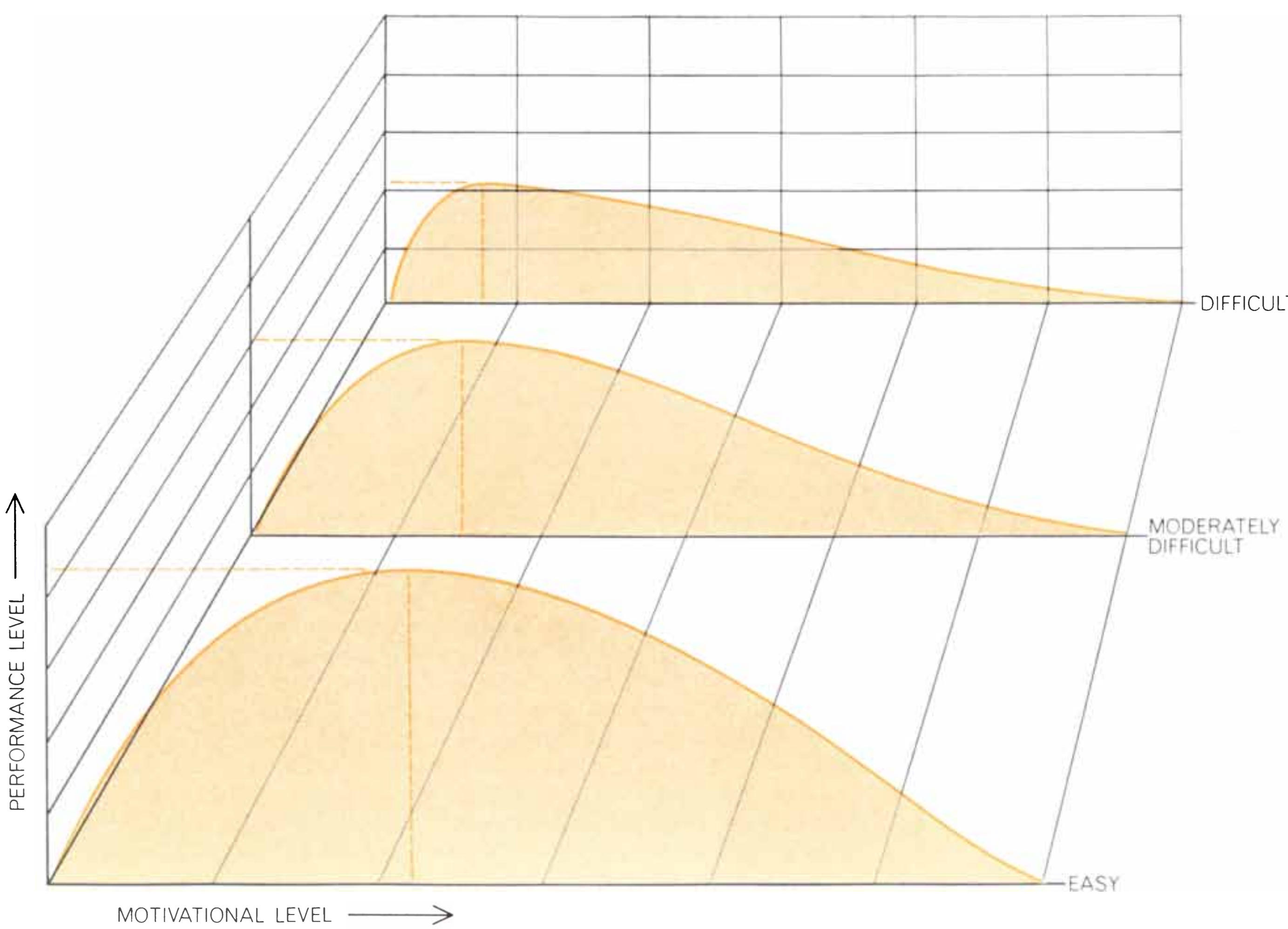
work of experimental psychologists for the existence of "reactive inhibition"; this is a kind of neural fatigue that makes it more and more difficult to pay attention to the task and to perform it at a high level of adequacy. The fatigue appears to increase as practice continues and to dissipate whenever practice ceases. It represents a negative drive, and in order to determine "effective drive" it should be subtracted from the positive drive under which the organism is working. In this view the massed-practice group is inferior to the distributed-practice group because the former is working under a heavy load of inhibition; the latter is constantly dissipating inhibition during the numerous rest pauses interpolated between work periods.

If this were true, we should expect the massed-practice group to have got rid of its load of inhibition during the 10-minute rest periods that were provided after five minutes and again after 10 minutes of work. Indeed, it will be seen that performance after the rest period, compared with performance before the rest period, is distinctly improved. This increment in performance, often observed to follow a rest pause, is technically known as "reminiscence." The well-demonstrated phenomenon of reminiscence gives strong support for some such theory as the one here outlined. As a measure of reminiscence we use the difference between the performance scored immediately before and that scored immediately after the 10-minute rest period.

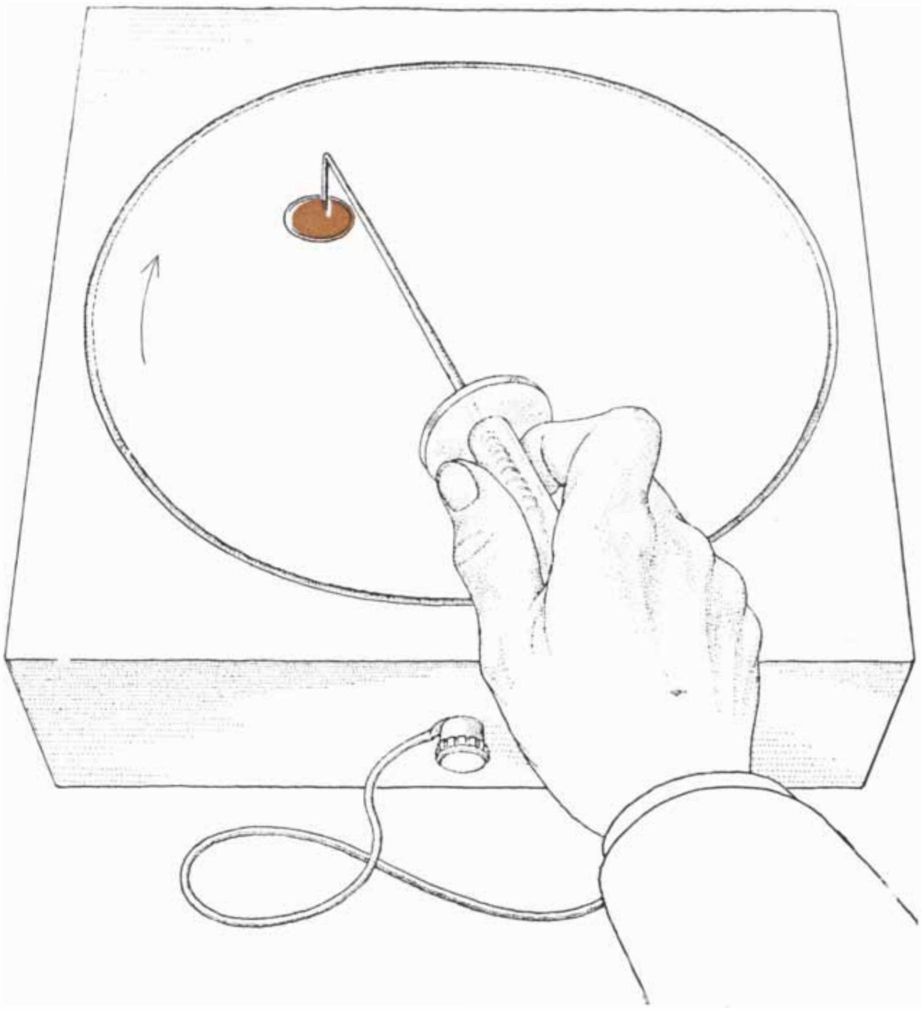
It can be shown that if a trial is continued long enough without a rest period, performance will actually fall to zero. How can this be accounted for? According to our theory reactive inhibition, or negative drive, can build up until it completely cancels whatever drive the subject possesses to start with. At this point performance simply ceases. This cessation of performance is known as an involuntary rest pause, or "block," and has been frequently observed since the 1930's, when Arthur G. Bills of the University of Chicago first drew attention to it. More recently it has been found that in an electroencephalogram such involuntary rest pauses coincide with the appearance of the large, slow brain waves characteristic of sleep.

Involuntary rest pauses are usually brief. Inhibition quickly dissipates and effective drive returns to give rise to some measurable performance. Immediately inhibition increases again until another involuntary rest pause occurs, and in this thermostat-like fashion performance rises and falls. A schematic representation of such a performance curve is presented at the top of page 134. Although involuntary rest pauses actually occur in our massed-practice trials on the pursuit rotor, they are concealed within the single values representing the summed performance for a 10-second trial. As we shall see, however, the involuntary rest pauses, when performance falls momentarily to zero, do drag down the over-all performance of the massed-practice group.

If a rest period can remove accumu-



MOTIVATION AND TASK DIFFICULTY influence performance in a complex way, as shown by this schematic illustration of the Yerkes-Dodson law. In general highest performance is achieved by subjects with an intermediate amount of motivation, or drive. More surprising is the finding that as tasks increase in difficulty, peak performance is achieved by subjects with less and less drive.



PURSUIT ROTOR is an apparatus used by the author to measure the effect of drive on performance. The subject tries to keep a metal stylus on a small target (*color*) in a turntable that revolves 60 times per minute. The time-on-target is summed during 10-second trials.

lated inhibition, why does the distributed-practice group perform better than the massed-practice group even after the latter has been given a 10-minute rest period? It does not do to say that 10 minutes may not be enough time for getting rid of all the inhibition, because we have found that increasing the length of the rest period does not lead to improved performance. Moreover, we must explain why the performance curve of the massed-practice group suddenly shoots up after the rest period (that is, after the reminiscence effect has already occurred, which should leave no further inhibition to be dissipated) only to decline again quite dramatically after some 100 seconds of further practice.

The explanation may lie in a curious effect known as "conditioned inhibition," or "the habit of not responding," which arises in the following fashion. According to learning theory, reinforcement, or reward, following a particular stimulus-response sequence makes it more likely that the response will occur in the future. Now, the involuntary rest pause following the accumulation of fatigue-like inhibition acts as a reinforcement because it allows the fatigue to dissipate. What is the stimulus-response sequence that is being strengthened by this reinforcement? It is the total stimulus pattern presented by the pursuit rotor, the stylus and other external paraphernalia, plus the bodily sensations emanating from the muscles engaged in the task. This stimulus complex is followed by the response of rest, of not moving the stylus, of not paying attention to the rotating disk. According to this theory, subjects should gradually build up a habit of not responding, of not performing the task. After five minutes of work this negative habit is already quite strong, and because it is a habit rather than a fatigue-like drive state, conditioned inhibition does not dissipate during the rest pause; it remains to depress performance even after the rest pause.

Unlikely as such a habit of not responding may sound, there is independent evidence for its existence. In one of our experiments rats that had been deprived of water for 23 hours were taught to run down an alleyway for a few drops of water. The run was repeated 30 times in succession, leaving the rats still somewhat short of complete satisfaction. They were then removed to a neutral cage for an hour and were finally returned to their own cages, where unlimited food and water were available. This regime was repeated day after day on the assumption that the gradual growth of conditioned inhibition would finally lead to a complete cessation of alleyway-running in spite of the strong thirst drive under which the rats were working. It was a close call as to whether conditioned inhibition would develop earlier in the rat than in the experimenter, but finally all the rats did in fact perform as predicted, remaining in their starting boxes and refusing to run in spite of having been without water for 23 hours. We have since applied this same principle to the elimination of tics and other automatic neurotic habits in human patients by making them repeat the unwanted movements over and over again under conditions of massed practice. In many cases the neurotic habit is extinguished completely and in others its intensity is much reduced.

This theory of conditioned inhibition also explains the impressive rise in performance after the rest pause. It is well known that conditioned responses are subject to extinction when reinforcement is withheld. For example, a dog that has been conditioned to salivate at the sound of a bell because he has regularly been given food when the bell sounded will ultimately stop salivating at the sound if the food is regularly withheld.

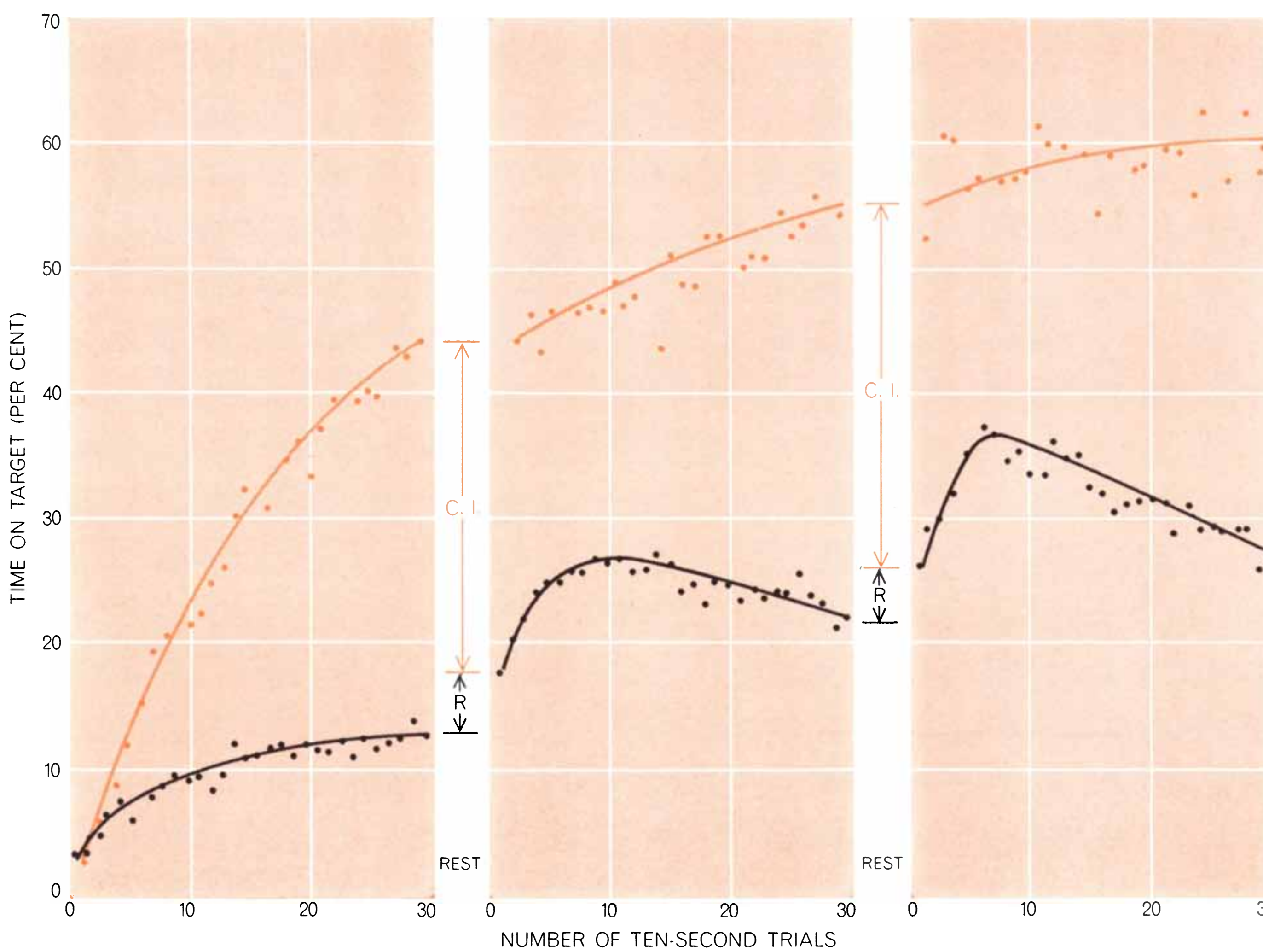
It will be recalled that in the pursuit-rotor experiment the unconditioned stimulus (analogous to the dog's food) is the involuntary rest pause. These rest pauses result when reactive inhibition has increased to the point where it completely cancels drive. During our massed-practice experiment all reactive inhibition built up in the massed trials is dissipated during the 10-minute rest periods, and when the trials are resumed, it takes a while for it to build up again. (Separate studies show that the build-up requires 90 to 120 seconds.) During this period the other sort of inhibition—conditioned inhibition—is not reinforced, and one would expect it to be extinguished.

It is this extinction of conditioned inhibition that shows up in the massed-practice curves as a dramatic improvement in performance. Once reactive inhibition has had time to grow, however, and again gives rise to involuntary rest pauses, extinction of conditioned inhibition ceases. At that point the combination of involuntary rest pauses and newly developed conditioned inhibition produces the sharp drop in performance that shows clearly in the curves.

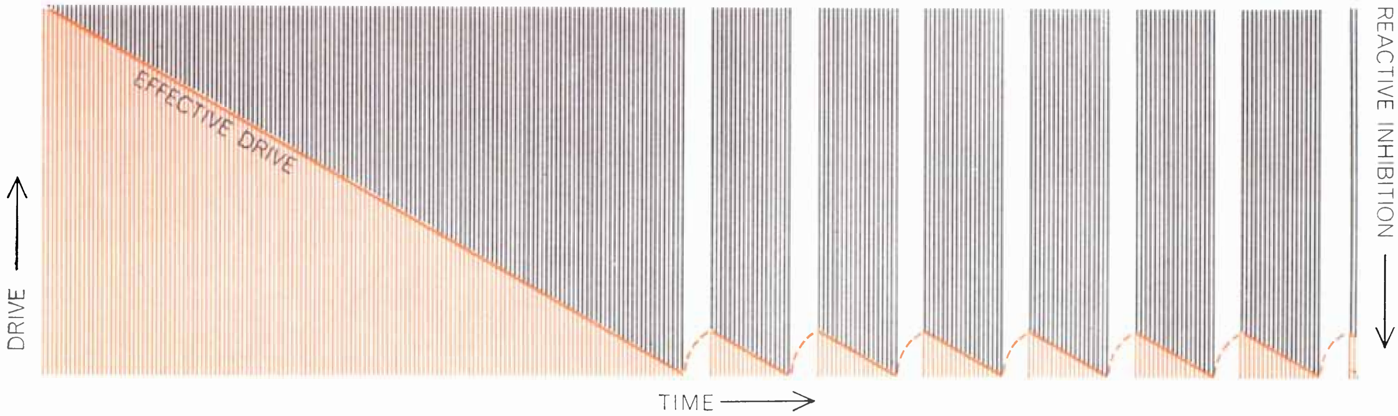
How does all this help us in the measurement of drive and motivation? The answer is as follows. It will be clear from what has been said that we can measure reactive inhibition with reasonable accuracy by virtue of the reminiscence phenomenon. If all inhibition dissipates during the rest pause of 10 minutes, then the improvement in performance due to the rest pause gives us an excellent measure of the amount of inhibition that was present before the pause. Although our theory makes no prediction about the rate of growth of inhibition, it does say that the final amount of inhibition is completely dependent on drive; in other words, reactive inhibition increases until it equals drive. This argument allowed us to predict that measuring reminiscence is equivalent to measuring reactive inhibition, which in turn is equivalent to measuring drive. Is the prediction correct?

We felt that we could easily verify such a prediction with the help of the pursuit rotor, provided that we could obtain one group of highly motivated subjects and another group—similar to the first in age, sex, social background, intelligence and temperament—that was less highly motivated. Most research in this field has been open to criticism because investigators have typically used school children or college students whose differences in motivation, if any, were unknown. The investigators have sought to manipulate drive by purely verbal instructions (for example, by exhortation or by giving information, or misinformation, about performance) or by involving the hypothetical effects of rivalry on performance. These and similar methods are subject to doubt and argument, and the results have been far from consistent.

We have preferred to rely on certain life situations where there can be very little doubt about the presence or absence of drive and motivation. For the high-drive group we chose applicants for an apprenticeship training scheme at a well-known motorcar company. These apprenticeships were so highly prized that more than 10 candidates applied for each vacancy, and many candidates traveled long distances to take part in the selection tests. Candidates were old enough to appreciate the importance of



PURSUIT-ROTOR PERFORMANCE varies markedly with the spacing of the trial, or practice, periods. Each dot represents the average time-on-target during a 10-second period. The colored curve shows the performance of subjects who were allowed a 30-second rest pause between each 10-second trial. The black curve shows the performance of subjects denied such a rest. Both groups were given two 10-minute rest periods. The improvement in performance shown by the "massed"-practice group immediately following the 10-minute break is called reminiscence (*R*), which is believed to be a measure of "reactive inhibition" accumulated during massed practice. The major depressant on scores of the massed-practice group, however, is "conditioned inhibition" (*C.I.*).



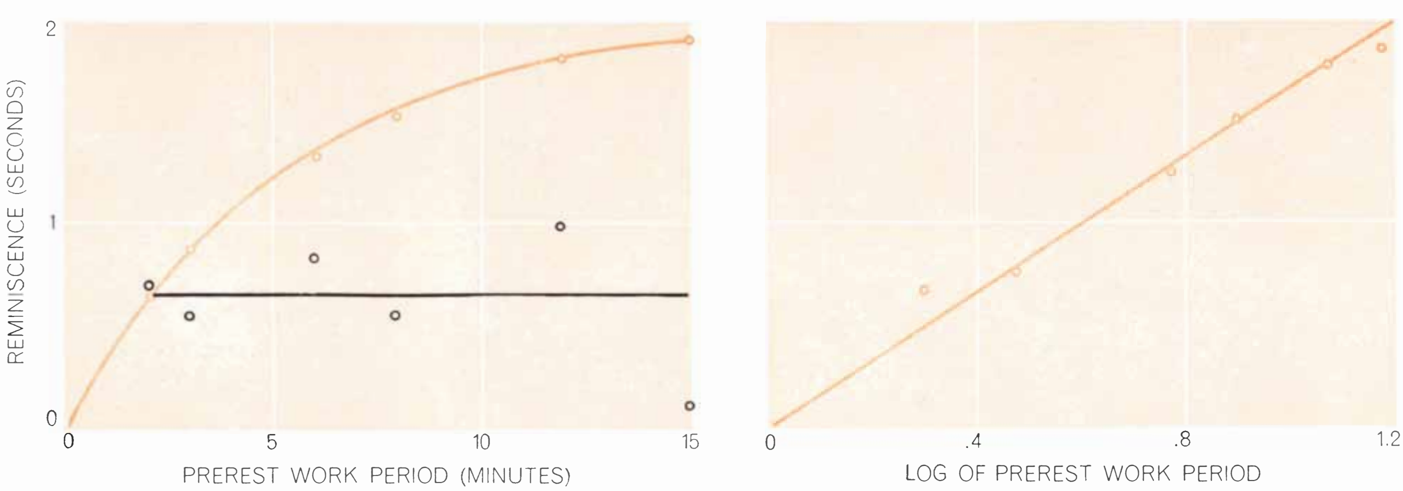
EFFECTIVE DRIVE falls as reactive inhibition builds up and cancels drive. When the effective drive reaches zero, an involuntary rest pause occurs (*blank vertical space in chart*). During the pause inhibition dissipates and performance resumes, only to fall again.

the occasion and to realize that this was perhaps their one and only chance to enter the "aristocracy of labor." If selected, they would escape from a life of insecure and ill-paid unskilled or semi-skilled work; they would be trained at no cost to themselves and upon the completion of training they would receive secure, well-paid and interesting jobs. Moreover, later performance on the job would have no bearing on advancement, because trade-union agreements make advancement dependent almost solely on seniority. It is precisely for this reason that the company regards initial selection as being so important.

The candidates for apprenticeship had to perform a large battery of selection tests, and we obtained permission from the firm to slip into this battery a series of tests with the pursuit rotor. These extra tests of course had no bearing on the candidate's acceptance or rejection. The candidates were not, however, informed of this fact, and therefore they tackled all the tests with equal vigor and determination. (As it turned out, the candidates rejected by the firm were just as adept at the pursuit rotor as those accepted.)

The low-drive group was made up of apprentices who had been selected in earlier tests, which had not included our special tests, and who were now going through their courses. They knew that the tests to which they would be asked to submit were of interest to psychologists, and they were assured that the test results would not be communicated to the company and would have no bearing whatever on their standing. Their lack of interest and low motivation were clearly apparent in their comments and their general behavior, just as had been the keenness and high drive of the members of the other group.

For the experiment proper we selected six groups of high-drive and six groups of low-drive subjects. Each group was given an initial practice session, a six-minute rest and then another four minutes of practice. The only difference among the six groups lay in the length of the initial practice session, which lasted for two, three, six, eight, 12 or 15 minutes. Our predictions were as follows. For the low-drive group we expected that it would take about two minutes for reactive inhibition to reach the level of drive and bring about an involuntary rest pause. It will be recalled that involuntary rest pauses can be recognized, even though they are brief, because they lead to conditioned inhibition and a general downturn in performance. According to our theory it is the extinction of



REMINISCENCE SCORES of two groups of young British workers, one with high drive and one with low drive, confirm the prediction that a measurement of reminiscence is equivalent to a measurement of drive. The two groups were given initial practice sessions on the pursuit rotor ranging from two to 15 minutes. When tested after a six-minute rest period, the low-drive group improved their time-on-target (reminiscence) only about .5 second in a 10-second trial, regardless of the duration of the prerest work period (*black curve at left*). In contrast, the reminiscence of the high-drive group (*colored curve at left*) increased steadily with the length of the initial work period. The curve at right shows that the high-drive curve approximates a straight line when the work period is plotted on a logarithmic scale, suggesting that reminiscence would have shown a further increase with longer initial practice.

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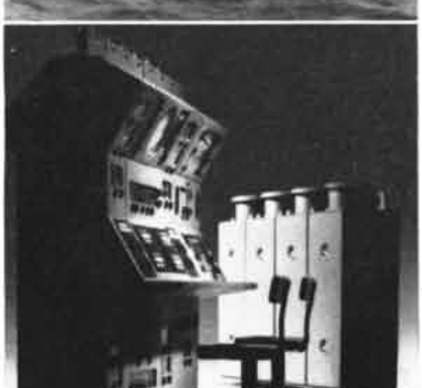
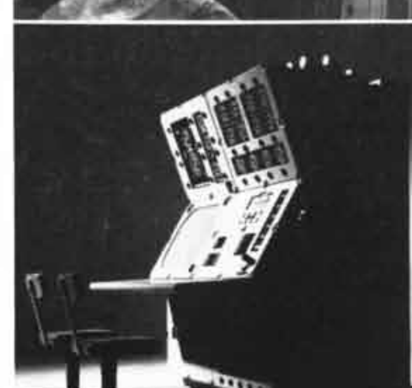
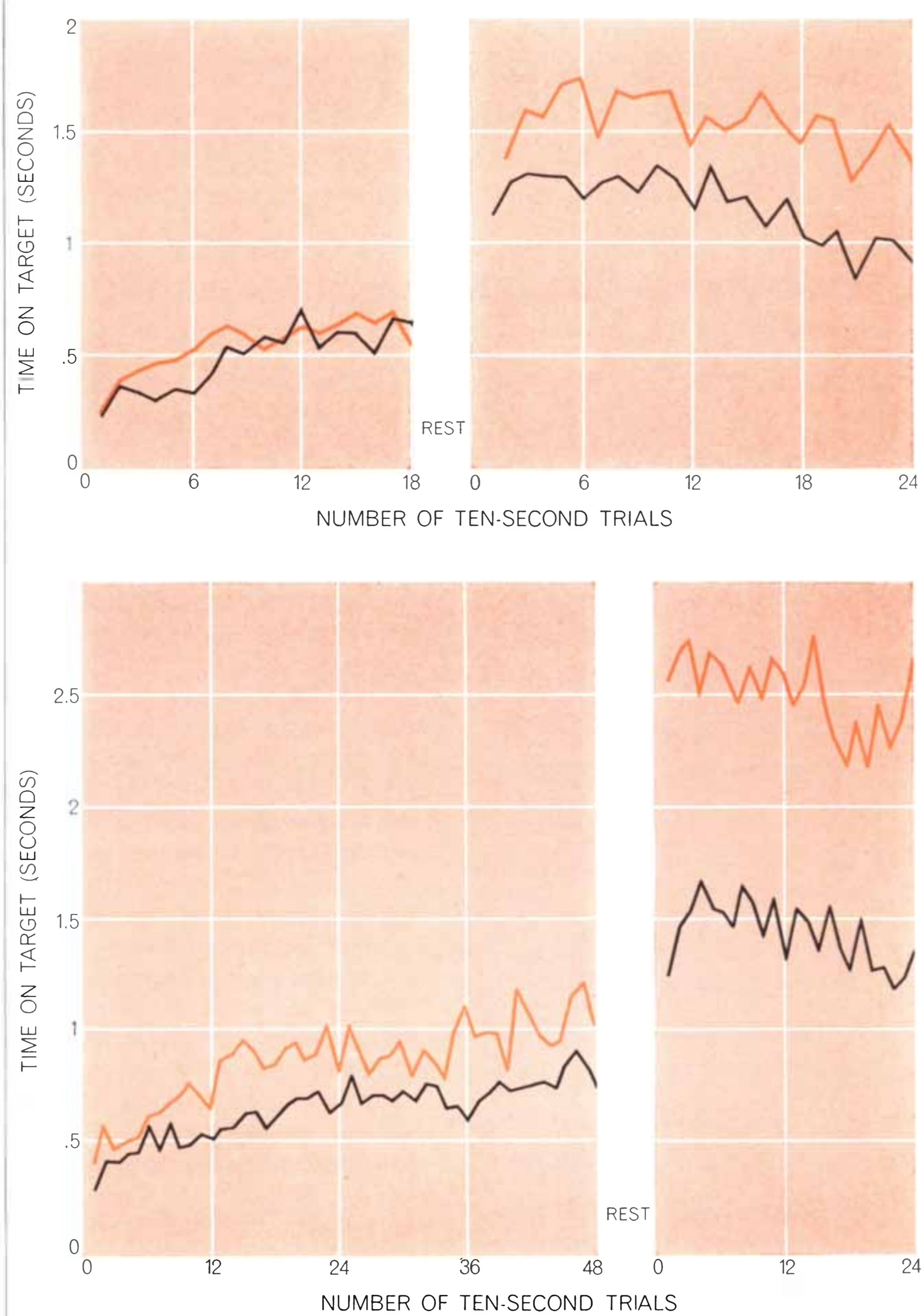




G3-20

conditioned inhibition, following the 10-minute rest period, that produces the rapid postrest upswing. We had found in previous experiments with poorly motivated groups that the postrest upswing did not appear unless the prerest practice had lasted for at least two minutes. It therefore seemed reasonable to postulate that no involuntary rest pauses occur until practice has been going on for two minutes or so, which would put the point where reactive inhibition equals drive at about this time interval. Since our theory states that reminiscence is proportional to reactive inhibition, we could predict further that reminiscence should increase for about two minutes in the low-drive group and then level off. This prediction follows directly from the consideration that reactive inhibition cannot exceed



SUPERIORITY OF HIGH-DRIVE SUBJECTS (*colored curves*) **does not become significant until after the six-minute rest period. These two sets of curves show part of the actual performance data from which the two bottom curves on page 134 were plotted. The upper pair of curves shows the scores of subjects given three minutes of initial practice; the lower curves, the scores for those given eight minutes. Under both conditions the low-drive subjects** (*black curves*) **show an improvement, or reminiscence, of only about .5 second in time-on-target following the rest periods. For the high-drive subjects, however, the reminiscence increases markedly with eight minutes of initial practice. Curiously, the high-drive and low-drive subjects achieve approximately equal scores in the initial practice trials.**

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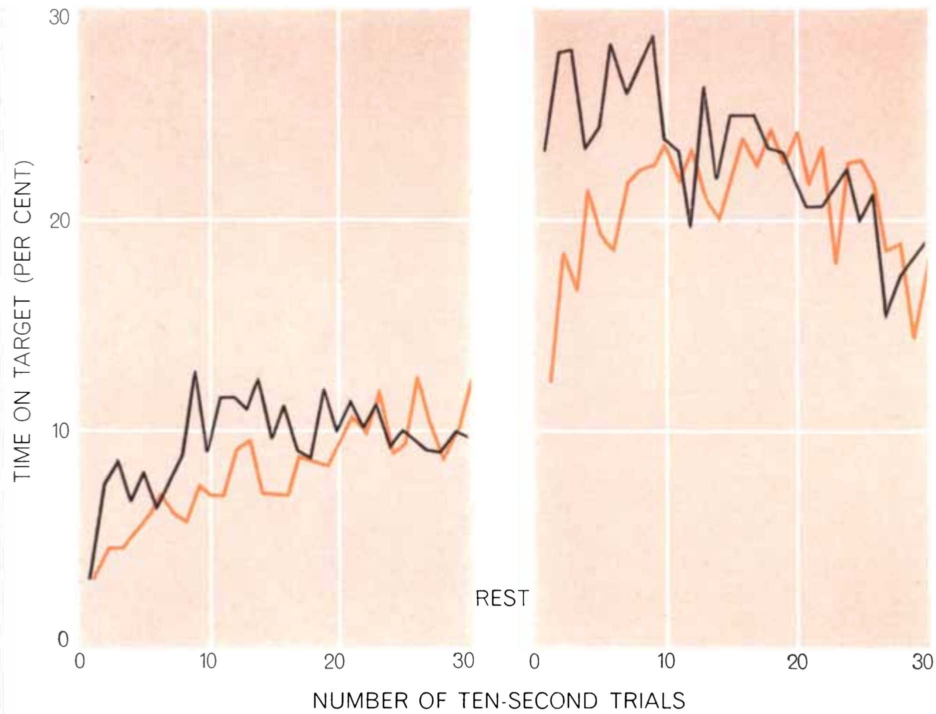

SCHIZOPHRENIC SUBJECTS *(colored curves)* **show no reminiscence after a rest period following 30 practice trials on the pursuit rotor. Normal subjects** *(black curves)* **show expected improvement. Results suggest that schizophrenics dissipate inhibition slowly.**

drive. Previous work suggested that reminiscence would consist of an improvement of .5 to .7 second in time-on-target during a 10-second trial.

For the high-drive group we expected that reminiscence would increase in parallel with that of the low-drive group until two minutes of prerest practice had been reached, and that it would thereafter increase with increasing prerest practice until reactive inhibition equaled drive—wherever that point might lie in the high-drive group. The theory could not, of course, predict when this point would be reached.

The bottom illustration on page 134 shows the results of the experiment. It is evident that all our predictions are in fact fulfilled, and that even after 15 minutes of practice the high-drive group still shows a gain in reminiscence, although the gain seems to be leveling off. For the low-drive group there is no significant gain in reminiscence after two minutes of initial practice.

Plots involving time as a variable can often be straightened out if one converts time to a logarithmic scale. When this is done, the reminiscence scores of the high-drive group fall reasonably well on a straight line, suggesting that the upper limit of reminiscence (or drive) is still quite some way off [*see right side of bottom illustration on page 134*].

Although the general theory I have expounded receives considerable support from these results, there are some curious features that require explanation. The main difficulty arises from the fact that high-drive and low-drive groups do not differ in performance before the rest pause. One would have expected the high-drive groups to be clearly superior by virtue of their motivation. The illustrations on page 136 show the actual performance scores for the three-minute and eight-minute groups. The high-drive subjects have slightly higher prerest scores, but the differences are not significant. For the 12-minute and 15-minute groups the low-drive groups are slightly but insignificantly better. And the two-minute and six-minute groups show absolutely no differences.

It is of course easy to invoke the Yerkes-Dodson law and say that the more highly motivated subjects would have done better if they had not tried so hard. Such an explanation, however, would lead one to expect changes in the relative performances of the two groups with changes in the development of habit strength. Thus at the beginning the low-drive group might be superior because of its lack of rigidity; with long practice the high-drive group might be expected to be superior because by then the correct habits should have become predominant. In other words, over-all equality in performance might be accompanied by superiority of one group or the other in different parts of the per-

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formance curve, yet no such shifting patterns are observed. The actual performance curves run parallel throughout the entire prerest practice period; after the rest pause the high-drive group is slightly better, but the two groups are still very close to each other in performance.

The demonstration that under suitable circumstances reminiscence can be used as a measure of drive enables one to tackle many theoretical problems that have in the past puzzled psychologists and psychiatrists alike. Consider just one of these problems. It is well known that schizophrenics tend to perform poorly in a variety of experimental and life situations; this has often been attributed to their "lack of drive." If this explanation were correct, we would expect schizophrenics to have lower reminiscence scores than normal or neurotic subjects. We have indeed found in several experiments that this is so; schizophrenics tend to have very low reminiscence scores. The results plotted in the illustration on page 138 are typical of many similar studies. Does this prove the correctness of the original hypothesis?

We put forward an alternative hypothesis: Perhaps schizophrenics are abnormally slow in dissipating reactive inhibition. Reminiscence is a good measure of drive only if the rest pause involved in its determination allows all, or almost all, reactive inhibition to dissipate. Ten minutes is enough for normal people; it may not be enough for schizophrenics. To test this hypothesis we measured reminiscence with two groups of normals and two groups of schizophrenics, using rest periods of 10 minutes in one experiment and 24 hours in another. If schizophrenics are genuinely lacking in drive, they should fail to show reminiscence under either condition; if they are suffering instead from slow dissipation of reactive inhibition, they should show a high reminiscence score after a 24-hour rest period. The experiment strongly supported the latter hypothesis. After 24 hours schizophrenics showed even greater reminiscence than did normals. Work is going on to see if reminiscence changes in line with response to treatment, if reminiscence scores can be used as predictors of outcome of treatment and if other known facts about the behavior of schizophrenics can be deduced from this general concept of slow dissipation of inhibition. This is only one application of the method of motivation measurement suggested here; it seems likely that it will be found useful in many different contexts.

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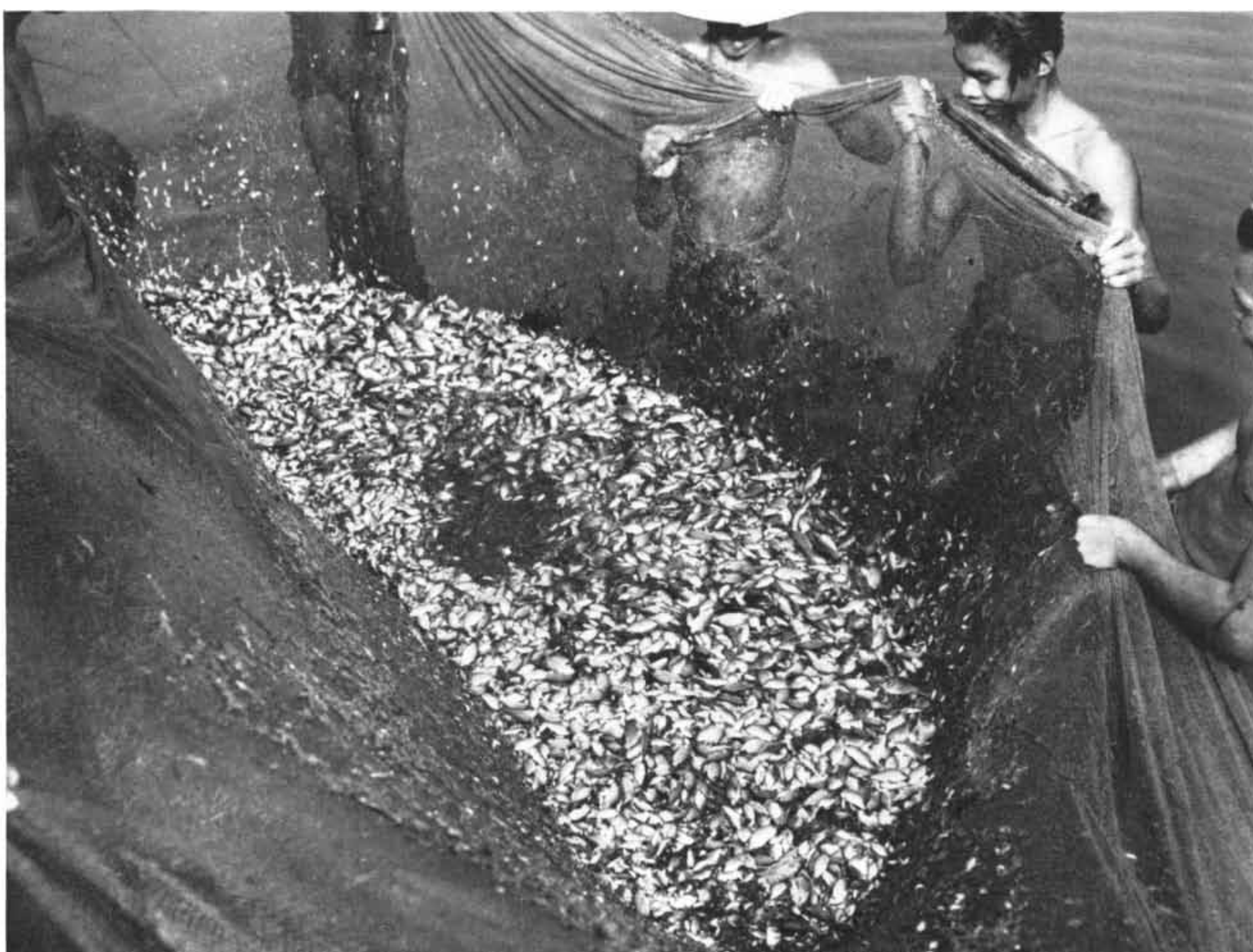
The Cultivation of Tilapia

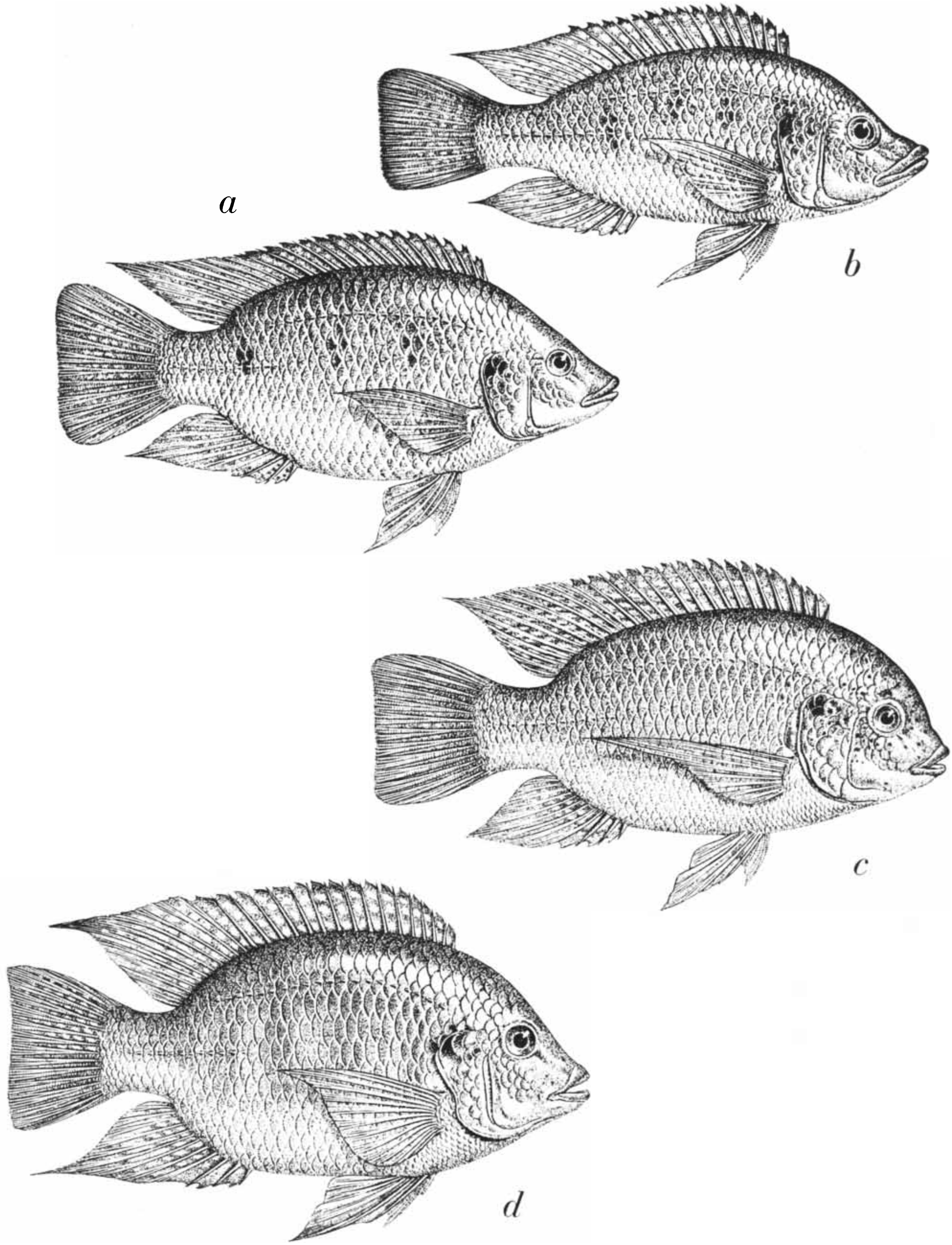
This prolific fish has been introduced into many less developed areas as a cheap source of protein-rich human food. A new method for making it grow larger in ponds may enhance its usefulness

by Charles F. Hickling

Tilapia, a fish native to the fresh waters of Africa and the Jordan valley in Asia Minor, seemed a few years ago to be destined for a major role in a 20th-century enactment of the miracle of the loaves and fishes. As anyone familiar with world food statistics knows, the hungry portion of the human population is starved for protein. The average per capita daily calorie intake of the two billion or so people who live in the less developed regions of the world comes to about 70 per cent of that in the more developed countries. The corresponding figure for animal protein consumption is about 20 per cent. Even this low figure considerably understates the actual deficiency, because the limited supply of animal protein in the less developed regions is so unevenly distributed that hundreds of millions of people



THOUSANDS OF TILAPIA FINGERLINGS are netted in a central breeding pond in Thailand for distribution to local farmers. Because they breed so prolifically and at such an early age, these fish would probably not grow much larger in the small ponds available to peasants. The small size attained by Tilapias when they are allowed to breed freely is their greatest drawback in pond culture.



PRINCIPAL SPECIES OF TILAPIA cultivated in ponds around the world are depicted. At the top are a female (*a*) and male (*b*) of the most widespread species, *Tilapia mossambica.* Below these is a male *Tilapia macrochir* (*c*), like *mossambica* a feeder on plankton and algae. At bottom is a male *Tilapia melanopleura* (*d*), which feeds on higher plant life and is widely cultivated in Africa.

consume inadequate quantities of these vital tissue-building foods day after day and year after year. It is hardly surprising that many persons and agencies concerned with the world food problem have been inclined to welcome with enthusiasm almost any potential source of cheap, abundant and palatable protein. Among the possibilities canvassed in the decade after World War II was the cultivation of *Tilapia mossambica*.

This fish—a relative of the common North American sunfish that has been known in Europe as the bream or the large-mouthed kurper and is now called the Tilapia throughout its vastly extended range—seemed to meet all the specifications. It feeds directly on the algae and other primary aquatic vegetation (and on the animal plankton as well) and so constitutes the terminus of a two-step food chain from inorganic ions to proteins. It is resistant to disease, it grows rapidly and multiplies abundantly, and it flourishes under crowded conditions in fresh or brackish waters. Moreover, its potential habitat, restricted only by water temperature (minimum, about 55 degrees Fahrenheit), coincides with the roughly defined belt of chronic human malnutrition that girdles the subtropical and tropical latitudes. Here, it was thought, was an excellent fish for cultivation in ponds. Under the auspices of international agencies such as the Food and Agriculture Organization of the United Nations, through bilateral technical assistance programs, the work of local fisheries staffs and by spontaneous development, Tilapia culture spread in a short time throughout Africa, to the islands of Indonesia and the Philippines, to the Asiatic mainland in India, Malaya and Thailand, to the Caribbean islands of Hispaniola and Jamaica and even to the southern U.S.

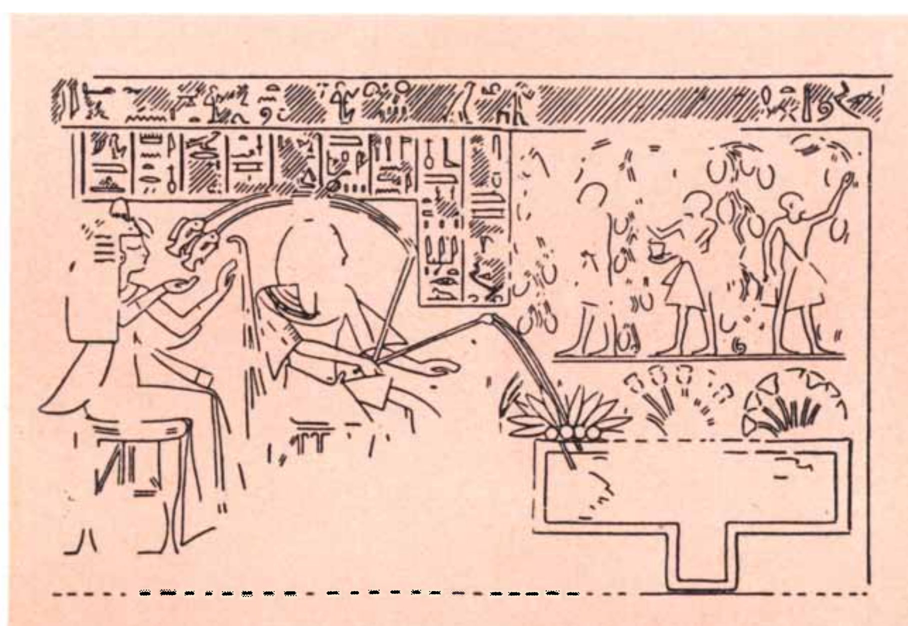
Before long, however, the remarkable fecundity of the Tilapia—one of its most welcome qualities—revealed itself as a serious drawback. For reasons still unknown the pond-raised fish become mature and start to breed when they are still very small: an ounce or less. As a result the waters of the pond swiftly become crowded with fish too small for marketing or even, according to most cuisines and tastes, eating. It would be fair to say that there has been some disillusionment; responsible authorities have been discouraging the overeager promotion of Tilapia culture as a panacea for protein deficiency and, in some countries, popular interest has waned.

This is unfortunate, because the Tilapia can still make a significant contribution to human nutrition. If Tilapia culture is regarded as a form of stock raising and conducted with corresponding care and thought, it is possible to overcome the disadvantages of the animal's fecundity by various stratagems and to harvest good yields. Meanwhile work in the laboratory has uncovered a hybrid line that is made up exclusively of male fish. The rearing of these fish in "monosex" cultures promises to vindicate in part the enthusiasm that carried the Tilapia around the world a decade ago.

The cultivation of Tilapia in ponds for human food is anything but a recent innovation. The earliest known representation of a fish-culture pond in history—a bas-relief from an Egyptian tomb dating from before 2000 B.C.—shows a pair of small fish that can be identified as *Tilapia nilotica*, a species still abundant in the Nile valley [*see illustration below*]. In Egypt and the Holy Land the Tilapia has always been regarded as an important food fish; its deep, somewhat foreshortened body, with the body cavity placed well forward, yields a triangular fillet of firm white flesh, of excellent flavor, from each flank.

The modern history of Tilapia culture can be said to have begun in 1939. In that year five fish of the species *Tilapia mossambica* were discovered in a lagoon in Java. How these few fish made the journey from their native waters in Mozambique on the east coast of Africa remains a mystery. In any case their arrival was fortunate, because from 1942 on wartime conditions had made the fry of the local milkfish unobtainable; in a remarkably short time the Tilapia replaced the milkfish as the predominant pond-cultured fish of Java. It was this experience and similar successes elsewhere that brought the fish to the attention of food scientists at the end of the war.

The Tilapia easily qualifies for pond-culture in terms of the first criterion of this branch of animal husbandry, which is the weight of fish that can be grown per unit of pond surface, sometimes called the maximum standing crop. The crop can be made several times larger by fertilizing the water; the addition of fertilizer to fishponds causes a manifold increase in primary plant production, which in the water as on the land is the basis of flesh production. If the fish in a pond (especially Tilapias) are also given supplementary fodder, the maximum standing crop can be still further increased in proportion to the amount and nutritive value of the fodder. In tropical countries a pond can support a much larger standing crop than in temperate regions, because uniformly high temperatures promote a rapid and continuous turnover of material in all the biological processes involved, including the rate of growth of the fish. Ultimately the limit of growth in a densely populated pond seems to result only from the accumula-



EGYPTIAN GENTLEMAN ANGLES for Tilapias in an artificial garden fishpond in this line drawing made from a bas-relief on the wall of a 4,000-year-old Egyptian tomb. His wife is about to unhook his catch—two specimens of *Tilapia nilotica*—as his servants pick fruit in the background. The pond itself features a deep, central drainage channel for harvesting the entire crop. This carving is the oldest known representation of a fish-culture pond.

TILAPIA PONDS IN UGANDA are carefully built and well tended by native farmers. The lush vegetation nearby provides plentiful fodder for the plant-eating species, *T. melanopleura* and *T. zillii*. Such ponds yield large crops consisting mostly of small fish.

HIGH SURVIVAL RATE of Tilapia fry probably results in part from this fish's peculiar habit of oral incubation. The fertilized eggs (several hundred in number) are taken into one or the other parent's mouth, where they are hatched about five days after spawning. In this photograph a female *T. mossambica* is shown taking her brood back into her mouth. The young fry are protected in this way for about another five days after they have been hatched. In most Tilapia species the female incubates the eggs and fry.

tion of harmful metabolic products of the fish themselves.

Ordinarily in areas where the culture of fish in ponds is an established art the fish are bred and raised to fingerling size in one pond and then transferred to raising ponds for feeding up to optimum size. The raising pond can therefore be stocked with a known number of small fish of an aggregate weight well below that of the maximum standing crop. These fish can then be made to grow as fast as possible, both by fertilizing the pond and by foddering, until the aggregate weight has increased to near that of the maximum standing crop. At this point the crop is harvested. Time as well as weight enters into the economics of fish culture. It sometimes pays to harvest considerably before the maximum standing crop is reached, because the rate of growth slows down as this limit is approached.

The species of fish usually cultured, such as the common carp, do not normally breed in the raising ponds, or at least not until they have grown to a commercially acceptable size. The population of the raising ponds is thus kept under control, and the number of fish harvested is roughly the same as the number stocked. The gain is the increase in weight of the individual fish.

The propensity of pond-reared Tilapias to start breeding at a small size and to breed all year round at frequent intervals negates this well-established practice. In a pond stocked with Tilapias the maximum standing crop is soon attained, not by the growth of the fish originally stocked but by the proliferation of thousands of fry and fingerlings. Moreover, the Tilapia's habit of mouth breeding—the female takes the fertilized eggs into her mouth and keeps the fry there for a short period after they have hatched—undoubtedly contributes to the high survival rate of the young [*see bottom illustration on opposite page*]. A case has been recorded of 150 adult Tilapias producing 15,000 fry in less than four months, and another case is known in which 14 fish became 14,000 in only two and a half months.

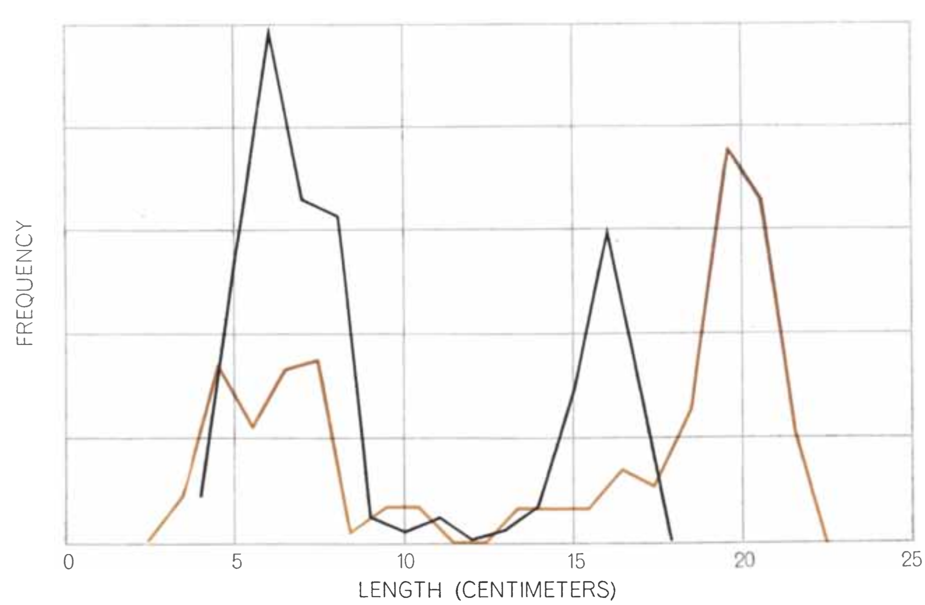
Since most of the Tilapia species feed by browsing on tiny algae and plankton, the adults have no competitive advantage over the young, and their growth slows down as thousands of additional mouths come to share the food supply. Thus although the maximum standing crop may be very high, it will consist largely of little "trash" fish. A well-foddered two-acre Tilapia pond in the Congo, for example, yielded an excellent harvest of almost 8,000 pounds of fish. Of this total, however, no less than 4,500 pounds were fish too small for marketing or fingerlings useful only for restocking. No more than 2,000 pounds of this big crop could be described as "large" fish, and even these were only 16 to 24 centimeters in length and weighed from a quarter-pound to a half-pound each.

In many parts of the world, particularly in the Orient, small fish are fried and eaten whole—scales, fins and all—or cut up into chunks for stewing or made into fish paste. These dishes, nutritious as they undoubtedly are, cannot be pressed on other peoples. For the optimum yield of fish flesh as it is more commonly eaten, the Tilapia must be raised to large size. As in the case of many other animals, the head and body of a Tilapia grow at different rates; a larger fish has more edible body meat than a smaller fish. At one pound a Tilapia yields about 24 per cent of its weight as boneless fillet, whereas a very large fish weighing, say, five pounds gives as much as 50 per cent of its total weight as edible meat. A single Tilapia weighing two pounds produces more meat than eight Tilapias weighing a quarter-pound each.

Nevertheless, the production of even small fish on a massive scale per unit of pond area can make an important contribution to human nutrition. The peasant owner of a small Tilapia pond can have frequent fish meals for himself and his family and still harvest a sizable surplus to sell or trade. To maximize the yield he should feed the fish abundantly with whatever cheap and readily available fodder can be had, and fish the pond intensively. In one small pond in the Congo, about a fortieth of an acre in surface area, the feeding of 1,200 pounds of ordinary household scraps combined with constant fishing produced about 100 pounds of fish in a year —a yield equivalent to two tons per acre in that period of time.

Even the elementary measures of vigorous feeding and fishing, however, are difficult to institute among many peasant peoples of Africa and Asia. The peasant—particularly the African peasant—takes little care of his livestock. He tends to treat his fishpond in the same way and seldom bothers to give the fish fodder. Since his four-footed beasts have free range, he may also have no dung with which to fertilize his pond. The necessity for intensive fishing also presents a problem. Tilapias are easily caught with a hook and line, but this fishing method can be tedious. A large dragnet would be uneconomically expensive for the owner of a small pond, and the use of the small casting net is unknown in much of Africa.

Larger fish can sometimes be obtained by raising them in saline water, which seems to have an inhibiting effect on breeding. Since most of the almost 100 known species of the *Tilapia* genus are able to tolerate a high degree of salinity, this practice is suitable for many of the brackish ponds of Indonesia and else-



POND IN TRINIDAD yielded a higher percentage of larger Tilapias when predatory guabines were also stocked (*colored curve*) than when the Tilapias were stocked alone (*black curve*). The guabines ate many of the fry, allowing the larger fish to thrive on the limited food supply. A 20-centimeter Tilapia weighs between a quarter- and a half-pound.

where. Such a practice would be doubly advantageous because it would open to cultivation waters too saline to be used for irrigation.

Another method for raising larger fish is to stock a pond with small Tilapias of the same size and weight and force their growth by feeding until they begin to breed. They are then harvested by the draining of the pond. This method requires a drainable pond as well as a separate breeding pond where the fingerlings are raised. Since the fish grown in this manner still mature when they are small, they grow no larger than those produced in a free-breeding pond, but the method yields a higher proportion of larger fish.

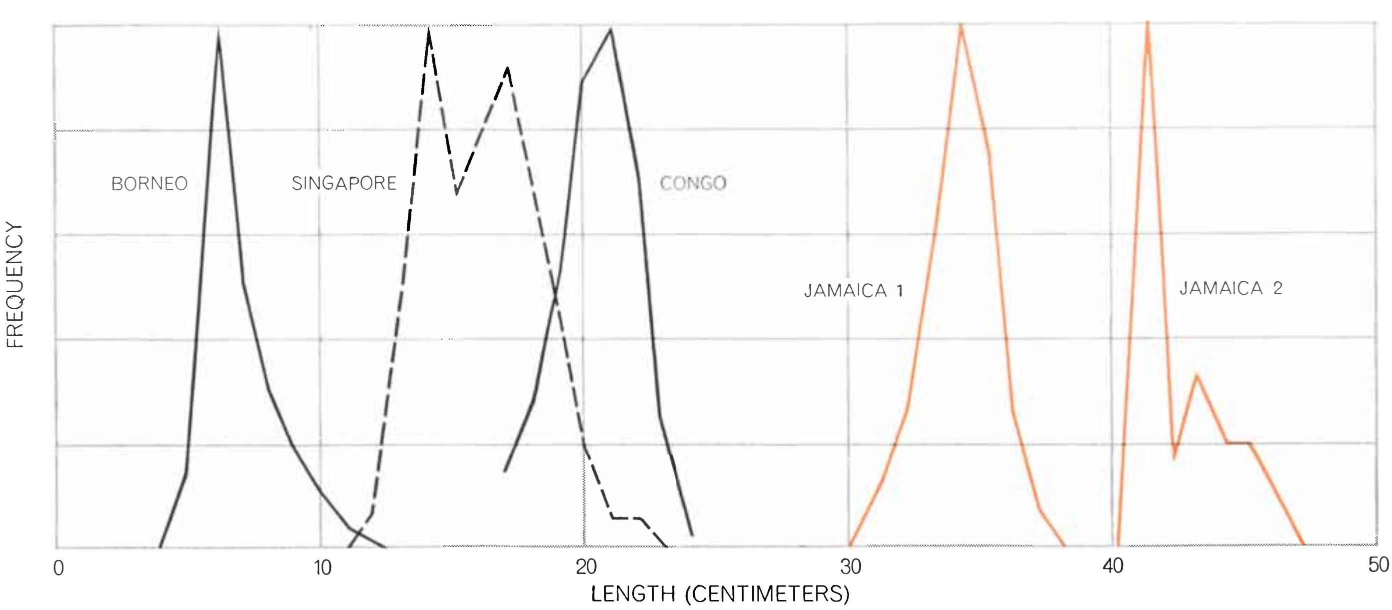
Special feeding can also promote an increase in the average weight of individual fish. Leaves of manioc, or cassava, when fed to the two plant-eating Tilapia species—*melanopleura* and *zillii*—seem to be more easily devoured by the adults than by their young. Further study may reveal other foodstuffs that favor the growth of adults rather than fry.

Another stratagem is to stock the pond with predatory fish. The predators will not only crop down the surplus fry and thereby permit better growth in the Tilapia population; they will also contribute to the variety and value of the total fish crop. The successful stocking of the large new lakes created by dams in the U.S. is based on the predation of the black bass on the bluegill sunfish. In the reservoirs of Trinidad *T. mossambica* may settle down into a similar adjustment with the native guabines, an efficient predatory fish. One reservoir has produced more than 6,000 pounds a year of good-sized Tilapias weighing between three-quarters of a pound and two pounds each.

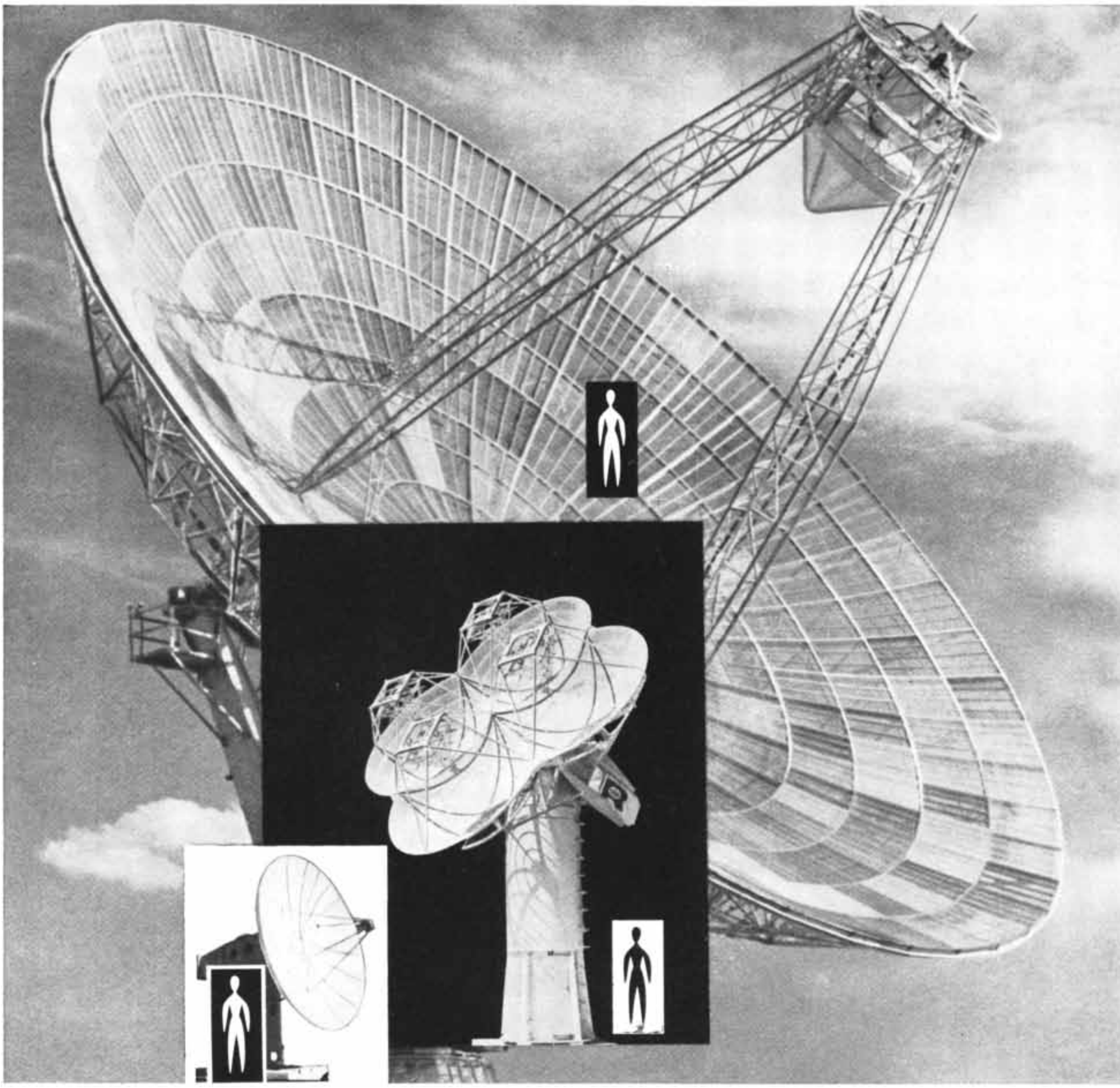
Several species of predatory fishes have been used for this purpose in other parts of the world. In East Africa the Nile perch, a fine sporting fish, has been tried; in the Cameroons the black bass and a fish related to the Tilapia called *Hemichromis fasciatus* have been stocked in Tilapia ponds; in Jamaica the local tarpon has served as an effective predator. Although it cannot be said that these experiments have been uniformly successful and that all of them are applicable to pond culture, the planting of a predator has produced in many instances a distinct improvement in the size and weight of the Tilapia [*see illustration on page 148*]. In order to keep the predator-prey balance at an advantageous level, there must be frequent stock-taking. This requires draining of the pond, sorting out the fish and restocking with the right proportion of predator and prey. The technique is a sophisticated one, with plenty of room for error.

The one technique that allows reliable control of the population is that of stocking the raising pond with fingerlings of a single sex. Some species of the genus *Tilapia*, although not as yet the vegetable-feeders *melanopleura* or *zillii*, can be easily sorted into males and females. Either the colors are sufficiently differentiated to serve as reliable sex-indicators, or the structure of the anal papilla is used—the opening of the oviduct being distinguishable in the female and not present in the male. With experience it is possible to sex even small, immature fish with speed and confidence. Since males grow much faster than females, only the male fingerlings are stocked in the raising ponds and the females are discarded. A second check is made when the fish have grown somewhat larger and distinctive sex-colorations are more discernible. Since this technique fails if there is a single female present in the raising pond, care must be taken to ensure that there are no females left over from a previous stocking.

With the estimated maximum standing crop of the pond in mind, a fish culturist can stock as many male fingerlings as will produce the best crop of fish at a planned average mean weight per fish. In Jamaica and elsewhere the method has produced results that justify the extra care, expense and effort. In order to supply fingerlings to small raising ponds on peasant farms it would probably be best to set up central breeding and sexing stations, either privately or publicly owned, to produce male fingerlings. Considering the fine size and weight attained by Tilapias under monosex culture and their considerable cash



MONOSEX CULTURE METHOD, by which young male and female Tilapias are manually segregated and only the faster-growing males are stocked, also results in an increase in the size of individual fish. As this graph indicates, the average size of Tilapias raised by monosex culture in two ponds in Jamaica (*colored curves*) is much larger than that attained in several other localities where males and females were stocked together and allowed to breed freely (*broken and solid black curves*). In each case the minimum size of the fish caught and measured is determined by the size of the holes in the net used to harvest the crop. All the ponds were used to raise *T. mossambica* except the one in the Congo, in which the closely related species *T. macrochir* was grown.

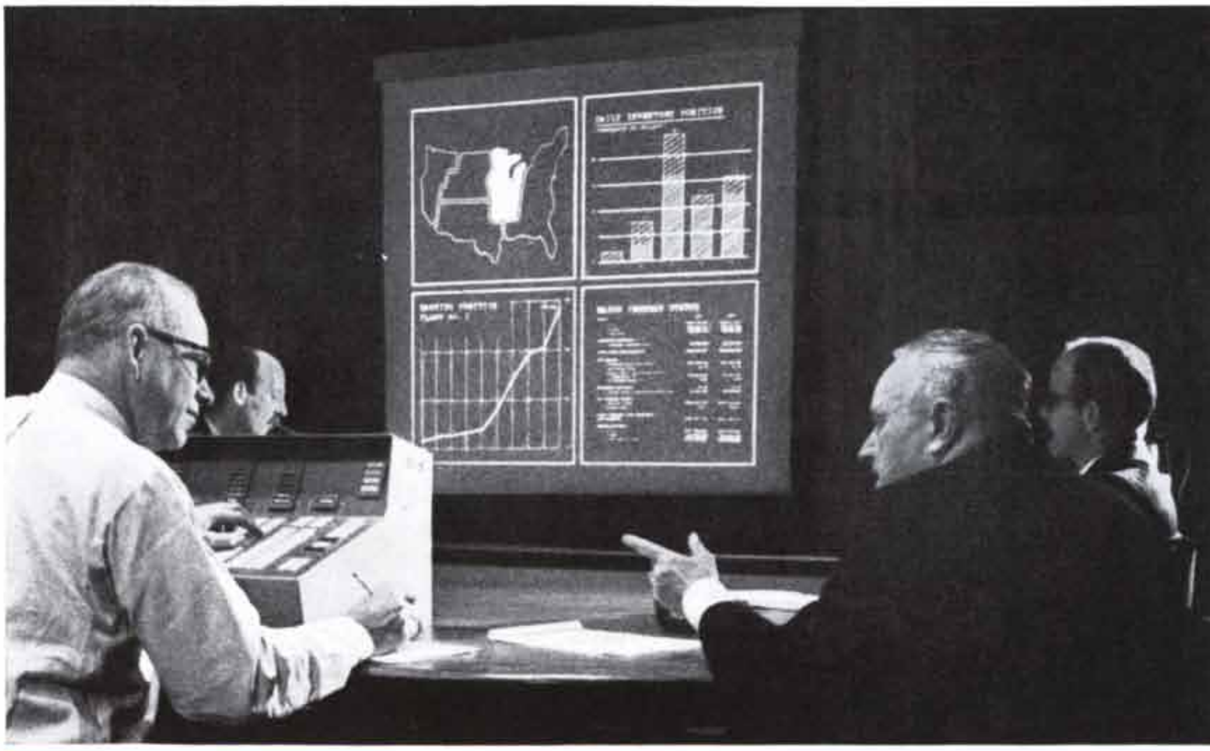


value per pound, such breeding stations could charge for the male fingerlings and make a profit if they were operated on a sufficiently large scale.

The sexing of small Tilapias, although feasible, is tedious in addition to being not entirely reliable. Moreover, since only the males are stocked, there is a waste of female fish. Accordingly my colleagues and I at the Tropical Fish Culture Research Institute at Malacca in the Federation of Malaya set out in 1958 to breed "mules," or sterile fish, by crossing two closely related but distinct subspecies of *T. mossambica*. One was a purebred local variety of *T. mossambica* descended from the original Tilapias first found in Java in 1939; the other was indigenous to brackish swamps on the island of Zanzibar off the east coast of Africa. To our surprise the hybrid fry of the Zanzibar males and the Javanese females all turned out to be males! When due care was taken to avoid contamination by uncovenanted fish, not a single female ever turned up among the hundreds of thousands of these crossbred fingerlings. These hybrids are fully fertile, and it is necessary to take the usual precautions to exclude females from the raising ponds.

We are thus able to produce all-male populations to stock the raising ponds, with no waste of female fish and none of the trouble and risk of sexing the fingerlings. To cap these advantages, our hybrids exhibit hybrid vigor, growing twice as fast as fish of either parent stock. Generally they grow to a weight of about one pound in six months and yield a crop of about 1,200 pounds per acre per year with no other encouragement than the fertilization of the pond with 20 to 30 pounds of triple superphosphate per acre. A combination of fertilization and foddering has not yet been tried, but even larger crops of uniformly large fish are anticipated. Attempts are now being made to crossbreed other Tilapia species in order to obtain additional strains of all-male hybrids; it would be surprising if success is not achieved eventually.

Meanwhile foundation stocks of the parent lines of the first all-male hybrids are being made available by the institute in Malacca for establishment of the method elsewhere. The uniformly large fish that can be harvested promise to revive the interest of small-pond operators in many parts of the world where free-breeding methods have failed. Tilapia may again be counted on to help in offsetting the protein deficiency afflicting such a high percentage of the world population.



STATUS SYMBOLS...IN NO UNCERTAIN TERMS It used to be that critical management decisions could wait until the next executive committee meeting. Today—in business, industry and national defense, the pace of decision-making is tremendously accelerated. Instrumentation, data communications and computers are pressed into service. But the critical moment comes when their signals and codes must be delivered to human beings. At this point, the hardware must say, in the vernacular: "Now look, this is how things stand." / ITT System companies have developed many sophisticated 'read-out-display' devices to accomplish this. They range from high-speed printers to slow-scan television. One especially versatile device, driven directly from computers which may be in remote locations, projects refined data in any desired form—tabulation, text, symbol, map, graph—in a full spectrum of colors for rapid discrimination. Its uses range from command of military operations to industrial administration, air traffic control and no end of other possible applications. / ITT is active in developing advanced data-processing, data-communication and display systems on a global scale—handling data traffic between the U.S. State Department and embassies abroad...working as the nerve center for a worldwide weather service. These are fields of growing importance to the world's largest international supplier of electronics and telecommunications. / International Telephone and Telegraph Corporation. Headquarters: 320 Park Avenue, New York 22, New York.

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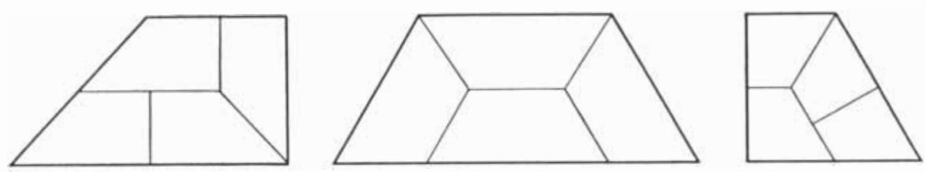
MATHEMATICAL GAMES

On "rep-tiles," polygons that can make larger and smaller copies of themselves

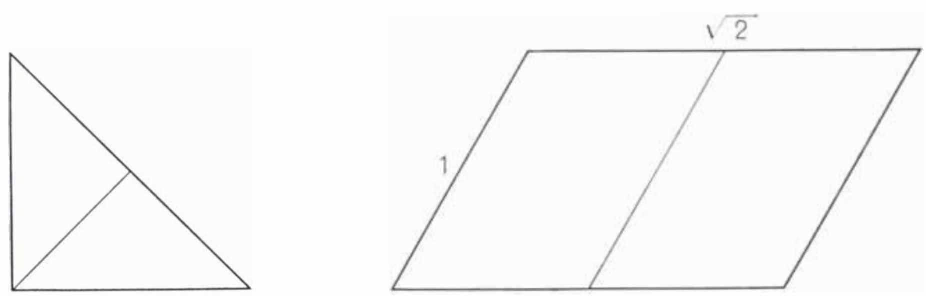
by Martin Gardner

Only three regular polygons—the equilateral triangle, the square and the regular hexagon—can be used for tiling a floor in such a way that identical shapes are endlessly repeated to cover the plane. But there is an infinite number of irregular polygons that can provide this kind of tiling. For example, a triangle of any shape whatever will do the trick. So will any four-sided figure. The reader can try the following test. Draw an irregular quadrilateral (it need not even be convex, which is to say that it need not have interior angles that are all less than 180 degrees) and cut 20 or so copies from cardboard. It is a pleasant task to fit them all together snugly, like a jigsaw puzzle, to cover a plane.

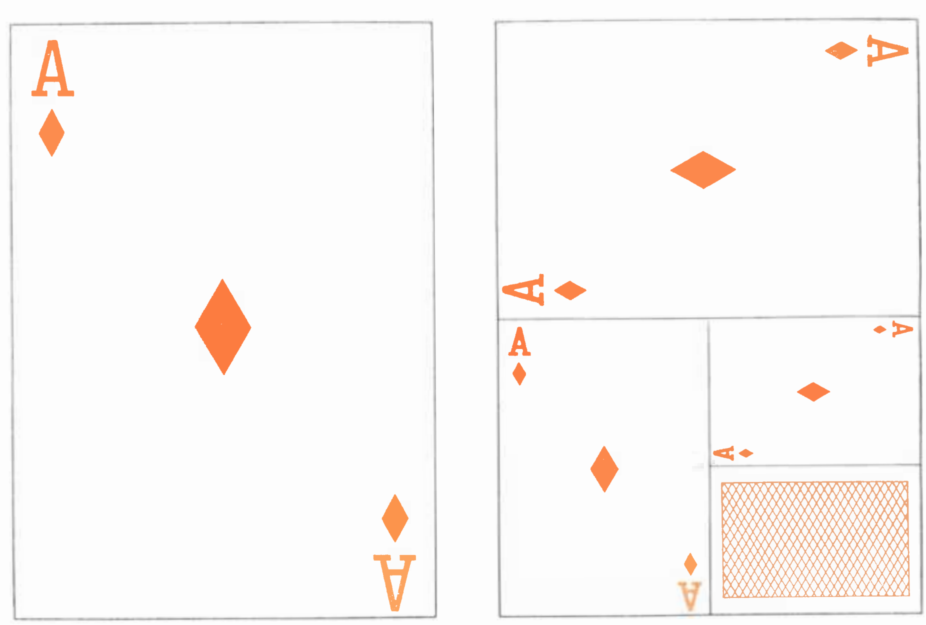
There is an unusual and less familiar



Three trapezoids that have a replicating order of 4



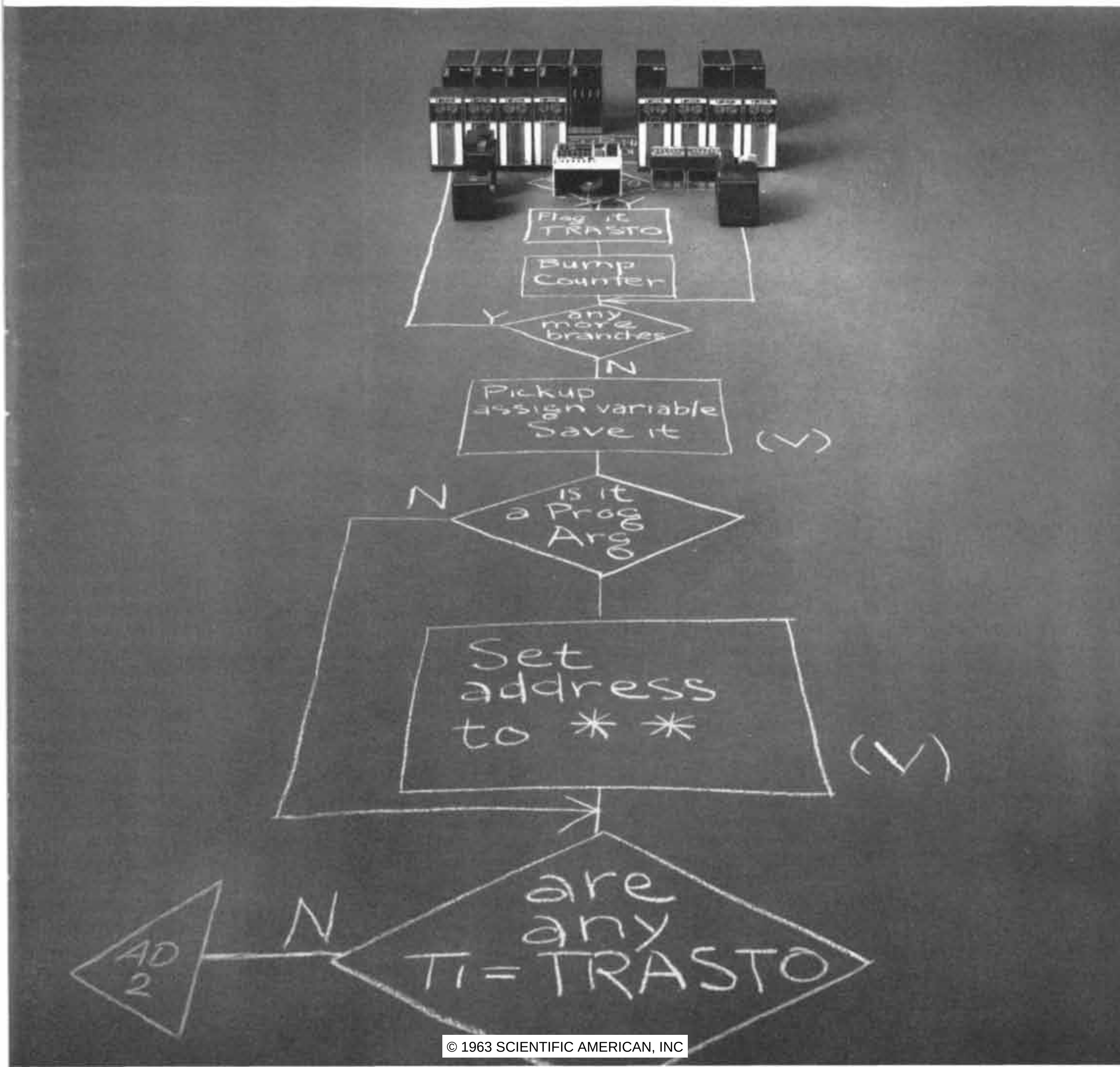
The only known rep-2 polygons



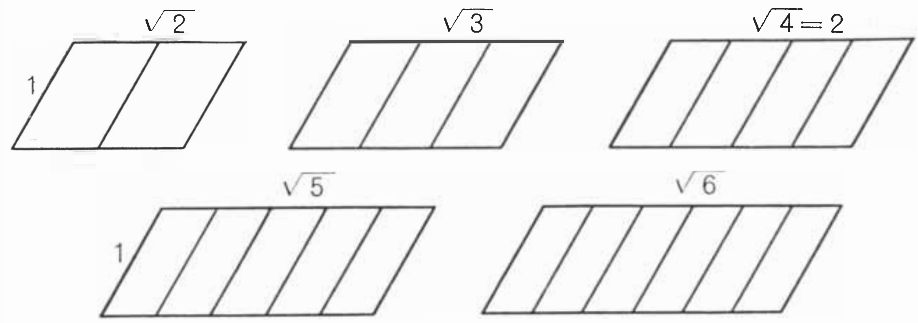
A trick diminishing card based on the rep-2 rectangle

The art of programming at IBM: Who charts the broad routes computers follow?

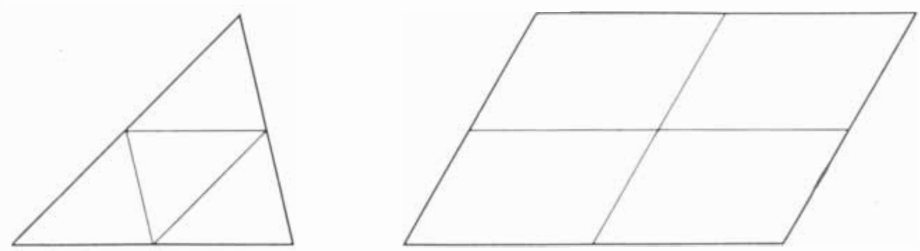
In the broad spectrum of computer applications, programs have been developed for one application which can be applied, often with minimal change, to other uses. The challenge inherent in developing such programs is to make them apply so broadly that they have the greatest possible flexibility—and so narrowly that they guide computing jobs without waste or omission. Furthermore, these generalized programs are an integral part of the computer systems. There are several kinds of programming systems which provide the broad routes for the work of IBM computers: Compiler programs, including FORTRAN, COBOL, and the Autocoders • Input-output control and monitor programs • Utility programs • Simulation programs: for technical details, write for a paper describing a particular simulator. The men and women programming at IBM perform a task comparable to that of the engineers and scientists designing machine configurations and other processing systems. Among the rewards of professional programming is the satisfaction of discovering practical, down-to-earth answers to questions of how to make computers do more and better work. They are not easy questions: they demand both stick-to-it logic and mental agility—as well as plain industriousness. If you wish to look into the opportunities open at IBM, an Equal Opportunity Employer, write to: Manager of Employment, IBM Corp., Department 659E, 590 Madison Ave., New York 22, N. Y.



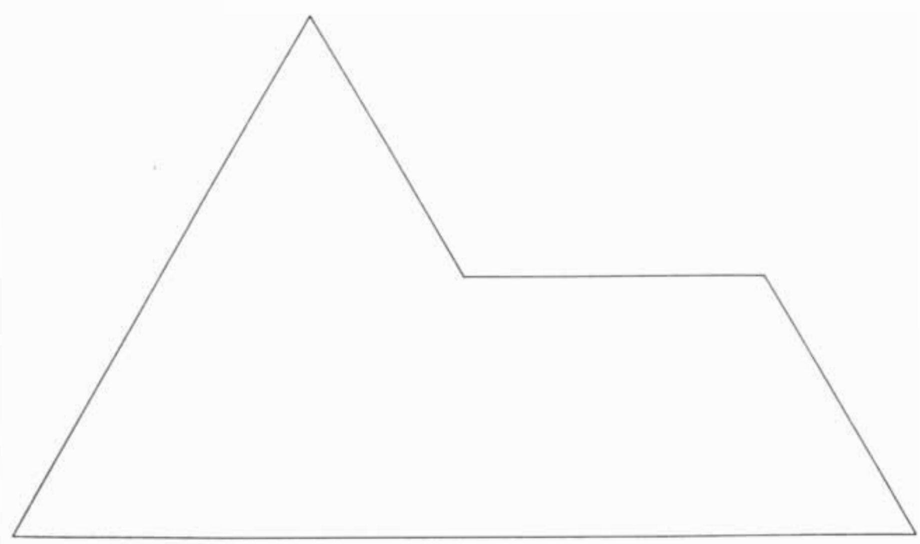
way to tile a plane. Note that each trapezoid in the top illustration on page 154 has been divided into four smaller trapezoids that are exact replicas of the original. The four replicas can, of course, be divided in the same way into four still smaller replicas, and this can be continued to infinity. To use such a figure for tiling we have only to proceed to infinity in the opposite direction: we put together four figures to form a larger model, four of which will in turn fit together to make a still larger one. The British mathematician Augustus De



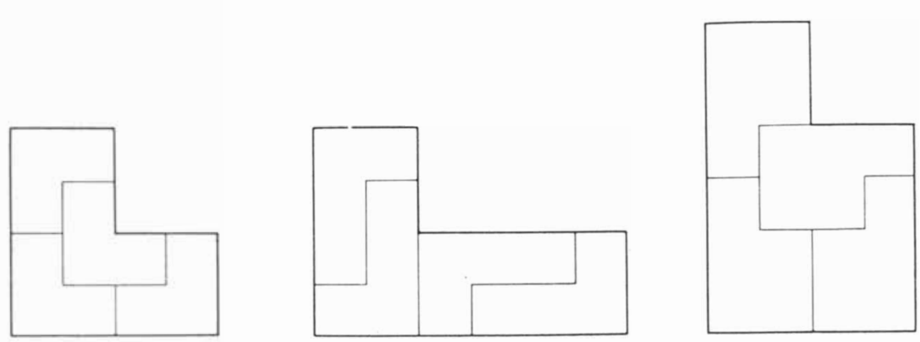
The 1-by-$\sqrt{k}$ parallelogram is a rep-k polygon



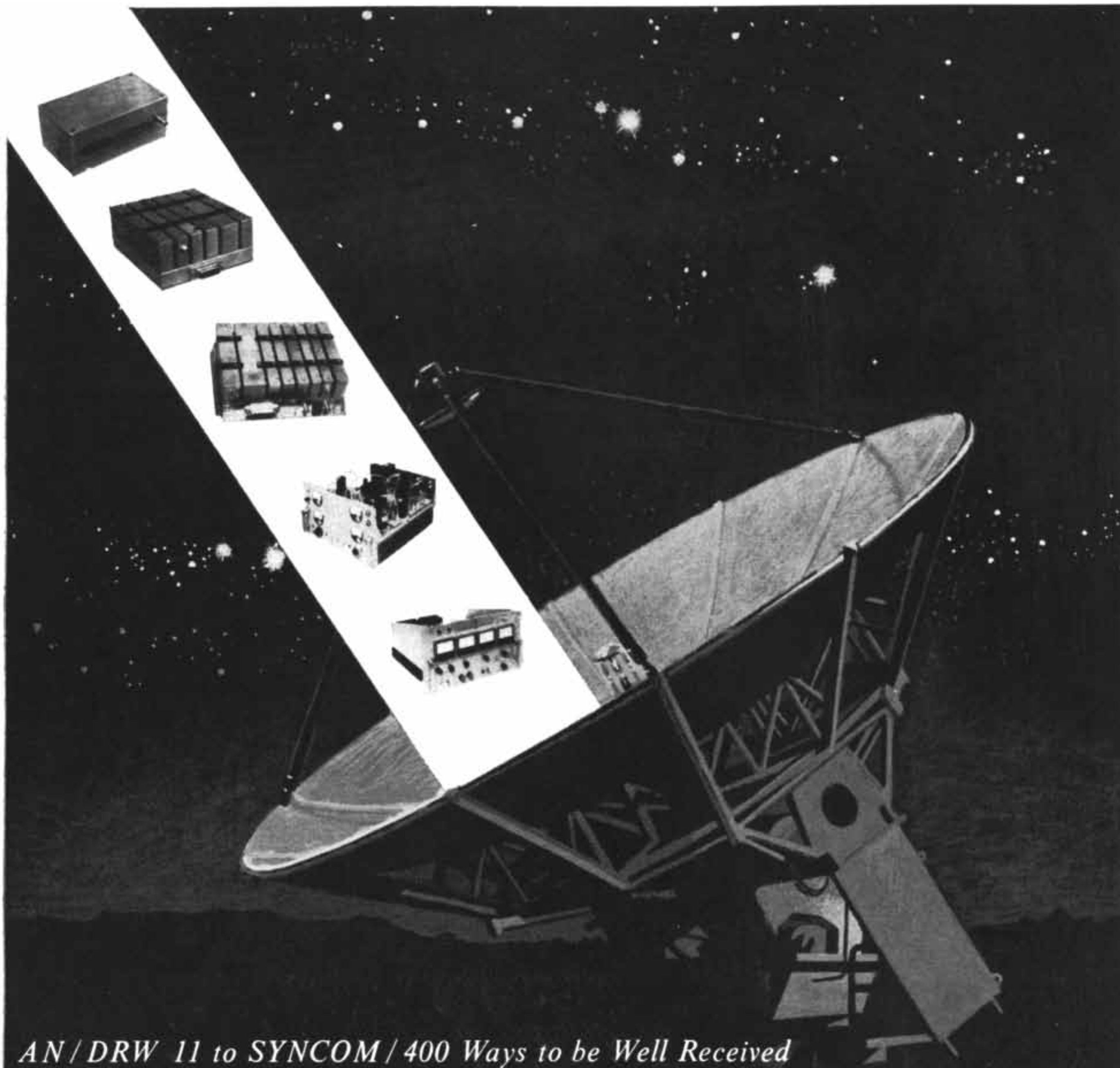
Every triangle and parallelogram is rep-4

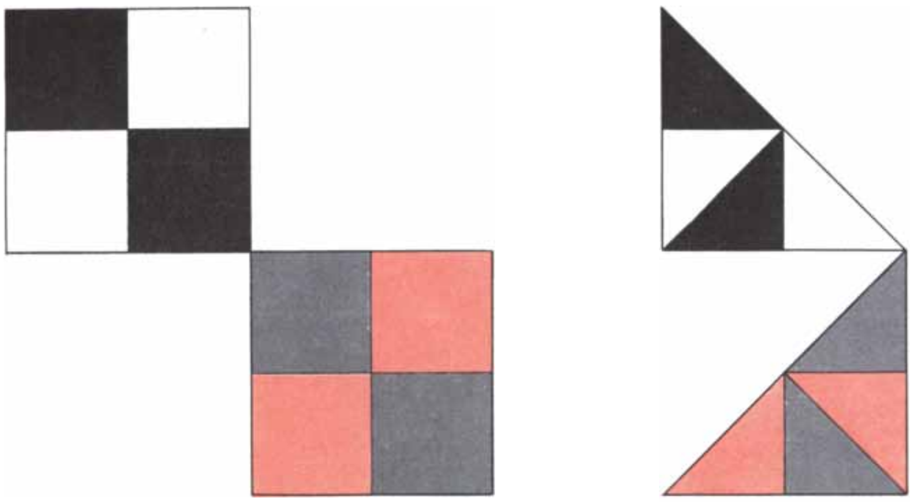


The Sphinx, the only known rep-4 pentagon

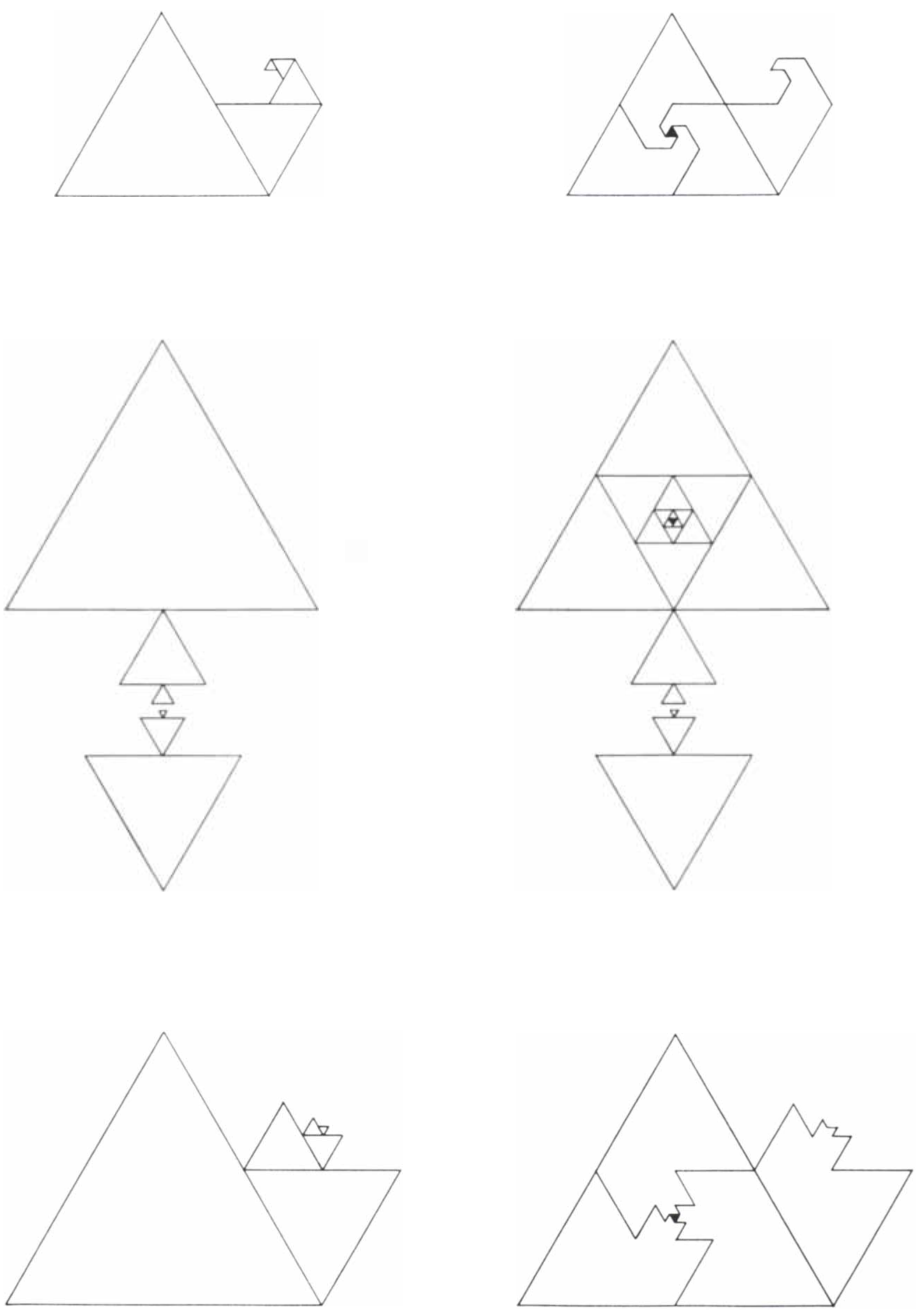


The three known varieties of rep-4 hexagons


AN/DRW 11 to SYNCOM/400 Ways to be Well Received



Two stellated rep-4 polygons



Three examples of rep-4 nonpolygons

Morgan summed up this sort of situation admirably in the following jingle, the first four lines of which paraphrase an earlier jingle by Jonathan Swift:

Great fleas have little fleas
Upon their backs to bite 'em,
And little fleas have lesser fleas,
And so ad infinitum.
The great fleas themselves, in turn,
Have greater fleas to go on;
While these again have greater still,
And greater still, and so on.

Until recently not much was known about polygons that have this curious property of making larger and smaller copies of themselves. In 1962 Solomon W. Golomb, who is on the staff of the Jet Propulsion Laboratory of the California Institute of Technology and is associate professor of electrical engineering at the University of Southern California, turned his attention to these "replicating figures"—"rep-tiles," as he calls them. The result was three privately issued papers that lay the groundwork for a general theory of polygon "replication." These papers, from which almost all that follows is extracted, contain a wealth of material of great interest to the recreational mathematician.

In Golomb's terminology a replicating polygon of order k is one that can be divided into k replicas congruent to one another and similar to the original. Each of the three trapezoids on page 154, for example, has a replicating order of 4, abbreviated as rep-4. Polygons of rep-k exist for any k, but they seem to be scarcest when k is a prime and to be most abundant when k is a square number.

Only two rep-2 polygons are known: the isosceles right triangle and the parallelogram with sides in the ratio of 1 to the square root of 2 [*see middle illustration on page 154*]. Golomb found simple proofs that these are the only possible rep-2 triangles and quadrilaterals, and there are no other convex rep-2 polygons. The existence of concave rep-2 polygons appears unlikely, but so far their nonexistence has not been proved.

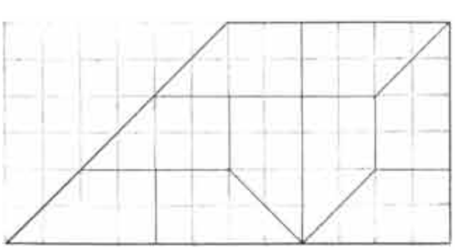
The interior angles of the parallelogram can vary without affecting its rep-2 property. In its rectangular form the rep-2 parallelogram is almost as famous in the history of art as the "golden rectangle," discussed in this department in August, 1959. Many medieval and Renaissance artists (Albrecht Dürer, for instance) consciously used it for outlining rectangular pictures. A trick playing card that is sometimes sold by streetcorner pitchmen exploits this rectangle to make the ace of diamonds seem to diminish in size three times [*see bottom illustration on page 154*]. Under cover of a hand movement the card is secretly folded in half and turned over to show a card exactly half the size of the preceding one. If each of the three smaller aces is a rectangle similar to the original, it is easy to show that only a 1-by-$\sqrt{2}$ rectangle can be used for the card. The rep-2 rectangle also has less frivolous uses. Printers who wish to standardize the shape of the pages in books of various sizes find that in folio, quarto or octavo form it produces pages that are all similar rectangles.

The rep-2 rectangle belongs to the family of parallelograms shown in the top illustration on page 156. The fact that a parallelogram with sides of 1 and $\sqrt{k}$ is always rep-k proves that a rep-k polygon exists for any k. It is the only known example, Golomb asserts, of a family of figures that exhibit all the replicating orders. When k is 7 (or any prime greater than 3 that has the form $4n - 1$), a parallelogram of this family is the only known example. Rep-3 and rep-5 triangles exist. Can the reader construct them?

A great number of rep-4 figures are known. Every triangle is rep-4 and can be divided as shown in the second illustration from the top on page 156. Among the quadrilaterals, any parallelogram is rep-4, as shown in the same illustration. The three trapezoids in the top illustration on page 154 are the only other examples of rep-4 quadrilaterals so far discovered.

Only one rep-4 pentagon is known: the sphinx-shaped figure in the third illustration from the top on page 156. Golomb was the first to discover its rep-4 property. Only the outline of the sphinx is given so that the reader can have the pleasure of seeing how quickly he can dissect it into four smaller sphinxes.

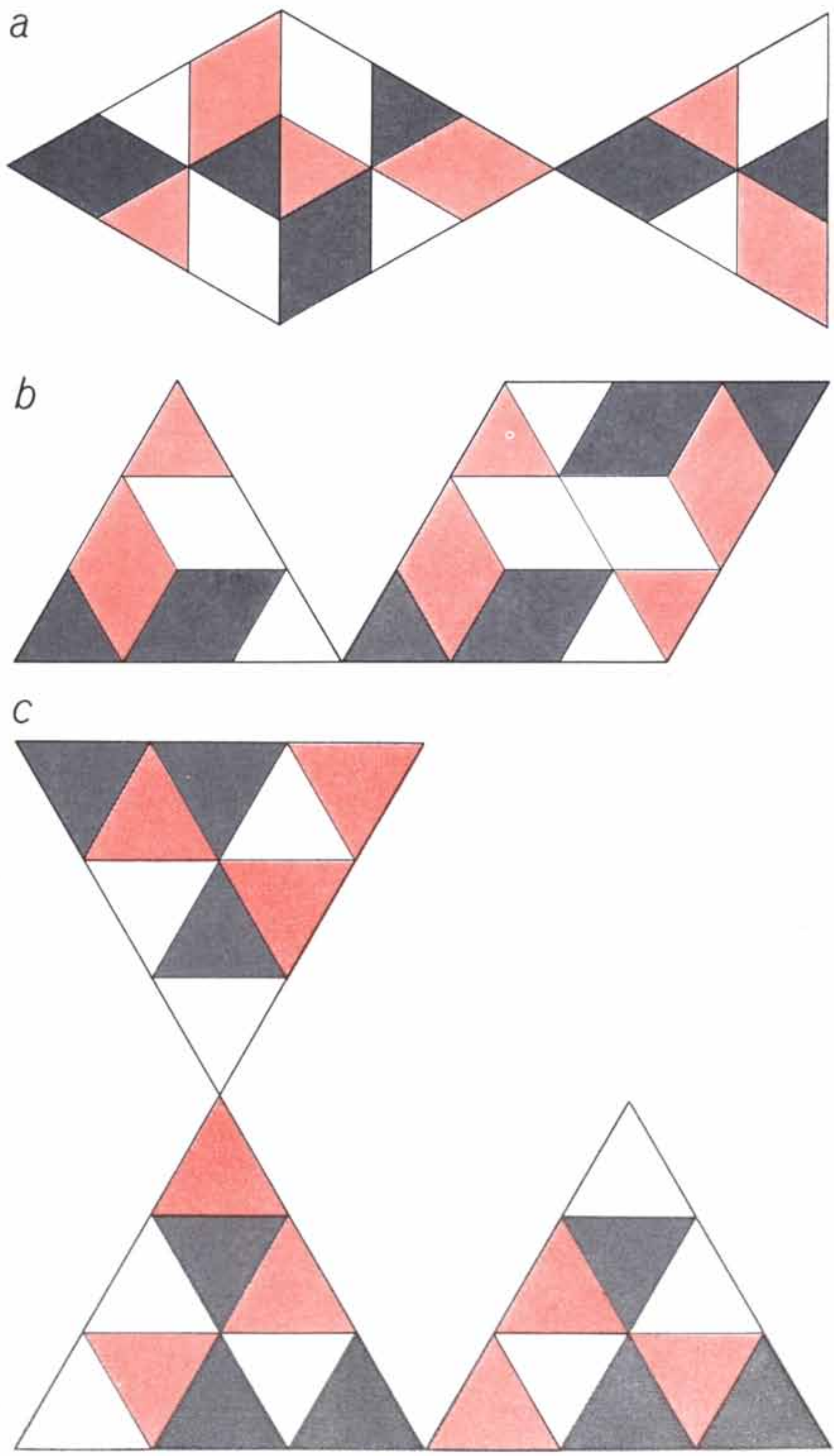
There are three known varieties of rep-4 hexagons. If any rectangle is divided into four quadrants and one quadrant is thrown away, the remaining figure is a rep-4 hexagon. The hexagon at



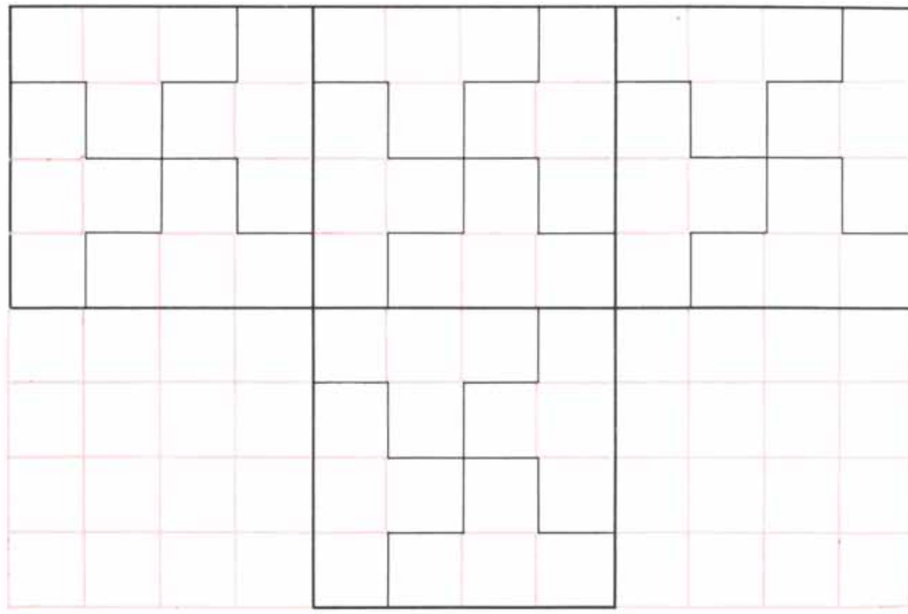
Every rep-4 polygon is also rep-9

the left at the bottom of page 156 shows the dissection (familiar to puzzlists) when the rectangle is a square. The other two examples of rep-4 hexagons (each of which can be dissected in more than one way) are shown at the middle and right in the same illustration.

No other example of a standard polygon with a rep-4 property is known. There are, however, "stellated" rep-4 polygons (a stellated polygon consists of two or more polygons joined at single points), two examples of which, provided by Golomb, are shown at the top of page 158. In the first example a pair of identical rectangles can be substituted for the squares. In addition, Golomb has found three nonpolygonal figures that



Stellated rep-9 polygons: The Fish (a), *The Bird* (b) *and The Ampersand* (c)



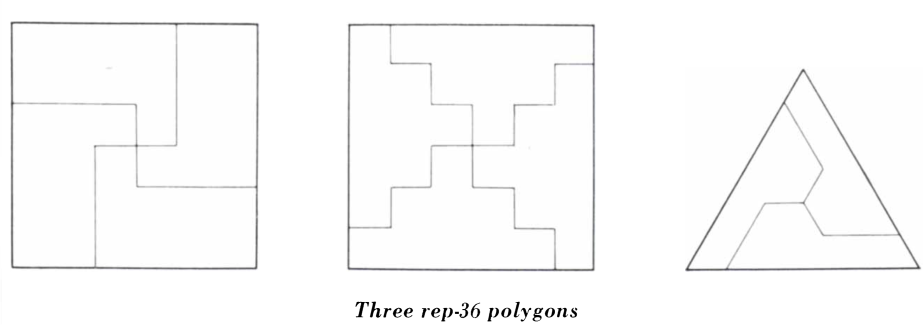
A rep-16 octagon

are rep-4, although none is constructible in a finite number of steps. Each of these figures, shown at the left in the bottom illustration on page 158, is formed by adding to an equilateral triangle an endless series of smaller triangles, each one-fourth the size of its predecessor. In each case four of these figures will fit together to make a larger replica, as shown at the right in the same illustration. (There is a gap in each replica because the original cannot be drawn with an infinitely long series of triangles!)

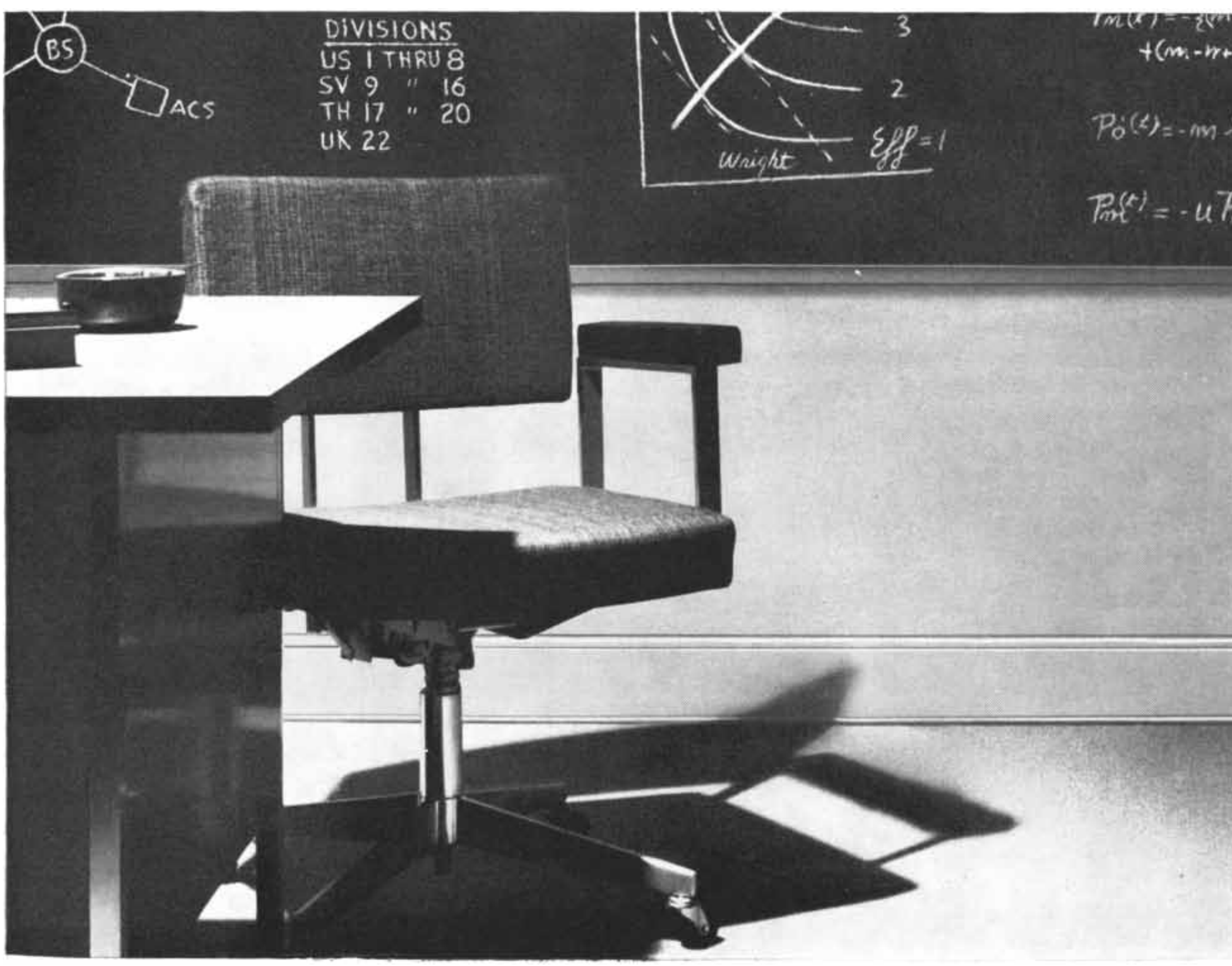
It is a curious fact that every known rep-4 polygon of a standard type is also rep-9. The rep-4 Nevada-shaped trapezoid on page 159 can be dissected into nine replicas in many ways, only one of which is shown. (Can the reader dissect each of the other rep-4 polygons, not counting the stellated and infinite forms, into nine replicas?) The converse is also true: All known standard rep-9 polygons are also rep-4. Three interesting examples of stellated rep-9 polygons, discovered and named by Golomb, are shown on page 160. None of these polygons is rep-4.

Any method of dividing a 4-by-4 checkerboard along grid lines into four congruent parts (as discussed in this department in November, 1962) provides a figure that is rep-16. It is only necessary to put four of the squares together to make a replica of one of the parts, as in the illustration above. In a similar fashion, a 6-by-6 checkerboard can be quartered in many ways to provide rep-36 figures, and an equilateral triangle can be divided along triangular grid lines into rep-36 polygons [*see illustration below*]. All of these examples illustrate a simple theorem, which Golomb explains as follows:

Consider a figure P that can be divided into two or more congruent figures, not necessarily replicas of P. Call the smaller figure Q. The number of such figures is the "multiplicity" with which Q divides P. For example, in the illustration below the three hexagons divide the triangle with a multiplicity of 3 and small equilateral triangles will divide each hexagon with a multiplicity of 12. The product of these two multiplicities (3×12) gives a replicating order for both the hexagon and the equilateral triangle: 36 of the hexagonal figures will form a larger figure of similar shape, and 36 equilateral triangles will



Three rep-36 polygons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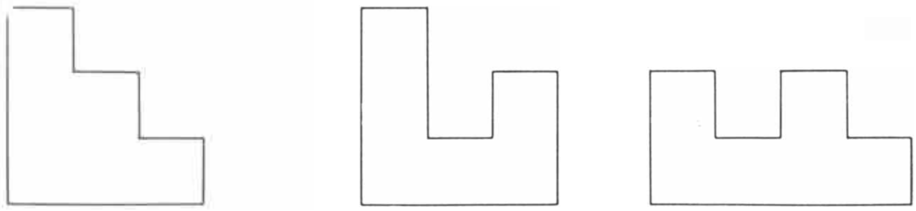


Three rep-144 polygons

form a larger equilateral triangle. In more formal language: If P and Q are two shapes such that P divides Q with a multiplicity of s, and Q divides P with a multiplicity of t, then P and Q are both replicating figures of order st ($s \times t$). Of course, each figure can have lower replicating orders as well. In the example given, the equilateral triangle, in addition to being rep-36, is also rep-4, rep-9, rep-16 and rep-25.

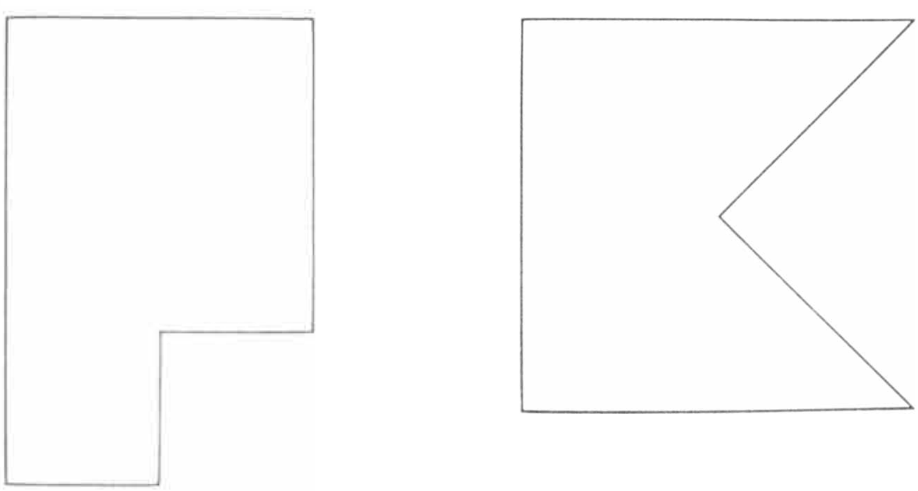
When P and Q are similar figures, it follows from the above theorem that if the figure has a replicating order of k, it will also be rep-k^2, rep-k^3, rep-k^4 and so on for all powers of k. Similarly, if a figure is both rep-s and rep-t, it will also be rep-st.

The principle underlying all of these theorems can be extended as follows. If P divides Q with a multiplicity of s, and Q divides R with a multiplicity of t, and R divides P with a multiplicity of u, then P and Q and R are each rep-stu. For instance, each of the hexominoes in the illustration above will divide a 3-by-4 rectangle with a multiplicity of 2. The 3-by-4 rectangle in turn divides a square with a multiplicity of 12, and the square divides any one of the three original shapes with a multiplicity of 6. Consequently the replicating order of each hexomino is $2 \times 12 \times 6$, or 144. It is conjectured that none of the three has a lower replicating order.

Golomb has noted that every known polygon of rep-4, including the stellated polygons, will divide a parallelogram with a multiplicity of 2. In other words, if any known rep-4 polygon is replicated, the pair can be fitted together to form a parallelogram! It is conjectured, but not yet proved, that this is true of all rep-4 polygons.

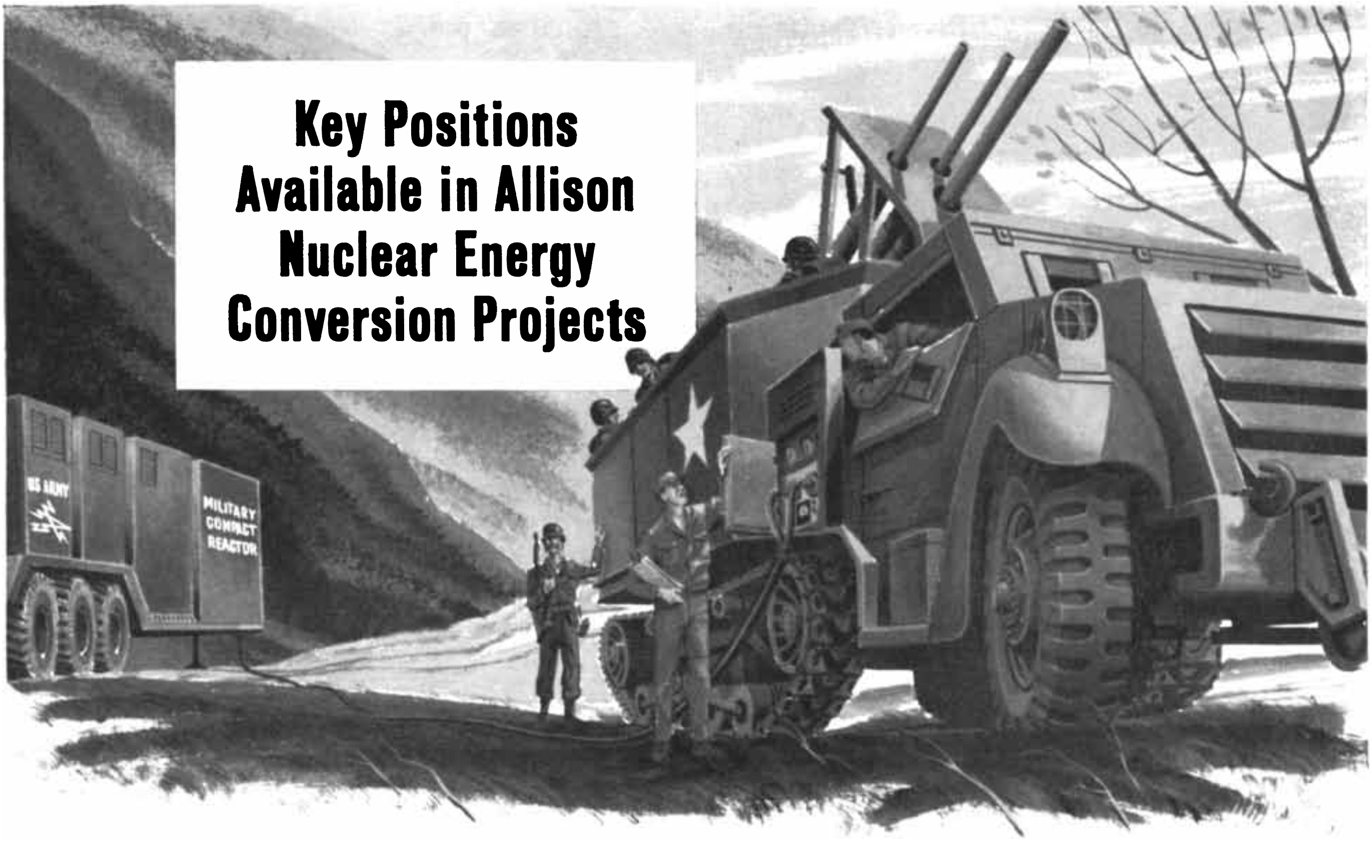
An obvious extension of Golomb's pioneer work on replication theory (of which only the most elementary aspects have been detailed here) is into three or even higher dimensions. A trivial example of a replicating solid figure is the cube: it obviously is rep-8, rep-27 and so on for any order that is a cubical number. Other trivial examples result from giving plane replicating figures a finite thickness, then forming layers of larger replicas to make a model of the original solid. Less trivial examples certainly exist; a study of them might lead to significant results.

In addition to the problems already posed, here are two unusual dissection puzzles closely related to what we have been considering [*see illustration below*]. First the easier one: Can the reader divide the hexagon [*left*] into two congruent stellated polygons? More difficult: Divide the pentagon [*right*] into four congruent stellated polygons. In neither case are the polygons similar to the original figure. Next month's column will give the answers to these as well as the preceding problems.



Two dissection problems

Key Positions Available in Allison Nuclear Energy Conversion Projects



● The Military Compact Reactor now being developed by Allison for the Atomic Energy Commission may also serve as the heart of a Nuclear Powered Energy Depot.

In one Energy Depot concept, the reactor system could be used to synthesize a fuel from universally available elements, such as air and water. Or, electricity produced by the reactor could be used to re-charge a fuel cell which would supply electric power for vehicle propulsion. A contract for development of a laboratory model of a combined liquid metal and sodium amalgam cell for this use was recently awarded Allison by AEC.

The Nuclear Energy Depot concept promises to be an effective solution to the ponderous military logistics of petroleum supply for a mechanized army. Finding the answers to problems posed by this advanced concept creates a distinct opportunity and exciting challenge.

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Senior Scientists Physicists and Chemists	In the applied sciences section of our Research Activity. Specific openings in: SOLID STATE PHYSICS, PHYSICAL CHEMISTRY AND ELECTRO-CHEMISTRY.
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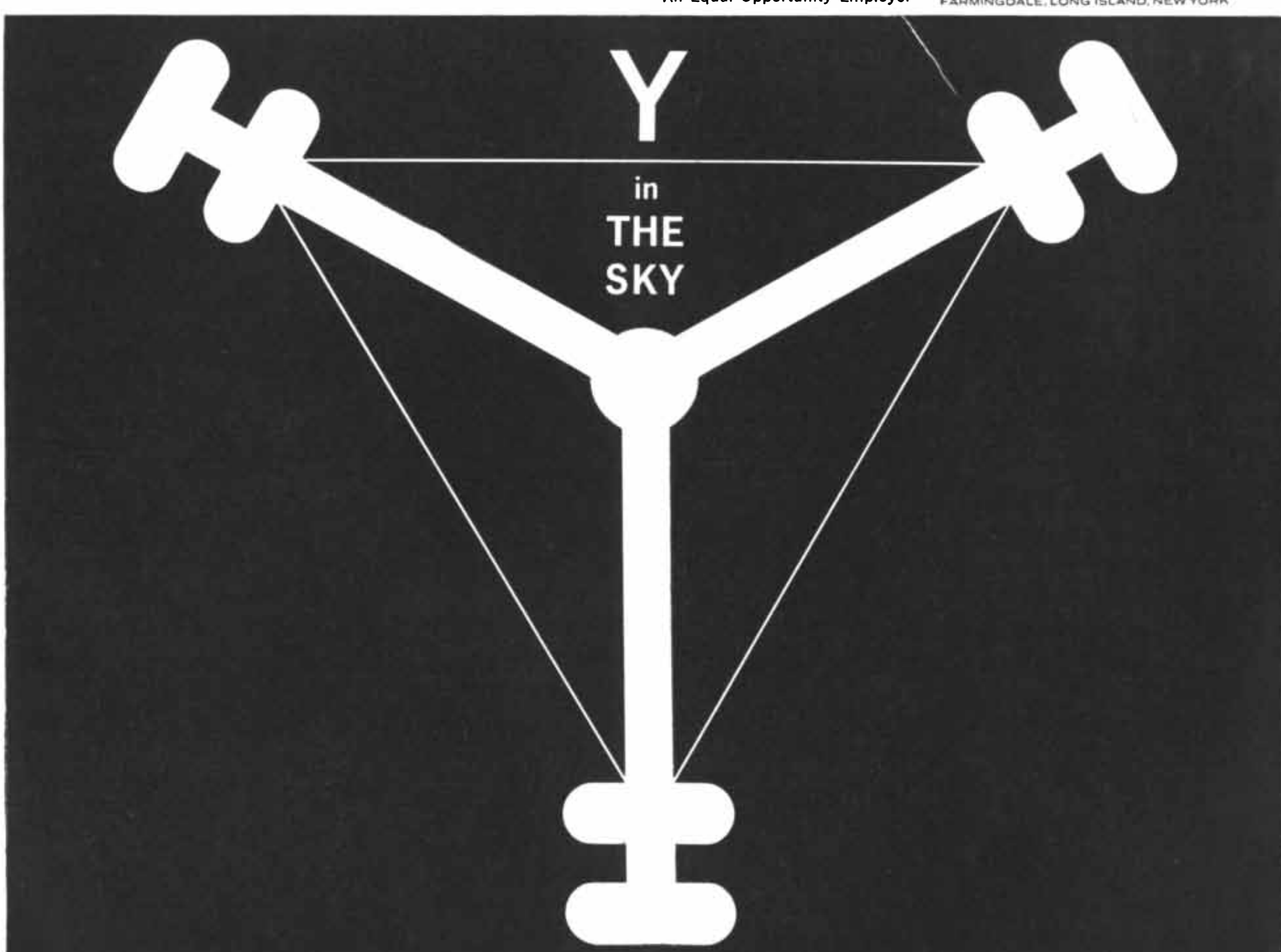


THE AMATEUR SCIENTIST

How to locate a thunderstorm and track it by detecting the radio waves it generates

Conducted by C. L. Stong

Lightning associated with thunderstorms radiates concentric patterns of electromagnetic waves known as sferics. With surprisingly inexpensive equipment an amateur can detect these waves and so track thunderstorms within a radius of several hundred miles. Indeed, with little more than a modified radio set a practiced observer can make reliable short-term forecasts of local thunderstorm activity simply by observing variations in the intensity of sferics and related fluctuations in the earth's electric field; increases in intensity are interpreted as meaning that a storm is approaching [see "The Amateur Scientist," March, 1959]. For several years Thomas P. Leary, an attorney in Omaha, Neb., has maintained a sferics station of this sort. Some months ago it occurred to Leary that his hobby might acquire additional interest if he could devise a radio compass with which to observe the bearing of storms as they meander through the Middle West.

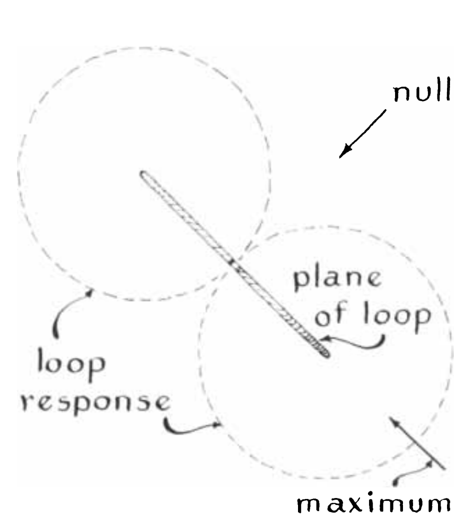
"There was nothing new in this idea," he writes. "Thunderstorm azimuth detectors were first put to use during the 1930's. No circuits have been published since World War II, however, and there appears to be little enthusiasm for such equipment except in Government weather projects. After investigating the general principles of radio compasses, I picked up a surplus cathode ray tube along with its accessories and finally succeeded in devising a simplified instrument that indicates the azimuth bearings of thunderstorms within three degrees of those given by our local weather radar station.

"The system consists essentially of two loop antennas crossed at right angles and oriented to the four points of the compass, together with amplifiers to actuate a cathode ray tube that displays the desired information. (As yet the system does not include any reliable provision for measuring the distance of storms. I have solved the problem to my own satisfaction for electrical disturbances within 300 miles of Omaha, but this feature of the instrument requires further development.) Watching this display and manipulating the controls during the passage of electrically active weather fronts has an almost hypnotic attraction. The active cells of storms can be seen to grow, move and decline; frequently it is possible to distinguish between cloud-to-cloud and cloud-to-ground strokes. The screen displays peculiar 'night effects' and other patterns, some of which are unexplained.

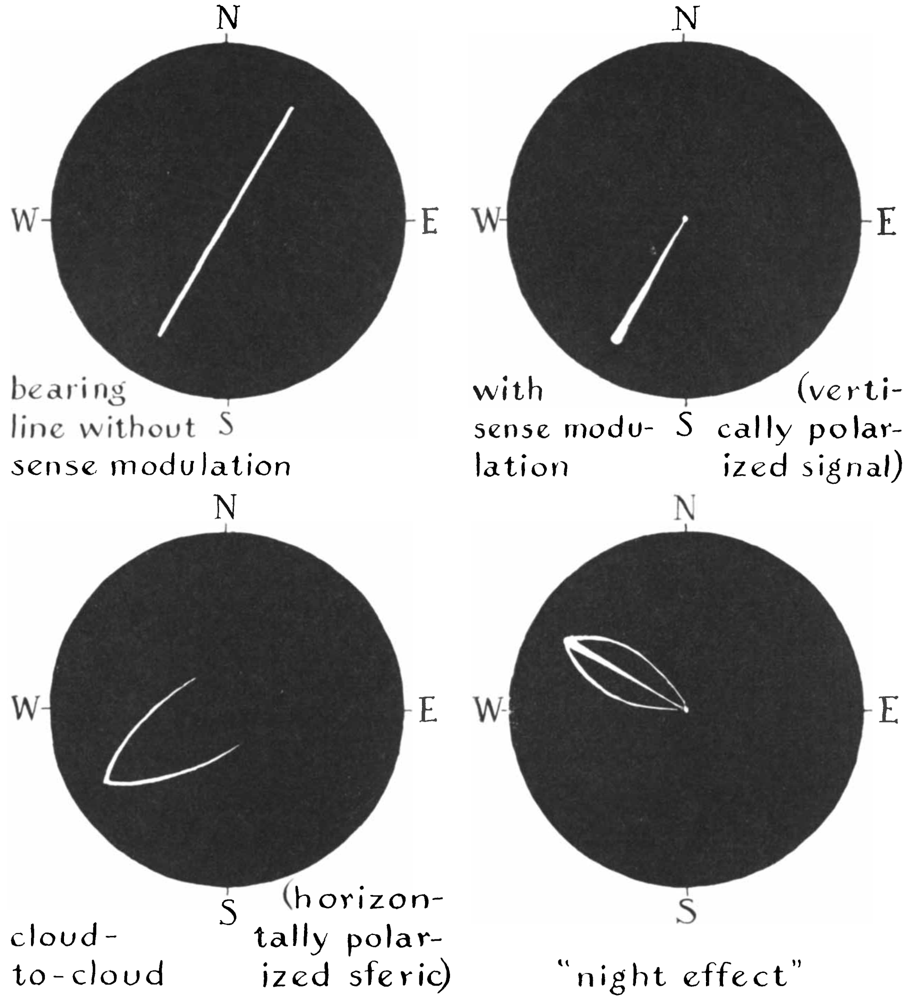
"The sensitivity of the system to the direction of electromagnetic waves derives from a property of the loop antenna. When a loop of wire that is half as wide as the waves are long from crest to crest is oriented in the direction in which the waves travel, a passing wave will induce a current in one direction in the leading side of the loop and in the opposite direction in the trailing side. The currents add and maximum voltage appears across the ends of the loop. (If the diameter of the loop differs from half of the wavelength, the output voltage is less than maximum but the same principle applies.) When the loop is oriented at right angles to the approaching wave, opposing currents are induced in the two sides. Destructive interference then occurs and no voltage appears across the terminals. (It is assumed that the loop is enclosed by an electrostatic shield so that fluctuations in neighboring electric fields, including the earth's field, do not induce spurious voltages.) The sensitivity of the loop to signals from various directions, when plotted on graph paper, takes the form of a figure eight, with maximum signal response in the direction of the plane of the loop and null, or minimum, response at right angles to this plane [*see illustration at right*].

"Two such loops are crossed at right angles and their amplified outputs are fed to the deflection plates of a cathode ray tube. If a storm occurs in the plane of one of the loops, the bearing of the incoming signal takes the form of a straight horizontal or vertical line across the face of the tube because the loop at right angles to the signal picks up no energy. When the direction of the signal is intermediate to the planes of the loops, however, each loop picks up energy in proportion to the angle between its plane and the impinging signal. The directivity patterns of the loop antennas are similar, with the result that as the signal source moves, voltage rises in one loop and falls in the other. The voltage changes deflect the beam, and the straight line displayed on the face of the tube rotates synchronously with the changing direction of the incoming signal. This assumes that the relative phase of the signal voltage induced in each loop is not shifted by the amplifiers and that the amplifiers have equal gain.

"In the elementary system just described the display, or bearing, line would have a 180-degree ambiguity. That is, it would indicate that a storm lies somewhere on a line extending through the antenna but it would not indicate on which side—whether east or west, for example. This information can be provided by a third signal picked up by a nondirectional antenna, such as a straight vertical wire. A separate circuit is arranged to amplify this 'sense' signal, shift its phase 90 degrees and apply the



Directional sensitivity of loop antenna



Cathode ray tube displays of various sferics

resulting voltage to the grid of the cathode ray tube. If a constant voltage that almost suppresses the beam is also applied to the control grid of the tube, the effect of the 'sense' signal is to black out half of the line displayed on the tube. The intensity of the remaining half varies from a faint trace at the center of the display to maximum brilliance at the outer end, as shown in the accompanying diagram [*above*].

"After experimenting with several circuits that employed narrow-band amplifiers operating in the range of 85 to 455 kilocycles, for which inexpensive intermediate-frequency transformers were available, I finally switched to broader-band components that operate in the audio- and low-radio-frequency spectrum. The construction was more difficult at the higher frequencies and the adjustments for maintaining proper phase-shift were critical. The simpler broad-band balanced amplifiers that were used in the final design dispensed with tuned circuits altogether and eliminated the necessity of matching the phase relation of signals in the two loop antennas. Sferics are essentially broad-band signals. A lightning stroke, particularly a cloud-to-ground stroke, dissipates an enormous amount of energy in a small fraction of a second. The potential difference between the earth and a cloud that discharges a 1,000-foot stroke can be on the order of a billion volts; the current varies between 10,000 and 500,000 amperes and the power amounts to as much as 100 kilowatt hours. The energy is radiated over a band of frequencies that extends from audio-frequencies through the spectrum of light.

"Part of the energy, in the form of low-frequency signals, impinges on the loop antennas directly and part after reflection from regions of the ionosphere. Reflection alters the polarization of the signals—the plane in which the waves vibrate. Loop antennas, although simple and dependable, are sensitive to polarization effects. Direct signals from cloud-to-ground strokes vibrate in the vertical plane; they are vertically polarized. My instrument displays them as a straight line on the face of the cathode ray tube. Reflection in the upper atmosphere can rotate the plane of polarization through a large angle that causes the line to broaden into an oval or wishbone-shaped display. This occurs in the case of cloud-to-cloud strokes. Two waves from the same stroke but of differing polarization (a sky wave and a ground wave) may reach the loops almost simultaneously. The superimposed signals are then displayed as an open oval bisected by a straight line. Because of ionospheric conditions this often takes place at night.

"I wound my loops on 'hula hoops,' those plastic rings that were such a fad among children a few years ago, primarily because I happened to find a pair priced at 19 cents each. One could substitute plastic hose or piping or some other material. A half-inch section was cut in the perimeter of the hoops, forming a channel to receive 50 turns of 20-gauge, plastic-insulated magnet wire. A coil of this size intercepts ample energy for detecting storms up to 600 miles away. The ends of the coil are connected to jacks of the type used in electric phonographs, mounted on small metal plates attached to the hoops [*see illustration below*]. Two identical loops are required. Each is wrapped with strips of aluminum foil about 1½ inches wide, which acts as an electrostatic shield. The foil is connected electrically to the metal plate that mounts the jacks and is covered with a wrapping of masking tape. A section of foil about half an inch wide is cut from the shielding at a point opposite the jacks to prevent the shielding from acting as a short-circuited turn. The loops are mounted at right angles, accurately aligned north-south and east-west, at least 20 feet above the ground and, as nearly as possible, directly over the receiving system. The loops should be placed as far as possible from vertical metal structures such as pipes.

"The loops and amplifiers are connected by four equal lengths of small-diameter coaxial cable such as type

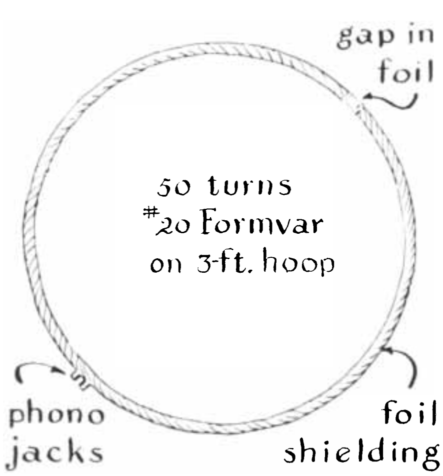


Diagram of loop antenna

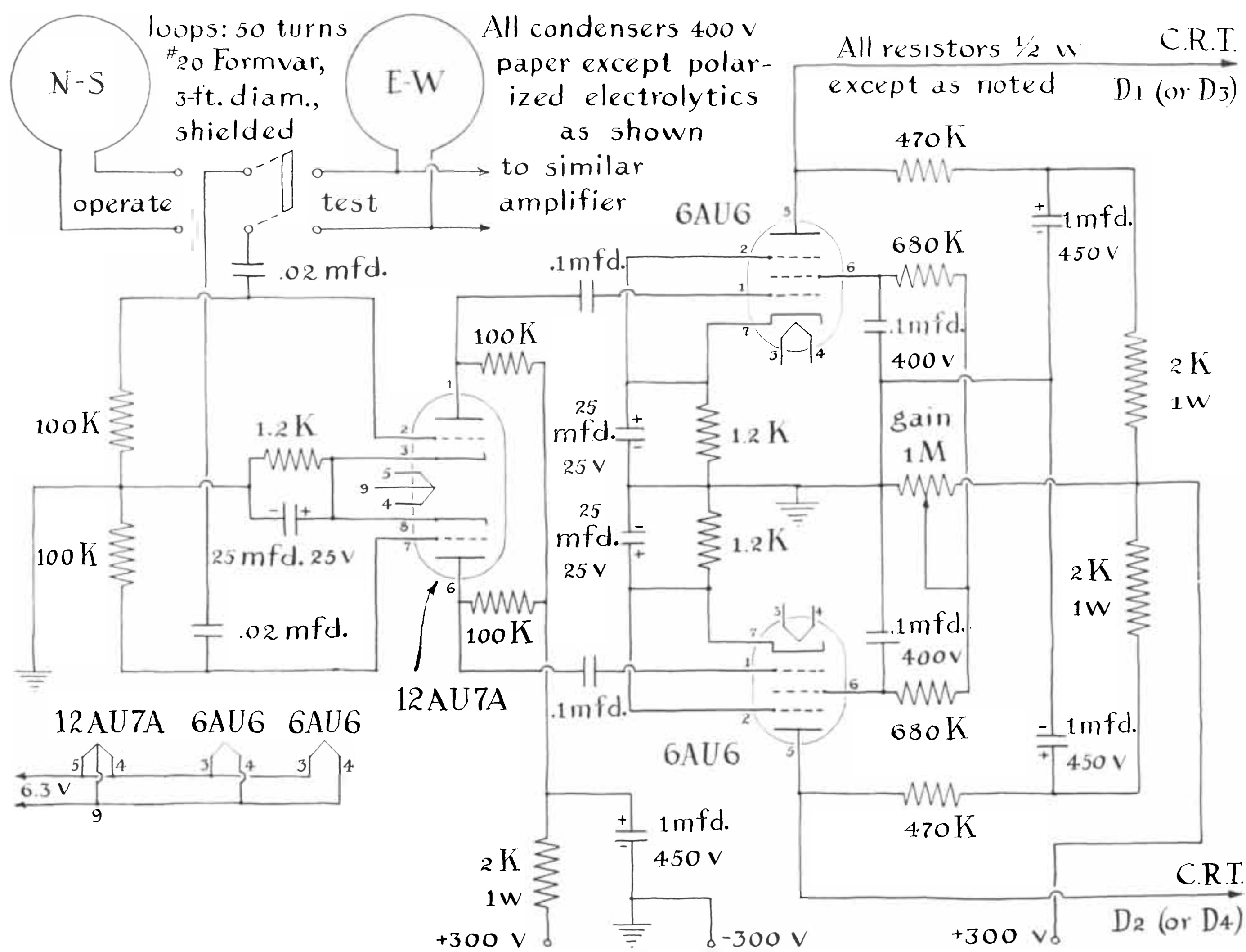
RG-78 U. The cables end in plugs that mate with phonograph jacks. The circuit includes a double-pole, double-throw toggle switch so that each amplifier can be connected to a different loop or both amplifiers to the same loop, depending on the position of the switch. The switch is to be used when the amplifiers are adjusted for equal gain.

"The amplifiers are of the push-pull, high-gain type designed for operation in the range of 100 to 12,000 cycles. As in all high-gain amplifiers, the ground connections for each tube should be made at a common point and the input and output circuits should be spaced as far apart as possible. Chance feedback and consequent oscillation will also be minimized by keeping the tubes widely separated. Decoupling filters made of appropriate resistors and capacitors are used in the plate circuits of both amplifier stages to prevent spurious currents from entering the units from the power supply, as shown in the accompanying diagram [*below*]. The amplifiers operate from any well-filtered power supply that delivers 250 to 300 volts at about 75 milliamperes of direct current and 6.3 volts at five amperes. A separate filament transformer is required for the cathode ray tube.

"The 'sense' antenna can be a vertical wire 30 feet or more in length suspended between insulators within a reasonable distance of the loops. If the distance between this antenna and its amplifier is more than 20 feet, the connection between the two should be made with coaxial cable. The signal enters the sense amplifier through a phase-shifting network composed of a series capacitor bridged by a 50,000-ohm potentiometer, which also serves as a control for reducing the intensity of the sense signal when sferics of exceptional strength are received [*see top illustration on page 172*]. The gain of the first stage of the sense amplifier is controlled by adjusting the potential applied to the screen grid. (This method of control does not influence the phase of the signal when the gain is altered, as would be the case if the gain were controlled in the cathode circuit.) The sense antenna should be equipped with a lightning arrester.

"The cathode ray tube is energized by a power supply capable of developing between 2,500 and 3,000 volts and two milliamperes of direct current. I am at present using a 3JP1 cathode ray tube. This component produces a brilliant display and is generally available from surplus dealers. Recently it was priced at $7.50 by Barry Electronics Corp. (512 Broadway, New York 12, N.Y.). This firm also offers for $10.90 a piece of apparatus that includes a 3JP7 cathode ray tube along with a magnetic shield, a milliammeter and other components useful in the construction. The 3JP7 tube is coated with a phosphor that produces a long-persistence image that must be viewed in the dark. (The long persistence may well produce confusing patterns when a really wild front comes through.) When working with any of these tubes, remember that the high voltage is lethal. Disconnect the line cord and short-circuit the capacitors with the blade of a screw driver before touching any part of the circuit.

"The arrangement of the parts on the chassis supporting the cathode ray tube



Circuit diagram of a directional amplifier

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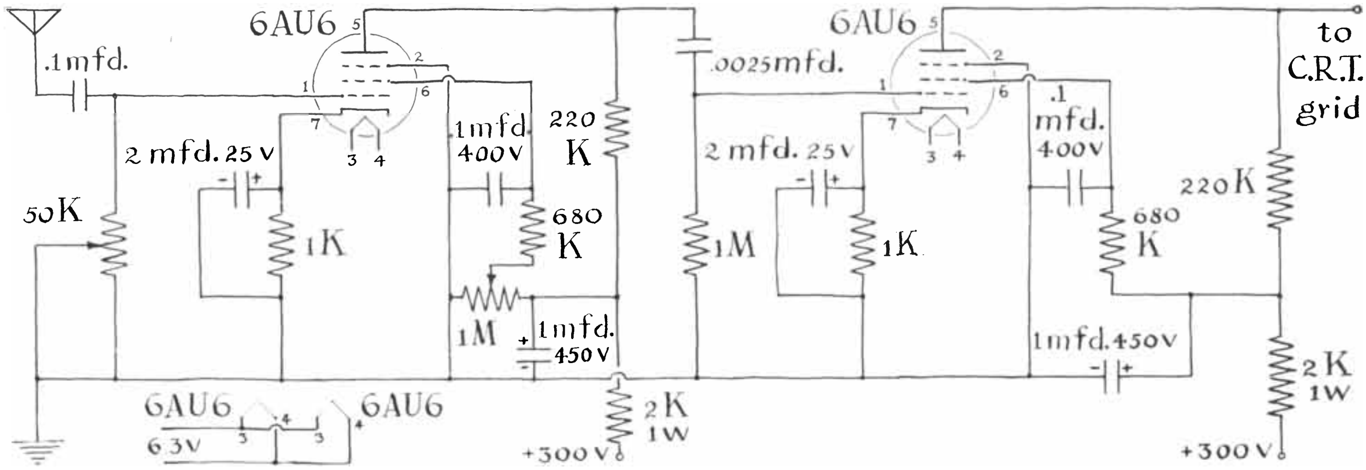


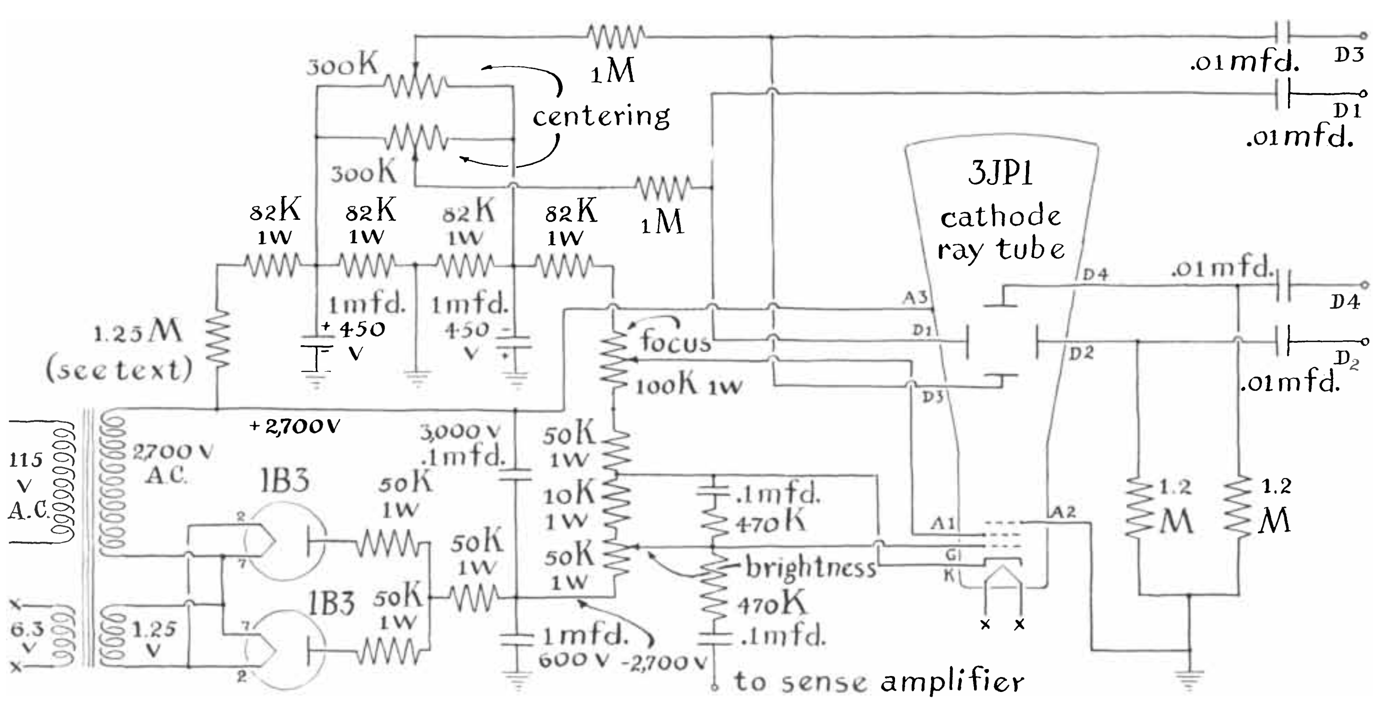
Schematic diagram of "sense" amplifier circuit

is not particularly critical. The controls used for centering the beam—two 300,000-ohm potentiometers—need not appear on the panel. They are adjusted only when a tube is installed or replaced. The focus and brightness controls operate at high potential and should be mounted under the chassis on insulating material and linked to knobs on the panel through an insulating coupling. The 1.25-megohm section of the voltage divider should be made up of four or five two-watt carbon resistors in series to prevent voltage breakdown [*see illustration below*]. The high-voltage transformer should be mounted as far away from the tube as possible to minimize the tendency of its alternating-current field to modulate the beam. The power supply and high-potential connection to the cathode ray tube should be wired with conductors specially insulated for high voltages. It is a good idea to inscribe the points of the compass or degree markings on the face of the cathode ray tube with a grease pencil or to attach a plastic compass rose to the face of the tube.

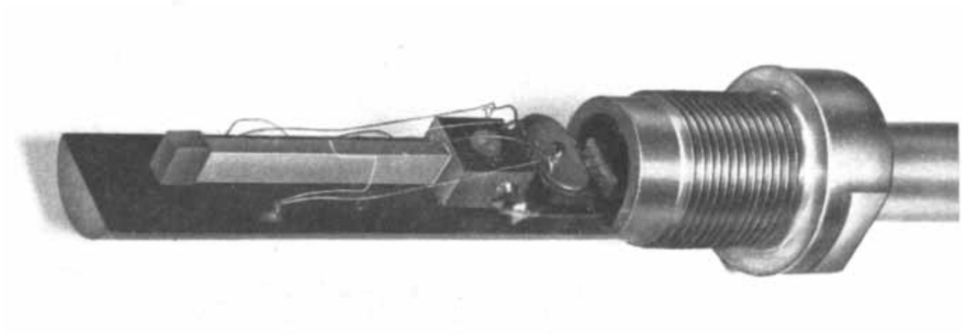
"To place the completed system in operation, first identify the two pairs of coaxial cables that are connected to the loop antennas by making continuity tests with an ohmmeter, and connect one pair to each of the signal amplifiers. (Do not make the mistake of connecting one end of each loop to each of the amplifiers.) Then connect the sense antenna to its amplifier. The shielding braid of all four loop cables must be electrically connected at each end and grounded to the amplifiers as well as to a water pipe.

"Now turn on the power. Turn the gain controls of both signal amplifiers to maximum and operate the double-pole, double-throw toggle switch in the antenna circuit to connect both amplifiers across one loop. If there is a thunderstorm within range, its sferic signal should now produce a sharp line extending across the face of the cathode ray tube 45 degrees from the vertical. If the line is not at a 45-degree angle, the gains of the two amplifiers are unbalanced. Reduce the gain of either amplifier (but not both) until the display is properly aligned. Then restore the toggle switch to its former, or operating, position.

"You must now determine the true bearing of the approaching storm by some means external to the system in order to orient your cathode ray tube with actual north and south. A call to the local weather bureau will usually provide the information, particularly if



Schematic diagram of cathode ray tube circuit



An elegant, but tiny refrigerator, utilizing the Nernst-Ettingshausen effect, has been demonstrated in the Solid State Physics Laboratories at Lockheed Missiles & Space Company. This type of cooling is applicable below 200° Kelvin, where thermoelectric cooling is no longer efficient. It shows particular promise for space application because of the reliability inherent in its all-solid state construction.

In the Nernst-Ettingshausen effect, heat is pumped as a result of an electrical current flowing in a magnetic field. The heart of the present device is a bismuth antimony single crystal. Other crystal systems are also being investigated.

This thermomagnetic cooling device is one of the results of the Lockheed research program in transport phenomena in solids.

Another investigation concerns the quantum theory of the electronic structure of crystals. An ingenious computer program has been devised for determining the essential features of the energy band structure of a wide variety of crystals. Results for a given case can be obtained in an hour or less. Conclusions drawn from the theoretical solution elucidate many of the electronic properties of crystals, and have widespread significance.

Lockheed scientists and engineers are also studying: Electron spin echo phenomena; the interaction of electrons with microwave phonons; coupled traveling waves in crystals; semiconductor lasers; antiserromagnetic resonance; various theoretical and experimental aspects of superconductivity.

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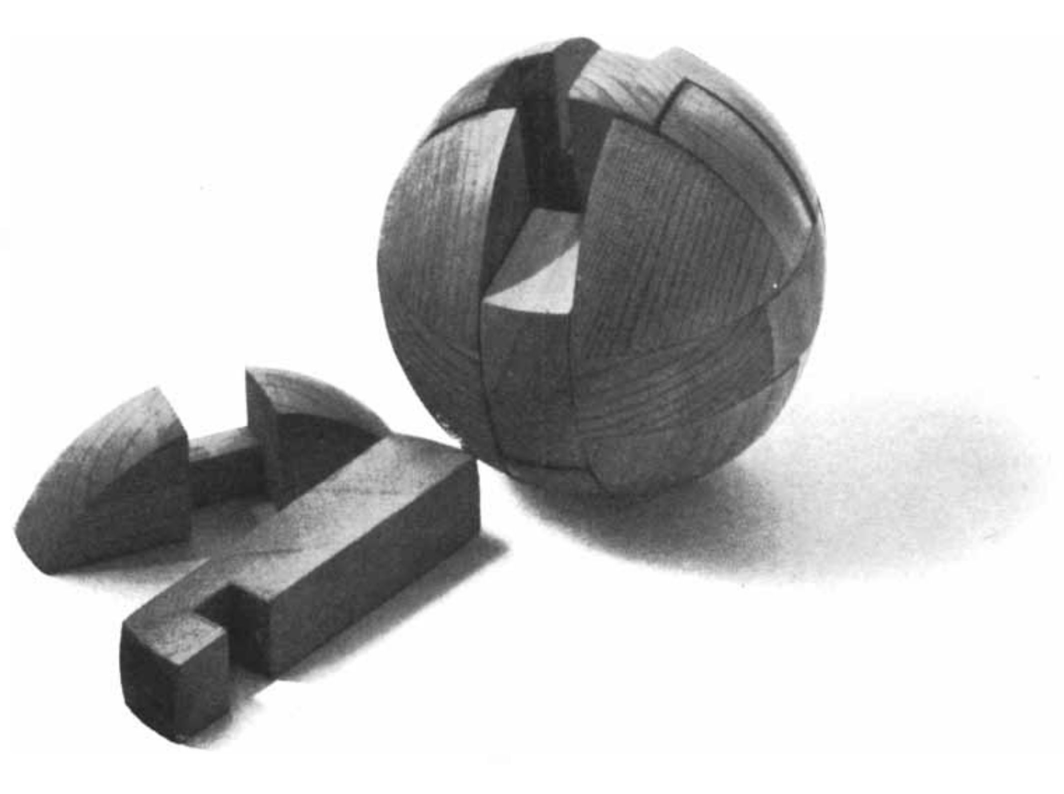


you explain what you are up to, because most of the nation is now covered by weather radar stations that keep track of all disturbances within 200 miles or so. Failing this expedient, you can tune in on an aircraft radio-range station with a radio receiver that can pick up the band between 150 and 350 kilocycles. These stations transmit continuous weather reports, including the location of such thunderstorms as may be in progress. As a last resort, simply wait until a storm appears in your vicinity and take a look. Once the true bearing of a storm has been determined, check the display on the cathode ray tube and, if necessary, interchange the lead-in cables from the loop antennas until the display is aligned with the bearing of the storm. Only four input combinations are possible, so that the task is not difficult. The procedure should be repeated with another storm, about 90 degrees removed from the first, as a double check.

"The knack of interpreting displays comes with experience. The length of the line on the scope indicates the strength of the incoming signals, and it is possible with experience to judge the range of a storm with reasonable accuracy on the basis of this signal strength. A storm at long range produces a short, straight line when the gain is set at maximum; storms at medium range produce longer lines. The line broadens into an ellipse when horizontally polarized sferics are received from strong cloud-to-cloud discharges. Thunderstorms in the immediate vicinity set up confused patterns.

"As an aid in learning to judge range one can use the hourly low-frequency reports, broadcast by radio-range stations, of the movement of frontal systems. Many thunderstorms occur along the line of a cold front. A strong sferics display in the direction of such a front at a known distance provides an opportunity to co-ordinate the appearance of the display with a reasonable approximation of distance. Storms occurring simultaneously at widely separated bearings produce simultaneous displays. Isolated storms not associated with major fronts produce single displays. If a display of this type remains fixed in azimuth but increases in intensity, it can be assumed that the storm is headed in your direction. In summer most cold fronts move through the Middle West at 20 to 25 miles per hour, so that it is possible to estimate the arrival time of the bad weather.

"As signals grow in strength, the gain of both signal amplifiers must be reduced to keep the end of the display from going off the face of the tube. Whenever the gain is thus altered, the gain of amplifiers must be equalized by the procedure previously described. The intensity, or brightness, control is ordinarily set so that the bright spot made by the beam is barely visible. The spot should be centered accurately by means of the centering controls. The optimum positions of the sense-input potentiometer and the sense-gain control depend on the location of the storm and the intensity of the signals. The operation of the controls must be learned by experience. The circuit operates with maximum gain and minimum attenuation when both controls are set for maximum resistance with respect to the ground.

"A few verified tornadoes have been observed. Any storm that produces rapidly repeated pips on the same bearing is suspect, particularly if the display persists for an appreciable time. Some observers report that tornadoes produce no cloud-to-ground strokes and that the cloud-to-cloud discharges in a tornado funnel are radiated principally above 100 kilocycles. At close range, however, it is possible to detect the 'tornado oscillator' at low frequencies. An 85-kilocycle receiver in use at my station has produced an elliptical display with rapidly recurring sferic pips on the azimuth of a small tornado 24 miles away. Thunderstorms and precipitation are almost always accompanied by observable electrical activity, and some 'severe-weather warnings' issued by local weather bureaus can be discounted if the sferic indicator does not show corresponding electrical disturbances.

"Another phenomenon that may show up on the scope is the 'clear-weather sferic,' a lightning discharge in an area of calm, clear skies, usually in summer. These have also been observed visually, although little is known about them.

"Giant electrical storms can also be detected on occasion. The clouds in these disturbances sometimes reach 12 miles into the stratosphere and develop as many as 10 to 20 cloud-to-cloud strokes per second. These enormous thunderheads, which often give rise to tornadoes, can actually be seen when they are more than 150 miles away. The signals they produce are characterized, according to one report, by a series of sferic pips that occur a fraction of a second apart and, at long range, on the same azimuth.

"Two or three sferics azimuth stations, separated by 100 miles or so, could obtain accurate fixes on thunderstorms if the problem of establishing communications between stations can be solved. Perhaps the solution can be found in amateur radio."

BOOKS

A critique of a recent history of philosophy

by John Passmore

THE CAREER OF PHILOSOPHY: FROM THE MIDDLE AGES TO THE ENLIGHTENMENT, by John Herman Randall, Jr. Columbia University Press ($13.95).

When St. Peter Damian, writing in the 11th century, described philosophy as "the handmaid of theology," he intended to cast philosophy in a menial role, but at least he did not impugn its respectability. Later scholastic theologians reinterpreted his dictum so as to ensure for philosophy a higher social status. A handmaid, they said—taking Abraham's Hagar as their prototype—was no mere servant: she shared the dignities and responsibilities of a lawful spouse. Professor Randall will have none of this; philosophy, he tells us, serves neither husband nor master. This is not, however, because she lives an independent life but because she constantly shifts her allegiance, transferring her affections to whatever form of human enterprise—be it theology, science or social reconstruction—is prepared to pay the highest fee for her services. Thus "handmaid" becomes a euphemism for "harlot."

Philosophy, Randall explicitly writes, "belongs to the oldest profession in the world: she exists to give men pleasure, and to satisfy their imperious needs." One could sum up his view by saying that Philosophy is the ideal mistress of the adolescent imagination, as depicted in innumerable historical novels. Courageous ("you will find her always where the fighting has been fiercest") and worldly-wise ("with the wisdom of her incredible experience she teaches [men] how to win"), Philosophy never forgets her primary responsibility, which is to offer delight and consolation. "She consorts with men, comforts men, tells them what they want to hear."

If Randall is right, what Plato called "the Sophists" are the true philosophers. In Plato's eyes, of course, the Sophists were the enemies of philosophy, the more dangerous because they imitated its external characteristics while falsifying its spirit. Yet he did not deny that they were gifted men; it is the nature of their gifts that aroused Plato's suspicion and contempt. In his *Gorgias* he tells us that the Sophists exhibit "a bold and ready wit, which knows how to manage mankind"; they are specialists in "the art of flattery"—the art of persuading men by telling them what they want to hear. This above all, Plato thought, is what proved them not to be true philosophers. I cannot recall that Plato ever described the Sophists as "courtesans" (he does call them "parasites"), but he might well have done so.

Writers will have their metaphors; perhaps we do wrong to take Randall's analogy seriously. Certainly *The Career of Philosophy* is not a *chronique scandaleuse*, nor is it a guide to the successful practice of intellectual prostitution. It resembles a modern sexual-historical novel only in being some 980 pages long. If it is our object in life to make friends and influence people, we shall not achieve our objective by imitating the philosophers to whose teachings Randall draws our attention. Indeed, although there certainly are, and always have been, philosophers whose sole concern is to tell men what they want to hear, historians, including Randall, are silent about their lives and works; they rapidly fade into the obscurity they so richly deserve.

Historians are not, however, silent about Socrates, who described himself as "that gadfly which God has given the State, and all day long and in all places is always fastening upon you, arousing and persuading and reproaching you." A strange way to describe the function of an ideal mistress who consorts with men, comforts men, tells them what they want to hear! If indeed Socrates, Giordano Bruno, Spinoza, Hume and Bertrand Russell set out to tell men what they want to hear, their manner of doing so must have been singularly inept or their audiences discouragingly ungrateful. Yet, implausible though it is, Randall's analogy expresses what are certainly his main convictions: that philosophy's role is "feminine," in the traditional sense of that adjective—to respond sympathetically rather than to create; that it seeks to reconcile; that it can succeed in that task only by telling men what they want to hear.

If he had been less provocative, Randall might have compared the philosopher with the statesman. If we pursue that analogy, we shall come closer to understanding what he is driving at and why his history of modern philosophy takes the somewhat strange form it does. The specific tasks that confront the modern statesman, we should all agree, are quite different from the tasks that confronted the medieval statesman, and the specific suggestions a medieval statesman might make—"arrange a dynastic marriage," for example—no longer have any relevance to modern conditions. Quite similarly, in Randall's view, we are not to look to a philosopher for "philosophical truths" of permanent value. It is not the philosopher's job to advance human knowledge; his task is rather to make peace between the intellectual and cultural forces of his time.

In what sense, then, does philosophy have any continuous history? If we can recognize a man as being a statesman, whether in ancient Greece or medieval Europe or modern America, this is only because statesmanlike techniques of adjustment can be applied in a variety of conflict situations; and the statesman makes use of perennially applicable concepts—such concepts as war and peace, alliance and pact, unification and partition, vital interest and security. A history of statesmanship would be an account of the way in which statesmen applied these concepts and these techniques at different stages in human history. Similarly, if Randall is right, past and present philosophers apply similar techniques of reconciliation and work with persistent reconciliatory concepts—concepts such as, in Randall's words, "the one and the many, permanence and change, the real and the ideal, reason and experience, form and matter, structure and process." A history of philosophy displays the philosopher making use of these concepts in ever changing social situations.

Some philosophers proceed, Randall admits, as if it were their task to criticize what their predecessors taught and to solve the problems their predecessors set. Randall believes, however, that the problems philosophers have to solve are set by society and not by other philosophers, and that there are, and can be, no philosophical refutations. From this general conclusion he draws a moral for the future: "If our scientific philosophies are destined to be superseded by other and more dogmatic views of nature and society, it will not be because they have been disproved, but because they have been made irrelevant by our intense need of social direction and military security, even at the sacrifice of the searching mind and the critical temper." Any philosopher with an eye to the future, it would seem, should be looking for a way to persuade society that social direction is what it really wants, and that what is now entrusted to the searching mind and the critical temper can safely be left to military security.

This, then, is the conception of philosophy that *The Career of Philosophy* is designed to illustrate. Naturally it involves Randall in historical innovations. Against the traditional pattern of histories of philosophy—which have ordinarily been composed on the assumption that philosophy is a persistent attempt to arrive at true conclusions—Randall raises a threefold objection: Such a history of philosophy "contains a fixed set of figures; they are indeed important, but the list is far too narrow. It leaves out some of the greatest names, men like Galileo and Newton, Marx and Darwin, without whose ideas there would have been no philosophical thought at all. And it leaves out practically all the history, all those great realms of ideas in which the philosophers have worked, all the social and intellectual conflicts that drove them to philosophy." Certainly none of these charges could be brought against Randall's history. He describes at considerable length the work of such scientists as Copernicus, Kepler, Galileo, Boyle and Newton; he has a good deal to say about the general significance of such broad historical movements as the Reformation and the Renaissance; he refers, particularly in his section on the Renaissance, to a great many minor writers of whom the ordinary educated philosopher will scarcely have heard. All this is consistent with his general conception of philosophy. If, as Randall believes, "philosophy is the expression in thought of cultural change itself," then in order to understand the philosophy of any period we shall assuredly need a detailed knowledge of the cultural changes it "expresses," and cultural changes are usually reflected more obviously in the work of minor writers than of major ones.

I am myself quite sympathetically inclined toward Randall's criticism of his scholarly predecessors. I should certainly agree with him that historians of philosophy have had a strong tendency to schematize rather than describe actual historical connections. They have noticed, for example, a certain kind of logical link between Locke, Berkeley and Hume and they have at once, and wrongly, concluded that Hume was a close student of Berkeley. They have ignored philosophers whose role in the transmission of ideas was in fact very important. They have paid far too little attention to the effects on philosophy of intellectual and social change, and as a result they have often failed to understand what philosophers were trying to do. They have not appreciated the significance of Newton for Berkeley and Hume, or realized how the change from a society based on status to a society based on contract affected British moral philosophy. Philosophy is not an entirely autonomous intellectual discipline, and the attempt to treat it as such will inevitably falsify its history.

The same can be said—and a good many historians of science have been saying it—for the history of science. Science draws ideas from philosophers and techniques from technologists; social and economic changes present it with problems, changes in government policy with opportunities and resources. Yet it is at the same time necessary to insist that science draws ideas from scientists, techniques from scientists, problems from scientists, that it creates opportunities and resources by its own scientific work. Although science is not autonomous, it is possible to write an illuminating history of science that treats it almost wholly as being autonomous, that refers beyond science to its social and intellectual environment only in a broad and general way. And there is a danger, if background is treated in such detail as to attenuate the distinction between background and foreground, that the history of science will disappear into an amorphous glue of "cultural history," with science's internal chronology hopelessly confused, its nature as an international testing ground for ideas no longer clearly apparent, its unique contribution to human culture dissipated. Something very similar, in my judgment, happens to the history of philosophy in *The Career of Philosophy*.

Chronology is regarded as unimportant. Adam Smith's moral theory, for example, is discussed before Hume's, even though Smith's *Theory of Moral Sentiments* appeared in 1759, some 20 years after the ethical section of Hume's *Treatise of Human Nature*, and even though Smith's work is partly a development and partly a criticism of Hume's. Leibniz is mentioned only in passing, although he died in 1716 and was both influenced by and himself influenced a great many of the philosophers to whom Randall refers, some of whom did not die until the middle of the 19th century. The metaphysics of Hobbes is described after the metaphysics of Ralph Cudworth, which was in large part a criticism of Hobbes. Admittedly it is hard to write the history of philosophy: chronology and convenience of grouping do not always go hand in hand. Furthermore, Randall has tried to cover ethics, politics, metaphysics and epistemology in a single volume, and this naturally intensifies the difficulty of telling a continuous story. But the fundamental fact is that the chronology of philosophers scarcely matters to Randall; he is not interested in philosophical argument or in controversy but only in types of attitude. Philosophy, as he sees it, is a series of "episodes," each originating separately as a reflection of the social scene, not growing out of preceding philosophical episodes.

The distinction between philosopher and sage is in Randall's book practically obliterated. That side of philosophy which makes it a discipline—as science is speculation controlled by experiment, so philosophy is speculation controlled by critical analysis—is scarcely displayed in Randall's history. The general reader will certainly be confirmed in his belief that in philosophy "you can say what you like" and that the "cracker-barrel philosopher" is distinguishable from the academic philosopher only in virtue of the fact that he has preserved his amateur status.

Proportions too are distorted in Randall's history, and for much the same reason. It would be foolish, of course, to expect a historian of philosophy to allot his pages in proportion to the importance of the philosophers he is discussing. But something has gone completely wrong when Berkeley and Henry More are allotted the same space—some 10 pages

each compared with 44 for Hume's ethics. The explanation, of course, is that Berkeley's philosophy is through-and-through argument. His conclusions can be summed up rapidly, and only his conclusions interest Randall.

Furthermore, Randall likes to pin a philosopher into a fixed attitude, like an exhibit in a museum; he is presented as a good specimen of a particular point of view. One is rarely left with any impression of those inner conflicts that issue in points of stress and strain within a philosopher's theory—in ambiguity, fallacy, inconsistency—and serve both as a warning and as an incentive to his successors. Take the case of Descartes. For Randall he is simply a specimen of a mathematical physicist. This approach could be a useful corrective to those histories of philosophy from which the reader would scarcely gather that Descartes was a mathematician. All the same, Descartes was not simply a mathematical physicist. He was also, for one thing, a biologist; there is an important conflict between his attitude toward experiment as a mathematician and his attitude toward experiment as a biologist. (When Randall talks about "science," he almost always means physics. He barely mentions William Harvey, and he does not mention John Ray at all, although the work of both men was of considerable philosophical importance.)

Then too, in the first edition of his *Meditations* Descartes promised to demonstrate the immortality of the soul; later he took that back and was content with claiming that he had demonstrated "the real distinction" between mind and body. But certainly his psychophysical dualism is not merely a product of his physics, as Randall suggests; it is a compromise that is still attractive to religious-minded physiologists. Furthermore, Descartes took his responsibilities as a metaphysician seriously; that is precisely why—unlike A. S. Eddington and James Jeans, with whom Randall absurdly compares him—he is of such permanent interest to philosophers. Any beginner in philosophy can see what is wrong with the arguments of Jeans and Eddington; many philosophers have still not seen what is wrong with Descartes's conception of consciousness.

If, on the other side, the Cartesian dualism has failed to satisfy most post-Cartesian philosophers, this is not because they have been less conscious than Descartes of the need for finding a place for mind in the sort of world a mathematical physicist describes, nor because, in a good many cases, they have been less anxious to demonstrate that the soul at least *might* be immortal. They believe that there are sound philosophical reasons for rejecting the Cartesian dualism; the Cartesian dualism does not work, not because it fails to comfort men but because it is for philosophical reasons untenable. To make the history of modern philosophy intelligible, I would therefore suggest that the historian has to take into account two distinct facts about philosophers. The first—and this is what lends substance to Randall's conception of philosophy—is that philosophers attempt, among other things, to bring into systematic interconnection what are ordinarily taken to be distinct modes of understanding the world. (It does not follow that they end by reconciling the claims of these modes of understanding; often the philosopher has brought not peace but a sword, rejecting the claims of magic or theology or deductive metaphysics or causal analysis or common sense to be a mode of understanding.) As a result of this fact their problems shift from time to time, as new modes of understanding arise or as men modify their claims for older modes—as they cease, for example, to think of poetry as being a principal source of moral wisdom or of theology as being a demonstrative science.

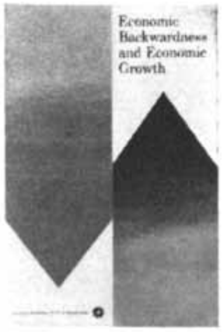
In Plato's time, as in ours, there were those who maintained that poetry or religion or science or mathematics or metaphysics was the sole, or at least the major, mode of understanding the world. So far Plato's problems are continuous with the modern philosopher's; but they are discontinuous too in so far as neither poetry nor religion nor science nor mathematics nor metaphysics is now what it once was, nor are the claims made on their behalf quite the same. Thus there are discontinuities in the history of philosophy that the historian of philosophy can only explain as arising out of intellectual changes that are external to it. Obviously the collapse of the Greek city, the rise of Christianity and the emergence of the modern state all have had important effects on the history of philosophy. It is fatal for the historian of philosophy to attempt to describe these changes in detail (this is part of my quarrel with Randall), but he must certainly refer to them, although not in such a way as to suggest that they are important for their own sake in the story he is telling.

The philosopher is unusually sensitive to certain types of difficulty, difficulties of a sort that it is natural to call "philosophical." Only by reference to this second fact can we understand why philosophers so often reject compromises and reconciliations that to the man in the street seem perfectly satisfactory. This sensitivity to intellectual difficulties drives philosophers into considering problems that are, from the point of view of the man in the street, purely technical —problems of logic, in the broad sense of that word.

Such problems are in fact the main daily concern of philosophers, much as the daily concern of scientists is the improvement and skillful management of experimental techniques. Technical problems, one can agree with Randall, are neither the be-all nor the end-all nor, historically speaking, the begin-all of philosophy. But neither is experimentation the be-all or the end-all or the begin-all of physics; it is nonetheless vital to it and it serves to distinguish it from mere guesswork. Many of the technical problems of philosophy are peculiarly difficult; we can see how difficult by reading such Platonic dialogues as the *Sophist* and the *Theaetetus;* many of the problems that Plato raises there we still do not see how to solve. But now we know at least that certain plausible-looking solutions, including some that Plato canvasses, are totally ineffective. Philosophers have learned a great deal in the few hundred years during which philosophy has flourished, but Randall's readers would scarcely realize that fact, or that there is such a thing as "learning" in philosophy.

So far I have been considering what seem to me the fundamental tendencies in Randall's approach to the history of philosophy. They are not peculiar to him; indeed, they have recently—partly as a delayed effect of John Dewey's *Reconstruction in Philosophy*—come to be extremely conspicuous in American scholarship. They are, I believe, dangerous both to philosophy and to the history of philosophy, encouraging an empty skepticism, hostility to rigorous argument, subservience to "social needs"; at their worst they give rise to easy moralizing, hasty generalizations, even mere intellectual chatter. Let me now, however, explain why, in spite of all I have said, I recommend the reading of Randall's book to anyone who is interested in intellectual history. But he should read it after he possesses, and not as a way of obtaining, at least an outline of the history of philosophy.

Throughout Randall is clear, bold and forthright. Even if one is often surprised by what he says, at least there is never any doubt about what he is saying. He has an eye for illuminating quotations and makes lavish use of them, particularly when he is talking about the lesser



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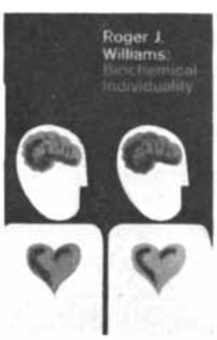

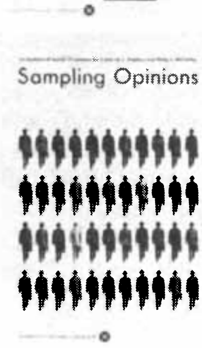

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philosophers. Although he seldom refers to other scholars (this is not a personal complaint; he refers generously, as it happens, to my own work, but not, for example, to that of Harry A. Wolfson or Arthur O. Lovejoy), he is fully aware of the latest developments in scholarship. His sketches of historical movements are lively and informative. Even his accounts of individual philosophers are often far better than his general approach would lead one to expect. He brings out very well indeed the indebtedness of modern philosophy to medieval traditions, of what is generally described as "Platonism" to Augustine, of British empiricism to William of Ockham. This is an excellent feature of his book that I hope will be generally noted and imitated.

His long acount of the Renaissance illustrates Randall's method at its best. He admits that quite a few of the Renaissance thinkers he discusses can scarcely be regarded as philosophers. They are interesting not because they thought critically and systematically but because they formulated ideas—ideas as various as the idea of a literary culture, the idea of systematic scientific research, the idea of a limited monarchy, the idea of a secular ethics—that are still importantly with us. They are not worth studying for their own sake; they do not, unlike Plato or Aristotle or Spinoza or Hume or Kant, reveal to us the nature of philosophical problems or help us toward their solution; we do them justice only by reading them in a social and intellectual context. And this is exactly what Randall helps us to do.

The section on the Renaissance is by far the most scholarly section of Randall's history; it incorporates his own important research on the naturalistic Aristotelianism of Padua and the origins of modern concepts of scientific method; it effectively introduces the reader to recent scholarly controversies about the relation between 14th- and 16th-century scientific ideas. The scholarship is detailed, as it is not in Randall's account of the great modern philosophers or the French Enlightenment. In short, Randall on the Renaissance is a contribution to scholarship; Randall on 17th- and 18th-century thought is an example of high-level popularization. Such differences in depth are perhaps inevitable in a book that covers such a wide field.

It is not inevitable, however, that the index should be so poor (there are many references in the text that are not in the index); it is not inevitable either that there should be no bibliographies. These are surely serious defects in a book that is bound to be used as both a reference work and an introductory text.

Short Reviews

JANE'S FIGHTING SHIPS, 1962–1963, compiled and edited by Raymond V. B. Blackman. McGraw-Hill Book Co., Inc. ($35). The 65th edition of *Jane's* has new data, many fresh photographs and much information, most of it not calculated to lift the irenic heart. Ghana has enlarged its navy. France has two new aircraft carriers and is building a cruiser helicopter-carrier and three guided-missile frigates. Japan is building destroyers armed with guided missiles. Great Britain, on the other hand, has scrapped all but a few of its remaining warships, has laid down no battleships, no aircraft carriers, no cruisers and no orthodox destroyers of postwar design. The British cannot afford the large ships, and they have no great confidence that capital ships—even aircraft carriers—are of any value. The U.S., on the other hand, is in the midst of a naval-construction boom. We have completed the world's first nuclear-powered aircraft carrier, the first nuclear-powered guided-missile carrier and the first nuclear-powered frigate. We have also completed a fleet of 26 nuclear-powered submarines. Thus we have what *Jane's* calls "the most imposing array of warships the world has ever known in peacetime." By 1967 the U.S. expects to have a fleet of 81 nuclear-powered submarines and to raise its nuclear-ballistic-missile submarine fleet to about 41 units. As for the U.S.S.R., its major emphasis seems to be on submarines of all kinds. The total number is believed to have risen to about 465, compared with 430 a year ago.

JANE'S ALL THE WORLD'S AIRCRAFT, 1962–1963, compiled and edited by John W. R. Taylor. McGraw-Hill Book Co., Inc. ($35). This *Jane's* judges the most important development in a year "crowded with progress and excitement in aviation and space" to be vertical take-off without the use of rotating wings. In the U.S. much effort is still being devoted to tilt-wing and tilting-duct designs, but almost all the European projects use the Bristol-Siddeley vectored-thrust (swiveling nozzle) or Rolls-Royce direct-jet-lift principles. In this year's annual, coverage has been extended to such items as sailplanes, air-cushion vehicles, guided missiles, rockets, space vehicles and piloted spaceships. For the first time there is no section on airships because lighter-than-air flight has almost disappeared. Still, the U.S. is building a three-hulled airship, and the Russians are said to be studying the possibilities of large lighter-than-air freighters. The North American X-15 has exceeded its design objectives of flight at 4,000 miles per hour and an altitude of 50 miles; the U.S.S.R. has its own craft, the E-166, that has set three major speed and height records. *Jane's* makes the point that the development of supersonic airliners progressed in 1962 to the stage where such craft could be put into service within four or five years. In general, however, "the airlines have made it clear that they do not want such an aircraft until the mid-'70's at the earliest to give them an opportunity to recoup the vast sums of money spent on the present generation of big jets." The British and French governments now seem inclined to go forward with the joint development of the Super-Caravelle, a prototype of which "could well be flying in 1965, with production aircraft ready for service by 1968." Apart from airline economics there are other problems—noise, increased air traffic control difficulties, runway requirements—that make this a matter of "some controversy." But the U.S.S.R. seems to have decided that supersonic airliners are "worthwhile from the viewpoints of both prestige and reduced journey time," and it is said that the Russians will have in service by 1970 airliners capable of speeds approaching Mach 2.

NEW PATTERNS IN GENETICS AND DEVELOPMENT, by C. H. Waddington. Columbia University Press ($10). This book by the Buchanan Professor of Genetics at the University of Edinburgh is based on the Jesup Lectures he gave at Columbia University in the spring of 1961. Waddington's main concern is with two problems, one rather new and one very old. The new problem is "the impact of the recent great advances in genetics on our understanding of the development of multicellular organisms." The old problem is "the ancient conundrum of morphogenesis—the appearance of organized structure within a vast range of sizes from the cellular organelle to the elephant." Waddington suggests that the enormous successes of biochemistry have tended to dominate present-day biology, leading to the neglect of structures that are too large to be handled by biochemical methods. From the theoretical and the experimental point of view, including work done in his own laboratory, Waddington examines the possibility of synthesizing embryology and genetics so as to achieve a better understanding of the complex processes by which cells become differ-

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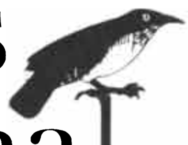

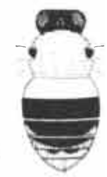

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816 pages. 65 figures. 43 tables. ***A Belknap Press Book.*** $11.95

Another side of evolution

ESSAY ON CLASSIFICATION *by Louis Agassiz, edited by Edward Lurie.* An epic of classical pre-Darwinian natural history, clearly demonstrating the stature of the opposition Darwin's theories were to face in the United States. *A John Harvard Library Book.* $5.00

And other views of biological problems

THE RED CELL *by John W. Harris.* Thoroughly analyzes the normal and abnormal red blood cell, including detailed treatment of the pathophysiology of clinical disorders resulting from changes in the production, metabolism, and destruction of the cell. *A Commonwealth Fund Book.* $5.75

CASE DEVELOPMENT PROBLEMS IN HEMATOLOGY *by John W. Harris and Daniel L. Horrigan.* Eight workbook problems tested for several years as a teaching supplement to *The Red Cell. A Commonwealth Fund Book.* $3.25

NERVE CELLS AND INSECT BEHAVIOR *by Kenneth Roeder.* Describes in clear-cut terms the relation of stimulus and behavior in the nervous systems of the moth, cockroach, and praying mantis. *Harvard Books in Biology, 4.* $4.75

PLANT METABOLISM *by Geoffrey Arthur Strafford.* A straightforward presentation of the latest findings in the field, including technical discussions invaluable to students and research workers. $2.75

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entiated and large biological organizations are formed. The specialist will find this a stimulating excursion, and even the general reader interested in biology will have much here that he can understand. Photographs and diagrams.

THE LIFE OF VERTEBRATES, by J. Z. Young. Oxford University Press ($10). A second, revised edition of a well-known survey of the anatomy and physiology of the vertebrates. It includes a description of the whole system of life by which the animals are maintained. Young has incorporated as much as possible of fresh work done since publication of the original edition in 1950. Many illustrations.

THE SCOPE OF PSYCHOANALYSIS: SELECTED PAPERS OF FRANZ ALEXANDER, 1921–1961. Basic Books, Inc. ($12.50). A selection of papers by a prominent psychoanalyst who has interested himself not only in the development of the theory and its clinical aspects but also in the bearings of psychoanalysis on sociology, politics, aesthetics, philosophy and literature. Alexander has stuck closer to Freud than many of his contemporaries, but he is not rigid in his outlook and has recognized the contributions of others to the broadening of the angle of vision of psychoanalysis.

DICTIONARY OF EGYPTIAN CIVILIZATION, edited by George Posener. Tudor Publishing Co. ($7.95). A translation from the French of a systematic and illustrated record of 3,500 years of Egyptian history, from the earliest prehistoric time to the Roman conquests. The articles, written by authorities from all over the world, deal with every phase of Egyptian civilization, and many of them are gems. There are 145 illustrations in color and 170 in black and white. A most attractive book.

STUDIES IN GENETICS: THE SELECTED PAPERS OF H. J. MULLER. Indiana University Press ($10). There has been collected in this volume, a tribute to Muller on his 70th birthday, a selection of his writings on genetics and related subjects. Muller was asked to make the selection himself and has included a larger proportion of his earlier writings than of his later ones, since the former are less known and less available to readers. He has also given preference, as he points out in his introduction, to the writings in which there was earlier mention of given principles, rather than to papers that consisted mainly of restatements. Joshua Lederberg, who describes the collection in a foreword as "a special benefice," observes that "it is not easy to find an original thought in biological theory that has not, in some way, been anticipated here—whether the topic be the ultramicroscopic gene, the fate of mankind on earth or the cosmic origins of life."

ENCYCLOPAEDIC DICTIONARY OF PHYSICS, VOLUMES II TO VII, edited by J. Thewlis and others. The Macmillan Co. ($298 the set). Except for an index and glossary still to come, these volumes complete this encyclopedic survey, which was described in this department some months ago. It is beyond the scope of a brief notice—or perhaps even of a much longer review—to attempt an assessment of an undertaking of such magnitude. Certain features, however, should be mentioned. Hundreds of leading specialists in the U.S. and Great Britain have contributed several thousand articles, some of which run to 2,000 words, covering the entire field of pure and applied physics from acoustics to X rays. The physical product itself achieves a high standard: excellent typography, cleanly executed illustrations, good paper and binding. Almost every article that is more than a mere definition has its own bibliography. Evidently this is a work that all scientific and technical libraries must acquire and that the practicing physicist who can afford it will want to have.

TOPICS IN CHEMICAL PHYSICS, BASED ON THE HARVARD LECTURES OF PETER J. W. DEBYE, by Alfred Prock and Gladys McConkey. American Elsevier Publishing Co., Inc. ($11). A few years ago Debye gave a series of lectures in chemistry and physics for students at Harvard University. This volume is based on these lectures, which discuss such topics as the fundamental laws of the static electric field, the basic concepts of statistical mechanics and the application of X rays and light-scattering techniques to the study of particle size and shape.

A DICTIONARY OF AGRICULTURAL AND ALLIED TERMINOLOGY, edited by John N. Winburne. Michigan State University Press ($15). One of the major difficulties in compiling this work was in deciding what words and phrases properly belong to the language of agriculture. Over the centuries since men began to raise crops and domesticate animals the language describing these activities has grown, has become more technical and has borrowed from and intertwined

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with the jargon of many disciplines from economics to veterinary medicine. That is not all; one must also include in a well-balanced agricultural dictionary examples from the speech of the practitioner: the dirt farmer, the sheep farmer, the rancher, the implement manufacturer, the pesticide salesman, the fungicide distributor, the poultry distributor, the feedlot buyer. Hence in the preparation of this useful volume many experts had to be consulted, many compromises had to be made, many limits imposed. Omissions will be noted, and specialists will complain: If this word, why not that one? Nevertheless, the final product will be welcomed not only by those interested or involved in agriculture but also by lovers of that huge, shapeless, marvelously supple and receptive organism, the English language. Here one can learn the meaning of such terms as easy hitch, hard pinch, hardware disease (when cattle and other ruminants decide to eat nails and baling wire), scorched neutralizer, school lunch program, mistletoe hook, thrips, single-rod agitator, red baneberry, peanut peg rot, Dow-Law planter, lambkill kalmia (an evergreen shrub that gives sheep indigestion), superheated milk, regal lily, Regels threewingnut, valorization, parsnip webworm, bog rider (a cowboy who rescues cows stuck in bogs), centrifugal cream separator, dogtrot, virgin dip, shin share (part of a plow), potato wart, omnivorous looper (an insect whose larvae munch on avocado trees), near-wilt of pea (a fungus disease of the pea), lodgepole needle miner (a moth whose larvae mine the needles of the lodgepole pine), Kharsgoard (a hard, skimmed-cow's-milk cheese made in Denmark), dieback, Embden groats, emasculatome (an instrument used for castration and for docking the tails of lambs), mule skinner, strip farming, smear 62 (a specific for the screwworm), ruffle fat, rabi (not the eminent physicist but crops sown in India in October and November), pokkah-bong (a fungus disease of sugar cane), optimal light income, orange fleabane, love-in-a-puff (the heartseed, or baloonvine), catclaw apes-earring, cattle-biting louse, rotary hog feeder, queen excluder, xenia, yabbie (a destructive fresh-water crayfish), yokel, zymurgy, Aaron's-beard, deathcup amanita, epilepsy and Epsom salts.

Observation and Interpretation in the Philosophy of Physics: With Special Reference to Quantum Mechanics, edited by S. Körner in collaboration with M. H. L. Pryce. Dover Publications, Inc. ($1.60). A paper-backed reprint of the proceedings of the Ninth Symposium of the Colston Research Society, held at the University of Bristol in 1957. It is gratifying to have an inexpensive edition of this unusually interesting symposium, reviewed in these columns some four years ago, but it is fair to sound a warning that economy has been achieved at the cost of a type size so unpleasantly small that for older readers the problems of presbyopia are apt to take precedence over those of the philosophy of physics.

THE DOMESDAY GEOGRAPHY OF SOUTH-EAST ENGLAND, edited by H. C. Darby and E. M. J. Campbell. Cambridge University Press ($22.50). Although the Domesday Book is recognized as being a unique source of information about legal and economic matters, its "bearing upon the reconstruction of the geography of England during the early Middle Ages has remained comparatively neglected." This book, the third of a series (the complete work will have six volumes) covering the whole of Domesday England, consists of contributions by various experts on different districts. The details extracted with scholarly skill and devotion from the Domesday folios make it possible not only to reconstruct the English landscape of the time, to learn of its political subdivisions, its plow teams and so on, but also to gain a deeper understanding of the economic life of the country. Many maps and tables.

THE CRESCENT DICTIONARY OF MATHEMATICS, by William Karush. The Macmillan Co. ($6.50). More than 1,400 entries deal with a wide range of mathematical material from arithmetic and elementary algebra to number theory, calculus, probability, topology, logic, foundations and information theory. Most of the definitions and explanations are accessible to readers who have had mathematical training up to the intermediate level, but some require a more sophisticated eye.

WILDLIFE'S TEN-YEAR CYCLE, by Lloyd B. Keith. The University of Wisconsin Press ($6). It is known that there are wildlife cycles, some with a span of three or four years and some with nine or 10. The populations of lemmings, mice and other small rodents are said to follow the shorter cycle; those of snowshoe hares and muskrats, the longer one. This book rounds up information from U.S. and Canadian sources that bears on the long cycle. None of the hypotheses that have been offered to explain it—

climatic change, overpopulation and the like—is wholly satisfactory and "only through a concerted research effort is the true explanation for this cycle likely to be found."

THE HORIZON BOOK OF LOST WORLDS, by the editors of *Horizon*. American Heritage Publishing Co., Inc.; distributed by Doubleday & Co., Inc. ($17.95). A splendidly illustrated survey of nine of the most notable civilizations of the past, which have vanished and been rescued from oblivion by archaeologists and other students. Accompanying the illustrations, some of which are magnificent, is an agreeable and enlightening narrative by Leonard Cottrell that traces the story of the Egyptians, the Mesopotamians, the Indus Valley people, the Minoans of Crete, the Mycenaeans, the people of Anatolia, the Etruscans, the Khmers, the Mayas. Time the great destroyer, Herbert Muller observed, is also the great preserver; this volume brings to our notice "the immense accumulation of products, skills, styles, customs, institutions and ideas that make the man on the American street indebted to all the peoples of history, including some who never saw a street."

LA SCIENCE CONTEMPORAINE. VOLUME I: LE XIX[e] SIÈCLE, edited by René Taton. Presses Universitaires de France. This is Volume III, Part 1, of Taton's *General History of the Sciences,* the first two volumes of which have been reviewed in this department. A distinguished group of contributors from many different countries covers various aspects of this most fruitful of scientific centuries. There are also separate chapters on scientific progress in Europe, the U.S., the Mohammedan countries and Asia. A feature is the excellent illustrations including photographs and reproductions of old drawings and engravings. There is a bibliography and a comprehensive index. A last volume covering the 20th century is promised; it will conclude this invaluable survey.

Notes

X-RAY OPTICS, by A. J. C. Wilson. John Wiley & Sons, Inc. ($4.50). The second edition of this monograph has been revised to incorporate fundamental advances of the past 15 years to cover the diffraction of X rays by finite and imperfect crystals.

THE UPANISADS, translated by F. Max Müller. Dover Publications, Inc. ($4). This two-volume paperback contains

Müller's well-known translation of the classical upanishads, the great mystical and philosophical treatises of India, which first appeared in his collection *Sacred Books of the East.*

THE KIOWAS, by Mildred P. Mayhall. University of Oklahoma Press ($5.95). A history of the Kiowa Indians, described as once being, along with the Cheyennes, "the most feared and hated of the Plains Indian tribes."

BARLEY AND MALT, edited by A. H. Cook. Academic Press ($21). The contributors to this volume are concerned with the biology, biochemistry and technology of one of the world's major crops.

A HISTORY OF THE MATHEMATICAL THEORIES OF ATTRACTION AND THE FIGURE OF THE EARTH, by I. Todhunter. Dover Publishers, Inc. ($7.50). A standard 19th-century history that covers the theoretical speculations of mathematicians from the time of Newton to that of Laplace regarding the question of the shape of the earth and the earth's gravitational pull.

KARL MARX, by Franz Mehring. Ann Arbor Paperbacks ($2.95). A soft-cover reissue of the best biography of Marx, which relates not only the details of his life but also the nature of his system of ideas.

POWER IN NEW ZEALAND, by Bryan H. Farrell. A. H. & A. W. Reed (42 shillings sixpence). A history of power usage and a geography of energy resources in New Zealand, the main aspects of which are coal, hydroelectricity, geothermal steam, petroleum and natural gas.

TRANSFORMATIONS OF SURFACES, by Luther Pfahler Eisenhart. Chelsea Publishing Company ($4.95). A reissue, with corrections of a number of errata in the first edition (published in 1923), of a standard monograph on certain aspects of the differential geometry of surfaces.

GREAT BRITAIN: GEOGRAPHICAL ESSAYS, edited by Jean Mitchell. Cambridge University Press ($7.50). A volume of essays planned to cover the geography of Great Britain regionally, each chapter written by a geographer who has made a special study of the region concerned.

ASYMPTOTIC APPROXIMATIONS, by Harold Jeffreys. Oxford University Press ($4.80). A general introduction to the theory and use of asymptotic approximations, a subject in which notable advances have been made in the past few decades.

Carolingian Portraits: A Study in the Ninth Century, by Eleanor Shipley Duckett. The University of Michigan Press ($5.95). Scholarly and readable essays on several outstanding figures of the ninth century whose lives were intertwined with the rise and fall of Charlemagne's empire.

Freud and the Post-Freudians, by J. A. C. Brown. Penguin Books, Inc. (95 cents). This original paperback explains the basic concepts of psychoanalytic theory and gives a short account of the 40-odd years of Freud's own work, of that of his contemporaries and immediate followers, and a synoptic view of the variations and deviations of others who have been influenced by him.

Volcanoes and their Activity, by A. Rittmann. Interscience Division, John Wiley & Sons, Inc. ($11.95). An English translation of the second edition of a German monograph on volcanology. It contains much descriptive information about volcanic phenomena and arguments on behalf of Rittmann's own theories about the theories and processes of volcanism.

Reason and Conduct, by Henry David Aiken. Alfred A. Knopf, Inc. ($6.75). A collection of essays on moral philosophy by a Harvard teacher. Some are quite technical; others are long book reviews that evaluate representative schools of thought during the past several decades.

The Antecedents of Man, by W. E. Le Gros Clark. Harper Torchbooks ($1.95). A fine introduction to the evolution of the primates by a foremost British student of the subject.

Civilization and Disease, by Henry E. Sigerist. The University of Chicago Press ($1.95). A paperback, in the Phoenix Books series, of the late Henry Sigerist's Messenger Lectures at Cornell University in 1940, dealing with the profound and varied influence of disease on every aspect of civilization.

Notes on Quantum Mechanics, by Enrico Fermi. The University of Chicago Press ($1.50). A soft-cover edition of a volume published in 1961, containing Fermi's own notes on a course in quantum mechanics at the University of Chicago.

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BIBLIOGRAPHY

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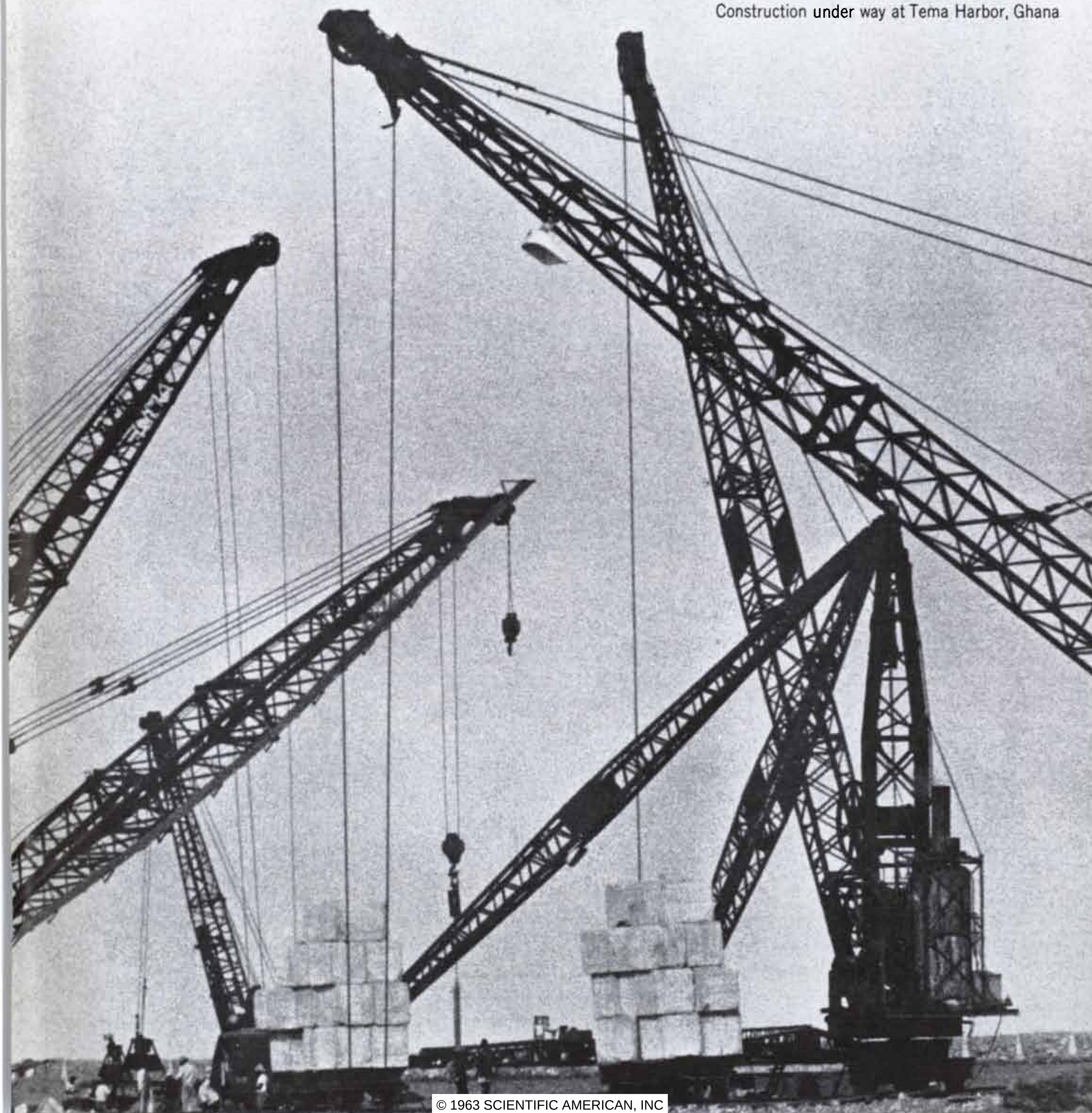

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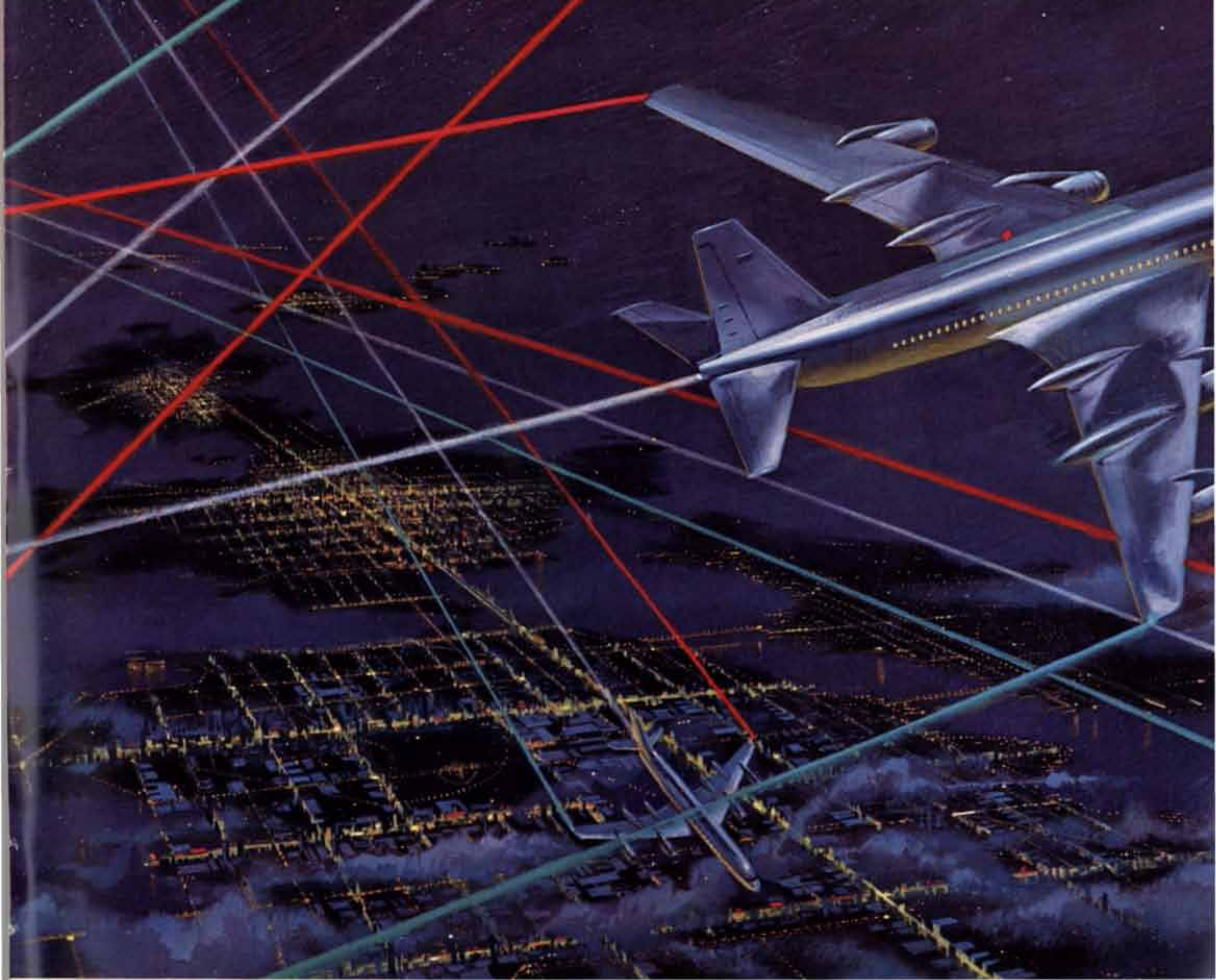

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